

**Evaluation of short-term conservative treatment  
in patients with tennis elbow (lateral  
epicondylitis): A prospective randomised,  
assessor-blinded trial.**

**Jeanette Tonks**

A thesis submitted in partial fulfilment for the requirements of the degree of  
Doctor of Philosophy at the University of Central Lancashire

**February 2012**

# STUDENT DECLARATION



## Student Declaration

### **Concurrent registration for two or more academic awards**

I declare that while registered as a candidate for the research degree, I have not been a registered candidate or enrolled student for another award of the University or other academic or professional institution

---

### **Material submitted for another award**

I declare that no material contained in the thesis has been used in any other submission for an academic award and is solely my own work

---

### **Collaboration**

Not applicable

### **Signature of Candidate**

**Type of Award**                      **PhD**

**School**                                      **of Sport, Tourism and Outdoors**

## ABSTRACT

The complexity of the pathophysiology of tennis elbow is reflected by the lack of consensus on management and remains a therapeutic challenge. This study was a prospective randomised, assessor-blinded trial. 64 patients with tennis elbow referred by their GP to either the physiotherapy, orthopaedic or MSK CAT services, subject to eligibility criteria, were randomised into one of 3 treatment arms: injection, ultrasound or exercise, to which the assessor remained blinded. The outcome measures of thermal difference, median frequency (MDF), patient-rated tennis elbow evaluation questionnaire (PRTEE), pain-free grip strength (PFG) and patient preference were assessed twice at baseline, at 10 days, 6 weeks and 6 months and analysed as an intention to treat analysis.

In the short term of 6 weeks injection was the most effective treatment demonstrating both statistically significant and minimum clinically important differences (MCID) for PFG and PRTEE in comparison to ultrasound and exercise. Patients had a strong preference for injection and a strong aversion for exercise. No statistically significant differences were found between ultrasound and exercise although a MCID was found in favour of ultrasound for thermal difference and MDF at 10 days. In to the long term of 6 months, although this was on a limited subgroup, no statistically significant differences were found between any of the groups. A MCID was found in favour of ultrasound for MDF and a MCID was found in favour of exercise over injection for all aspects of PRTEE and over ultrasound for PRTEE pain only.

This research supports the superior effectiveness of injection in the short term of 6 weeks and should be advocated for patients who present early with severe limiting pain and have important short term goals, although patients need to be warned that a 1/3<sup>rd</sup> will have a recurrence of symptoms within 6 months. In contrast, for those patients who present with moderate to low pain physiotherapy including exercise and/ or ultrasound should be advocated. Thermal difference is a sensitive outcome measure for tennis elbow. Continuous 3 MHz therapeutic ultrasound at 2W/cm<sup>2</sup> for 5 minutes utilises thermal effects which optimise the healing process and demonstrate an accumulative effect of ultrasound in to the long term. Further research on the effectiveness of a combination of injection with physiotherapy is required.

## PRELIMINARIES

Student declaration	ii
Absract	iii
Contents	iv
List of figures	vii
List of graphs	viii
List of tables	x
Acknowledgements	xii
List of abbreviations	xiii

## CONTENTS

Chapter 1: Introduction	i1
Chapter 2: Aims and objectives	3
Chapter 3: Literature review	5
3.1 Anatomy, function and physiology of extensor carpi radialis brevis	5
3.2 Tennis elbow	8
3.3 Aetiology and pathology of tennis elbow	9
3.4 Current treatments	12
3.4.1: Injection	13
3.4.1.1: Therapeutic effects of injection on tissue healing	22
3.4.2: Ultrasound	23
3.4.2.1: Therapeutic effects of ultrasound on tissue healing	27
3.4.3: Exercise therapy	31
3.4.3.1: Therapeutic effects of exercise on tissue healing	33
3.5 Outcome measures	34
3.5.1 Thermography	35
3.5.2 Pain free grip strength	38
3.5.3 Electromyography	39
3.5.4 Patient – rated tennis elbow evaluation questionnaire	42
3.6 Literature review summary	45
Chapter 4: Protocol developments	46
4.1 Thermography protocol development	46
4.2 Pain free grip strength protocol	53
4.3 Median frequency protocol development	54
4.3.1 Double versus single differential electrode study	57
4.3.1.1 Method	57
4.3.1.2 Results	58
4.3.1.3 Conclusion	59
4.4 Patient preference questionnaire	59
4.5 Protocol developments summary	59
Chapter 5: Normative studies	60
5.1 Ethics	60
5.2 Normative study 1	60
5.2.1 Normative study 1 Methods	60
5.2.2 Normative study1 Results	61
5.2.2.1 Descriptive statistics	61
5.2.2.2 Thermography	62
5.2.2.3 Pain free grip strength	63
5.2.2.4 Median frequency	64
5.2.3 Discussion	67

5.3 Normative study 2: Thermal effects of ultrasound .....	68
5.3.1 Normative study 2 methods .....	68
5.3.2 Expected thermal effects of ultrasound.....	68
5.3.3 Normative study 2 results .....	69
5.3.4 Normative study 2 discussion .....	70
5.3.5 Normative study 2 conclusion.....	72
5.4 Normative studies summary of recommendations for the clinical trial .....	72
Chapter 6: Internal pilot .....	73
6.1 Methods.....	73
6.1.1 Sample.....	75
6.1.1.1 Inclusion Criteria.....	76
6.1.1.2 Exclusion Criteria.....	76
6.1.2 Randomisation .....	77
6.1.3 Blinding.....	77
6.1.4 Treatments.....	78
6.1.4.1 Injection Therapy .....	78
6.1.4.2 Ultrasound.....	80
6.1.4.3 Physiotherapy rehabilitation .....	80
6.1.5 Data collection .....	81
6.2 Ethics.....	82
6.3 Statistical Methods .....	83
6.3.1 Data analysis .....	83
6.4 Pilot results.....	84
6.4.1 Pilot sample.....	84
6.4.2 Pilot descriptive statistics.....	86
6.4.3 Minimum clinically important differences .....	87
6.4.4 Patient pilot study analysis.....	90
6.4.4.1 Thermal difference .....	91
6.4.4.2 Median frequency shift .....	92
6.4.4.3 Pain free grip strength .....	92
6.4.4.4 Patient rated tennis elbow evaluation total.....	92
6.4.5 Treatment group analysis .....	93
6.4.5.1 Thermal difference .....	94
6.4.5.2 Median frequency shift .....	95
6.4.5.3 Pain free grip strength .....	96
6.4.5.4 Patient rated tennis elbow evaluation total.....	97
6.5 Stability of grouped data .....	97
6.5.1 Methods.....	98
6.5.2 Results.....	98
6.5.3 Discussion .....	101
6.5.4 Conclusion .....	102
6.6 Single case history.....	102
6.6.1 Results.....	102
6.6.2 Discussion .....	104
6.7 Internal pilot study summary of recommendations for the clinical trial .....	105
Chapter 7: Clinical trial.....	106
7.1 Results .....	106
7.1.1 Sample.....	106
7.1.2 Descriptives.....	107
7.1.3 Statistical analysis .....	109
7.1.3.1 Injection Group .....	109
7.1.3.2 Ultrasound Group.....	110

7.1.3.3 Exercise Group.....	112
7.1.3.4 Short term between group analysis .....	113
7.1.3.5 Long term between group analysis .....	121
7.1.4 Treatment preference analysis .....	127
7.1.4.1 Injection group .....	128
7.1.4.2 Ultrasound group.....	128
7.1.4.3 Exercise group.....	129
7.1.5 Summary of results .....	130
Chapter 8: Discussion .....	136
8.1 Results .....	136
8.1.1 Sample.....	136
8.1.2 Injection group .....	138
8.1.3 Ultrasound group.....	139
8.1.4 Exercise group.....	140
8.1.5 Short term group analysis .....	141
8.1.6 Long term group analysis.....	145
8.1.7 Patient preference.....	146
8.1.8 Summary of findings.....	148
8.2 Clinical implications .....	148
8.3 Limitations of the clinical trial.....	154
Chapter 9: Conclusions .....	157
Chapter 10: References .....	160
Chapter 11: Appendices .....	174
11.1 Normative study consent form .....	174
11.2 Normative study information sheet.....	175
11.3 Normative study data collection sheet .....	177
11.4 Normative study faculty of health ethics committee approval.....	178
11.5 Standardised subjective and objective assessment proforma.....	179
11.6 Patient information sheet.....	181
11.7 Informed consent sheet .....	183
11.8 Patient rated tennis elbow evaluation.....	184
11.9 Patient preference questionnaire .....	185
11.10 Treatment diary .....	186
11.11 Data collection sheet .....	188
11.12 Accumulative data collection sheet.....	190
11.13 Local regional ethics committee approval .....	191
11.14 Faculty of health ethics committee approval .....	193
11.15 Exercise programme (Pienimaki et al. 1996).....	194
11.16 Poster presentation Chartered Society of Physiotherapy Congress .....	195
11.17 Poster presentation British Elbow and Shoulder Society.....	196

## LIST OF FIGURES

Figure 4.1: Thermal image equipment .....	47
Figure 4.2: Anatomical markers on the olecranon and cubital crease. ....	48
Figure 4.3: Set up for recording thermal images.....	49
Figure 4.4: ROI quadrant (AR02) and unaffected quadrant (AR03). ....	49
Figure 4.5: The area of interest (AR01) .....	50
Figure 4.6: Diagonal lines (LI01 and LI02) .....	51
Figure 4.7: Method of <i>Tsk</i> measurement (AR01, LI01, LI02, AR02 and AR03) .....	51
Figure 4.8: Additional marker on ROI.....	52
Figure 4.9: EMG set up .....	54
Figure 4.10: DELSYS Bagnoli EMG system .....	55
Figure 4.11: ECRBr muscle belly location .....	56
Figure 4.12: DELSYS single (top) and DE-3.1 double differential electrodes ..	56
Figure 6.1: Injection technique. ....	79
Figure 6.2: Ultrasound application.....	80
Figure 6.3: Patient flowchart through the study up to the 6 week endpoint. ....	85
Figure 7.1: Patient flowchart through the study up to the 6 month endpoint....	107
Figure 8.1: Application of research findings (Haynes and Haines, 1998). .....	151

## LIST OF GRAPHS

Graph 4.1: Power spectral density for double versus single differential electrodes.....	58
Graph 5.1: Normative study 1 maximum $T_{sk}$ for ROI (AR02) and control (AR03) .....	62
Graph 5.2: Mean maximum grip strength for normative study 1 .....	63
Graph 5.3: Median frequency of 50% maximum grip strength over 70 seconds .....	64
Graph 5.4: Mean dominant median frequency of 50% maximum grip strength over 70 seconds .....	65
Graph 5.5: Notch filtered median frequency of 50% maximum grip strength over 70 seconds .....	66
Graph 5.6: Thermal difference overtime for ultrasound and sham ultrasound in a healthy participant.....	69
Graph 6.1: Means profile plot for thermal difference ( $^{\circ}\text{C}$ ). .....	94
Graph 6.2: Means profile plot for median frequency.....	95
Graph 6.3: Means profile plot for pain free grip strength. ....	96
Graph 6.4: Means profile plot for patient rated tennis elbow evaluation total. ..	97
Graph 6.5 Thermal difference cumulative mean and SD of thermal difference for the injection group.....	98
Graph 6.6 Thermal difference cumulative mean and SD of difference for the exercise group. ....	99
Graph 6.7 Thermal difference cumulative mean and SD of difference for the ultrasound group. ....	99
Graph 6.8 Median frequency shift cumulative mean and SD of shift for the injection group. ....	100
Graph 6.9 Median frequency shift cumulative mean and SD of shift for the exercise group. ....	100
Graph 6.10 Median frequency shift cumulative mean and SD of shift for the ultrasound group. ....	101
Graph 7.1 Profile plot for thermal difference.....	115
Graph 7.2 Profile plot for median frequency shift. ....	116
Graph 7.3 Profile plot for pain free grip strength.....	117
Graph 7.4 Profile plot for patient rated tennis elbow evaluation pain. ....	118

Graph 7.5 Profile plot for patient rated tennis elbow evaluation function.....	119
Graph 7.6 Profile plot for patient rated tennis elbow evaluation total. ....	120
Graph 7.7 Profile plot for thermal difference.....	122
Graph 7.8 Profile plot for median frequency. ....	123
Graph 7.9 Profile plot for pain free grip strength.....	124
Graph 7.10: Profile plot for patient rated tennis elbow evaluation pain. ....	125
Graph 7.11: Profile plot for patient rated tennis elbow evaluation function.....	126
Graph 7.12: Profile plot for patient rated tennis elbow evaluation total.....	127

## LIST OF TABLES

Table 4.1: Intrinsic and extrinsic variables affecting vasomotor control.....	46
Table 4.2: Thermal image analysis of the symptomatic patient in Fig. 4.4 .....	50
Table 5.1: Descriptive statistics comparison.....	61
Table 5.2: Frequency of prognostic indicators.....	62
Table 5.3: Comparison of prenotched and notched median frequencies .....	67
Table 5.4: Painfree grip comparison .....	68
Table 6.1: Justification of time point data collection.....	81
Table 6.2: Descriptive statistics for the internal pilot. ....	86
Table 6.3: Descriptive statistics for the internal pilot patients.....	86
Table 6.4: Internal pilot and normal baseline outcome measures: mean (SD). ..	88
Table 6.5: Outcome measures means (SD) overtime for the affected elbow.....	91
Table 6.6: Maximum temperature ( $^{\circ}\text{C}$ ) for single case study participant .....	102
Table 6.7: Dominant versus nondominant median frequency shift overtime for single case study participant.....	103
Table 7.1: Baseline characteristics.....	108
Table 7.2: Outcome measures means (SD) overtime for the injection group...	109
Table 7.3: Outcome measures means (SD) overtime for the ultrasound group. .....	111
Table 7.4: Outcome measures means (SD) overtime for the exercise group....	112
Table 7.5: Mean differences, significance and 95% CI for thermal difference.	114
Table 7.6: Mean differences, significance and 95% CI for median frequency shift.....	115
Table 7.7: Mean differences, significance and 95% CI for pain free grip strength. .....	116
Table 7.8: Mean differences, significance and 95% CI for patient rated tennis elbow evaluation pain. ....	117
Table 7.9: Mean differences, significance and 95% CI for patient rated tennis elbow evaluation function. ....	118
Table 7.10: Mean differences, significance and 95% CI for patient rated tennis elbow evaluation total. ....	120
Table 7.11: Mean differences, significance and 95% CI for thermal difference for all groups. ....	121

Table 7.12: Mean differences, significance and 95% CI for thermal difference. .....	121
Table 7.13: Mean differences, significance and 95% CI for median frequency shift.....	122
Table 7.14: Mean differences, significance and 95% CI for pain free grip strength.....	123
Table 7.15: Mean differences, significance and 95% CI for patient rated tennis elbow evaluation pain. ....	124
Table 7.16: Mean differences, significance and 95% CI for patient rated tennis elbow evaluation function. ....	125
Table 7.17: Mean differences, significance and 95% CI for patient rated tennis elbow evaluation total. ....	126
Table 7.18: Patient preference for treatment.....	127
Table 7.19 MCIC and statistically significant changes (SSC) summary for the injection group overtime. ....	131
Table 7.20 MCIC and statistically significant changes (SSC) summary for the ultrasound group overtime. ....	131
Table 7.21 MCID and statistically significant changes (SSC) summary for the exercise group overtime. ....	132
Table 7.22 MCID and statistically significant differences (SSD) summary at 10 days. ....	132
Table 7.23 MCID and statistically significant differences (SSD) summary at 6 weeks.....	133
Table 7.24 MCID and statistically significant differences (SSD) summary at 6 months.....	133
Table 7.25: MCID, SSD and group ranking summary. ....	134

## **ACKNOWLEDGEMENTS**

I wish to thank my supervisors Professor James Selfe, Professor Jim Richards and Doctor Dave Fewtrell for their valued support and advice so generously given. I also wish to acknowledge with gratitude the statistical support received from Chris Sutton.

I also wish to show my appreciation for the continued support received from my line manager Linda Atherton and the assistance of both the administrative team and select team of treating physiotherapists involved with the clinical trial at Bridgewater Community Healthcare NHS Trust.

## LIST OF ABBREVIATIONS

<b>ACPOM</b>	Association of Chartered Physiotherapists in Orthopaedic Medicine
<b>ANOVA</b>	analysis of variance
<b>ASHT</b>	American Society of Hand Therapists
<b>CET</b>	common extensor tendon
<b>DASH</b>	Disabilities of the arm, shoulder and hand questionnaire
<b>DNA</b>	did not attend
<b>ECM</b>	extracellular matrix
<b>ECR</b>	extensor carpi radialis
<b>ECRBr</b>	extensor carpi radialis brevis
<b>ECRL</b>	extensor carpi radialis longus
<b>ECU</b>	extensor carpi ulnaris
<b>ED</b>	extensor digitorum
<b>EMG</b>	electromyography
<b>ERA</b>	effective radiating area
<b>ES</b>	effect size
<b>FHEC</b>	Faculty of Health Research Ethics Committee
<b>ITT</b>	intention to treat
<b>LOCF</b>	last observation carried forward
<b>MDF</b>	median frequency
<b>MCIC</b>	minimum clinically important change within groups
<b>MCID</b>	minimum clinically important difference between groups
<b>MPSF</b>	median power spectral frequency
<b>MSK CATS</b>	Musculoskeletal Clinical Assessment and Treatment Service
<b>MVC</b>	maximum voluntary contraction
<b>NNT</b>	number needed to treat
<b>NSAID</b>	non-steroidal anti-inflammatory drug
<b>PEDro</b>	Physiotherapy Evidence Database
<b>PEMF</b>	pulsed electromagnetic field therapy
<b>PFFQ</b>	pain free function questionnaire
<b>PFG</b>	pain free grip strength
<b>PRTEE</b>	patient-rated tennis elbow evaluation questionnaire
<b>PSD</b>	power spectral density

<b>RCL</b>	radial collateral ligament
<b>RCT</b>	randomised controlled trial
<b>ROI</b>	region of interest
<b>SEM</b>	standard error of measurement
<b>SD</b>	standard deviation
<b>SRM</b>	standardised response mean
<b>SDD</b>	smallest detectable difference
<b>SSC</b>	statistically significant change
<b>SSD</b>	statistically significant difference
<b>Tsk</b>	skin surface temperature
<b>UCLan</b>	University of Central Lancashire
<b>UTA</b>	unable to attend
<b>VAS</b>	visual analogue scale
<b>WWL REC</b>	Wrightington, Wigan and Leigh Regional Ethics Committee

## CHAPTER 1: INTRODUCTION

Tennis elbow is the most commonly diagnosed elbow condition (Vicenzino and Wright, 1996) and is defined by lateral elbow pain on palpation of the common extensor origin and pain on resisted wrist extension. It is generally considered to be due to repetitive microtrauma from the overuse of the wrist extensors and subsequent failure of the tendon to heal. Although it has a well-defined clinical presentation and there is an abundance of research on tennis elbow, the complexities of both the underlying aetiological and pathophysiological processes remain in contention. Specifically, whether inflammation is an integral part of the pathogenesis.

Although a myriad of therapeutic interventions are available for the treatment of tennis elbow, of the comparatively few randomised controlled trials which have been undertaken, no one treatment has been proven to be universally effective; generating little consensus on management (Bisset et al., 2005) which accounts for tendon problems remaining a therapeutic challenge (Gaujoux-Viala et al., 2009). Additional well designed pragmatic trials are required to provide evidence for the efficacy of physiotherapeutic interventions (Smidt et al., 2003).

Outcome measures in previous studies have consistently been a form of questionnaire and grip strength, rather than physiological measures of temperature and muscle function which would be more directly relevant to current conservative treatment on tennis elbow. Thermography and electromyography (EMG) have not been used to evaluate the treatment effects of injection therapy, ultrasound or physiotherapy rehabilitation to date. Previously published protocols for both have inherent fundamental flaws and deficiencies. Through the development of a novel scientifically robust model, for thermography, and application of concepts in a unique way, for EMG, these measures have been standardised, as part of this thesis, in an optimum manner which negate these inherent potential variables. Subsequently, the use of these innovative developments has enabled a more robust trial providing details which are directly clinically relevant to the increase in temperature and reduction of muscle function seen in this patient group. Through thermographic and EMG evaluation this study has the potential to identify whether the alterations in muscle function and disability found in tennis elbow are fully reversible solely through pain relief by

injection therapy or ultrasound or whether rehabilitation is a prerequisite to reversibility and subsequently prevention of recurrence. Although the use of a combination of conservative treatments is the norm in clinical practice it is important that the specific elements of treatment are evaluated to identify their individual effectiveness prior to evaluation of possible interactions.

A systematic review on ultrasound by van der Windt et al. (1999) concluded that tennis elbow was the only condition for which there was favourable weak evidence for its use. Low intensity ultrasound is advocated in practice, which does not utilise the thermal effects of the available high superficial doses. However, previous work by Williams (2003) found high dose ultrasound to be highly effective in the short term.

Thermographic evaluation of tennis elbow has allowed an indirect analysis of the potential inflammatory nature of this condition. Current research proposes that tennis elbow is an angiofibroblastic tendinosis which is distinctly non-inflammatory (Kraushaar and Nirschl, 1999), however corticosteroid injections only known mechanism of action to relieve pain and diminish disability is by a reduction in inflammation (Cyriax, 1984). Other mechanisms of pain relief by corticosteroids have not been established (Speed, 2001). Due to the fact that injection therapy has been proven to be the best treatment option in the short-term for tennis elbow patients with success rates of 92% (Smidt et al., 2002) one is left with a clinical dilemma due to the lack of an inflammatory pathology.

Thermographic analysis should provide more evidence on the debate on both the nature of tennis elbow and action of injection therapy. Surface EMG should allow more detailed analysis of muscle function and provide improved knowledge of the pathogenesis of tennis elbow over time.

## **CHAPTER 2: AIMS AND OBJECTIVES**

The primary aim of this study is to evaluate the effectiveness of current conservative treatments relevant to tennis elbow (which include ultrasound, injection therapy, and physiotherapy rehabilitation) in the short-term of 10 days and 6 weeks.

The secondary aim is to evaluate treatment effectiveness in the long-term of 6 months.

The objectives are to:

1. investigate whether thermal and EMG changes show a relationship with function and disability.
2. investigate the immediate effects, 10 days, on temperature using thermographic analysis and on muscle function using EMG with any treatment and subsequently comparison of the different treatment groups.
3. investigate the sustainability, up to 6 months, of thermographic and EMG changes in the different treatment groups.
4. determine whether temperature using thermography and muscle function using EMG can be altered solely by injection and ultrasound alone or by physiotherapy exercise rehabilitation.

The aims and objectives were addressed through a pragmatic prospective randomised, assessor-blinded trial of 64 patients who were referred by their GP to either the physiotherapy, orthopaedic or MSK CAT services of Ashton, Leigh and Wigan PCT or Wrightington, Wigan and Leigh NHS Trust.

This thesis has been structured sequentially to direct the reader logically through the area of research. Chapter 3 reviews the literature on the anatomy and physiology of extensor carpi radialis brevis (ECRBr), the pathophysiology of tennis elbow, the 3 commonest treatments for tennis elbow: corticosteroid injection, ultrasound and physiotherapy exercise rehabilitation and the outcome measures of thermography, pain free grip strength, electromyography and patient-rated tennis elbow evaluation questionnaire (PRTEE). Chapter 4 describes the protocol developments for both thermography and electromyography. Chapter 5 tests these protocols on a healthy sample to identify normative data. These normative studies also evaluate the thermal effects of ultrasound versus sham ultrasound on a single healthy individual. Chapter 6 details the methods of the randomised trial and the internal pilot, of the first 20 patients.

The internal pilot was carried out to test procedures on the clinical tennis elbow population, identify minimum clinically important differences (MCID) and to evaluate the sample size through analysis of the stability of data. This chapter also includes an illustrative single case history. Chapter 7 explores the results of the clinical trial which are discussed in chapter 8 alongside the clinical implications and limitations with the conclusions drawn in chapter 9.

## **CHAPTER 3: LITERATURE REVIEW**

Preparatory work included a literature review which was undertaken to determine the current evidence available on tennis elbow and subsequently identify any pertinent gaps in the knowledge regarding the current clinical practice for this condition. This chapter has been structured to lead the reader sequentially through the anatomy, function and physiology of ECRBr, tennis elbow, aetiology and pathology, current treatments and therapeutic effects of injection, ultrasound and exercise therapy and the outcome measures of thermography, pain free grip strength, electromyography and patient-rated tennis elbow evaluation questionnaire.

This comprised of a comprehensive online literature search of Cochrane, Pedro, PubMed, Cinahl (1982-2011), Medline (1992-2011), AMed (1985- 2011) and Embase (1992-2011) databases. Key words used were tennis elbow, lateral epicondylitis, common extensor tendinopath\* +/- injection, exercise, ultrasound, outcome measures or steroid injection.

### ***3.1 Anatomy, function and physiology of extensor carpi radialis brevis***

Within the area of the lateral epicondyle there are complex intimate relationships between the tendons, fascia and muscles. On review of the functional anatomy and biomechanics the clinical significance of the comparatively large forces which are repeatedly exerted on both the origin and tendon of extensor carpi radialis brevis (ECRBr) can be seen.

ECRBr arises from the anterolateral aspect of the lateral epicondyle of the humerus by the common extensor tendon (CET), with extensor carpi ulnaris (ECU), extensor digitorum (ED) and extensor carpi radialis longus (ECRL), and the radial collateral ligament (RCL). Superficially the ECRBr tendon is continuous with the antebrachial fascia and with the intermuscular septum between the ED muscle and itself distally. Both ED and ECU attach to the fascia and part of both ECRL and ED also attach to the septum. ECRBr runs deep to ECRL, with brevis's muscle belly lying more distally, before it inserts through a flat tendon into the radial aspect of the dorsal surface of the

base of the 3<sup>rd</sup> metacarpal, distal to the styloid process, and to the adjacent part of the base of the 2<sup>nd</sup> metacarpal (Williams and Warwick, 1980).

Milz et al. (2004) examined 12 cadavers and reported that the entheses of the CET and the RCL are fused. This single enthesis aids stress dissipation through both the tendon and ligament. Furthermore, the RCL is also fused with the annular ligament which wraps around the radial head which further supplements force transmission over a larger area.

The extensibility of tendons varies with only 1-2% lengthening of extensor carpi radialis (ECR) in animals (Kjaer, 2004). ECRBr is a vascular tendon which does not procure its nutrition from a synovial sheath.

Although pathological changes have been reported in the other extensors and indeed twenty-six different causes of non-specific lateral elbow pain have been suggested, ranging from Panner's disease (avascular necrosis of the lateral epicondyle) to radial tunnel syndrome and cervical referral (Noteboom et al., 1994) the origin of ECRBr accounts for 90% of all cases of tennis elbow (Cyriax, 1982). ECRBr as the primary site has been confirmed by extensive work on over 600 surgical cases by Nirschl (1992).

ECRBr is distinguished from the other extensors for a number of reasons (Stoekart et al., 1989): the tenoperiosteal junction on the lateral epicondyle of ECRBr is small when compared to that of both ECRL and ECU. In addition, forces are concentrated to both the tendon and tenoperiosteal junction of ECRBr through the contraction of ECRL and ED, which both arise from this tendon, through active elbow flexion as the origin of ECRBr is above the elbow joint and lengthening of ECRBr in pronation with wrist flexion and ulnar deviation. The fascial origin of ECRBr is equally small when compared to ED and ECU and should there be anatomical variation and poor development of the fascia the forces generated by ED, for example, may be transferred to a greater degree to the origin and tendon of ECRBr rather than the fascia.

Although ECRBr is a wrist extensor and radial deviator, it has been shown to be strongly activated during grasping and pinching activities, acting as a synergist, stabilising the wrist by preventing the flexion moment when the finger flexors are activated.

The extracellular matrix (ECM), of which collagen fibrils and proteoglycans are a universal feature, plays an important role, especially in tendons, in the force transmission and maintenance of tissue structure. Evidence is evolving that tendons are dynamic structures which adapt, both structurally and functionally, to the mechanical loads they are subjected to through collagen turnover, metabolic activity and circulatory responses. This process is termed mechanotransduction and the increase in type I collagen turnover, occurring in response to mechanical loading through training, may reflect both damage repair and physiological adaptation. It is speculated that this upregulation initially allows reorganisation of the tissue followed by a net synthesis through prolonged training which potentially alters tissue strength (Kjaer, 2004). Type I fibres are termed slow oxidative fibres due to their slow contraction velocity which can produce a moderate force and are very fatigue resistant.

Tendons have a relatively limited vascularity comprising of only 1-2% of the ECM and the effects of mechanical loading on blood flow remain unclear and indeed whether it adequately meets the oxidative needs of the tendon during exercise. It should be noted that with regard to vascularity and morphology, tendons can be very heterogeneous along their length and subsequently any adaptive collagen responses are correspondingly region specific.

These morphological and physiological adaptations, which occur due to the long-term functional demands a muscle is placed under, are shown by ECRBr in the dominant elbow having a higher proportion of Type I muscle fibres in comparison to the nondominant elbow which could be attributed to the repetitive use of the dominant hand in gripping (Fugl-Meyer et al., 1982).

With age accumulation of advanced glycation end products lead to a number of changes: a stiffer and more load-resistant tendon, a reduced ability of adaptation due to a markedly reduced collagen turn-over rate and also an upregulation in fibroblast connective tissue growth factor which leads to fibrosis (Kjaer, 2004).

### **3.2 Tennis elbow**

Tennis elbow or lateral epicondylitis is a common significant problem with an estimated incidence in the region of 4-7 per 1000 patients seen in general practice per year (Smidt et al., 2002). Saunders (2002) reported that 9% of all peripheral and soft tissue injections undertaken in a General Practice during 1991-1999 were for tennis elbow. Furthermore, from epidemiology studies Verhaar (1994) found a yearly incidence of between 1-2% of the adult general population and that only half of these patients would seek medical attention. Overend et al. (1999) reported 35-61% of cases were work related whilst 5-8% were tennis related.

Tennis elbow is almost invariably experienced in the dominant hand occurring in equal proportions of male and female patients with a mean age of between 35 -50 years (Vicenzino and Wright, 1996). It is defined by lateral elbow pain on palpation of the common extensor origin and pain on resisted wrist extension.

The natural evolution of tennis elbow is generally considered to be self- limiting with spontaneous recovery occurring commonly around one year after onset. This was supported by Assendelft et al. (2003) who reported 80% of patients who had tennis elbow for at least 4 weeks became asymptomatic after one year in a general practice trial of expectant waiting policy. However, in contrast Bot et al. (2005) reported from a large observational cohort study including 181 patients with elbow complaints poor recovery; only 13% reported recovery at 3 months and 34% at 12 months with only a further 24% and 21% of the remainder, respectively, reporting substantial improvement. This research included a variety of elbow complaints, although they reported that tennis elbow was the most common elbow complaint found in their population and 54% of patients reported previous symptoms within the past year. They found predictors of longer duration of symptoms before GP consultation, musculoskeletal comorbidities and using retreating as a coping style were associated with poorer outcomes of pain and disability. In addition, at 3 months less social support and at 12 months previous history and using worrying as a coping style were associated with poorer outcomes. Smidt et al. (2006) prospectively evaluated 349 patients to identify prognostic indicators associated with pain. They reported high baseline pain severity, long duration and concomitant

shoulder pain as indicators for poor outcome at 1 month and concomitant neck pain for poor outcome at 12 months.

Predisposing factors influencing the frequency of tendon overload include both intrinsic and extrinsic factors. Extrinsic factors include overuse, technique and equipment. Intrinsic factors include genetic, age, gender (protective female hormones) and concomitant chronic disease such as hypertension, diabetes and hyperlipidemia. High body weight (waist girth lipids) and muscle flexibility are also specified as moderately important factors but it must be noted that these are associations rather than based on demonstrable cause and effect relationships (Kjaer, 2004 and Malliaras, 2008).

### ***3.3 Aetiology and pathology of tennis elbow***

Although it has a well-defined clinical presentation and there is a wealth of research on this condition, the complexities of the underlying pathophysiological and aetiological processes remain in contention. In particular, whether inflammation is an integral part of the pathogenesis and whether tennis elbow is a self-limiting disorder.

The view from histological studies was a non inflammatory and degenerative process leading to a disorganised and immature tendon repair termed angiofibroblastic tendinosis (Kraushaar and Nirshl, 1999) which was characterised by 4 key changes: increased cell numbers and ground substance, neovascularisation, increased neurochemical concentration and disorganised and immature collagen. This occurs when a tendon has failed to heal after an injury or after repetitive microtrauma through overuse. However, it should be noted that these histological results may not be representative of the tennis elbow population as a whole as the biopsies researched are those from a specific sub-population of recalcitrant tennis elbow requiring surgery. Furthermore, the pathological appearances may be iatrogenic in nature having been confounded by previous conservative therapy such as steroid injection therapy.

Although these studies found acute inflammatory markers to almost invariably be absent, chronic inflammatory cells were occasionally scattered in the surrounding muscular and fibrous connective tissue which led to the authors to categorise stage one tennis elbow as probably inflammatory. Kjaer (2004) found it difficult to completely

exclude an inflammatory component due to a number of factors: clinical observation of swelling and warmth, the proven positive effect of anti-inflammatory drugs and corticosteroids. It still remains unknown whether inflammation precedes degeneration in the more acute phase of this condition (Speed, 2001).

In addition, Milz et al. (2004) assessed 12 normal cadaver elbows, 6 cadavers with a mean age of 47 years and 6 cadavers with a mean age of 84 years. They found that fibrocartilage was a constant feature in all entheses, regardless of age, and furthermore reported that the elderly entheses demonstrated extensive microscopic damage. This led them to conclude that both these appearances may simply be a normal feature, which reflects functional adaptation to not only the tensile forces but also the shear and compressive forces implicated at the enthesis, rather than evidence of a pathological tendinosis.

On an ECM level it is hypothesised that the adaptive mechanism is driven by biochemical and physiological processes regulated by an exercise induced increase in collagen degradation followed by an increase in synthesis in cases where recovery time is too short to allow for physiological adaptation from repeated loading. This suggests that overuse conditions are a mismatch between degrading and synthesis biochemical processes. The other proposed mechanism is repair processes of resultant tissue damage following repeated microtrauma in particular when a tendon is subjected to high and sudden loads near the structural limit (Kjaer, 2004).

Unfortunately, most research at this level (Kjaer, 2004) has used animal models, and with ultrasound muscle has been widely researched, with the notable exception of a few human lower limb tendinopathies with achilles tendon in particular. Some of this work can be extrapolated but it is important to note their very different tendon specific roles and subsequently the differences in the area of pathology being at the tenoperiosteal junction of ECRBr compared to the musculotendinous junction of the achilles tendon.

It is also important to note that with the absence of acute inflammatory markers the histopathological studies fail to explain the pain mechanisms involved although recently neovascularisation has been proposed to be a source of pain due to the close association between the microvasculature, neural structures and neurochemicals at the tenoperiosteal junction of ECRBr. Equally of interest is that no clear relationship

between pain and pathology has been found: no correlation has been found on Doppler ultrasound between the amount of neovascularisation and pain severity or dysfunction, asymptomatic tendon damage has been found on ultrasonography and symptoms can be evident despite normal imaging (Khan et al., 2000).

It has been proposed that the pain mechanisms are due to central sensitisation and the triggering of nociceptors by neurotransmitters or biochemical irritation due to the noxious products of cellular activity (Kraushaar and Nirschl, 1999 and Khan et al., 2000). Using microdialysis in overused achilles and patellar tendons a raised level of glutamate was found at rest. Substance P has been found at the origin of ECRBr. Despite the exact role being unknown, glutamate is both an excitatory neurotransmitter pain modulator in the central nervous system and has an additive nociceptive role to substance P (Kjaer, 2004). Substance P also has a very powerful influence on vasoactivity which controls thermal emission and can be monitored by thermography.

Alterations in sympathetic nervous system function has been proposed as a contributory factor in the pathogenesis of tennis elbow as thermographic studies have identified characteristic hot spots at the lateral epicondyles of symptomatic patients. Whilst it has been suggested that these hot spots support an inflammatory, vascular pathology (Thomas et al., 1992) others advocate they may reflect subtle alterations in microvascular control (Vicenzino and Wright, 1996).

Fatigue of the wrist extensor muscles is also thought to be a contributory factor in the pathogenesis of tennis elbow. Hagg and Milerad (1997) evaluated forearm fatigue in healthy individuals during simulated gripping work by EMG. They found that the fatigue effects were generally larger on the extensor side.

Until the true nature of the underlying pathological processes of tennis elbow is fully understood the goals of therapeutic treatment remain in contention which is demonstrated by the wide array of treatments advocated.

Coombes et al. (2008) presented a model of the current understanding of tennis elbow which integrated 3 interrelated components: tendon pathology, pain system dysfunction and motor system impairments and through evaluation of the relative expression of each

of the components specific treatments can be targeted at the individual patient. Due to the heterogeneity of the clinical presentation with high variability between patients and over the course of symptoms they propose a multimodal approach to the treatment of tennis elbow.

### **3.4 Current treatments**

A myriad of therapeutic interventions are available for the treatment of tennis elbow and a systematic literature review identified 2629 potential studies on physiotherapeutic interventions for this condition (Bisset et al., 2005). Of these studies, 28 randomised controlled trials (RCTs) could be identified with acceptable quality of >50% on a modified Physiotherapy Evidence Database (PeDro). Most notably, the 2 criteria of intention to treat analysis and concealment of subject allocation were absent in 93% and 86% of papers respectively. This was supported by Cowan et al. (2007) who reported that 92% of the published prospective randomised therapeutic trials on tennis elbow were considered to be of low quality/ level II according to the Oxford levels of evidence with inadequate recruitment descriptions, power calculation, randomisation, blinding, participant flow and follow up.

Despite the large number of trials undertaken on tennis elbow no one treatment has been proven to be universally effective generating little consensus on its management (Bisset et al., 2005). This review supported the systematic review of 23 RCTs by Smidt et al. (2003) who used the Amsterdam-Maastricht consensus list to assess the methodological quality of the papers, weighting each paper in relation to their internal validity, clinical relevance and statistical significance and power. However, although they reported insufficient evidence for most physiotherapeutic interventions, weak evidence for the efficacy of ultrasound was found. It remains questionable whether the contradictory treatment effects among studies are determined through actual clinical differences or are due to methodological quality or insufficient power.

### 3.4.1: Injection

Regardless of the fact that the rationale for the use of corticosteroid injections remains in contention and that the long term efficacy is lacking, injections remain the mainstay of treatment for tennis elbow (Speed, 2001) and have been identified in the literature as giving the most consistent benefit in the short term (Smidt et al., 2002 and Smidt and van der Windt, 2006). There remains no consensus on the optimum dosage, volume, drug, time or technique for injection. Haslock et al. (1995) received 172 returned questionnaires out of 200 consultant rheumatologists and reported a wide divergence in almost all aspects of injection therapy practice.

Smidt et al. (2002) undertook a systematic review on corticosteroid injection therapy for lateral epicondylitis which combined a comprehensive search up to July 1999 and an additional search of Medline over the previous 2 years which failed to find any supplementary papers. Thirteen randomised controlled trials, from 248 abstracts and 29 papers, were identified and their methodological quality assessed using the Amsterdam-Maastricht consensus list. Unfortunately, most studies were found to have poor internal validity with a prevalence of inadequate control, poor co-intervention reporting and lack of blinding. Of these only 2 studies, 3 trials, obtained a relatively high validity score: Hay et al. (1999) and Price et al. (1991). They concluded that evidence showed statistically significant and clinically relevant differences for pain, global improvement and grip strength, demonstrating superior effectiveness for corticosteroids, over placebo, local anaesthetic and conservative treatment, in the short-term ( $\leq 6$  weeks). However, no significant beneficial effects were extended into either the intermediate (6 weeks to 6 months) or the long-term ( $\geq 6$  months). In contrast, there were more favourable long-term outcomes, of pain relief and increased grip strength, with physiotherapy and medication. Adverse effects are reported as 11-58% of cases with post injection pain and 17-40% of cases with skin atrophy, but irrespective of whether patients had received a corticosteroid injection or control treatment.

Hay et al. (1999) evaluated the efficacy of 20mg of methylprednisolone with 0.5ml of 1% lidocaine injections versus a 2 week course of naproxen 500mg or placebo vitamin C tablets taken twice daily. They undertook a multicentered pragmatic randomised controlled trial in primary care on 164 patients who had not presented with tennis elbow

in the previous 12 months. The median duration of symptoms was 9 weeks. Unfortunately, patients with cervical dysfunction and bilateral symptoms, whose tennis elbow could potentially be due to referred pain or neurodynamic dysfunction rather than true tennis elbow, were not excluded. If the baseline data is observed only 42-48% of cases had definite pain on resisted wrist extension and only 28-43% had definite tenderness. As tennis elbow is defined by lateral elbow pain on palpation of the common extensor origin and pain on resisted wrist extension this highlights the question of potential misdiagnosis. Although, patients were randomly allocated and formed homogenous groups at baseline, as all patients were prescribed with co-dydramol and an advice sheet the use of a placebo tablet group as a control is questionable. A blind observer recorded relevant outcome measures of patient's global assessment of change, pain free grip strength (PFG), pain, severity, function and disability questionnaire, pain on resisted wrist and 3<sup>rd</sup> finger extension and local tenderness at 4 weeks, 6 and 12 months. Using an intention to treat analysis they concluded that injection was significantly superior in the short term at 4 weeks, with a success rate of 82% compared to 48% in the naproxen group and 50% in the analgesia group. However, a good outcome was reported in all groups at a year (84%, 85% and 82% respectively).

Price et al. (1991) undertook a two-phased double-blinded study on tennis elbow comparing the use of 2ml 1% lignocaine with 10mg triamcinolone or 25mg hydrocortisone, made up to 2ml with 1% lignocaine, injections. Twenty-seven to thirty patients were randomly allocated to each group and included patients with recently failed treatment. All injections were performed by the same physician and repeated at 4 weeks if necessary. Two blinded observers recorded the outcome measures of visual analogue scale (VAS), tenderness and pain-weighted grip strength at 4, 8 and 24 weeks. The intention to treat analysis was appropriate and they reported that, although not statistically significant, more rapid relief was gained with 10mg triamcinalone rather than 25mg hydrocortisone and triamcinalone required significantly less repeat injections. Both steroid injections were statistically significantly better than lignocaine alone. However, at 6 months there was no difference between groups. They also undertook a second study which compared the use of 10mg with 20mg of triamcinolone and found no statistically significant difference between the 2 dosages.

Barr et al. (2009) undertook a systematic review on the efficacy of corticosteroid injection compared with physiotherapeutic interventions for tennis elbow using the

PEDro searching to the end of 2009. They identified 5 randomised controlled trials: Smidt et al. (2002), Bisset et al. (2006), Verhaar et al. (1996), Uzunca et al. (2007) and Tonks et al. (2007). Of interest is that this latest review did not include Halle (1986), as identified by Smidt et al. (2002) who compared injection with physiotherapy including ultrasound, transcutaneous electrical nerve stimulation, ice massage, tennis elbow cuff and advice and a degree of variation is evident in the assessed quality between the reviewers who used PEDro (Barr et al., 2009) and the Amsterdam-Maastricht, (Smidt et al., 2002 and van der Windt et al., 1999) validity scores; Verhaar et al. (1996) 7/10 compared to 5/12 respectively. They concluded that corticosteroid injections are effective in the short term and physiotherapy is effective in the intermediate through to the long term. However, they advise that due to the limited number of high quality RCTs and the differences in physiotherapeutic interventions conclusions must be interpreted with caution.

Smidt et al. (2002) conducted a robust randomised controlled trial in primary care. A good sample size of 185 patients with tennis elbow were randomly allocated to 3 groups: corticosteroid, physiotherapy or wait and see. Block randomisation was undertaken after prestratification for both duration +/-13 weeks and research centre and although acknowledged, despite randomisation, slight differences between the groups were apparent. The sample only included patients who were symptomatic for at least 6 weeks with a resultant range from 8-21 weeks and 25-40% of patients had had previous episodes of lateral elbow pain (greatest in the injection group). Although this was a pragmatic trial, between 14-29% of cases had concomitant neck disorders (greatest in the injection group) which questions the potential involvement of cervical referred pain and neurodynamics in the diagnosis,. All doctors received injection technique training and although 72 physiotherapists undertook the exercise training, such a large number has the potential to question the intercare provider reliability of technique. Three blinded assessors undertook all assessments and a reproducibility study found good to excellent agreement. The wait and see group were seen once by their GP for advice and if necessary paracetamol and naproxen were prescribed. The patients were then 'encouraged to await further spontaneous recovery'. The use of medication, although acknowledged, could influence the results and preclude the true picture of the natural history of tennis elbow. The injection group received a maximum of 3 injections, described as peppering every tender spot until resisted wrist extension was asymptomatic, using a 2ml volume of 1ml triamcinolone (10mg) with 1ml of 2%

lidocaine. A median volume of 0.9ml was used which equates to possibly only 0.45ml of triamcinolone being injected which equates to 4.5mg of triamcinalone. Saunders (2002) recommends using 0.25ml of kenalog 40, i.e.: 10mg triamcinalone. However, 27% of patients required 2 repeat injections and 15% required 3 injections. The physiotherapy group who received 9 treatments of 1:4 pulsed ultrasound (7.5 minutes of  $2\text{Wcm}^2$ ), deep transverse frictions and the Pienimaki exercise programme, (see Chapter 6.1.4.3 Physiotherapy rehabilitation, p.78 and Appendix 11.15, p.195) included a large number of variables. Also, it should be noted that only 9 treatments were given over 6 weeks whereas in clinical practice ultrasound would be given at a minimum of twice weekly. Outcome measures were recorded at baseline, 3, 6, 12, 26 and 52 weeks and included a modified pain-free function questionnaire, both pain-free and maximal grip strengths and pressure-pain threshold. They concluded that injection was the best treatment option in the short-term of 6 weeks with success rates of 92% for injection compared with 47% for physiotherapy and 32% for wait and see. The differences between the injection group and both the physiotherapy and wait and see groups were significant and clinically relevant. However, at intermediate (6 months) through to long term (1 year) physiotherapy, with a 91% success rate, was significantly more effective than injection, with a 69% success rate, and although more effective than wait and see, with a 83% success rate, the difference was not significant. These results were interpreted as wait and see combined with naproxen is probably the most cost effective treatment for patients with tennis elbow in the long term, although physiotherapy may be useful. However, a patient may argue that pain relief and ability to function without limitation in the short-term is equally of paramount importance for them as a year is a long time to wait with pain and disability associated with potential loss of economic productivity.

The cost effectiveness of corticosteroid injection, physiotherapy or wait and see from this trial was evaluated by Korthals-de Bos et al. (2004) and they reported that the difference in costs and effects showed no dominance and it was consequently difficult to decide which was the optimum treatment.

Bisset et al. (2006) undertook a randomised controlled trial which compared 10mg triamcinolone acetonide with 1ml 1% lidocaine injection plus a repeat injection after 2 weeks if required versus 8x 30 minute sessions over 6 weeks of elbow mobilisation with movement and exercise plus a home exercise programme using theraband and self

manipulation versus a wait and see group who were reassured that their tennis elbow would settle and received advice on activity modification; remaining active without pain aggravation, analgesia use, heat, cold and brace if needed. All patients received an information booklet outlining tennis elbow and advice on self management including ergonomics. 198 patients with symptoms of at least 6 weeks and who had not received any treatment within the past 6 months were recruited through advertisements and media releases and randomised into the 3 groups. Such recruitment methods could limit the generalisation of these findings although median duration was reported at 22 weeks. Outcome measures of severity of elbow complaint, pain severity, PFG, pain free function questionnaire and global improvement were recorded at 3, 6, 12, 26 and 52 weeks by blinded assessors. Through the use of an intention to treat analysis they found that injection was significantly better than both physiotherapy or wait and see and that physiotherapy was significantly better than the wait and see group in the short term at 6 weeks with a number needed to treat (NNT) of 3. However, at 12 through to 52 weeks physiotherapy was significantly better than injection. At 52 weeks there was no significant difference between physiotherapy and wait and see. They highlighted higher recurrence rates for injection and reported physiotherapy patients sought significantly less other treatment at 21%.

Verhaar et al. (1996) compared Cyriax physiotherapy, (12 sessions of deep transverse frictions and Mill's manipulation over 4 weeks), and 1ml 1% triamcinalone acetate with 1ml 1% lidocaine injection randomising a total of 106 patients, who were referred to the hospital with tennis elbow by their GP over the course of a year. Duration was for a mean of 33 weeks and mean treatments of 1 injection and 8 physiotherapy treatments were reported. Patients who had received up to 3 injections within the past 6 months were eligible as were those with concomitant cervical symptoms. The authors report that patients with cervical symptoms were more likely to be associated with a poor outcome which gives strength to the importance of accurate diagnosis and appropriate treatment accordingly. Outcome measures of pain severity, mean grip strength, resisted wrist and 3<sup>rd</sup> finger extension, local tenderness and patient satisfaction were assessed at 6 and 52 weeks, unfortunately, although acknowledged, not by an independent observer. An intention to treat analysis was used. They concluded that injection was significantly more effective at 6 weeks. However, by 1 year no significant differences were found.

Uzunca et al. (2007) compared 1cc methylprednisolone with 1cc prilocaine versus 15 sessions of pulsed electromagnetic field therapy (PEMF) over 3 weeks versus sham PEMF on 60 patients. Outcome measures of VAS with rest, activity, night and resisted wrist extension and supination were recorded at 3 and 12 weeks. They found VAS levels during activity and on resisted wrist extension were significantly better with injection compared to PEMF. Only pain levels on resisted wrist extension and supination were significantly better with PEMF compared to sham PEMF. At 12 weeks PEMF had better pain levels during rest, activity and night compared to injection although this was not significant.

Their 5th study reviewed was Tonks et al. (2007) which was research undertaken by the author preliminary for a Masters degree and continued after completion to increase power. It was a randomised controlled trial on 48 tennis elbow patients comparing a 10mg triamcinolone with 2% lignocaine injection versus Pienimaki exercise programme versus injection plus Pienimaki exercise programme versus no treatment. Outcome measures of PFG, patient rated forearm evaluation questionnaire and extensor weight strength were assessed at 7 weeks. Significant improvement in all outcome measures for injection only were found, for both efficacy and effectiveness, compared with physiotherapy only, injection plus physiotherapy and no treatment.

Bisset et al. (2007) combined the data set from Bisset et al. (2006) and Smidt et al. (2002) to analyse subgroup effects on treatment outcome. It must be noted that the 2 physiotherapy packages were not comparable with pulsed ultrasound, deep friction massage and exercise versus mobilisation with movement and exercise and the need for additional treatment was 81% and 21% respectively. The outcome measures used were global improvement, pain severity and PFG, although due to different instrumentation used for the latter it was converted to a percentage of the unaffected maximum grip strength which Stratford et al. (1993) reported does not correlate as highly as the raw scores. Unfortunately due to significant differences in the outcome measures at baseline, which could not be explained, only global improvement and pain severity were used for the analysis. At 6 weeks injection was reported to be significantly superior to both physiotherapy and wait and see and physiotherapy was superior to wait and see but by 1 year injection was significantly worse than both physiotherapy and wait and see. For pain severity physiotherapy remained significantly better than wait and see, although not a clinically important difference, but not for global improvement.

Bisset et al. (2007) evaluated subgroups, of manual, non-manual and non-workers, and at 6 weeks small effects of baseline pain severity on pain outcome were found; patients who presented with more severe pain were reported to not respond significantly better with physiotherapy than wait and see. A significant interaction was found for outcome for global improvement, at 1 year, with the success rate for injection reported as significantly worse when compared to wait and see for only non manual workers. The explanation for this remains in question with suggestions of a possible chance finding to both manual workers and non workers resting more. However, when the employment status is observed there is a higher percentage of non manual workers, at 45.5% of the whole, which would give this sub group the best chance of statistical power, which is one of the issues around low numbers in subgroup analysis. Alternatively, there could potentially be a higher incidence of concomitant neck and potential neurodynamic involvement with desk based non manual workers for which injection is unlikely to be beneficial. When the data is observed there is also a lower percentage, although not significant, for the non workers which may imply that manual workers are simply unable to work with tennis elbow and are subsequently more compliant with treatment than those which can continue with non manual work and activities of daily living. Or it could support the association of tennis elbow with the inability to acquire the typically greater wrist extensor strength in the dominant arm (Strizac et al., 1983) which both the non manual and non workers would be more likely to present with rather than the manual workers.

Gaujoux-Viala et al. (2009) also undertook a systematic review and a meta-analysis to evaluate the efficacy and safety of steroid injections for both shoulder and elbow tendonitis (64.3%) up to April 2008. From 218 papers 20 RCTs were identified with the data from 16 papers analysed for pain and 7, (3 elbow papers), for function. The tennis elbow trials included were Saartok et al. (1986), Price et al. (1991), Hay et al. (1999), Smidt et al. (2002), Lewis et al. (2005), Bisset et al. (2006) and Tonks et al. (2007). The pooled analysis found only short term efficacy for pain and function in favour of steroid injection versus control. In comparison at long term follow up no difference for pain was found and steroid injection was less effective than pooled other treatment for function in particular. The effect size (ES) for pain at 1-3 weeks was 1.18, 4-8 weeks 1.3, 12-24 weeks -0.38 and 48 weeks 0.07. The ES for function was 0.2, 0.66,-0.27 and 0.00 respectively. The ES is a standardised measure of change derived from dividing the mean change from baseline by the SD of the baseline values. An ES of 0.2 is considered

small, 0.5 moderate and 0.8 large or important and >1.2 as very large. They reported that steroid injections were more effective in acute or subacute, (< 12 weeks), tendonitis and concluded that the optimum timing for injection may be in the early weeks of symptoms. Safety was assessed using the number needed to harm, which is the number of patients treated to find an additional adverse event in the treatment group in comparison to the control group. They found that transient pain after 10.7% of injections was the main side effect and concluded that steroid injections are well tolerated with only minor and infrequent side effects. For non-steroidal anti-inflammatory drugs (NSAID) gastrointestinal upset was reported in 3.9%.

Lewis et al. (2005) studied pain intensity and medication use diaries of 164 patients with a new episode of tennis elbow during the 5 days following treatment of injection, naproxen or placebo. 95% of patients received their randomised treatment and good compliance was found with 92% of diaries completed. Although at baseline the injection group had both higher pain scores and medication use, with adjustment for baseline pain severity the pain scores were significantly lower in the injection group compared to placebo by day 3 and compared to naproxen by day 4. Post injection pain was evident in 62% of patients in the injection group although the mean pain score increase of 0.5 points was not significant and one would question any clinical importance. They concluded that post injection pain was modest and perceived as acceptable.

The latest systematic review and meta-analysis using pain scores evaluating the efficacy and safety of corticosteroids and other injections for tendinopathy was undertaken by Coombes et al. (2010). Of the 3824 hits identified from the search only 41 RCTs met the inclusion criteria of scoring >50% on a modified PeDro scale, of which 17 were for tennis elbow. The efficacy for tennis elbow was assessed by 18 analyses from 12 trials on 1171 participants: Saartok et al. (1986), Price et al. (1991), Haker and Lundeberg (1993), Hay et al. (1999), Verhaar et al. (1999), Newcomer et al. (2001), Okcu et al. (2002), Smidt et al. (2002), Bisset et al. (2006), Tonks et al. (2006) and Lindenhovius et al. (2008). They reported consistent findings from pooled data from 3 trials with sufficient homogeneity Smidt et al. (2002), Bisset et al. (2006) and Tonks et al. (2006) for pain relief with steroid injections favoured compared with no intervention for tennis elbow in the short term (0-12 weeks) with a standardised mean difference (SMD) 1.44. No intervention was favoured at intermediate term (13-26 weeks) SMD -0.4 and long

term (52 weeks) SMD -0.31. This was mirrored by the function analysis with SMDs of 1.5, -0.51 and -0.31 respectively. The SMD is the difference in mean effects between groups divided by the pooled standard deviation (SD). The injection data of Smidt et al. (2002), Bisset et al. (2006) and Tonks et al. (2006) was also analysed compared to physiotherapy: function SMDs of 1.29, -0.64 and -0.57 and pain SMDs of significant heterogeneity at short term, due to the array of different interventions used in the physiotherapy groups, -0.56 and -0.48. They also reported poorer outcomes with repeated steroid injections, mean of 4.3 injections with a range of 3-6 within 6 months than with a single injection. When injection was used in combination with either NSAIDs or physiotherapy, as is the norm in clinical practice, no differences in effect were reported with these cointerventions. In comparison, non corticosteroid injections, such as sodium hyaluronate may be of benefit for tennis elbow treatment in the long term with a short term SMD 3.91, intermediate SMD 2.89 and long term SMD 3.91 when compared to placebo.

Newcomer et al. (2001) assessed the efficacy of 5ml of a 4:1 mix of 0.25% marcaine with 6mg betamethasone injection or sham injection (5ml 0.25% marcaine) in combination with rehabilitation in a double blind study on 39 patients. Rehabilitation included instruction in ice massage, avoidance of activities and a progressive concentric and eccentric strengthening programme for both wrist flexors and extensors. Due to the evidence of spontaneous recovery, particularly with patients with such a short duration of symptoms, it is questionable whether a local anaesthetic injection and rehabilitation is a true control. Equally an injection of 5ml is atypical of the injections given in U.K. clinical practice. Unfortunately, the sample size was small and only included patients with acute tennis elbow with durations of less than 4 weeks which would lead to limited generalisation of the findings. This was further exacerbated due to the recruitment by word of mouth and advertisement in local health and racquet clubs which has the potential to increase the proportion of sport related cases above the generally accepted 5-8%. Patients were stratified by age and sex before randomisation. Outcome measures of VAS, functional pain questionnaire and painless grip strength were recorded at 4 and 8 weeks although the long term 6 month data collection was only by telephone and excluded the objective measure. Baseline characteristics appeared homogenous and an intention to treat analysis was undertaken. They reported no significant differences in outcome up to 6 months, with the exception of a significant reduction in the pain VAS from 8 weeks to 6 months in the experimental group. As acknowledged, this result is in

contrast to the conclusion drawn from the systematic review (Smidt et al. 2002) that corticosteroids are superiorly effective in the short term. These results could potentially be attributed to the drugs used or to the risk of a Type II error having occurred. Subsequently, they highlighted a need for the study to be repeated with a more chronic sample and that injection with or without rehabilitative therapy is needed to address the efficacy of injection +/- rehabilitative therapy. Two trials are currently underway to evaluate whether the addition of physiotherapy as a co-intervention can reduce the high rate of recurrence associated with injection alone (Coombes et al., 2009 and Olausson et al. 2009).

#### **3.4.1.1: Therapeutic effects of injection on tissue healing**

Corticosteroid injections only known mechanism of action to relieve pain and diminish disability is by a reduction in inflammation (Cyriax, 1984). Other mechanisms of pain relief by corticosteroids have not been established (Speed, 2001) although it has been suggested to be attributed to alteration in noxious chemical release and their subsequent effect on nociceptors (Paavola et al., 2002). Due to the proven positive effect of both anti-inflammatory drugs and potent anti-inflammatory corticosteroid injections and furthermore, that injection therapy has been proven to be the best treatment option in the short-term for tennis elbow patients with success rates of 92% (Smidt et al., 2002) one is left with a clinical dilemma due to the lack of an inflammatory pathology. Of equal consideration is the suggestion that corticosteroid injections inhibit collagen and ECM production (Paavola et al., 2002) which may be in part responsible for the high recurrence rate found in tennis elbow.

It has been suggested that the mechanical disruption caused by the injection itself, regardless of the chemical used, may transform a failed intrinsic healing process into an extrinsic response. However, this is challenged by Price et al. (1991) who undertook a two-phased double-blinded study as previously discussed. They reported that both 10mg triamcinalone and 25mg hydrocortisone, made up to 2ml with 1% lignocaine, injections were statistically significantly better than lignocaine alone.

Although the chemical injected must have the potential to modify the pathological process of the tendon, it remains questionable whether a chemical could fully restore

functional quality as this is interdependent with the forces delivered to the tendon. More recently, it has been hypothesised that corticosteroids shut down protein synthesis (Riley, 2010) and this would support the theories which suggest that overuse conditions, such as tennis elbow are a mismatch between degrading and synthesis biochemical processes.

### **3.4.2: Ultrasound**

Ultrasound is the most commonly used treatment modality used by physiotherapists (Watson, 2008). Greenfield and Webster (2002) surveyed the treatment of chronic lateral epicondylitis in Scotland of 120 physiotherapists with an 80% response rate. They found 74.2% always or frequently use ultrasound for this condition with 44.2% using pulsed and 30% using continuous.

Ultrasound is the application of mechanical vibration energy at a higher frequency than sound to the target tissue. The vibration causes a pressure wave with high and low pressure areas which causes tissue molecules to oscillate and generate heat. In addition to this thermal component there are important non-thermal effects. As the wave passes through the tissue the energy of the wave itself attenuates as energy is transferred to the tissue.

All tissues present impedance to sound waves causing reflection at boundary interfaces with 99.9% reflected at the steel ultrasound transducer/ air interface. To minimise this a gel-based coupling medium is utilised in clinical practice. Furthermore, refraction can also occur if the wave does not penetrate the boundary surface at  $90^{\circ}$ . At the skin interface the critical angle is approximately  $15^{\circ}$ , i.e.: if the transducer head is at an angle  $>15^{\circ}$  to the skin surface the majority of the ultrasound wave will be refracted parallel to the skin surface rather than reaching the target tissue. The radiating area is the surface area of the ultrasound transducer head through which ultrasound is delivered and due to application with the transducer in motion the area of application can be increased by varying degrees. For example, 2x the effective radiating area (2x ERA) would be applying ultrasound over an area of slightly less than twice the size of the ultrasound transducer.

The available modes on therapeutic ultrasounds are pulsed or continuous and selection is dependent on the current state of the target tissue. After the acute state tissues appear to respond more favourably to concentrated energy delivery (Watson, 2006).

Similarly, the intensity in  $W/cm^2$  is dependent on the current state of the target tissue. More chronic conditions require a greater intensity to stimulate a physiological response. Furthermore, energy absorption by other tissues through which the ultrasound travels to reach the target tissue needs to be taken into consideration. This means that to deliver sufficient energy to achieve the therapeutic response in the target tissue a higher intensity will need to be delivered at the skin surface. However, as the tenoperiosteal junction of ECRBr is superficial this effect will be negligible. Demmink (2007) reported that for 3MHz continuous ultrasound induced heat therapy can only exist with settings of  $>1W/cm^2$  from thermal image analysis of pig cadaver hind leg. Enwemeka (1989) reported that the tenotomised rabbit achilles tendon had a significantly larger cross-sectional area and tensile strength and energy absorption capacity than controls which suggests a higher collagen content following the use of 5 minutes of 1MHz continuous ultrasound at  $1W/cm^2$  given daily for 9 consecutive days.

The available frequencies are 1 or 3MHz and the selection is dependent on the depth of the target tissue in relation to half-value depth, i.e.: the depth at which 50% of ultrasound energy is absorbed. The half-value depth of 1MHz is 2.5cm and 0.8cm for 3 MHz (Draper et al., 1995). Therefore, for superficial lesions (i.e.: 0.8 to 1.6cm depth), such as tennis elbow, 3MHz ultrasound is more rapidly absorbed and is subsequently the effective frequency of choice. With the use of 1MHz the half-value is greater and is therefore more suitable for deeper structures requiring a greater penetration. However, all the tennis elbow studies included in van der Windt et al.'s (1999) systematic review of ultrasound utilised 1MHz. The reason for this, according to Draper and Picard (1995), was that prior to 1994 ultrasound treatment parameters had not been established and the 'newer' 3MHz frequency had not been researched. The only study published after this date was Pienimaki et al. (1996). Furthermore, when 3MHz is used, as more of the energy is absorbed in the superficial structures, little energy reaches the bone and subsequently a higher intensity can be used with this frequency to bring about the desired temperature increase without additional risk (Draper et al., 1995). This may be the reason all 3 studies had to use pulsed ultrasound to limit the energy reaching the bone and allow heat dissipation to prevent both periosteal pain during treatment and

potential damage and furthermore, this has the potential to account for the limited efficacy of ultrasound in these studies.

Large or small treatment heads are available and as the target tissue area in tennis elbow is only small in size the small 0.5cm<sup>2</sup> transducer is appropriate; see figure 6.2 (p. 78) for a photograph illustrating the clinical application of ultrasound. Haker and Lundeberg (1991) used a 5cm<sup>2</sup> transducer which would pose a difficulty to maintain the correct angle to the skin interface in order to deliver ultrasound to the small anterolateral facet of the lateral epicondyle and prevent the majority of the ultrasound wave being reflected parallel to the skin surface rather than reaching the target tissue.

A systematic review on ultrasound was undertaken by van der Windt et al. (1999) who identified 6 studies on lateral epicondylitis. All 3 placebo-controlled studies obtained a relatively high validity score, from 2 independent reviewers using the Amsterdam-Maastricht Consensus list for Quality Assessment, and were found to be clinically homogenous. Statistical pooling of these three studies found a pooled estimate for the difference in success rate of 15% and NNT of 7, which could be considered of some importance. Due to the inconsistent results it was concluded that there is weak evidence in favour of ultrasound for tennis elbow.

Binder et al. (1985) was the only study to report statistically significant and clinically important results in favour of ultrasound. They evaluated the efficacy of pulsed ultrasound over placebo in 76 lateral epicondylitis patients. Although equal numbers were assigned to each group by an external therapist the randomisation method was not stated. Those in the active ultrasound group received 1:4 pulsed 1 MHz at 1-2W/cm<sup>2</sup> for 5-10 minutes and the placebo received sham ultrasound of which the procedure was unclear. Both treatments were set by an external person ensuring that both patients and therapists remained blinded to treatment. However, the procedure for increasing intensity was not stated. All patients received 12 treatments over 4-6 weeks with follow up at 8 weeks and 12 months. They found a statistically significant improvement greater in the ultrasound group (63% significantly improved) over the placebo group (29%) for grip strength and pain score.

Haker and Lundeberg (1991) also evaluated the efficacy of pulsed ultrasound over placebo but in only 45 lateral epicondylitis patients. Eligibility criteria were appropriate

and although randomised the procedure was unclear. Baseline characteristics were similar in both groups. Those in the ultrasound group received a total of 10 treatments of 1:4 pulsed 1 MHz at  $1\text{W}/\text{cm}^2$  using a  $5\text{cm}^2$  transducer for 10 minutes at a frequency of 2-3x a week and the placebo received sham ultrasound. By using an identical machine which gave sham ultrasound both patient and therapists remained blinded. Follow up was at 3 and 12 months. Outcome measures were isometric pronation and supination in 90 degrees elbow flexion, vigorimeter test to evaluate PFG through a ratio of the affected to the unaffected arm and a lifting test. They found no statistically significant difference between ultrasound and placebo.

Lundeberg et al. (1988) reported on 99 patients who were randomly allocated to 3 groups: continuous ultrasound, placebo ultrasound and rest. The randomisation and treatment allocation procedure was unclear. Those in the ultrasound group received a total of 10 treatments of continuous 1 MHz at  $1\text{W}/\text{cm}^2$  over 5-6 weeks and the placebo received sham ultrasound. Follow up was at 6 weeks and 3 months. A significant difference was found between ultrasound and placebo for pain, on a VAS at 3 months, but not for global improvement or maximum grip strength. A significant difference was found between ultrasound and rest. As will be discussed in chapter 3.5.2 maximum grip strength is not as sensitive to change as PFG.

One of the reasons that tennis elbow was the only injury to have some weak evidence base may be attributed to the fact that different tissues absorb ultrasound to varying degrees with the denser collagen based tissues, such as tendon, being excellent absorbers of ultrasound (Watson, 2008). When the treatment parameters for the 3 high quality studies are considered the only difference between the positive outcome of the Binder et al. (1985) study was that it utilised an increased intensity up to  $2\text{W}/\text{cm}^2$ , although due to the pulsing this would be reduced markedly.

Bisset et al.'s (2005) systematic review pooled the global improvement data at 3 months for Haker and Lundeberg (1991) and Lundeberg et al. (1988). They reported no difference between ultrasound and detuned ultrasound with a relative risk of 1.01 although Lundeberg et al. (1988) found significant pain reduction at 3 months with ultrasound when compared to placebo.

Smidt et al.'s (2003) systematic review pooled the intermediate outcome data from Binder et al. (1985) and Lundeberg et al. (1988) and reported a large effect size (SMD-

0.98) for pain in favour of ultrasound over placebo but concluded that there was insufficient evidence to favour ultrasound compared to other interventions.

### **3.4.2.1: Therapeutic effects of ultrasound on tissue healing**

The process of tissue repair is a complex series of chemically mediated consequences for which therapeutic ultrasound is pro-inflammatory by acting as an 'inflammatory optimiser'. It has been proposed that the main effect of ultrasound on an injured tissue is to stimulate and increase the efficiency of the normal healing process and enhance the quality of repair (Watson, 2008). The therapeutic effects can be considered to be either thermal or non-thermal in nature. Although both therapeutic effects will be utilised concurrently with any ultrasound treatment the specific parameters will influence which may dominate.

The mechanical disturbance caused by the pressure wave is responsible for the non thermal effects of ultrasound of stable cavitation and acoustic streaming. Stable cavitation is the formation of gas bubbles in a fluid which vibrate and acoustic streaming is the unidirectional movement of the fluid which causes high velocity gradients to develop between the fluid and bubbles or cells. Both these result in a change in cell permeability through modification of the cell membrane potential and transport mechanisms which have the therapeutic effects of alteration of the release of the cell contents, vascular permeability, local blood flow, angiogenesis, protein synthesis and collagen content and alignment.

To effectively utilise the thermal effects a relatively high intensity in continuous mode is required and will have a greater efficacy in denser collagen based tissues such as tendon. Historically, it was generally accepted that a biologically significant thermal effect could be achieved if the temperature of the tissue was raised between 40-45<sup>0</sup>C for at least 5 minutes (Kitchen, 2002). However, little research has been able to achieve this temperature range with ultrasound. This may be explained as the original research was undertaken on anaesthetised animals or cadaver tissue samples which could be heated to greater temperatures due to a lack of pain sensitivity or vasomotor control to maintain homeostasis. More recent research of ultrasound on in vivo human tissue proposes that therapeutic thermal effects can be attained with a 1-4<sup>0</sup>C increase from baseline; mild

heating ( $1^{\circ}\text{C}$ ) to treat mild inflammation through an increase in metabolism, moderate heating ( $2\text{-}3^{\circ}\text{C}$ ) to increase blood flow, reduce muscle spasm, pain and chronic inflammation and vigorous heating ( $\geq 4^{\circ}\text{C}$ ) to inhibit sympathetic activity and decrease collagen viscoelasticity (Draper et al., 1995). The intensity to achieve this varies from  $1\text{-}2\text{W}/\text{cm}^2$  constant (Michlovitz, 1986). It has been found that the temperature stabilises once it has been raised to between  $39$  and  $41^{\circ}\text{C}$  and this has been proposed to be due to the cooling effect of the increased blood flow to the area (Bishop et al., 2004).

In an in vivo study (Draper et al., 1995) of 24 asymptomatic college students two thermistors were inserted in the medial triceps surae: at  $2.5$  (half-value depth) and  $5\text{cm}$  depths for half the subjects who received  $1\text{MHz}$  and at  $0.8$  (half-value depth) and  $1.6\text{cm}$  for those who received  $3\text{MHz}$ . Each subject received 4 treatments of continuous ultrasound using a  $5\text{cm}^2$  transducer at  $0.5$ ,  $1.0$ ,  $1.5$  and  $2\text{W}/\text{cm}^2$  for 10 minutes. They found after treatment, for all doses, at the half-value depth ( $0.8\text{cm}$ ) at  $3\text{MHz}$  the heating effect was nearly  $4\text{x}$  greater than at the half-value depth ( $2.5\text{cm}$ ) at  $1\text{MHz}$ . Furthermore, 3 minutes of  $3\text{MHz}$  at  $2\text{W}/\text{cm}^2$  ultrasound was required to raise the temperature by  $4^{\circ}\text{C}$ , regardless of depth of tissue, although only measured at  $.8$  and  $1.6\text{cm}$  depths, for  $2\text{x}$  ERA.

Draper and Picard (1995) went on to undertake the first in vivo study measuring temperature cooling following ultrasound to determine the stretching window, i.e.: the time period when tissues are vigorously heated. The temperature was measured at 30 second intervals using a thermistor inserted  $1.2\text{cm}$  deep into the medial triceps surae of 20 subjects.  $3\text{MHz}$  ultrasound at  $1.5\text{W}/\text{cm}^2$  with a  $2\text{x}$  ERA was received until the temperature increased by  $5^{\circ}\text{C}$ . They reported that the temperature was raised an average of  $5.3^{\circ}\text{C}$  above baseline in an average of 6 minutes and it took  $18 \pm 3.5$  minutes for the temperature to return to baseline. Interestingly, the temperature continued to cool an average of  $0.8 \pm 0.56^{\circ}\text{C}$  until it stabilised after approximately 25 minutes. Using a step-wise nonlinear regression analysis temperature decay as a function of time was predicted. They concluded that through the use of ultrasound when the tissue temperature is increased by  $5^{\circ}\text{C}$  stretching will be effective for an average of 3.3 minutes. When stretch is continued after heating the greatest lasting increase in tissue length occurs due to reorganisation of the collagen during cool down.

Another in vivo study (Hayes et al., 2004) of a repeated measures design compared continuous 1 and 3MHz ultrasound at  $1.5\text{W}/\text{cm}^2$  with sham using a  $5\text{cm}^2$  transducer applied to an asymptomatic medial calf. Temperature was taken at 10 second intervals for 10 minutes unless the temperature stabilised for 1 min,  $40^{\circ}\text{C}$  was reached or the treatment became uncomfortable, using a thermocouple implanted at 2.5cm. Although they found 1MHz did not produce vigorous heating during the 10 minute treatment, 3MHz produced a  $4^{\circ}\text{C}$  increase at a mean of  $3.35\pm 1.23$  minutes and an increase to  $40^{\circ}\text{C}$  at a mean of  $4.13\pm 1.69$  minutes at a depth of 2.5cm. These results suggest that 3MHz can potentially heat 0.5cm deeper than previously theorized. This study also reported that 3MHz ultrasound at  $1.5\text{W}/\text{cm}^2$  had to be applied for 2 minutes before the temperature increased at a depth of 2.5cm in comparison to sham ultrasound which did not show any temperature increase over a 10 minute treatment.

Of the little research available on the therapeutic effects of ultrasound on human tendon, an important paper researching the patellar tendon is by Chan et al. (1998) Sixteen normal college students received 3MHz continuous ultrasound at  $1\text{W}/\text{cm}^2$  using a  $5\text{cm}^2$  transducer at 2x ERA and 4x ERA. Using a thermistor inserted into the medial aspect of the patellar tendon the temperature was recorded every 30 seconds during and for 20 minutes after the 4 minute treatment. The 2 ERA treatment increased  $8.3^{\circ}\text{C} \pm 1.7^{\circ}\text{C}$  compared to the 4 ERA treatment  $5.0^{\circ}\text{C} \pm 1.0^{\circ}\text{C}$  over the 4 minute treatment. A significant difference in the rate of temperature increase during treatment and decrease for the first 5 minutes after treatment between treatment size was found ( $p<.001$ ). Furthermore, 50% of tendons had not returned to their baseline temperature after 20 minutes. They also compared their study with that of Draper et al. (1995) on the gastrocnemius muscle and found that, for the 2 ERA, tendon has a 3.45 faster rate of temperature increase than muscle. Furthermore, vigorous heating was sustained for 120% longer than muscle giving a 4 minute stretching window.

Using the rate of heating proposed by Draper and Picard (1995) using the parameters used by Binder et al. (1985) of 1MHz at  $2\text{W}/\text{cm}^2$  which with 1:4 pulsed would reduce to  $0.5\text{W}/\text{cm}^2$  the tissue would be heated at  $0.04^{\circ}\text{C}$  per minute and would therefore increase the tissue temperature by  $0.4^{\circ}\text{C}$  over a 10 minute treatment. However, as the research by Draper and Picard (1995) was undertaken on muscle and Chan et al. (1998) not only found tendon to have a 3.45 faster rate of temperature increase but also that heating is sustained longer in tendon than for muscle it can be postulated that the treatment

parameters used by Binder et al. (1985) had the potential to increase the temperature by  $1.38^{\circ}\text{C}$  which could utilise the thermal effects of ultrasound through mild heating.

However, the model only researched down to an intensity of  $0.5\text{W}/\text{cm}^2$  and the treatment parameters used by Haker and Lundeberg (1991) of 1 MHz at  $1\text{W}/\text{cm}^2$  which with 1:4 pulsed would reduce to  $0.2\text{W}/\text{cm}^2$  for 10 minutes is unlikely to have utilised a thermal effect and possibly explain the lack of a statistically significant difference between ultrasound and placebo.

But in contrast, if the treatment parameters of Lundeberg et al. (1988) of continuous 1 MHz at  $1\text{W}/\text{cm}^2$  are considered this had the potential to increase the temperature at a rate of  $0.2^{\circ}\text{C}$  which over 10 minutes gives a potential temperature increase of  $2^{\circ}\text{C}$  which would utilise the thermal effects of ultrasound through heating. However, only a significant difference was found between ultrasound and placebo for pain (VAS) not global improvement or maximum grip strength and a significant difference was found between ultrasound and rest.

However, Watson (2008) argues that over the past 15 years the non-thermal effects are more effective as ultrasound is 'relatively inefficient at generating sufficient thermal change in the tissues to achieve this therapeutic effect when applied at commonly applied clinical doses'. He quotes Garrett et al. (2000) who measured temperature, at minute intervals until it returned to baseline after treatment, using 3 thermistors at 5cm intervals implanted at a depth of 3cm into the medial triceps surae on 16 healthy subjects. This study compared treatments of 20 minutes of continuous 1MHz ultrasound at  $1.5\text{W}/\text{cm}^2$  over 40x ERA, (the size of the diathermy drum), with pulsed shortwave diathermy. They found that diathermy heated the calf muscle significantly more than ultrasound and that return to baseline took  $14.88 \pm 4.7$  minutes for ultrasound compared to  $38.50 \pm 6.61$  minutes for diathermy. They concluded that in heating a large muscle mass pulsed shortwave diathermy was more effective than 1MHz ultrasound and resulted in the muscle retaining heat for longer.

However, one would challenge that it is highly unrealistic in clinical practice to ultrasound an area as large as  $200\text{cm}^2$  as in the Garrett et al. (2000) study and also that this study used 1MHz whereas 3MHz has greater heating at half depth than 1MHz. Also, this was undertaken on healthy muscle when it is known that tendon, absorbs

ultrasound more efficiently whereas pulsed short-wave diathermy is more preferentially absorbed in wet, low resistance tissues and therefore most effective in muscle. Furthermore, from Chan et al. (1998) there is a significant difference in the rate of temperature increase during treatment and decrease for the first 5 minutes after treatment between treatment size in favour of 2x ERA over 4x ERA, 50% of tendons had not returned to their baseline temperature after 20 minutes, that for the 2 ERA tendon has a 3.45 faster rate of temperature increase than muscle and vigorous heating was sustained for 120% longer than muscle. Indeed in the discussion of Garrett et al. (2000), they quote Chan et al. (1998) as substantiating ultrasound recommendations of only treating a maximum area of 2-3x larger than the transducer which would result in vigorous heating. So one should argue that ultrasound for large muscle areas is clearly less effective than pulsed shortwave diathermy, rather than labelling ultrasound, for all conditions *carte blanche*, an ineffective modality to achieve therapeutic thermal effects.

### **3.4.3: Exercise therapy**

The primary complaint of tennis elbow is pain limited function (Vicenzino and Wright, 1996). The priority of treatment is to control the pain and subsequently enable earlier rehabilitation of the deconditioned musculature (Speed, 2001). Once the pain has been addressed a strengthening and flexibility programme is recommended (Burgess, 1990). The review by Noteboom et al. (1994) proposed that this is a fundamental element in rehabilitation in order to provide controlled stresses to facilitate appropriate tissue remodelling. They suggested starting early rehabilitation through a pain free, low load and high repetition programme.

From the Greenfield and Webster (2002) survey on the treatment of chronic lateral epicondylitis in Scotland 75.8% of physiotherapists always or frequently use progressive strengthening exercise for this condition and 88.8% use progressive stretching exercise.

Research findings have also been indicative of the therapeutic value of stretching. Post exercise stretching has been hypothesised to be advantageous in both the reconditioning of muscles and assisting desensitisation of painful soft tissues (Vicenzino, 2003).

Although it is generally accepted that patients with tennis elbow usually present with unlimited joint range of movement (Chard and Hazleman, 1989), inadequate forearm muscle flexibility is thought to be a contributory factor in patients with tennis elbow. Solveborn and Olerud (1996) researched the elbow and wrist range of movement of 123 patients with tennis elbow using a goniometer. An intratester reliability study had previously established the precision of the measuring technique. They reported that wrist flexion, pronation and elbow extension were the most reduced range of movements, which all affect the wrist extensor length. As the dominant arm tends to be stronger and subsequently less flexible this may be partially responsible for the reason that the dominant arm is more frequently affected.

A systematic review and meta-analysis on physiotherapy for tennis elbow (Bisset et al., 2005) found only one study specifically evaluating an exercise programme that satisfied the quality criteria. Pienimaki et al. (1996) reported the superior efficacy of a pain free progressive strengthening and stretching exercise programme compared to pulsed 1: 5 MHz ultrasound at 0.3- 0.7 Wcm<sup>2</sup> over a 5cm<sup>2</sup> radiated area for 10- 15 minutes 2-3x a week for 6-8 weeks. It should be noted that with the use of these parameters utilisation of the therapeutic thermal effects of ultrasound is improbable. The sample was 39 patients, referred by their GP, who presented with tennis elbow for over 3 months who had failed to respond to treatment. Pertinent eligibility criteria were stated and the patients were randomly allocated, by drawing lots, to the exercise or ultrasound group which were fairly well matched despite being relatively small. The exercise programme was clearly stated and shown in a series of photographs to support explanation and was supervised by the same physiotherapist throughout. However, several physiotherapists undertook the ultrasound treatments. Due to the nature of the treatment interventions neither the patients nor therapists could be blinded. Outcome measures were a pain and disability questionnaire, maximum isometric grip strength and isokinetic muscle performance. An independent and blind physiotherapist assessed the muscle function. They concluded that the exercise programme was significantly better than ultrasound in both subjective and objective outcomes in the short term of 6-8 weeks. Bisset et al. (2005) reported a SMD of 0.97 for pain, as supported by Smidt et al. (2003), but no significant difference was found for grip strength, which may be due to maximum grip strength being used as an outcome measure instead of PFG.

Pienimaki et al. (1998) evaluated long-term efficacy, at a mean of 36 months, by following up 30 of these patients. 23 patients responded to a well-structured retrospective postal questionnaire and they found that the exercise group patients showed beneficial long-term effects compared to those in the ultrasound group. They reported that there was no significant change in pain level at 36 months compared to at the end of the original treatment, at 6-8 weeks, in either group. They concluded that a stretching and strengthening exercise programme may prevent chronicity. It was interesting to note that, in contrast to the majority of studies on tennis elbow, that the proposed self-limiting nature of tennis elbow was not evident in this sample during the 36 month follow-up. However, as the data of only 23 out of a population of 39 patients was evaluated the possibility of a selective sample, with reduced power and an increased risk of bias needs to be considered.

Eccentric exercise programmes have also been advocated following their success in research on the achilles tendon in particular. As previously discussed, extrapolation from this research should not be undertaken due to the inherent differences between the two conditions. In addition, the higher muscle tension developed during eccentric exercise is thought to be the primary cause of tendon failure (Croisier et al., 2001). It may be that these exercise programmes are beneficial in the more advanced phases of strengthening (Kraushaar and Nirschl, 1999). However, a systematic review concluded that there was insufficient evidence to support eccentric exercise when compared to concentric exercise for tennis elbow (Woodley et al., 2007).

#### **3.4.3.1: Therapeutic effects of exercise on tissue healing**

The cyclical tensile loads through controlled low impact repetitive exercise therapy in addition to stretching may instigate reorganisation of collagen and up regulate synthesis of type I collagen in particular. This will modify both the mechanical and viscoelastic properties of the tendon, reduce stress and make it more load resistant. Furthermore if the biochemical hypothesis for pain is considered, collagen repair would rebalance the biochemical milieu and promote pain relief (Khan et al., 2000).

Although there is no clear relationship between type of training and adaptive responses of collagen synthesis, in equine extensor tendon subjected to low-level repetitive stress

a higher level of collagen was found when compared to flexor tendon subjected to high stress. This suggests the importance of intensity and loading patterns on extracellular matrix adaptation. An increase in cross-sectional area and collagen content with an increase in both the load-deformation and stress-strain properties of swine digital extensor tendons supports that training improves both structural and mechanical properties of tendon. However it should be noted, that due to the specificity of tendons extrapolation to ECRBr may not be definitive. Of equal importance is that due to the variable vascularity and cross-sectional area found along the length of a tendon adaptation due to training of a tendon is region specific (Kjaer, 2004).

### **3.5 Outcome measures**

On review of the literature it was apparent that a wide array of outcome measures has been used for research on tennis elbow; including general improvement (Smidt et al., 2002), maximum grip strength (Newcomer et al., 2001), PFG (Haker and Lundeberg 1991), VAS (Uzunca et al., 2007), questionnaires (Bisset et al., 2005), tenderness (Hay et al., 1999), resisted wrist extension (Verhaar et al., 1996) and isokinetic muscle performance testing (Pienimaki et al., 1996). Most randomised controlled trials on tennis elbow and the efficacy of physiotherapy have consistently used pain scores and grip strength (Smidt et al., 2002), rather than measures of temperature and muscle function which would be more directly relevant to current conservative treatment. The availability of thermography and surface EMG as outcome measures will enable a more robust trial providing details which are directly clinically relevant to the reported increases in temperature and reduced muscle function in this patient group.

To ensure the internal validity of this study the outcome measures needed to be both reliable and valid in addition to be sensitive to change with the minimal clinical important difference identified. Validity is the extent an outcome measures what it purports to measure and reliability is the extent of consistency and reproducibility of the values measured with repeated use under the same conditions.

### 3.5.1 Thermography

This primary outcome measure was selected to enable a more robust trial providing details which are directly clinically relevant to the debate on whether inflammation is an integral part of the pathogenesis of this patient group and the action of steroid injection therapy.

Thermography measures the cutaneous infrared heat emission from the body which is a function of subcutaneous perfusion. The thermal camera converts the infrared energy into a visible digital image, the thermogram, which maps the temperature distribution of the area in question.

The skin is an important thermoregulatory organ with an extensive microcirculation and consequently vascular changes in the skin are the most accessible to analyse inflammation. Through the use of thermography precise non contact skin surface temperature (*T<sub>sk</sub>*) measurement can be determined. Non contact *T<sub>sk</sub>* is advantageous due to the avoidance of potential heat transfer from the instrumentation itself leading to spurious data (Magdeburg et al., 1986). Subsequently, this measurement tool has the ability to monitor underlying inflammatory processes and evaluate the efficacy of interventions in superficial structures such as tendons. Infrared thermography is a valuable technique for the diagnosis of tennis elbow (Haake et al., 2002). The relationship between increased temperature and tenderness in tennis elbow has been reported with patients with hotspots having a 9-fold risk for a pressure pain threshold <2.5kg and a 1.3-fold risk of pain development on resisted wrist extension (Ammer, 1995). Thomas et al. (1992) reported infrared thermography as a 'sensitive, objective investigational procedure for the assessment of tennis elbow'. There is high precision of the visualisation of inflammatory changes and frequently changes in temperature are one of the earliest symptoms of a pathological process (Jung and Zuber, 1998).

The degree of heat emission is associated with skin vascularity, cellular metabolism and subcutaneous adipose tissue with the latter effectively acting as an insulator impeding any potential heat transfer. The sympathetic nervous system is the controlling mechanism for dermal microcirculation and thermal emission. The dermal vessels are maintained in a constricted state by vasomotor tone which inhibits heat loss from the

higher core temperature. Decreased sympathetic function would increase thermal emission due to vessel vasodilation due to receptor fatigue, on account of excessive release of a vasoactive substance such as substance P for example (BenEliyahu, 1990). In addition, substance P is a neurotransmitter associated with sensory afferent pain signals.

The mechanisms for the generation of hotspots include: increased blood flow, potential vasodilative chemicals or transient substances and neurotransmitters (Ammer, 2008). When inflammatory reactions are present hyperthermic images are evident whereas in comparison degenerative processes reveal hypothermic images (Garagiola and Giani, 1990). In overuse injuries such as tennis elbow there is a contemporaneous presence of inflammatory reaction and degenerative process with hyperthermy found when the inflammatory reaction predominates.

Hotspots are considered diagnostic of tennis elbow (Ammer, 2008) although the reliability of hotspot identification is poor. Ring et al. (2005) reported that there is poor reproducibility, even intraoperator, with the usual practice of rectangle selection or free drawing of the region of interest (ROI). However, very good reproducibility was reported, both intra and interoperator, when described anatomical landmarks were used to draw a ROI. Subsequently, to reduce interoperator variability to a minimum a protocol using a defined ROI based on anatomical limits is required (Ring, 2002). Even so, frequently the specific point location is determined on the thermal image itself, of which the accuracy of specific landmark detection is brought into question due to inadequate clarity of the thermal image. Subsequently, Selfe et al. (2006) developed an anatomic marker system which was reported as an accurate and reliable method for thermal data analysis. The advantage of this system are that the landmarks are identified on palpation, which is patient specific taking in account for variation in individual size and anatomy.

Pizzetti et al. (1984) treated 31 upper limb tendonitis patients with 8 daily 15 minute sessions of laser and compared pre and post treatment thermal images. Although the authors state that they directed their attention to tennis elbow, unfortunately the actual number of patients with tennis elbow was not reported. Similarly, the robustness of the thermal analysis also comes into question: by using the same colour gradient scale the normal and affected limb were compared and they consistently found 'a different

thermal gradient corresponding to the areas of greatest pain'. Using descriptive reports of visual thermal patterns is highly subjective. They reported a direct relationship between the state of tendon inflammation, acute versus chronic, and thermal image, i.e.: acute tennis elbow can be distinguished from chronic tennis elbow:  $T_{sk}$  +1.5 to 2 °C higher compared to 0 to + 0.5 °C respectively. The thermography was undertaken in a standardised environment and although time was allowed for acclimatisation, the standardisation of potential confounding variables such as smoking, alcohol, caffeine and physical exercise were not alluded to. The mean age of the patients in this study was 30 years and no indication of duration of symptoms is given. The authors state that most patients had received other forms of treatment including injections and comment that 70.9% of patients were playing tennis after the course of treatment. As a mean of 30 years of age is lower than would be expected in a typical tennis elbow patient one has to question the generalisation of these findings to the tennis elbow population as a whole. Unfortunately, although this paper was translated, a lack of reported detail is evident and the robustness of the protocol of thermographic analysis is brought into question.

Binder et al. (1983) studied 56 tennis elbows from 50 patients who were reported as fairly representative of a typical tennis elbow population and 60 age and sex matched normal controls. Clinically, severity was assessed using 5 parameters: localised tenderness, pain on resisted wrist dorsiflexion, supination/pronation and ability to lift different weights on a scale of 1 to 3 and grip strength. Thermographic analysis was taken initially and at 6 weeks/ or earlier on discharge. A 15 minute stabilisation period was carried out but no attempt to standardise potential confounding patient variables was reported. This lack of detail was accentuated throughout the paper. The method of data collection was to centre a box, of constant size, over the abnormal area and then move it medially so that one side of the box dissected the centre of the abnormality to calculate the slope and distance of the thermal gradient. One may question the specificity of this procedure of  $T_{sk}$  of the ROI data collection. They found a discrete localised hotspot (1-3°C) in 53 out of 56 tennis elbows and 3 out of 120 normal subjects. Of interest they also found that 30% of patients had a hot spot near the unaffected lateral epicondyle and 2 of these 16 patients developed pain at a later date. The authors postulated that this may be due to increased use so as to protect the symptomatic arm or an 'underlying susceptibility' in these patients to tennis elbow. This adds support to an additional potential variable for thermal image data analysis if one compares the affected with the unaffected elbow.

Thomas et al. (1992) studied 26 mainly female tennis elbow patients, 9 of which had bilateral symptoms with infrared thermography and isotope bone scan. A mean elbow spot temperature of 31.1<sup>0</sup>C, proximal forearm gradient of 1.1<sup>0</sup>C and distal forearm gradient of 1.5<sup>0</sup>C was reported compared to 30.5<sup>0</sup>C, 0.6<sup>0</sup>C and 0.7<sup>0</sup>C respectively. They reported a hot focus on thermal imaging in 94% of unilateral tennis elbow patients and increased epicondylar activity on isotope bone scanning in 71% of patients. They also found somatosympathetic responses, peripheral regional cooling, in 54% of patients with thermography and reduced perfusion in 58% of patients on blood pool isotope bone scan. A somatosympathetic reflex is a reflex sympathetic efferent response secondary to painful nociceptor stimulation which is reflected by a cooling response. Analysis was visual which is highly subjective and subsequently brings into question their conclusions.

### **3.5.2 Pain free grip strength**

The main complaints of tennis elbow patients are pain and decreased grip strength (Chard and Hazleman, 1989). By virtue of the methodology PFG is an indirect measure of the pain system as it reflects the force required to cause pain rather than a measure of strength (Coombes et al., 2008). The use of PFG as an objective quantitative outcome measure has been endorsed by a number of studies. Smidt et al. (2002) recommended using PFG due to it not only being reliable and relatively easy to execute but that it has been associated with other measures of functional disability. Stratford et al. (1993) evaluated a number of outcome measures on a representative sample of 40 patients with tennis elbow. They found that PFG and pain free function questionnaire (PFFQ) were the most valid outcome measures of change over time in tennis elbow patients. High reliability coefficients for PFG (0.87) and PFFQ (0.93) had previously been reported (Stratford et al., 1987).

In consideration of sample size PFG and PFFQ were more efficient when compared with other measures such as maximum grip strength and VAS. With 64 and 63 versus 8063 and 119 patients per group needed respectively, considering the risk of committing a Type I error set at 5% and the probability of committing a Type II error of 20% (Stratford et al., 1993). Type I error is the standard significance level to risk accepting a false significant difference between interventions when one does not actually exist.

Type II error is that through a lack of statistical power the study does not have the capacity to demonstrate a significant difference between interventions when one may actually exist. Also, PFG and pain free function correlated significantly with the patient's global impression of change: correlation coefficient  $r = 0.59$  whilst maximum grip strength did not:  $r = 0.07$ . Previous analysis by the same authors in 1987 had already demonstrated that maximum grip strength was not as sensitive to change. Regrettably on review of the research on tennis elbow, maximum grip strength was used frequently, 11 in comparison to 14 for PFG (Bisset et al., 2005) and consequently one must question the value of such studies. Stratford et al. had also found that ratios of grip strength with the uninvolved arm did not correlate as highly as the raw scores.

Newcomer et al. (2005) evaluated the sensitivity of a number of outcome measures for tennis elbow and reported good sensitivity with a standardised response mean (SRM) of 0.8. A SRM enables the responsiveness of different outcome measures to be compared through assessing the relative magnitude of change and is derived from dividing the mean change from baseline by the SD of the change. The higher the mean the greater the sensitivity with  $<0.5$  considered insensitive and  $>0.8$  large. A moderate ES of 0.6 was also reported.

When attempting to determine a minimum clinically important difference (MCID) a real change in outcome must be at least the smallest detectable difference (SDD) of an outcome measure. Smidt et al. (2002) assessed the interobserver reproducibility, within their robust RCT, of a number of outcome measures including PFG. During follow-up from 3 to 52 weeks, to ensure a wide range of patients with varying severity, a random sample of 50 patients were assessed by 2 independent research physiotherapists. The SDD for PFG was reported as 1.4kg. This was well below the predefined acceptable difference between observers of 10%.

### **3.5.3 Electromyography**

EMG is the recording of the electrical signal produced by the depolarisation of motor units, change in cell membrane potentials, during a muscle contraction. Surface EMG is the summation of all motor unit action potential trains from all active motor units within the pick up area of the electrode. A muscle fatigues as it tries to maintain a sustained submaximal contraction which is recorded as a decrease in the frequency of the surface

EMG signal. This frequency shift is caused by the slowing of the sodium and potassium ion movement across the cell membranes reducing the motor unit firing rate. The degree of fatigue can be quantified by analysing the median frequency (MDF) which is the middle frequency of the magnitude or power versus frequency graphs (De Luca, 1997). See graph 4.1 (p.58) for an example of the power spectral density (PSD) and MDF comparing the use of single and double differential electrodes. The MDF was calculated every second for the duration of the contraction and plotted overtime to demonstrate the rate of fatigue. See graph 5.3 (p.64) for an example of a steady decrease in MDF over 70 seconds, for a 50% maximal grip contraction, illustrating substantial fatigue.

The MDF during a sustained contraction is both a sensitive and reliable measure of fatigue (De Luca, 1984). This measure was selected by reason that it allowed a direct measure of ECRBr muscle fatigue which is thought to be a contributory factor in the pathogenesis of tennis elbow. Consequently, surface EMG allowed more detailed analysis of muscle function and provided improved knowledge of the pathogenesis of tennis elbow over time.

Both wrist flexors and extensors are recruited in gripping with ECRBr playing a key role in stabilisation of the wrist preventing the flexion moment around the wrist. Hagg and Milerad (1997) evaluated forearm fatigue in 9 healthy females during intermittent 25% maximum gripping work by EMG and found greater fatigue in ECR when compared with the flexors. They proposed that the greater fatigue was a factor of the pathogenesis of tennis elbow and was related to the impeded blood flow caused by the static loading. It is thought that this local ischaemia will also affect the poorly vascularised corresponding tendons leading to a degenerative tendinosis after an initial inflammatory stage.

There was a dearth of research on fatigue in tennis elbow until recent work by Alizadehkhayat et al. (2007) explored both the strength and fatigability of selected upper limb muscle groups; including ECR (Brevis and Longus examined together), extensor digitorum communis and flexor carpi ulnaris and flexor digitorum superficialis using surface electrodes during grip strength at 50% maximum voluntary contraction (MVC) at 90 degrees elbow flexion until exhaustion. The normative study was undertaken on 6 healthy subjects who were age matched but not gender matched to a typical tennis elbow population. Although they found the wrist extensors significantly

weaker than the wrist flexors, in contrast to Hagg and Milerad (1997) they found no significant difference in fatigue on normalised median frequency slope. A potential reason for this difference is that Hagg and Milerad (1997) tested at 25% MVC whereas at 50% maximum there is equal activity in both flexor and extensor groups whereas at lower percentages greater extensor activity is present (Mogk and Keir, 2003). The authors made no attempt to distinguish between ECRBr and ECRL and comment that any conclusions need to be regarded with caution due to possible crosstalk with surface EMG, i.e.: the data collected may have originated from other muscles in close proximity to the muscle in question rather than ECRBr and ECRL respectively. Chapter 4.3 (p.53) discusses the issue of cross talk and how it was addressed in the clinical trial.

This technique was then used to compare 16 patients with dominant arm tennis elbow with 16 age and gender matched controls. They reported a 25% reduction in grip strength in the tennis elbow group compared to the control group and a significant 11% greater grip strength in the dominant compared to the non dominant side of the control group. However, no significant difference between the affected and unaffected side of the tennis elbow group was found. In contrast, clinical experience suggests a reduction in grip strength of the affected elbow to be typically evident in tennis elbow which is supported by research finding pain free grip strength reduced by 43-64% (Coombes et al., 2008). One may question their technique of assessing grip strength in 90 degrees flexion whereas testing in extension has been shown to be a more sensitive measure (Stratford et al., 1993), as discussed later in Chapter 4.2 (p.52), and likewise use of maximum grip strength not pain free grip strength and subsequent potential lack of statistical power of the study due to the small numbers involved. They further report a significantly reduced activity of ECR in the tennis elbow group but no significant differences in fatigability of forearm muscles between the control and tennis elbow group. This contrasts to Bauer and Murray (1999) who found earlier, longer and increased extensor activity during tennis in 16 tennis elbow patients compared to controls. The authors comment that the lack of fatigue findings may be in part due to the reduced ECR activity found in their study. Another issue to be raised is that due to the ambiguity of methods of recruitment and unreported symptom duration the generalisation of findings to the tennis elbow population as a whole is questionable.

Alizadehkhayyat et al. (2008) followed up the motor function of patients who had been asymptomatic for a minimum of 6 months in a subsequent study. They reported that, albeit with the exception of the finger extensors, weakness persisted in the entire upper

limb when compared with the controls implying incomplete functional recovery despite pain attenuation. They suggested that tennis elbow patients increase finger extension strength as compensation for the wrist extensor weakness.

Unfortunately, Alizadehkhayat et al. (2007) report conflicting evidence with respect to the scarce research available on this subject and they have only added to the controversy of the pathogenesis of tennis elbow. Through applying several concepts in a novel manner a more sensitive protocol was developed which aims to allow more specific and detailed analysis of ECRBr function and provide improved knowledge of this muscle's role in the pathogenesis of tennis elbow over time.

### **3.5.4 Patient – rated tennis elbow evaluation questionnaire**

Overend et al. (1999) developed this tool to assist the clinician in understanding the impact of tennis elbow on a patient. The objective of the patient-rated tennis elbow evaluation questionnaire (PRTEE) is to provide an uncomplicated, standardised, quantitative description of pain and functional disability, which can be completed in 5 minutes, (Appendix 11.8). Due to the patient being requested to describe their average arm symptoms over the past week accurate memory recall is ensured, within this timeframe, whilst avoiding the potential for erroneous responses from any acute fluctuations in symptoms. The questionnaire is devised of five questions which assess pain and ten questions assessing function, using a ten-point scale with 0 being no pain/ no difficulty to 10 being worst pain imaginable/ unable to do. Therefore, the higher the score (maximum 100) the greater the pain severity and degree of dysfunction. The function subscale score is divided by 2 so that both pain and disability contribute 50% each to the total.

The use of a patient completed functional questionnaire has the advantage of limiting potential observer bias, which may occur if the researcher was to question the patient and then fill in their responses (Turchin et al., 1998).

Overend et al. (1999) determined the interclass correlation coefficients (ICC) for test-retest reliability for 47 patients with unilateral tennis elbow for at least 3 weeks who were part of a trial investigating PFG and bracing. ICC is the ratio of the variance

amongst the subjects over the total variance (subject, observer and random error variability) with 1= perfect reliability and 0= no reliability. Patients completed a patient rated forearm evaluation questionnaire (PRFEQ), the forerunner to the PRTEE with a maximum score of 10, after clarification of the instructions and a reminder that the responses were to be based on the average symptoms over the past week and after a PFG measure. They were then provided with a 2<sup>nd</sup> copy with a stamped addressed envelope to be completed at the same time the following day. 3 subgroup comparisons were evaluated; male: female, subacute: chronic and work: non-workers. The concurrent validity; the degree to which one outcome measure score correlates with another outcome measure score when given on the same occasion, was also assessed through correlation with the PFG.

It was interesting to note that the mean scores overall and for subscales were significantly higher for females and the mean scores overall and for function were significantly higher for non workers. No differences were found for the stage of condition. For the reliability analyses the overall (ICC=0.89) was excellent with subscales of pain (ICC=0.89) and function (ICC=0.83). On subgroup analysis reliability coefficients were all excellent (ICC>0.75) with no significant differences for the reliability coefficients for male: female or stage of conditions. However, they reported that the ICCs overall and for the pain subscale for the working subgroup were significantly lower than the non workers. PFG was significantly related to overall (r=-0.36) and both pain (r=-0.37) and function (r=-0.30) subscales with fair correlations. However, the standard error of measurement (SEM); which quantifies the expected variation from the true score with repeated testing, was +/- 0.6 with 95% confidence interval of +/- 1.2.

Newcomer et al. (2005) evaluated the sensitivity, reliability and concurrent validity of the PRFEQ on 22 subjects with chronic tennis elbow of >3 months on 3 consecutive days who were partaking in a concurrent trial investigating the effect of exercise on lateral epicondylitis. The outcome trial compared the PRFEQ to VAS, PFG, Disabilities of the arm, shoulder and hand questionnaire (DASH) and Medical Outcomes Study 36-item Short Form Health Survey which were completed at baseline, 6 weeks and 3 months. 15 subjects were assessed prior to treatment and 7 after in order to determine whether reliability was affected by either treatment or time. Sensitivity is the ability of a measure to detect change overtime.

Measurement error was reported as a score of 1. Excellent reliability was reported for total PRFEQ (ICC=0.96), pain (ICC=0.96) and function (ICC=0.92) subscales and that generally correlations were moderate with the other outcome measures. At 6 weeks the pain subscale had a SRM of 1.2 and an ES of 1.3, the highest compared to the other outcome measures, which is as expected due to the PRFEQ being the only functional measurement specifically for tennis elbow. A negative correlation with PFG was reported with pain ( $r=-0.35$ ) and function and total ( $r=0.45$ ) which supports the findings of Overend et al. (1999). Consequently, although PFG measures an important aspect of tennis elbow PRFEQ is a better functional measure. They concluded that the 'PRFEQ is reliable, reproducible and sensitive for assessment of lateral epicondylitis' and 'should be a standard primary outcome measure in lateral epicondylitis research'.

Newcomer et al. (2005) made some minor changes to some of the wording in order for the activities to be more familiar and subsequently easier to understand by their American population. MacDermid (2005) agreed with the need for terms which can be applied across a broader population, both gender and cultural to provide clarification and to identify more clearly the nature of the activity. The scoring was also revised with both pain and function each contributing 50% to the total score (0 to 100) to bring it in line with its sister outcome measures. Consequently, with these relatively minor modifications in terminology and scoring the PRFEQ became the PRTEE and MacDermid (2005) proposed that the published data on reliability and validity remained applicable, although the PRTEE would be revalidated.

Rompe et al. (2007) evaluated the reliability, internal consistency, reproducibility, construct validity and sensitivity to change of the revised version of the PRTEE. Internal consistency is the degree that the responses to different components of the questionnaire agree which indicates that each component is measuring different aspects of the same condition in question. Construct validity is to what extent the questionnaire correlates to other established outcome measures within the theoretical context.

Rompe et al. (2007) reported the validation on a chronic sample, (> 1yr duration having had a minimum of 3 courses of conservative treatment), of 78 subjects with a mean duration of 2 years who presented with unilateral tennis elbow confirmed on MRI who played tennis recreationally and were participating in a concurrent RCT comparing low-energy shockwave treatment with placebo. The PRTEE was compared to the VAS and

DASH questionnaires, the Roles and Maudsley score and the Upper extremity Function Scale, at baseline, (1 week and immediately before treatment), and at 12 weeks for the 34 subjects who received treatment. Reliability and internal consistency were excellent (0.94). Correlation between the subscales and total were good compared to both VAS and DASH. Test- retest reliability was excellent ( $r^2= 0.87$ ). Sensitivity to change correlated well to the DASH. A SRM of 2.1 for the PRTEE was the highest for all the outcome measures indicating that the PRTEE was the most responsive to detecting change. This supports the evaluation of Newcomer et al. (2005) who reported the superiority of the PRTEE and concluded that the PRTEE was a reliable, sensitive and reproducible outcome measure for chronic tennis elbow.

### ***3.6 Literature review summary***

The literature review highlighted the poor understanding of the pathophysiology of tennis elbow, which remains in contention due to a dichotomy of an inflammatory versus degenerative pathology and whether an inflammatory component is present in the early stages. This is fundamental to the myriad of treatments available and the lack of evidence based practice for therapeutic interventions for this challenging condition. Clinicians are left with a clinical dilemma as the most common treatments are injection which is anti-inflammatory and ultrasound which is pro-inflammatory. Injection therapy has been shown to be superior in the short term but with high recurrence rates in to the long term whilst wait and see with NSAIDs have been advocated to be superior in the long term, which are again anti-inflammatory.

There is weak evidence, from 2 systematic reviews, in favour of therapeutic ultrasound, albeit only for tennis elbow. Apart from 2 small and poor methodological trials all utilised 1MHz ultrasound and a favourable outcome was found in those trials which used higher intensities which utilise thermal effects in addition to the non thermal effects. However, currently, low intensity ultrasound has been advocated in practice. One other trial using 3MHz was identified with a fair sample size but pulsed ultrasound was used to evaluate whether the addition of mobilisations with movement would improve outcome. Unfortunately, the control group was selective and subsequently validity became an issue.

## CHAPTER 4: PROTOCOL DEVELOPMENTS

Further preparatory work was undertaken to develop a novel scientifically robust model for thermographic analysis and to develop a robust protocol for electromyographic analysis through the application of concepts in a unique way. This chapter presents a comprehensive review of these protocol developments

### ***4.1 Thermography protocol development***

On review of the literature, as discussed in Chapter 3.5.1, previously published protocols for thermographic analysis have fundamental flaws and deficiencies. Consequently, a novel scientifically robust model had to be developed.

*Tsk* data collection is inherently difficult to standardise due to potential intrinsic and extrinsic variables (Table 4.1) which affect vasomotor regulation. Consequently a strict standardised procedure for data collection is needed (Mayr, 1995 and Scudds and Helewa, 1995).

<b>Intrinsic variables</b>	<b>Extrinsic variables</b>
caffeine	environmental temperature
alcohol	draughts
smoking	heat sources
recent physical activity	acclimatisation to the recording environment

Table 4.1: Intrinsic and extrinsic variables affecting vasomotor control.

The participants were requested to refrain from alcohol from the night before the test and not to apply any creams to the area on the day of the test. Any brace was needed to be removed and food consumption, strenuous exercise, drugs, caffeine and nicotine avoided for 2 hours prior to the test if possible. On arrival the patient was asked to expose the elbow area whilst avoiding localised sources of heat, sunlight or draughts to allow the elbow to acclimatise to room temperature for 15 minutes (Mayr, 1995).

In the protocol developed the thermographic measurement was taken in a standardised manner using a FLIR A40M thermovision infra-red thermal imaging camera (Danderyd, Sweeden) mounted on a Bilora PRO 930 tripod (Kurbi and Niggeloh, Germany), Figure 4.1, focused on the lateral epicondyle and aligned parallel with the skin overlying the area. The thermovision system demonstrates high and unique detection parameters with the manufacturer's technical specification for the camera accuracy to within 2% of the data point onscreen reading. An inhouse reliability experiment for the camera, over a 3 hour period, had already been undertaken by Eivazi and Selfe (unpublished data, 2010) and had demonstrated good consistency. The object and room temperature were maintained at a constant level and during the first 30 minutes an image was taken every 5 minutes and then at 10 minute intervals until the end of the 3 hour period. The mean temperature showed a maximum variability of 0.2<sup>0</sup>C difference between the baseline mean temperature and the mean temperature of the thermal image.

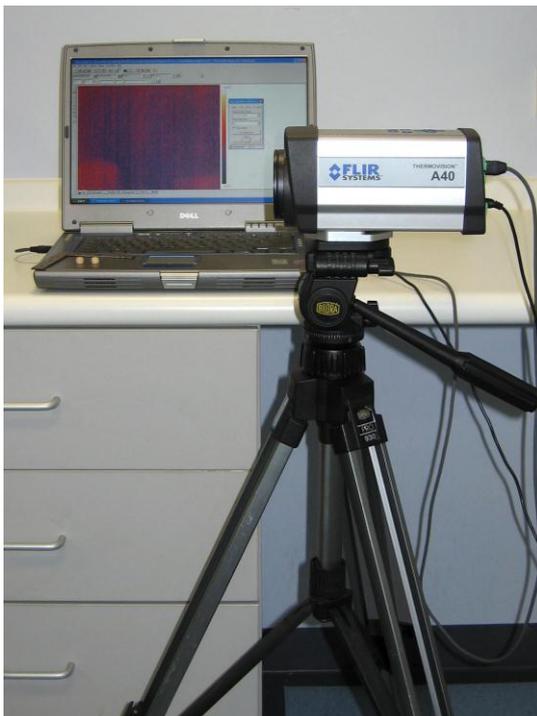


Figure 4.1: Thermal image equipment

The use of thermally inert wooden anatomical markers as described by Selfe et al. (2006) was applied in a unique manner for tennis elbow.



Figure 4.2: Anatomical markers on the olecranon and cubital crease.

As shown in Figure 4.2 two specific anatomic locations were used: the first was placed on the midpoint of the olecranon and the second placed in the same plane in the cubital crease whilst the patient was stood at a distance of 80cm from the camera lens with the elbow flexed to 90 degrees and in full forearm supination (Figure 4.3). In this manner the forearm was in a horizontal position and the upper arm vertical. A distance of 80cm gave optimal pixel viewing with optimum resolution of a full image of the ROI. This is supported by Karki et al. (2004) who took thermal images of a  $0.5\text{m}^2$  reference object at a series of camera distances of 80, 100, 120 and 200cm. For the 200cm camera distance a pixel resolution of only 12 pixels/ $\text{m}^2$  was reported compared to a greater resolution of 90 pixels/ $\text{m}^2$  at 80cm. At the minimum camera distance of 50cm there was an inadequate area of the image available for analysis and at 1 meter the resolution became too poor. The choice of placement on the olecranon was due to it being a bony prominence which is fixed and easily reproducible in a consistent manner. Both use of the lateral epicondyle or the radial head could lead to spurious data from the marker itself or ambiguity in exact location. i.e.: the lateral epicondyle is the ROI and the radial head too ill defined in the sagittal plane and similarly in close proximity of the ROI. The choice of the cubital crease as the second marker was chosen as it could be easily reproduced in relation to the olecranon and enables the ROI to be located within a fixed anatomical area.



Figure 4.3: Set up for recording thermal images.

This procedure enabled a reliable and accurate method for the thermal image data collection using FLIR Systems ThermoCAM Research Pro 2.8 software and the subsequent analysis through the development of a novel scientifically robust model.

A unique method of measuring the  $T_{sk}$  of the insertion of ECRBr was developed in a standardised manner which was both easy and consistently reproducible. The ROI quadrant (AR02) was compared with the unaffected quadrant (AR03) which acts as a control (Figure 4.4). The thermal difference between the maximum  $T_{sk}$  (AR02 – AR03) for the ROI was then recorded.

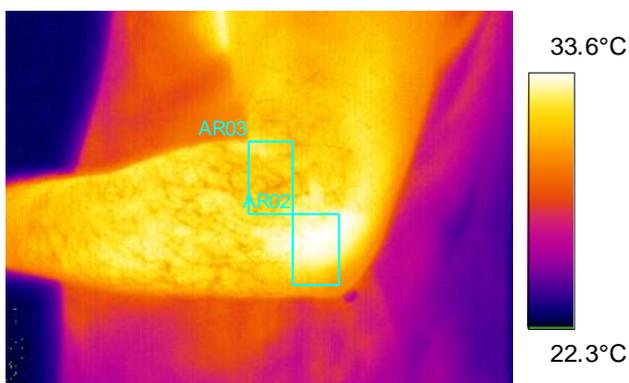


Figure 4.4: ROI quadrant (AR02) and unaffected quadrant (AR03).

( <sup>0</sup> C)	Min	Max	Range	Mean	SD
<b>AR02</b>	30.1	33.7	3.7	32.3	0.8
<b>AR03</b>	29.7	32.4	2.6	31.3	0.4

Table 4.2: Thermal image analysis of the symptomatic patient in Fig. 4.4

As can be seen in the patient shown in Figure 4.4 and Table 4.2 a difference of +1.3<sup>0</sup>C was found for the maximum  $T_{sk}$  in the ROI: AR02 (33.7) – AR03 (32.4) = +1.3

In comparison, when this patient’s contralateral non affected ROI was analysed:  
AR02 (32.7) - AR03 (32.7) = 0

The method used to draw AR02 and AR03 was as follows: Draw a rectangle of the area of interest (AR01) which originated with the + cursor arms just touching the superior and distal outer extremities of the 2 anatomical markers (Figure 4.5). In this manner the rectangle originated from the centre of the cursor which importantly did not touch the marker and therefore would not lead to spurious data from the marker itself.

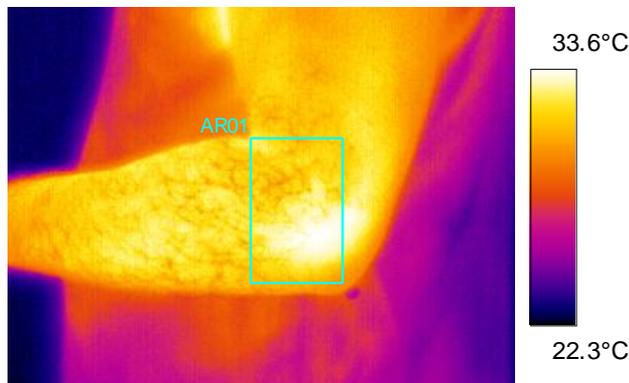


Figure 4.5: The area of interest (AR01)

Two diagonal lines were drawn (LI01 and LI02) between the opposite corners. These intersected at the midpoint of the rectangle AR01 (Figure 4.6).

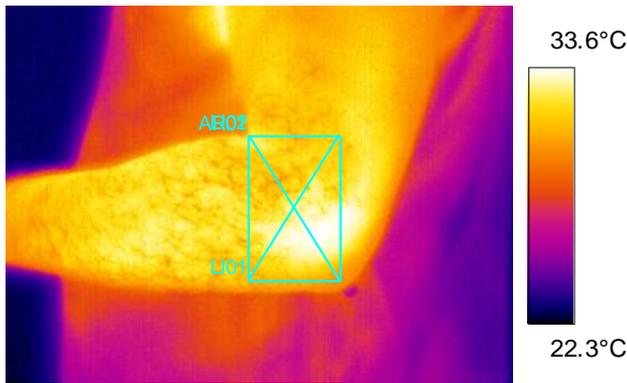


Figure 4.6: Diagonal lines (LI01 and LI02)

Two small rectangles (AR02 and AR03) of equal volume were then drawn originating from each anatomical marker (Figure 4.7). The corner of each of the small rectangles (AR02 and AR03) met at the midpoint of the large rectangle (AR01) which corresponds to the intersection of LI01 and LI02. The large rectangle (AR01) and the 2 diagonal lines (LI01 and LI02) were then deleted leaving the 2 quadrants (AR02 and AR03) for the analysis.

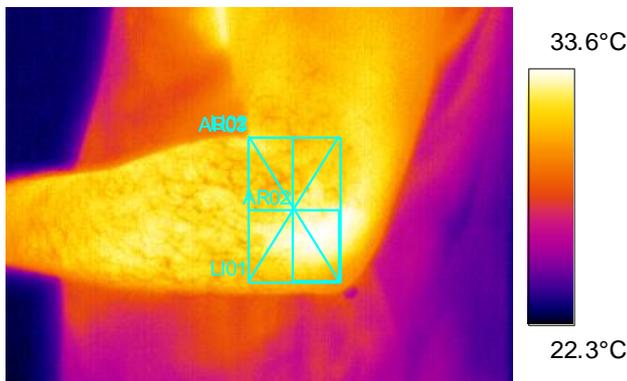


Figure 4.7: Method of Tsk measurement (AR01, LI01, LI02, AR02 and AR03)

Following peer review of this novel method 2 comments were identified: the validity of the ROI in proportion to anthropometrics and the use of the maximum Tsk in lieu of the mean which is used more frequently in thermal imaging work. In defence for the choice of standardised procedure the validity of the two specific anatomic locations in proportion to anthropometrics was verified by review of the thermal image, using the standardised procedure described, for 5 normative subjects with an additional marker placed on the ROI (see figure 4.8).

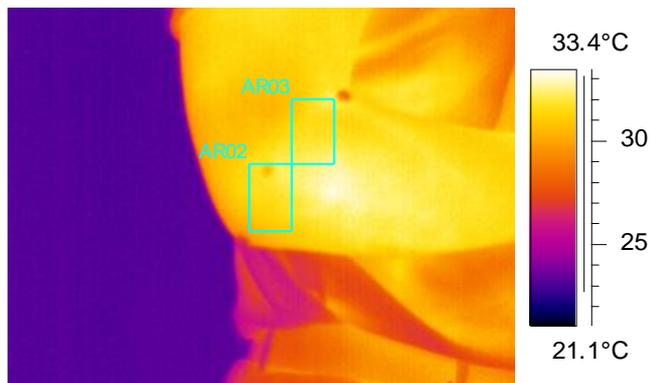


Figure 4.8: Additional marker on ROI

The sample was comparative to a typical tennis elbow population: 3 females and 2 males with a mean age of 47.8 years. The ROI did not migrate into either the control area or the intersection point of the ROI and control squares for any subject.

The maximum  $T_{sk}$  was the optimum measurement as it was not dependent on the size of the area of interest and subsequently was more consistent. Whereas, in contrast, the mean was dependent and would vary with the size of the area of interest. Equally, mean temperature demonstrated a significant diurnal variation with an increase in the afternoon compared to a non significant increase in the maximum temperature (Binder et al., 1983). Consequently, due to the repeated measures design with data taken at different times convenient to the subjects the use of the maximum temperature would increase accuracy and negate this potential variable.

By the use of an ipsilateral control in this unique method previous potential flaws in the accuracy of the use of thermal imaging, on both a specific occasion and on repeated occasions, due to the variability attributed to the intrinsic and extrinsic variables of vasomotor control, as detailed in Table 4.1, were negated. Furthermore, it was felt that an ipsilateral comparison as the control would be more accurate due to the potential factors of potential difference of blood flow to the affected versus the unaffected side and the fact that 30% of patients in Binder et al. (1983) had a hot spot on the unaffected elbow. However, through the use of an ipsilateral control, the temperature increase would affect both the ROI and control and be negated as the outcome measure is the difference between the 2 areas. Thomas and Savage (1989) compared the spot temperature of the tennis elbow region with the ipsilateral forearm temperature and reported that with clinical improvement after acupuncture treatment although right and

left elbow temperatures had become equivalent a larger temperature gradient between the elbow and ipsilateral forearm persisted on the affected side. They concluded that lateral epicondyle temperature combined with forearm gradient maybe of more clinical value than either lateral epicondyle temperature alone or side to side analysis.

#### ***4.2 Pain free grip strength protocol***

The PFG was taken using a Saehan hand dynamometer manufactured by Saehan Corporation, Korea. As recommended by the American Society of Hand Therapists (ASHT) and used by studies assessing the reliability of this measure (Smidt et al., 2002 and Turchin et al., 1998) the contact surfaces were on the second bar for all participants to ensure maximum grip strength (Firrell, 1996).

The concept of PFG was explained to the participants who were instructed to slowly squeeze the dynamometer and to stop the instant any discomfort was first felt. No other encouragement was given. The participant was asked to only look at the dynamometer dial during the third grip strength in order to maintain 50% maximum on the unaffected side. The testing procedure was standardised as elements of arm position can affect grip strength (Ng and Fan, 2001): the participant stood with the shoulder adducted and in a neutral position, the elbow was in extension and the forearm was in neutral. In a neutral forearm position skin sliding over the muscles is eradicated when compared to pronation or supination (Duque et al.,1995). Although for assessing grip strength the ASHT recommended the participant to be seated with the elbow at ninety degrees, the standing position with the elbow extended was endorsed by a number of studies on tennis elbow (Stratford et al., 1993) as it reflected a more sensitive outcome. This protocol was used by Smidt et al. (2002). De Smet et al. (1997) found a marked reduction in grip strength in patients with tennis elbow with the elbow in extension when compared with ninety degrees of flexion.

Three attempts with 20-second intervals between were recorded and the mean value, in kilograms (kg), calculated. Stratford et al (1989) demonstrated that no statistical differences existed between repetitions on different occasions or for patient repetition and occasion repetition interactions. They found that no fatigue or learning occurred during the testing and to achieve a representative estimate of the patient's strength an average of three repetitions should be used. The ASHT endorsed this protocol.

### ***4.3 Median frequency protocol development***

In this research the EMG studies were undertaken in a standardised manner. In order to acquire an optimum signal the electrical resistance of the skin must be kept below a certain threshold to maintain a good signal-to-noise ratio and furthermore, the skin resistance needs to be kept constant overtime on repeated occasions as a prerequisite to repeatability and accuracy of the data collected. The skin was prepared with slight abrasion with an alcohol wipe to ensure optimal continuous skin contact and prevent movement of the electrode which could cause the production of artefacts preventing optimum signal acquisition. In addition, the ground or reference electrode was attached to the dorsum of the hand on the unaffected arm which facilitates optimal signal acquisition free from artefacts through providing an electrical reference of the surrounding electrical activity from both internal electrical activity and external equipment.

The EMG electrodes were attached to the participant and the MPSF recordings taken whilst the participant undertook a sequential series of 3 PFGs, (Figure 4.9). The MPSF analysis was recorded during the final PFG whilst it was maintained for 45 seconds. During the EMG analysis the PFG and subjective pain was recorded concurrently at 15 second intervals. The unaffected arm was assessed first.



Figure 4.9: EMG set up

The DELSYS Bagnoli EMG system (Figure 4.10) enables a high quality and reliable EMG to be recorded. To ensure that the optimum magnitude and fidelity of signal was acquired a number of components needed to be considered.

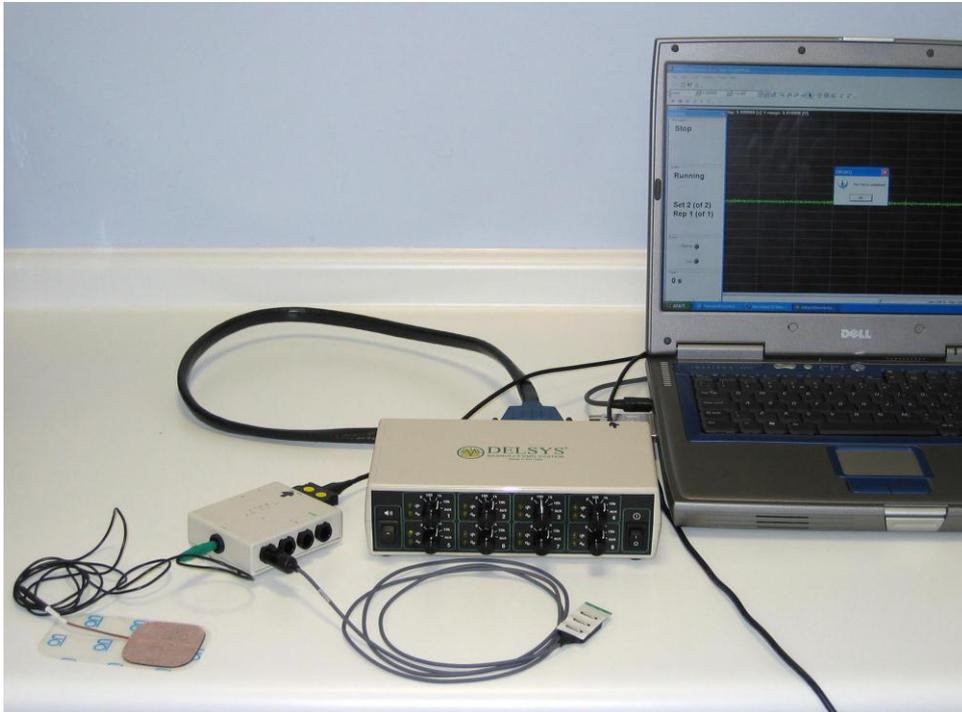


Figure 4.10: DELSYS Bagnoli EMG system

Location and standardisation of electrode placement was a requisite to be controlled to enable a reliable and valid EMG recording. Previously, selective EMG recording of ECRBr was thought to be unviable unless fine wire indwelling electrodes were used and even then it could not be distinguished from ECRL due to crosstalk. This was overcome by Riek et al. (2000) who described a new technique for the selective recording of ECRBr and ECRL EMG using intramuscular electrodes. They examined 10 cadaver specimens and their data demonstrated a significant separation of each muscle belly. These location data were then used on 3 healthy volunteers: The initial measurement was taken from the lateral epicondyle of the humerus to the styloid process of the radius with the elbow in 90 degrees flexion and neutral pronation/supination. The origin of ECRL was calculated by taking 7.8% of this initial measurement up the lateral humerus. The distance from the origin of ECRL to the radial styloid process was then measured and 47.6% along this length the ECRBr belly was identified, (Figure 4.11). Although they reported consistent overlap of the proximal fibres of ECRBr, (24.3% +/- 2.4%) and distal fibres of ECRL (39.5% +/- 2.4%) significant separation of the muscle bellies was identified; 47.6% +/- 3.4% and 17% +/- 2% respectively. This technique allowed the

optimum electrode position of in the midline of the muscle belly between the musculotendinous junction and nearest innervation zone to be identified.



Figure 4.11: ECRBr muscle belly location

The use of the DELSYS DE-3.1 double differential electrodes (Figure 4.12) addressed the issue of crosstalk (De Luca, 1997).



Figure 4.12: DELSYS single (top) and DE-3.1 double differential electrodes

Where muscles are in close proximity and particularly where the muscle belly is small it can be difficult to differentiate the activity of a specific muscle using surface electrodes. The presence of EMG signals originating from muscles adjacent or deep to the muscle of interest is known as crosstalk and can be reduced with the use of specifically designed double differential electrodes. Single differential electrodes comprise of 2 bar electrodes placed 1 cm apart, within a single solid electrode, as depicted in figure 4.12. This configuration removes the signal that is common to both electrodes and amplifies the difference or differential, which effectively removes external noise. Double differential electrodes work on the same principles but have 3 bar electrodes whose signals are compared. This not only facilitates greater noise reduction but also has the advantage of reducing the pick up volume and consequently reducing any potential effects of the adjacent muscles and crosstalk (Kirtley, 2006).

### **4.3.1 Double versus single differential electrode study**

To ensure that the optimum signal was acquired a comparative study between the use of double and single differential electrodes was undertaken for ECRBr during gripping to ascertain which gave the optimum magnitude and fidelity of signal.

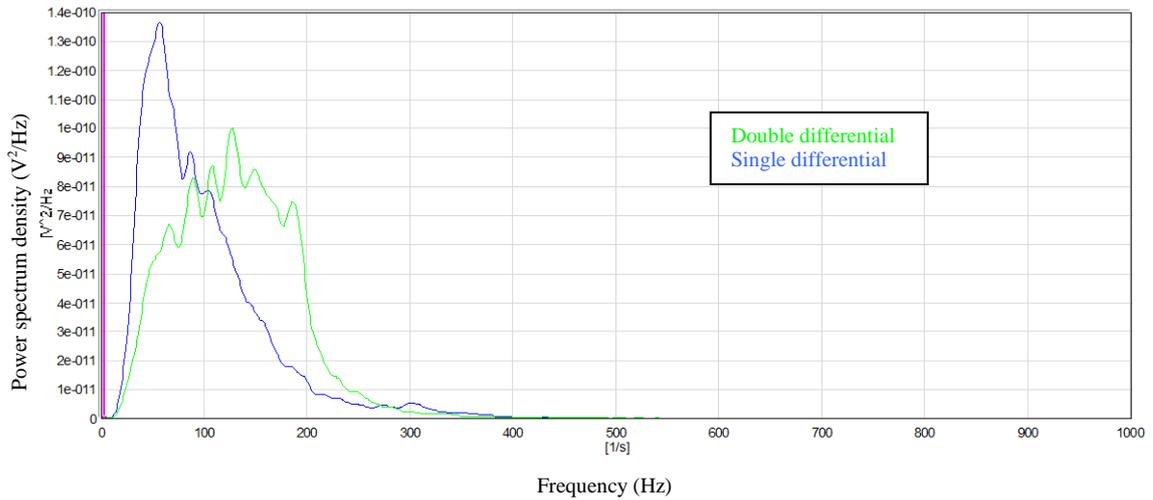
#### **4.3.1.1 Method**

The muscle belly of ECRBr was identified and marked, as in figure 4.11, on 5 normal participants as per Riek et al. (2000). Each participant was asked to do 5 successive maximum voluntary grip contractions with an electrode in situ. After a rest of 1 minute the participant was asked to repeat the set of 5 successive maximum voluntary contractions with the alternative electrode in situ. The double and single differential electrodes were applied in a randomised order.

The mean maximum grip strength from 5 data sets was recorded and the magnitude and fidelity of the signal was analysed. The PSD was visually compared and the MDF calculated.

### 4.3.1.2 Results

As an example, the following graph 4.1 demonstrates the difference, for one healthy participant, between the single and double differential EMG signal.



Graph 4.1: Power spectral density for double versus single differential electrodes.

The mean maximum grip strength was 30kg (range 22.5 to 41.1).

On visual analysis of the PSD both the single and double differential electrodes demonstrated good consistency throughout.

On calculation of the MDF the mean for the single electrode was 77.2Hz and the double was 101.88Hz.

It can be seen that the power spectral frequency for the single differential electrode has a lower frequency spectrum with a peak @50Hz and group mean MDF of 77.2Hz (depicted by the blue line). This is typical of a recorded EMG which includes cross talk from signals which have originated from muscles further away. In contrast, the group mean MDF shift for the double differential electrode was 101.88Hz (depicted by the green line) without the lower frequency peak, demonstrates that crosstalk, originating from muscles further away, has been removed.

### **4.3.1.3 Conclusion**

The double differential electrodes were utilised as they gave better magnitude and fidelity of signal without cross-talk.

### **4.4 Patient preference questionnaire**

The patient preference questionnaire was designed for this research to provide a qualitative impression of patient treatment preference overtime, (Appendix 11.9). It included the patient's perspective on treatment and may highlight reasons for patients who did not attend (DNA) and emphasise areas for development to facilitate service improvement. The patient's wishes and collaboration in treatment choice is an important aspect to consider (Haynes, 1998).

Also of paramount importance to research is the need to reduce potential bias, in particular when patients can not be blinded to the treatment intervention and subjective outcome measures are used. Through documenting patient preference an evaluation can be undertaken of whether the preferred treatment had some influence on success rates.

### **4.5 Protocol developments summary**

In conclusion the following outcome measure data was collected using the methods previously described:

- Thermal difference of the maximum  $T_{sk}$  of the ROI compared to the control
- Mean PFG
- MDF of ECRBr during PFG using double differential electrodes
- PRTEE questionnaire (pain, function and total)
- Patient preference questionnaire

## **CHAPTER 5: NORMATIVE STUDIES**

As there was no existing data for thermal difference or MDF using the developed models on either a healthy or tennis elbow population this chapter presents the preliminary studies. Normative study 1 tested the developed protocols and explored the range of values for thermography and EMG of a sample of 20 participants who were pain and pathology free and were age and gender matched to the tennis elbow population.

In order to assess the validity of the developed thermographic model, normative study 2 presents the evaluation of the immediate thermal effects following a treatment session of therapeutic ultrasound.

### **5.1 Ethics**

These studies conformed to the declaration of Helsinki and ethical approval was gained from Faculty of Health Ethics Committee (FHEC) of the University of Central Lancashire (UCLan) prior to any data collection (Appendix 11.4).

### **5.2 Normative study 1**

#### **5.2.1 Normative study 1 Methods**

The normal population comprised of staff and students at the UCLan who did not have any pain or problems with either of their elbows. A request for participants was initially sent to the Department of Allied Health Professions staff via email and followed up with telephone and face-to-face requests for non responders. All participants were issued with an information sheet, (see appendix 11.2). Informed consent was gained from those who were suitable with respect to age and gender of patients who complain of tennis elbow, (see appendix 11.1).

Using the standardised methods as described in Chapter 4.1 the maximum  $Tsk$  for the ROI was calculated for both elbows (Table 5.2). In order to calculate a realistic optimum hold to gain significant fatigue in the tennis elbow population a 70 second

50% maximum hold was undertaken which allowed MPSF data collection at 10, 35 and 60 seconds. The maximum MDF was taken during the first 10 seconds to allow for the variability of potential subject delay on squeezing the dynamometer when requested and at 60 seconds to account for any potential subject anticipation of release.

All data was collected on the normative study data collection sheet, appendix 11.3. Although data was taken bilaterally, on account of tennis elbow typically affecting the dominant arm the MDF was initially assessed on the dominant arm. From previous work by Tonks et al. (2007) 50% of the mean of the subject's first two maximum grip strengths was thought to be comparable to a patient with tennis elbow performing PFG. This percentage is also supported by De Luca (1984) who reported that MDF demonstrates the greatest fall at 50% maximum contraction.

## 5.2.2 Normative study1 Results

### 5.2.2.1 Descriptive statistics

The descriptive statistics of the normative study population was compared with the tennis elbow population data (n=48) from Tonks et al. (2007) in table 5.1. This showed that the normative study was broadly similar to the age and gender of a typical tennis elbow population.

	<b>Tennis elbow population Tonks et al. (2007)</b> (n=48)	<b>Normative study Current</b> (n=20)
<b>Female</b>	22 (46%)	11 (55%)
<b>Male</b>	26 (54%)	9 (45%)
<b>Mean age (range)</b>	44.3 yrs (27-61)	40.6 yrs (27-56)
<b>Tennis players</b>	2 (4%)	2 (5.5%)

Table 5.1: Descriptive statistics comparison

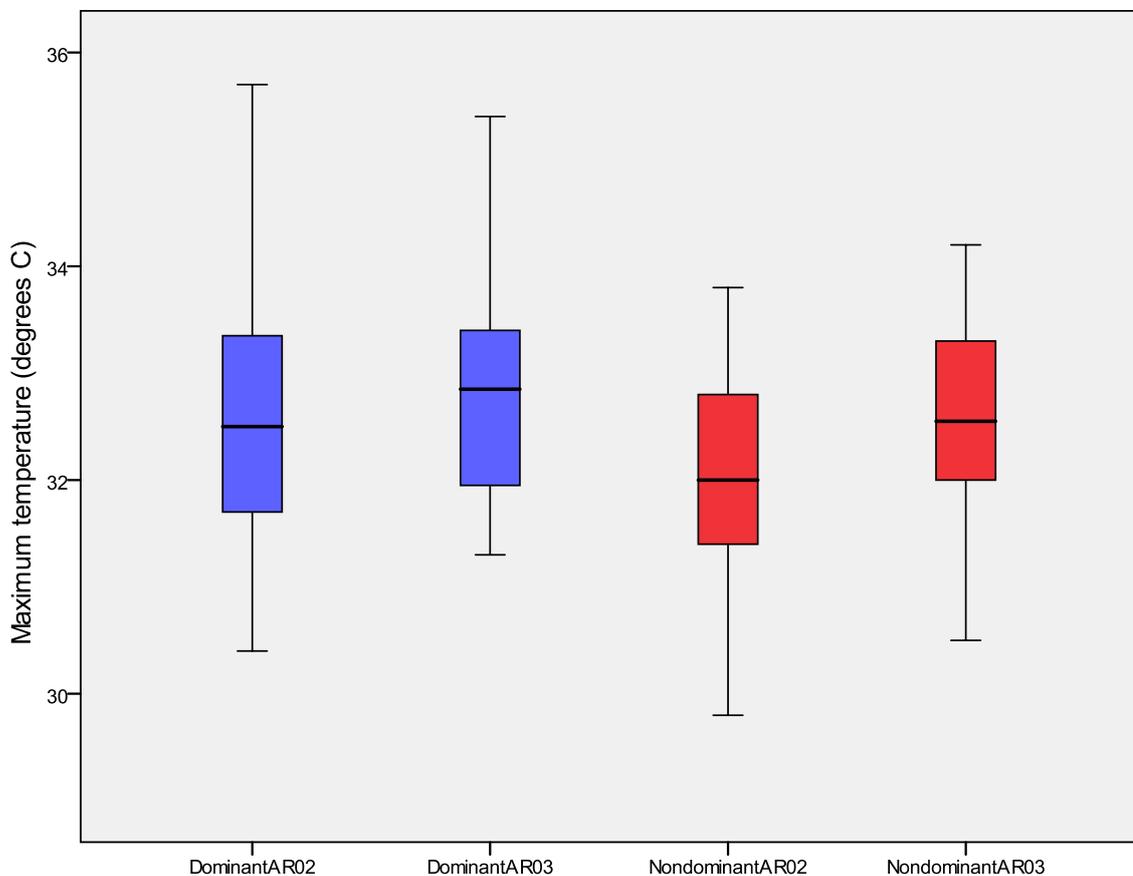
This was also supported by the literature review; (Chapter 3.2) that tennis elbow is typically experienced in the dominant hand in equal proportions of male and female patients during the 3<sup>rd</sup> and into the 5<sup>th</sup> decades (Vicenzino and Wright, 1996).

The frequency of prognostic indicators are shown in table 5.2.

Prognostic indicator	Number
Smoking	0
Diabetes	0
Circulatory problems	0
Elbow problems in the past 6 months	0
Elbow problems >6 months ago	1

Table 5.2: Frequency of prognostic indicators

### 5.2.2.2 Thermography



Graph 5.1: Normative study 1 maximum Tsk for ROI (AR02) and control (AR03)

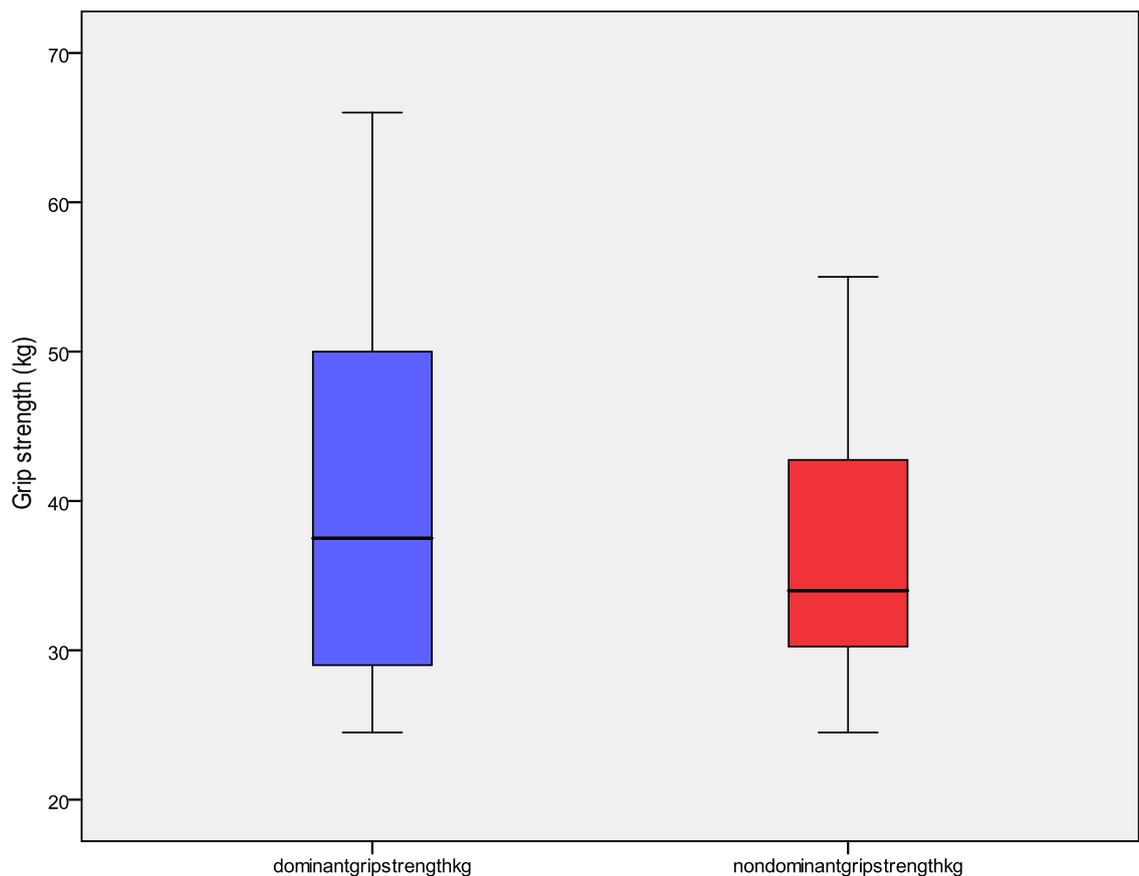
Graph 5.1 shows the box plot for the maximum  $T_{sk}$  ( $^{\circ}\text{C}$ ) for the ROI and control quadrants for both elbows for normative study 1.

For the dominant arm the mean maximum temperature for the ROI (AR02) was  $32.5^{\circ}\text{C}$  and the control (AR03)  $32.8^{\circ}\text{C}$  which gave a mean thermal difference of  $-0.3^{\circ}\text{C}$

For the nondominant arm the mean maximum temperature for the ROI (AR02) was  $32.1^{\circ}\text{C}$  and the control (AR03)  $32.5^{\circ}\text{C}$  which gave a mean thermal difference of  $-0.4^{\circ}\text{C}$

### 5.2.2.3 Pain free grip strength

Graph 5.5 shows the maximum grip strength for both the dominant and nondominant arms for the normative study 1.



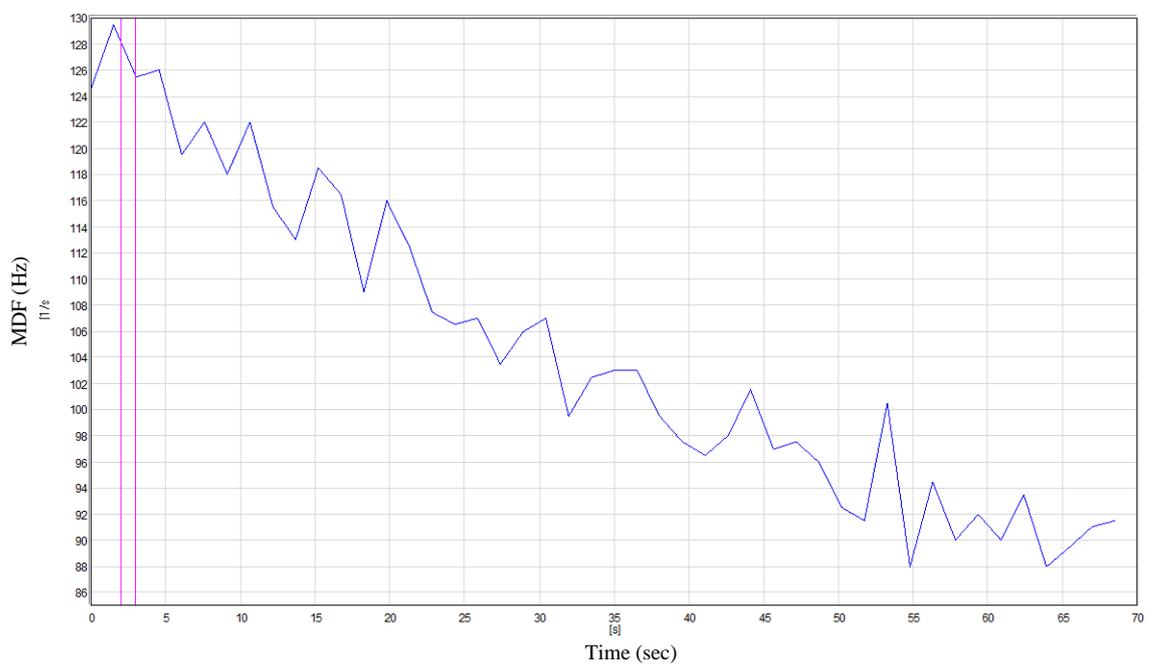
Graph 5.2: Mean maximum grip strength for normative study 1

For the dominant arm the mean maximum grip strength was 39.9kg with a range of 24.5-66

For the nondominant arm the mean maximum grip strength was 37.2 with a range of 24.5-55

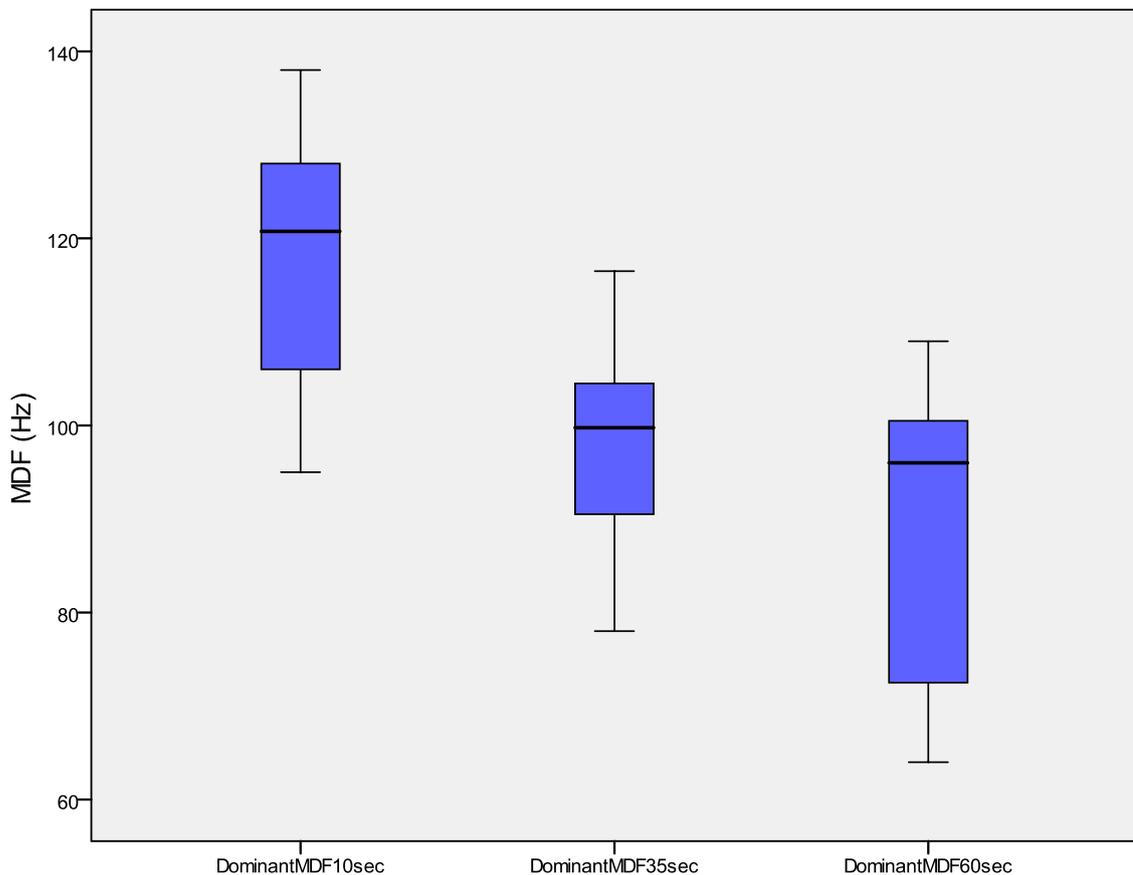
### 5.2.2.4 Median frequency

As an example, graph 5.3 shows the MDF of maximum grip strength over 70 seconds in a healthy participant for ECRBr. A reduction in frequency was evident over this period of time which demonstrates marked fatigue.



Graph 5.3: Median frequency of 50% maximum grip strength over 70 seconds

Graph 5.4 shows the box plots for the mean dominant MDF of 50% maximum grip strength at the data collection points of 10, 35 and 60 seconds for normative study 1.



Graph 5.4: Mean dominant median frequency of 50% maximum grip strength over 70 seconds

To assess over what time period significant fatigue was evident at 50% maximum grip strength for the dominant arm a repeated measures analysis of variance (ANOVA) was used with alpha set at  $p < 0.05$  with 95% confidence levels:

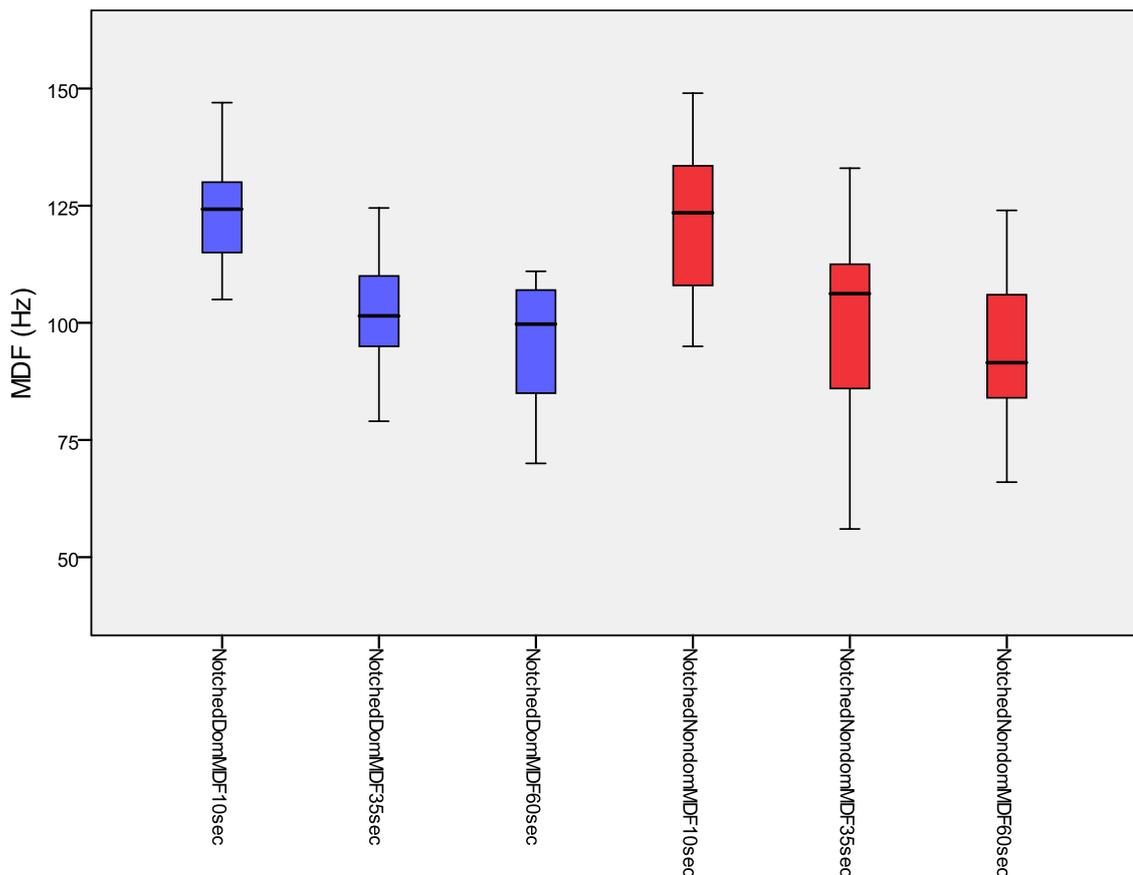
Mean difference between 10 sec and 35 sec was 20.8Hz (95% CI 16.3- 25.3)  $p < 0.001$

Mean difference between 10 sec and 60 sec was 29.8Hz (95% CI 21.6- 38)  $p < 0.001$

One can conclude that 35 seconds was required for significant fatigue to be evident in ECRBr at 50% maximum grip strength in an age and gender matched normal population.

On visual analysis of the MDF of the first 20 patients a number of anomalies became evident and consequently on checking the PSD in the region of 20% had a 50Hz peak evident which was attributed to the patient data being collated in the clinical environment with the intermittent use of electrotherapy within the immediate surroundings causing some potential interference. This electrical noise interference of the data was removed by notch filtering which is the removal of a narrow band of

frequencies around the interference. This has the effect of removing both the electrical interference and EMG signal indiscriminately between the 2 selected frequencies which has the potential to distort the data, in particular the MDF, by a small degree. Although this was not ideal, where a large amount of interference is present it became necessary (Richards, 2008). Thus for consistency, all data was notch filtered IIR using a Butterworth at the 2<sup>nd</sup> order with a band stop of 48-52Hz. The response was sharper using 48-52Hz when compared with 49-51Hz. Graph 5.4 shows the box plots for the notch filtered MDF of 50% maximum grip strength for 70 seconds.



Graph 5.5: Notch filtered median frequency of 50% maximum grip strength over 70 seconds

Subsequently, on repetition of the statistical analysis using a repeated measures ANOVA with alpha set at  $p < 0.05$  with 95% confidence levels:

For the dominant arm:

Mean difference between 10 sec and 35 sec was 21.7Hz (95% CI 18.4- 24.9)  $p < 0.001$

Mean difference between 10 sec and 60 sec was 30.3Hz (95% CI 24.2- 36.4)  $p < 0.001$

For the nondominant arm:

Mean difference between 10 sec and 35 sec was 20.5Hz (95% CI 14.9- 26.1)  $p < 0.001$

Mean difference between 10 sec and 60 sec was 27.3Hz (95% CI 21.3- 33.4)  $p < 0.001$

<b>Mean difference of MDF between 10 seconds and:</b>	<b>Prenotched data</b>	<b>Notched data</b>
<b>35 seconds</b>	20.8Hz	21.1Hz
<b>60 seconds</b>	29.8Hz	28.8Hz

Table 5.3: Comparison of prenotched and notched median frequencies

As can be seen on comparison of the notched and prenotched data in table 5.3 there was only a maximum of 1Hz difference between the mean differences and the significant fatigue evident over both 35 and 60 seconds remains.

### **5.2.3 Discussion**

When normative study 1 was considered it can be seen that the ROI was a mean of 0.3 to 0.4°C cooler when compared to the control; i.e.: a negative thermal difference. This was supported by Binder et al (1983) who found a positive thermal gradient from the olecranon to the elbow joint was often present in the 120 elbows of 60 normal subjects they examined. This would imply that the magnitude of the positive thermal difference, (i.e.: the ROI is hotter than the control), found in the symptomatic patient in Figure 4.4 and Table 4.2 was underrepresented.

If the PFG data from Tonks et al. (2007) is considered one can confirm the reduction in the region of 50% in symptomatic tennis elbow patients (Table 5.4). Subsequently, one can validate the use of 50% maximum grip strength for the unaffected side and the normal population.

Mean PFG	Tonks et al. 2007	Normative study 1
Baseline	18.5kg (range 4.7- 47)	Dominant: 39.9kg Nondominant: 37.2kg
7 weeks post treatment	25.7kg (range 7.3-54)	N/A

Table 5.4: Painfree grip comparison

The MDF analysis concluded that significant fatigue was evident at 35 seconds for ECRBr at 50% maximum grip strength and has informed the patient study that a 45 second hold was required to detect a significant difference on the 3<sup>rd</sup> PFG to allow for a 10 second potential delay at onset and a 10 second anticipatory release.

### **5.3 Normative study 2: Thermal effects of ultrasound**

#### **5.3.1 Normative study 2 methods**

In order to assess the validity of this model, the immediate thermal effects following a treatment session of therapeutic ultrasound using an EMS Medi- Link system (Greenham, Oxford) to the tenoperiosteal junction of ECRBr was explored, as per trial protocol (continuous 3 MHz using a 0.5 transducer with gel at 2W/cm<sup>2</sup> for 5 minutes), on a healthy participant. This was repeated on a separate occasion on the same participant with sham ultrasound. (i.e.: the ultrasound package without the ultrasound switched on.

A thermal image was taken immediately prior to ultrasound, within 1 minute post ultrasound and then at 1 minute intervals until 20 minutes inclusive. Then at 25 and 30 minutes post ultrasound.

#### **5.3.2 Expected thermal effects of ultrasound**

If the expected thermal effects during the application of an ultrasound package are considered; the initial application of the coupling medium gel to the skin, despite being at room temperature, would have a marked cooling effect, a reduction in *Tsk*, through the evaporation of water. This reduction in *Tsk* is further accentuated by the contact of

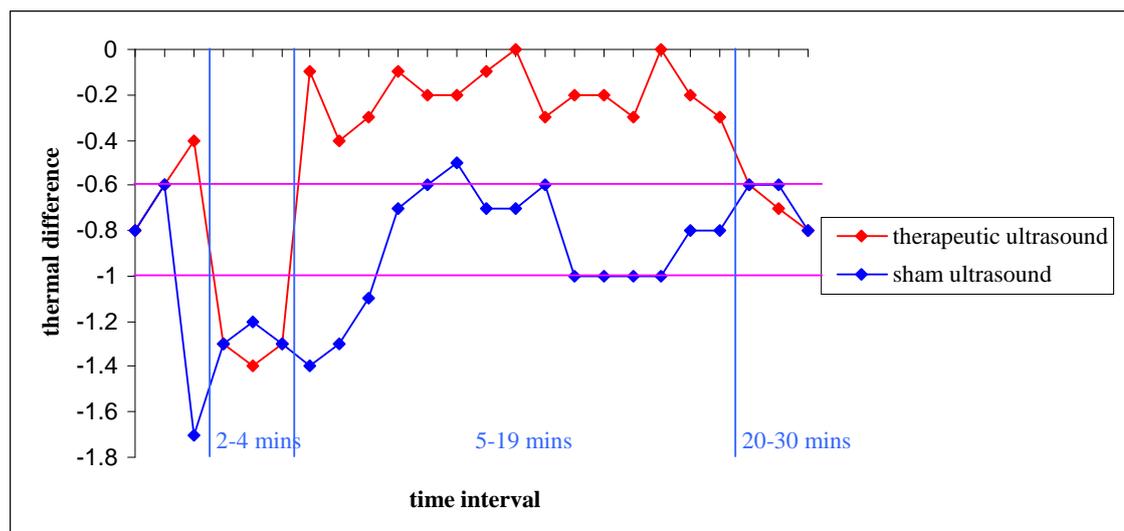
the relatively cold metal transducer to the skin which creates a temperature gradient causing a cooling of the skin and a rise in temperature of the transducer as they attempt to gain thermal equilibrium.

In contrast, there is the potential for a  $T_{sk}$  increase with the friction caused by the transducer juxtaposed to the skin which is in continual motion during administration although this would be minimal due to the use of the coupling gel. The  $T_{sk}$  increases due to the therapeutic effects of the ultrasound as mechanical vibration energy is applied which causes the physiological effects of vasodilatation and an increase in blood flow to the area.

### 5.3.3 Normative study 2 results

The novel protocol for thermographic analysis with the normative data, single case history and thermal effects of ultrasound was presented as a poster at the Chartered Society of Physiotherapy Congress in Liverpool in October 2009 (Appendix 11.16).

Graph 5.6 shows the thermal difference overtime with a minimal clinically important difference of  $0.2^{\circ}\text{C}$  from baseline highlighted by the 2 pink lines for both therapeutic ultrasound (red) and sham ultrasound (blue).



Graph 5.6: Thermal difference overtime for ultrasound and sham ultrasound in a healthy participant.

### 5.3.4 Normative study 2 discussion

As can be seen during the first 2 minutes post therapeutic ultrasound the initial negative thermal difference reduces in magnitude, i.e.: an increase in  $T_{sk}$  from baseline ( $-0.8^{\circ}\text{C}$ ). This would be expected through the application of energy from the ultrasound treatment. It could also be attributed to the removal of the gel masking the cooling effects of the contact of both the gel and transducer and potentially, although minimal, to the mechanical effects of the friction of the transducer.

However, from 2 minutes through to 4 minutes post ultrasound a marked increase in thermal difference to the region of  $-1.3^{\circ}\text{C}$  is apparent, i.e.: a clinically important reduction in  $T_{sk}$ . This could be attributed to the cooling effect of the gel and contact with the transducer which are no longer masked by the friction from the actual application of the ultrasound.

In comparison, with sham ultrasound, there is only a minimal increase in  $T_{sk}$  immediately post treatment which would substantiate this being attributable to the removal of the gel masking the cooling effects of the contact of both the gel and transducer and potentially, although minimal, to the mechanical effects of the friction of the transducer. Subsequently, significant cooling in the region of  $-1.3^{\circ}\text{C}$  is evident from a minute post application for a longer duration of 6 minutes. The delay in cooling in the therapeutic ultrasound group could be attributed to the slight warmth patient's often comment on during treatment due to the application of energy through therapeutic ultrasound.

With therapeutic ultrasound, after 5 minutes through to 19 minutes a clinically important change of  $>0.2^{\circ}\text{C}$  can be seen with a marked reduction in thermal difference, ranging from 0 to  $-0.4^{\circ}\text{C}$ , i.e. a clinically important increase in  $T_{sk}$ . This can be attributed to the therapeutic effects of ultrasound through the application of mechanical energy. This is validated as no clinically important increase in  $T_{sk}$  is evident with sham ultrasound. This supports previous research which found that 3MHz ultrasound at  $1.5\text{W}/\text{cm}^2$  had to be applied for 2 minutes before the temperature increased at a depth of 2.5cm in comparison to sham ultrasound which did not show any temperature increase over a 10 minute treatment (Hayes et al., 2004).

It is interesting to note the 5 minutes delay for the effects of ultrasound and the vascular response to become apparent, although it may be explained as a result of the initial cooling effects of the application of the gel and transducer.

The duration of these effects are in the region of 20 minutes when the thermal difference demonstrates a trend to return to pre ultrasound levels by 30 minutes. This is rather longer than the approximate 12-20 minutes for the temperature at 1 cm depth to return to baseline during a repeated measures study comparing the use of gel versus a gel pad using 3MHz continuous ultrasound at  $1\text{W}/\text{cm}^2$  using a  $5\text{cm}^2$  transducer for 10 minutes to an asymptomatic posterolateral ankle (Bishop et al., 2004). However, this may be attributed to the fact that less energy would have been applied and subsequently a lower maximum temperature achieved. Another study assessing the rate of temperature decay at 1.2cm depth of the medial gastrocnemius following a rise of a minimum of  $5^{\circ}\text{C}$  using 3MHz ultrasound at  $1.5\text{W}/\text{cm}^2$  found that the temperature remained at greater than  $3^{\circ}\text{C}$  for a mean of 3.3 minutes before returning to baseline in 18 minutes (Draper et al., 1995). However, it must be noted again that not only was the ultrasound at a lower intensity, but it was also undertaken on muscle which is less collagenous and subsequently a less efficient absorber of ultrasound energy when compared to tendon. Of the little research available on the therapeutic effects of ultrasound on human tendon, an important paper researching the patellar tendon using 3MHz continuous ultrasound at  $1\text{W}/\text{cm}^2$  using a  $5\text{cm}^2$  transducer found 50% of tendons had not returned to their baseline temperature after 20 minutes. They also found that tendon has a 3.45 faster rate of temperature increase than muscle and sustained vigorous heating for 120% longer than muscle (Chan et al., 1998). Subsequently, although it may be argued that the therapeutic window following a single ultrasound treatment is rather short; clinically ultrasound would be given on a regular basis and the accumulative nature following a course of treatment warrants further research. A multiple phase single case study evaluating the effectiveness of continuous 3 MHz using a  $0.5\text{cm}^2$  transducer with gel comparing  $0.25\text{W}/\text{cm}^2$  versus  $2\text{W}/\text{cm}^2$  for 5 minutes to the tenoperiosteal junction of ECRBr of a symptomatic tennis elbow of 3 month duration was undertaken by the author (Williams, 2003). It was found that there was an accumulative functional improvement whilst the patient received 5 treatments over 10 days for the higher intensity. This was supported by a paper which found a continuation in functional improvement, until follow up at 4 weeks, post 8 sessions of pulsed 1MHz ultrasound at  $1\text{W}/\text{cm}^2$  on a tennis elbow sample (Davidson et al., 2001). Both the initial

delay in progress and continuation of improvement following ultrasound may be explained by the proposed pro-inflammatory nature of ultrasound promoting tissue healing which may take a number of weeks to complete.

### **5.3.5 Normative study 2 conclusion**

In conclusion, 3 MHz ultrasound therapy using a 0.5 transducer with gel administered at  $2\text{W}/\text{cm}^2$  to the tenoperiosteal junction of ECRBr for 5 minutes causes a clinically important increase in *Tsk* which validates both the use of the developed novel protocol for the thermographic analysis of tennis elbow and the clinically important thermal effects of therapeutic ultrasound at these parameters for tennis elbow.

This protocol is particularly useful as it uses a non-invasive infra-red thermal imaging camera rather than thermistor needles and is therefore more user friendly in a clinical environment.

### ***5.4 Normative studies summary of recommendations for the clinical trial***

- Thermal difference of the maximum *Tsk* for the ROI compared to the control.
- A negative thermal difference of  $0.35^{\circ}\text{C}$  was found for the normative study.
- 50% maximum PFG for the MDF recording of the unaffected arm comparable with the PFG reduction found in symptomatic tennis elbow patients.
- MDF of ECRBr recorded during PFG for 45 seconds demonstrated significant fatigue.
- The therapeutic ultrasound parameters used in this thesis demonstrate clinically important thermal effects.

## CHAPTER 6: INTERNAL PILOT

This chapter presents the methods utilised for both the internal pilot and clinical trial. An internal pilot of the first 20 tennis elbow patients was undertaken to test procedures and explore the range of values for thermography and MDF which were compared to the normative study 1 data. The determination of minimum clinically important changes and differences and the analysis of the stability of data throughout the clinical trial, to confirm the adequacy of sample size, are described. A single case study is also presented as an illustrative example.

### **6.1 Methods**

The methods (6.1), ethics (6.2) and statistical methods (6.3) from this chapter apply to both the internal pilot and clinical trial as the data recorded from the first 20 patients from the clinical trial was utilised for the internal pilot.

As there is no existing data on a tennis elbow population for either, the primary outcome measure, thermal difference or MPSF it is not possible to pre-specify either a minimal clinically important difference or the likely between-patients standard deviation. Based on a number of previously published trials (Knebel et al., 1999, Hagg and Milerad, 1997 and Albrecht et al., 1997) which used surface EMG measurements and sample sizes in the range 18 to 29 patients per group), a preliminary sample size of 22 per group (in line with Hagg and Milerad, 1997) was chosen to give a robust analysis of the efficacy of the treatment interventions. In Tonks et al. (2007) 76 tennis elbow patients were referred over 11 months. Of these 35 (46%), were eligible for inclusion. This trial had an overall 25% drop-out rate. Through alterations in methodology, with an elite team of treating physiotherapists who could offer a wider choice of both treatment locations and times the drop-out rate should become more in line with other studies. Subsequently, the sample size was inflated to allow for a dropout rate of approximately 15%. Thus, with proportionate recruitment a realistic sample size of approximately 78 (26 patients per group) was randomised and expected to be recruited in 2 years.

Knebel et al. (1999) studied the MPSF of a normal population with and without a forearm support band. With an ES of 0.9 they found a mean difference in MPSF of

12Hz with a SD of 14Hz. With a 90% statistical power and a significance level of 5% a sample size of 29 patients in each group was appropriate. Hagg and Milerad (1997) studied EMG magnitude in a normal population to study forearm muscular exertion during intermittent gripping. With an effect size of 1.0 they found a mean difference in EMG magnitude of ECRBr of 0.065 with a SD of 0.065. With a 90% statistical power and a significance level of 5% a sample size of 22 patients in each group was appropriate. Albrecht et al. (1997) studied therapy resistant patients with tennis elbow pre and postoperatively and with an effect size of 1.4 found a mean difference in EMG latency of ECRL of 6ms with a SD of 4.2ms. With a 90% statistical power and a significance level of 5% a sample size of 11 patients in each group was appropriate, although it should be noted that this is based on within group change which is usually larger than between group difference and subsequently requires a smaller sample. They also found a mean difference in polyphasic potential EMG magnitude of ECRBr of 13% with a SD of 12%. With a 90% statistical power and a significance level of 5% a sample size of 18 patients in each group was appropriate.

Subsequently, an internal pilot was used to evaluate minimum clinically important differences. A comparative study of the baseline values of the first 20 tennis elbow patients with the normative study (n=20) was undertaken to explore the range of values for thermography and MDF in the tennis elbow population. The range of values at baseline was used to determine what might be a minimum clinically important difference between groups (i.e. difference important to patients not to miss). The first 20 patients were analysed up to the 6 week endpoint with the analyst blind to group codes. To confirm that a sufficient sample size had been recruited the stability of data was analysed to ensure that the group recruited was not considerably smaller or larger than necessary. The study was a prospective randomised, assessor-blinded trial.

Barr et al.'s (2009) review of Tonks et al. (2007) highlighted the importance of methodological quality and facilitated the methodological development of the current research. Furthermore, it emphasised that it is imperative to publish comprehensive information and data in order to allow a more valid review of future research. In rebuttal extensive baseline data had been taken but only mean age had been reported, in contrast to the reviewers stating otherwise, without gender or duration, with the outcome measures. Likewise, they state that the duration and frequency of the exercise programme is not detailed. Although not explicitly reported, it was described as the

exercise programme devised by Pienimaki et al. (1996) and referenced. Outcome measures were assessed at baseline, 1, 4 and 7 weeks and 6 months but again not reported. The loss to follow up was very high at 6 months making data analysis unfeasible with such a low and unevenly distributed sample. An intention to treat analysis was undertaken but again not reported. In retrospect in defence, some of the under reporting may have been done unintentionally due to trimming to meet the strict word limit on publication. Due to the nature of the interventions including injection and exercise the patients could not be blinded and as there were no qualified physiotherapy injectors, other than the researcher, at the time of the research the therapist was unable to be blinded either. However, within these constraints patients were randomly allocated with concealed allocation to prevent bias at this stage. In this current PhD work, due to the research being undertaken Trust wide over a number of sites with injectors now on all sites an elite team of trained physiotherapists have undertaken the treatments, so although patients and physiotherapists are unable to be blinded due to the nature of treatment it has enabled the assessor to be blinded to treatment allocation and consequently improve the methodological quality of the current research work presented in this thesis.

### **6.1.1 Sample**

The sample of convenience comprised of any patient referred by their GP, with tennis elbow, to the Musculoskeletal Clinical Assessment and Treatment Service (MSK CATS) or Physiotherapy Department of Ashton, Leigh and Wigan PCT or Orthopaedic Department of Wrightington, Wigan and Leigh NHS Trust. Members of staff were also eligible for inclusion through the self-referral physiotherapy scheme. All patients with tennis elbow were included from both those who presented with a first episode of symptoms to recalcitrant cases in both acute and chronic stages. Subsequently, this would allow improved generalisation of the study's findings to the general tennis elbow population as a whole.

The selection criteria for tennis elbow were based on those of Cyriax (1982) and Stratford et al. (1993). All patients were assessed by the researcher for consideration for inclusion in the study subject to the following eligibility criteria:

### **6.1.1.1 Inclusion Criteria**

Patients had to present with both of the following criteria:

Pain reproduced on palpation of the common extensor origin.

Pain reproduced on resisted wrist extension with the elbow extended.

### **6.1.1.2 Exclusion Criteria**

Vulnerable patients: children under 18 or people with learning difficulties

Cervical spine involvement.

Previous elbow surgery.

Other significant pathology involving the upper quadrant (e.g.: significant dupytrens contracture which would prevent gripping the dynamometer and subsequently limit grip strength causing spurious data to be collected).

Bilateral symptoms

Physiotherapy or steroid injection, for the presenting condition, within the previous 6 months.

Contraindications for injection therapy (Ashton, Leigh and Wigan Community Healthcare Patient Group Direction for the administration of triamcinolone acetonide version 1/2008):

- Heart, liver or renal failure.

- Children under 18 years.

- Haemarthrosis /recent trauma.

- Joint, local or systemic infection.

- Cancer/ HIV/ hepatitis.

- Epilepsy.

- Hypersensitivity to local anaesthetic.

- Prosthetic joint/unstable joint.

- Avascular area.

- Poorly controlled diabetes.

- Immunosuppressed.

- Anticoagulant therapy.

- Psychogenic patient.

- Bleeding disorders.

- Pregnancy/ breast-feeding.

Concurrent oral steroids.

Known osteoporotic.

Allergies.

The researcher assessed all patients using a standardised subjective and objective assessment proforma developed specifically for this research (Appendix 11.5). If the patient was eligible for inclusion in the study written informed consent was sought (Appendix 11.7). The patient would have received a patient information sheet with their appointment letter to allow them to have sufficient time, minimum 3 days, to consider participation in the research (Appendix 11.6). For those consenting, baseline study data were collected on a standardised data collection sheet (Appendix 11.11) and accumulative data collection sheet (Appendix 11.12) which included recording details of possible extraneous variables and potential prognostic factors. Patients were requested to refrain from altering any ‘treatment’ that they were already undertaking such as NSAID or brace use and not to divulge what treatment they have received to the researcher at review appointments.

### **6.1.2 Randomisation**

Patients were randomised into one of the 3 treatment arms according to randomly permuted blocks selected by a computer random-number generator. The randomisation process was undertaken by a non-clinical academic third party and the treatment group details were sealed in a series of sequentially numbered, opaque, envelopes by Research and Development support staff. The envelopes were opened by the patients after baseline 1 data collection under supervision of administrative and clerical support who then arranged the appropriate treatment and review appointments. This enabled their initial treatment appointment to be arranged promptly after baseline 2 data collection.

### **6.1.3 Blinding**

The researcher remained blinded to the randomisation of patients. The physiotherapist who treated the patients recorded all treatments given and any adverse reactions or side-effects on the treatment diary sheet (Appendix 11.10). If the treatment had to be altered from protocol in anyway the physiotherapist informed the researcher following the 6

week end point data collection. As is common in trials of physical interventions it was not possible to blind patients from their treatment in this trial.

To evaluate the blinding process and negate any potential bias the researcher documented which intervention, including reasons; they thought the patient had received at both the 10 day and 6 week reviews which were reviewed at the 6 week end-point.

#### **6.1.4 Treatments**

The 3 treatment groups were injection therapy, ultrasound and physiotherapy rehabilitation programme. All are part of normal clinical practice and were undertaken by a select team of experienced physiotherapists in any of the Ashton, Leigh and Wigan Community Healthcare's physiotherapy or MSK CATS departments. Although the use of a team of treating physiotherapists may be considered disadvantageous due to the potential increase of variability in the study it was strongly negated by the advantages:

It enabled a more robust study as the author, who undertook all assessments and data collection, remained blinded to the treatment and therefore any potential bias negated. The use of more than one therapist meant that those patients who needed further treatment at the 6 week end point remained under the care of the same therapist enabling continuity of care, which follows normal clinical practice more closely. A therapist on each of the 3 sites within the Trust facilitated recruitment and retention as the patient could be seen at a more convenient locality to either their home or work. The treatment protocols were all standardised with the physiotherapists prior to the commencement of the study.

##### **6.1.4.1 Injection Therapy**

The experienced physiotherapist injector, who had undertaken a Diploma in Injection Therapy, used an aseptic technique according to the Association of chartered physiotherapists in orthopaedic medicine (ACPOM) guidelines (1999). The patient was ½ lying with the elbow flexed to 90 degrees, forearm supinated and supported on a pillow.

The 25G needle was inserted in line with the cubital crease perpendicular to the lateral epicondylar facet to caress the bone (Figure 6.1). The solution of 10mg of kenalog 40 (steroid) with 0.75ml of lidocaine 2% (local anaesthetic) was peppered around the tenoperiosteal junction (Saunders 2002).



Figure 6.1: Injection technique.

Recruitment started in June 2007 and 4 patients received injections as per protocol. However, shortly after the commencement of the clinical study the Primary Care Trust's patient group directions were reviewed on account of new government guidelines effecting a change in practice not allowing mixing of drugs. This meant that 0.75 ml of lidocaine would be peppered around the tenoperiosteal junction followed by peppering of 0.25ml of kenalog. This would not only have the effect of increasing the length of the procedure but also any potential effect of twice the amount of needle peppering into the area. Subsequently, practice was changed accordingly to the use of a solution of 10mg adcortyl only. Both adcortyl and kenalog are of the same drug triamcinolone acetonide in different dosages and have duration of action in the region of 6 weeks (Saunders 2002). Due to the fact that it would be difficult to effectively pepper 0.25ml of kenalog the more dilute 1ml of adcortyl became the drug of choice. From clinical experience patients find this a relatively pain free procedure and the only disadvantage of not using the local anaesthetic is that the therapist is unable to retest the patient's objective markers immediately following the injection to assess outcome.

The patient was then requested to relatively rest for 10 days, i.e.: to avoid excessive elbow use in aggravating conditions as per guidelines (Saunders, 2002).

### 6.1.4.2 Ultrasound

The ultrasound treatment was performed in a standardised manner. The patient received 6 treatments of ultrasound during the first 2 to 3 weeks of treatment ensuring treatment was administered as a minimum of twice weekly, as per normal clinical practice. The patient was in ½ lying with the elbow flexed to 90 degrees, forearm supinated and supported on a pillow. Continuous 3 MHz ultrasound therapy using a 0.5 transducer with gel was administered at  $2\text{W}/\text{cm}^2$  to the tenoperiosteal junction for 5 minutes (Figure 6.2). The EMS Medi-Link system was checked/ calibrated regularly as per departmental procedure.



Figure 6.2: Ultrasound application.

### 6.1.4.3 Physiotherapy rehabilitation

The physiotherapist was an experienced clinician. The physiotherapy exercise rehabilitation followed the stretching and progressive strengthening exercise programme as defined by Pienimaki et al. (1996). Patients started step one immediately. The appropriate exercises were taught and the patient given an exercise sheet (Appendix 11.15). Compliance was recorded on the treatment diary sheet. Patients were advised that each exercise should be pain free and was to be done ten times slowly to the count of eight. The whole exercise programme was then repeated three times prior to stretching both wrist flexors and extensors. The exercises were reviewed on 2 further occasions and progressed accordingly.

## 6.1.5 Data collection

All data collection at the review appointments was undertaken by the researcher in a standardised manner to ensure consistency throughout.

The primary outcome measure was thermographic analysis of *Tsk* over the ECRBr origin which enabled an indirect measure of inflammation through temperature changes.

Secondary measures were:

- PFG which provided a measure of strength
- surface EMG MDF during PFG which enabled a direct measure of extensor muscle fatigue.
- PRTEE which provided a standardised, quantitative description of pain and functional disability.
- patient preference questionnaire which provided a qualitative impression of patient treatment preference overtime.

TIME POINTS	OBJECTIVE NUMBER	DATA ANALYSED	JUSTIFICATION
Baseline 1		All baseline data	To check homogenous groups at baseline
Baseline 2		Change from baseline 1	Evaluate the stability of the patient's condition and any evidence of spontaneous healing
10 days	1,2 and 4	Change from baseline 1	Evaluate any immediate treatment effect
6 weeks	3	Change from baseline 1	Identify which treatment is sustainable in the short term
6 months	3	Change from baseline 1	Identify which treatment is sustainable in the intermediate term

Table 6.1: Justification of time point data collection.

These were recorded at baseline 1 and baseline 2 (week 1 to 2) prior to treatment, 10 days (after commencement of treatment), 6 weeks and 6 months (Table 6.1). Data was collected for both the affected and unaffected arms.

The primary trial endpoint was at 6 weeks. If a patient was not asymptomatic (i.e.: therapy-resistant patients) at this time alternative treatment was made available as appropriate and recorded on the treatment diary sheet. Only those patients who remained in their original treatment group as per protocol were reviewed at 6 months.

The patients filled in the PRTEE (Appendix 11.8) at every data collection review without assistance. The Patient preference questionnaire (Appendix 11.9) was also filled in at the 10 day, 6 week and 6 month reviews. Clarification was only given on the first assessment, if required. The thermographic measurement and EMG studies were then taken in the standardised manners as previously described in Chapter 4.1 and 4.3 respectively. The unaffected arm was assessed first.

## **6.2 Ethics**

This study conformed to the declaration of Helsinki and ethical approval was gained from both Wrightington, Wigan and Leigh Regional Ethics Committee (WWL REC) (appendix 11.13) and FHEC UCLan (appendix 11.14). All research management and governance was in place from Ashton, Leigh and Wigan Primary Care Trust before commencement of the study.

No patients were from vulnerable groups, e.g.: children under 18 or people with learning difficulties. Patients did not receive any payment for inclusion in this study. Written informed consent, using the Trust consent form, was requested from all patients who were eligible for inclusion into the study. Each patient received the patient information sheet. Patients were given a minimum of 3 days to consider if they wished to participate and were given the opportunity to ask any questions. Subjects were informed that participation in the study was voluntary and that they were under no obligation. They had the right to withdraw at any stage without justification of their decision or penalty to any future treatment.

All interventions were part of clinically accepted ‘normal’ care and the use of strict

eligibility criteria minimised any potential risks. Therefore, subjects did not incur any further risks or potential hazards from their inclusion in the study. Their participation was unlikely to cause any additional discomfort or distress. Potentially beneficial treatment was not withheld from certain subjects according to their randomisation. Patients were offered the most appropriate physiotherapeutic or orthopaedic treatment after the six-week end point, if required.

Confidentiality of personal records was maintained: stored on Trust sites as per Trust policies. Any data leaving Trust premises for analysis was only identifiable by the patient's unique code which was documented on the front of the patient's personal NHS hospital records. No patient names were stored outside of Trust premises. All patient data was kept confidential and individual patients were not identifiable from any publication of this study.

## **6.3 Statistical Methods**

### **6.3.1 Data analysis**

Descriptive statistics were used to illustrate any important features of the baseline data: The means and standard deviations of all outcome measures and percentages for any categorical variables (e.g. sex, therapy resistance) were shown.

Changes from baseline data were analysed using an ANOVA with the Scheffe post-hoc test for multiple comparisons as an intention to treat analysis (ITT) throughout the trial. The Scheffe was chosen over the Bonferonni as the latter is more aggressive and, therefore, although it would not find a false positive it has the potential to miss subtle clinically important differences.

Patient's data of those who withdrew or DNA was included using the last observation carried forward (LOCF). For all patients who DNA every effort was made to contact them in order to arrange a convenient appointment for follow-up. The data was also analysed as per protocol with LOCF and with exclusion of patients who had either withdrawn or had missing data to check the sensitivity of the findings to the 'assumptions' about any data from patients who drop-out: i.e.: the assumption that the

patients who DNA are better. For all analyses the significance level was set a priori at 5% ( $\alpha < 0.05$ ) and 95% CIs were reported.

The patient preference questionnaire was analysed qualitatively by categorising answers to identify themes for each treatment group and data reported as percentages for each theme.

## **6.4 Pilot results**

The internal pilot was presented as a poster at the British Elbow and Shoulder Society's 20<sup>th</sup> annual scientific meeting held at UCL, London, in June 2009 (Appendix 11.17).

### **6.4.1 Pilot sample**

The 20 tennis elbow patients were randomised by a third party prior to the onset of the clinical trial, into 3 treatment arms in equal numbers: injection (n= 7), ultrasound (n=6) and exercise rehabilitation (n=7).

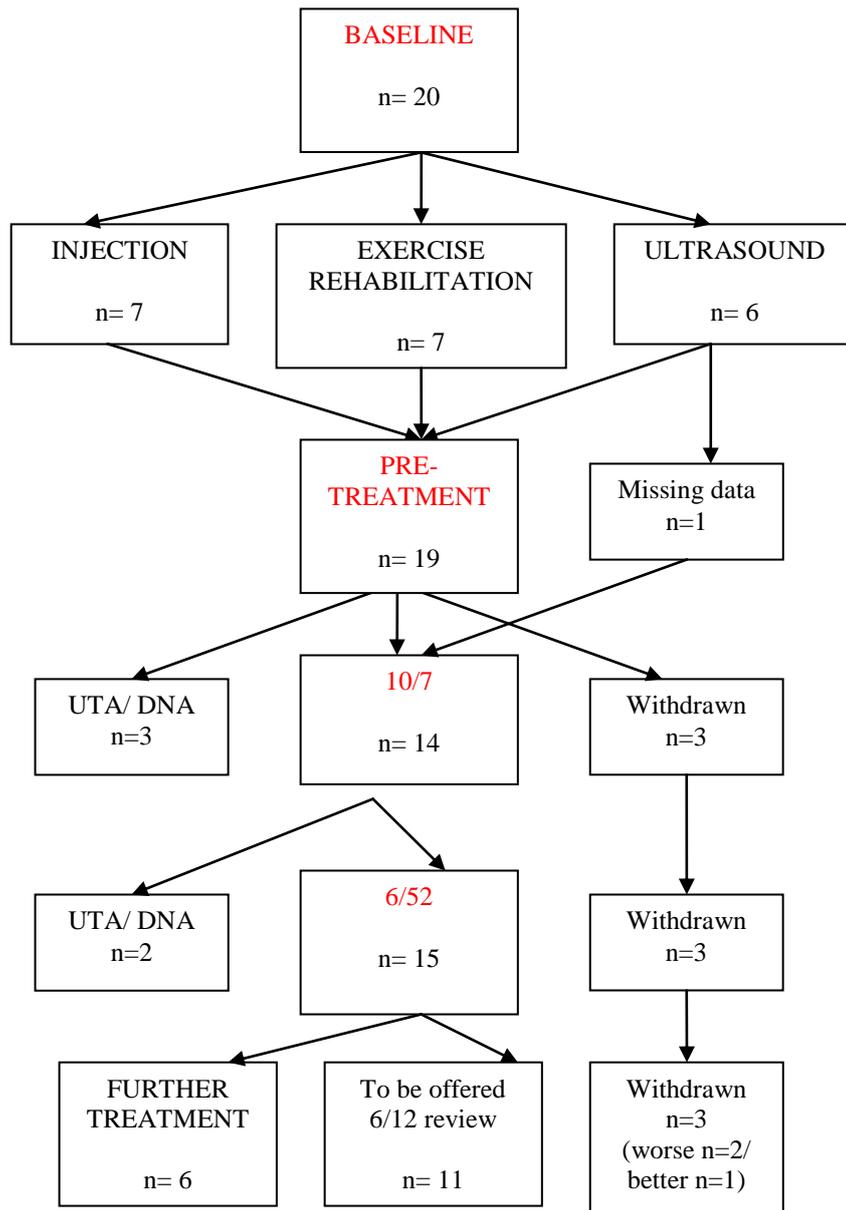


Figure 6.3: Patient flowchart through the study up to the 6 week endpoint.

As can be seen from the flowchart (Figure 6.3) 15% of patients (n=3) had withdrawn prior to the 6 week endpoint and a further 10% of patients (n=2) DNA their 6 week review. Subsequently, 30% of patients (n=6) required further treatment at the 6 week endpoint leaving the remaining 55% of the patient population (n=11) to be offered a 6 month review.

## 6.4.2 Pilot descriptive statistics

The healthy subjects were age and gender matched to the presenting tennis elbow population (Table 6.2).

	<b>Patients</b>	<b>Normals</b>
<b>Gender F</b>	11	11
<b>M</b>	9	9
<b>Mean age (range)</b>	47yrs (23-61)	40.6yrs (27-56)
<b>Dominance R *</b>	18	16

Table 6.2: Descriptive statistics for the internal pilot.

- \* It interesting to note that the 2 patients who were left handed both complained of tennis elbow affecting their right nondominant elbows.

The descriptives of the 20 patients in the internal pilot are shown in table 6.3.

<b>Mean symptom duration (range)</b>	7 months (0.5-24)
<b>Dominant affected</b>	11
<b>Previous treatment *</b>	3
<b>NSAID</b>	2
<b>Analgesia use</b>	3
<b>Brace use</b>	4
<b>Aggravating occupation</b>	13
<b>Aggravating hobbies **</b>	8
<b>Positive Smoking status</b>	2
<b>Previous smoker</b>	3

Table 6.3: Descriptive statistics for the internal pilot patients.

- \* Previous treatment included repeated injections, exercise and ultrasound.
- \*\* Aggravating hobbies included golf, fishing, squash, gardening, painting, dressmaking and playing the guitar.

### **6.4.3 Minimum clinically important differences**

The aim of any clinical research is to evaluate the effectiveness of treatment and although statistical significance is indispensable, alone it may be insufficient to establish a difference in effect between 2 treatment approaches. The clinical importance of any effect must also be identified to ensure that results are clinically relevant to patient care. The minimum clinically important change (MCIC) is the threshold value of a change which is considered meaningful and worthwhile to a patient such that if it was necessary, and if the patient had the choice, they would consider repeating the treatment (Copay et al., 2007). The MCIC is the within group change and the MCID is the difference between change in 2 or more groups which is used for the interpretation of treatment effects in a randomised trial.

However, determination of a MCIC is difficult, especially when the subjective nature of pain, for example, is considered for which one has to rely entirely on the patient for assessment which is further exacerbated due to the large variation in patient interpretation of measurement scales (Farrar et al., 2001). Secondly, a mismatch between clinical measures and patient evaluation of improvement, in terms of pain and disability, do not always correspond. The determination of the MCID is even more difficult; however it is usually smaller than the MCIC which therefore requires a larger sample, particularly if all the interventions under investigation are potentially effective.

Determination of a MCIC can be derived from 2 different methods; anchor-based and distribution-based. The former compares the change in a patient-reported outcome with a measure such as a global assessment rating. Ideally, an established association between the two should exist so that meaningful inferences can be made. Distribution-based approaches compare the change in a patient-reported outcome with a measure of variability such as the ES, the standard error of measurement (SEM) or smallest detectable change (SDC), with reliance on either of the latter ensuring statistical soundness. However, the purpose of a MCIC is to distinguish clinical importance from statistical significance which may potentially be limited due to the dependence on the variability of the scores within a sample. The changes in scores corresponding to the small ES, of 0.2, is considered the MCIC (Copay et al., 2007). However, others would argue that 0.2 is small for a MCID with very few trials having sufficient power to achieve a sample size in the region of 400 patients per group.

	Mean (SD)			
	Tennis elbow Patients		Normative participants	
	Affected	Unaffected	Dominant	Nondominant
<b>Thermal difference</b> ( <sup>0</sup> C)	0.4 (0.42)	-0.2 (0.46)	-0.3 (0.51)	-0.4 (0.43)
<b>MPFS 10sec</b> (Hz)	130.2(14.42)	128.7(17.71)	124.1(12.24)	121.3(15.19)
<b>MPFS 35sec</b> (Hz)	111.6(10.99)	102.2(20.21)	102.4(10.95)	100.7(17.97)
<b>MDF shift</b> (Hz)	-18.6 (13.15)	-26.5 (13.45)	-21.7	-20.6
<b>Grip strength</b> (kg)	17.4 (12.5)	31 (13.5)	39.9 (13.6)	37.2 (9.5)

Table 6.4: Internal pilot and normal baseline outcome measures: mean (SD).

A reduction in *Tsk* of 0.2<sup>0</sup>C can be accepted as a MCIC. If the MCIC is calculated using effect size, using the baseline SD of 0.4 in table 6.5 and multiplying by 0.2, (a small effect size), this gives a MCIC of 0.1<sup>0</sup>C. The body is generally accepted as being thermally symmetrical. Selfe et al. (2008) concluded from a narrative literature review that a 0.5<sup>0</sup>C *Tsk* difference in asymmetry at the anterior knee is clinically important which is inline with the mean *Tsk* difference of 0.6 <sup>0</sup>C found between the affected and unaffected elbows in table 6.4. Vardasca et al. (2007) evaluated the thermal symmetry in the extremities of normal subjects, using high resolution digital thermal imaging technology, in which a maximum *Tsk* difference of 0.16<sup>0</sup>C was reported on regional views which is in line with the 0.1<sup>0</sup>C difference found between the normative participants elbow shown in table 6.4. However, both Selfe et al. (2008) and Vardasca et al. (2007) have assessed the difference between the mean temperature for left and right limbs whereas the thermal protocol utilised in this research is the mean thermal difference found between the ROI and an ipsilateral control. When the baseline *Tsk* are considered, it is interesting to note that the patient's affected elbow has a mean positive thermal difference when compared to either the patient's unaffected elbow or either of the normal elbows (Table 6.4). A mean difference of 0.6 <sup>0</sup>C is found between the affected and unaffected elbows and an even greater 0.75<sup>0</sup>C when compared to the normative data. Subsequently, to accept a MCIC as 0.5<sup>0</sup>C equates to an improvement in return of temperature in the region of 2/3rds which would be questionable at the very least to be classed as minimal. A reduction in *Tsk* of 33% or 0.2<sup>0</sup>C would be more acceptable. Furthermore, the 0.2<sup>0</sup>C MCIC is supported by Binder et al. (1986) who

evaluated the maximum temperature at the lateral elbow of 50 patients with tennis elbow. Using the data provided to calculate the effect sizes, with a SD of  $0.93^{\circ}\text{C}$  in the morning and  $0.72^{\circ}\text{C}$  in the afternoon this gives MCICs of  $0.19^{\circ}\text{C}$  and  $0.14^{\circ}\text{C}$  respectively. It is interesting to note when considering the SD there is less variability in the current research in comparison to that of Binder et al. (1986) which can be attributed to both the advances in thermal image technology and the robust protocol developed. Thomas et al. (1992), who applied the methods of Binder et al. (1983) on 35 cases of tennis elbow, reported a SD of mean elbow spot temperature of  $0.88^{\circ}\text{C}$  which gives a MCIC of  $0.18^{\circ}\text{C}$ . A MCIC of  $0.2^{\circ}\text{C}$  is also larger than the SDD of  $0.03^{\circ}\text{C}$  reported by Uematsu et al. (1988), although as suggested by Selfe et al. (2008) this is somewhat ambitious considering this was using predigital thermal technology.

It is also of interest that the MDF shift of the patient's affected elbow is 30% less than the patient's unaffected elbow. The difference between the affected and unaffected side may be attributable to the fact that the patient was performing a PFG and was able to reduce their grip if they should experience any pain during the test. Whereas, in comparison, on the unaffected arm they maintained 50% of their maximum grip strength by virtue of having visual feedback from the dynamometer dial.

A 38% change in MDF of 3Hz can be accepted as a MCIC. There is a lack of previous work available to identify a MCIC with MDF. If the MCIC is calculated using effect size, using the baseline SD of 13.1 in table 6.5 and multiplying by 0.2, (a small effect size), this gives a MCIC of 3Hz.

An increase in PFG of 3kg can be accepted as a MCIC. If the MCIC is calculated using effect size, using the baseline SD of 12.5 in table 6.5 and multiplying by 0.2, (a small effect size), this gives a MCIC of 2.5kg which is larger than the SDD of 1.4kg Smidt et al. (2002) reported. On validating outcome measures for tennis elbow Stratford et al. (1987) reported a baseline SD of 10.37kg and 11.27kg for a failures and successes comparison which gives MCICs of 2.1kg and 2.25kg respectively, using effect size calculations. This is also supported by Abbott (2001) who evaluated the effect of mobilisation with movement on PFG in patients with tennis elbow. They reported a baseline SD of 12.3kg which gives a MCIC of 2.5kg and described a 17% increase in PFG to be clinically significant. The PFG of the affected elbow was 56% less than the

unaffected maximum grip strength and subsequently a 22% increase in PFG of 3kg can be accepted as a MCIC.

For PRTEE pain and function a 25% reduction in pain or increase in function which equates to a reduction in score of 5 points could be classed as a MCIC. If the MCIC is calculated using effect size, using the baseline SD in table 6.5 for pain = 9, function =10.2 and total =18.6, calculated by multiplying by 0.2, (a small effect size), this gives a MCIC of 2, 2 and 4 respectively. However, due to the scoring protocol of 5x items for pain, 10x items for function which is then divided by 2 so that both pain and function subscales contribute 50% to the total this would equate to a mean change for each item of 0.4 which is not only less than the minimum change detectable in score of 1 but also less than the SEM of 0.6 reported by Overend et al. (1999) for the PRFEQ. In contrast, 1 SEM may be used as the yardstick for true change (Copay et al., 2007) which equates to a 25% reduction in pain and disability if the mean scores at baseline for PRTEE are considered: Pain subscale = 21.3, function subscale = 17.8 and total 39.2 which, due to the scoring protocol, equate to a mean individual score for each item of 4.3 for pain, 3.6 for function and 3.9 for total. Furthermore, if the mean for each PRTEE item is taken as 4 this MCIC is supported by data using an anchor-based method from the evaluation of the clinical importance of changes in chronic pain intensity measured on an 11-point numerical rating scale (Farar et al., 2001) who reported that a reduction in 1 point or a percent change of -14.5% would be classed as minimal, much or very much improved on a standardised 7-point patient global impression of change. This was supported by Bot et al. (2005) who reported that although the MCIC of the modified pain free function index, which has a maximum score of 100, was unknown in most cases the MCIC appears to be in the region of  $\frac{1}{2}$  a SD, i.e.: an ES of 0.5, which they calculated as 10 points. Subsequently, the MCIC for PRTEE pain or function subscale can be accepted as a reduction in score of 5 and the MCIC for PRTEE total can be accepted as 10.

#### **6.4.4 Patient pilot study analysis**

A repeated measures ANOVA was used with alpha set at  $p < 0.05$  with 95% confidence levels.

For the sample population as a whole no statistical differences were found at any time interval for the patient's unaffected arm and are not reported on further. Similarly, no statistical difference was found between baseline 1 and baseline 2 for any outcome measure which demonstrates the stability of the patient's condition and suggests that there is no evidence of spontaneous healing in the study population.

Table 6.5 shows the outcome measures means and SD overtime of the affected elbow.

	Mean (SD)			
	Baseline 1	Baseline 2	10 days	6 weeks
<b>Thermal difference (<sup>0</sup>C)</b>	0.4 (0.4)	0.3 (0.6)	-0.03 (0.5)	0.1 (0.5)
<b>MPFS shift 10s-35s (Hz)</b>	-18.6 (13.1)	-20.1 (9.1)	-18.5 (11.5)	-23.3 (13.4)
<b>PFG (kg)</b>	17.4 (12.5)	16.8 (11.2)	21.4 (13.9)	21.6 (13.8)
<b>PRTEE pain</b>	21.2 (9.0)	21.5 (9.8)	17.9 (9.9)	12.8 (9.0)
<b>PRTEE function</b>	17.2 (10.2)	18.5 (11.1)	13.6 (9.3)	10.1 (8.9)
<b>PRTEE total</b>	38.4 (18.6)	40.0 (20.0)	31.5 (18.4)	22.9 (17.0)

Table 6.5: Outcome measures means (SD) overtime for the affected elbow.

#### **6.4.4.1 Thermal difference**

Mean change between baseline 1 and baseline 2 was  $-0.09^{\circ}\text{C}$   $p= 0.5$  with a 95% CI (-0.2 to 0.38)

Mean change between baseline and 10 days was  $-0.35^{\circ}\text{C}$   $p= 0.07$  with a 95% CI (-0.04 to 0.74)

Mean change between baseline and 6 weeks was  $-0.18^{\circ}\text{C}$   $p= 0.2$  with a 95% CI (-0.13 to 0.48)

This analysis of the patient study population demonstrates no statistically significant reduction at any time intervals. A MCIC ( $0.2^{\circ}\text{C}$ ) in Tsk of the ROI at 10 days was found although it was not maintained through to the 6 week endpoint.

#### **6.4.4.2 Median frequency shift**

Mean change between baseline 1 and baseline 2 was -3.8Hz p= 0.215 with a 95% CI (-2.7 to 10.3)

Mean change between baseline and 10 days was -3.7Hz p= 0.37 with a 95% CI (-5.2-12.7)

Mean change between baseline and 6 weeks was 0.2Hz p= 0.96 with a 95% CI (-9.3-8.9)

This analysis of the patient study population demonstrates no statistical changes were found for median frequency shift at any time intervals, although a MCIC (3Hz) was found at both baseline and 10 days which was not maintained through to 6 weeks.

#### **6.4.4.3 Pain free grip strength**

Mean change between baseline 1 and baseline 2 was -2.7kg p= 0.08 with a 95% CI (-5.9 to 0.4)

Mean change between baseline and 10 days was 0.4kg p= 0.80 with a 95% CI (-3.1 to 3.9)

Mean change between baseline and 6 weeks was 1.5kg p= 0.45 with a 95% CI (-2.8 to 5.9)

This analysis of the patient study population demonstrates no statistical change or MCIC (3kg) was found for PFG at any time intervals.

#### **6.4.4.4 Patient rated tennis elbow evaluation total**

Mean change between baseline 1 and baseline 2 was 1.1 p= 0.59 with a 95% CI (-5.3 to 3.2)

Mean change between baseline and 10 days was -5.2 p= 0.35 with a 95% CI (-6.6 to 17.1)

Mean change between baseline and 6 weeks was -14.9 p= 0.003 with a 95% CI (6.4 to 23.5)

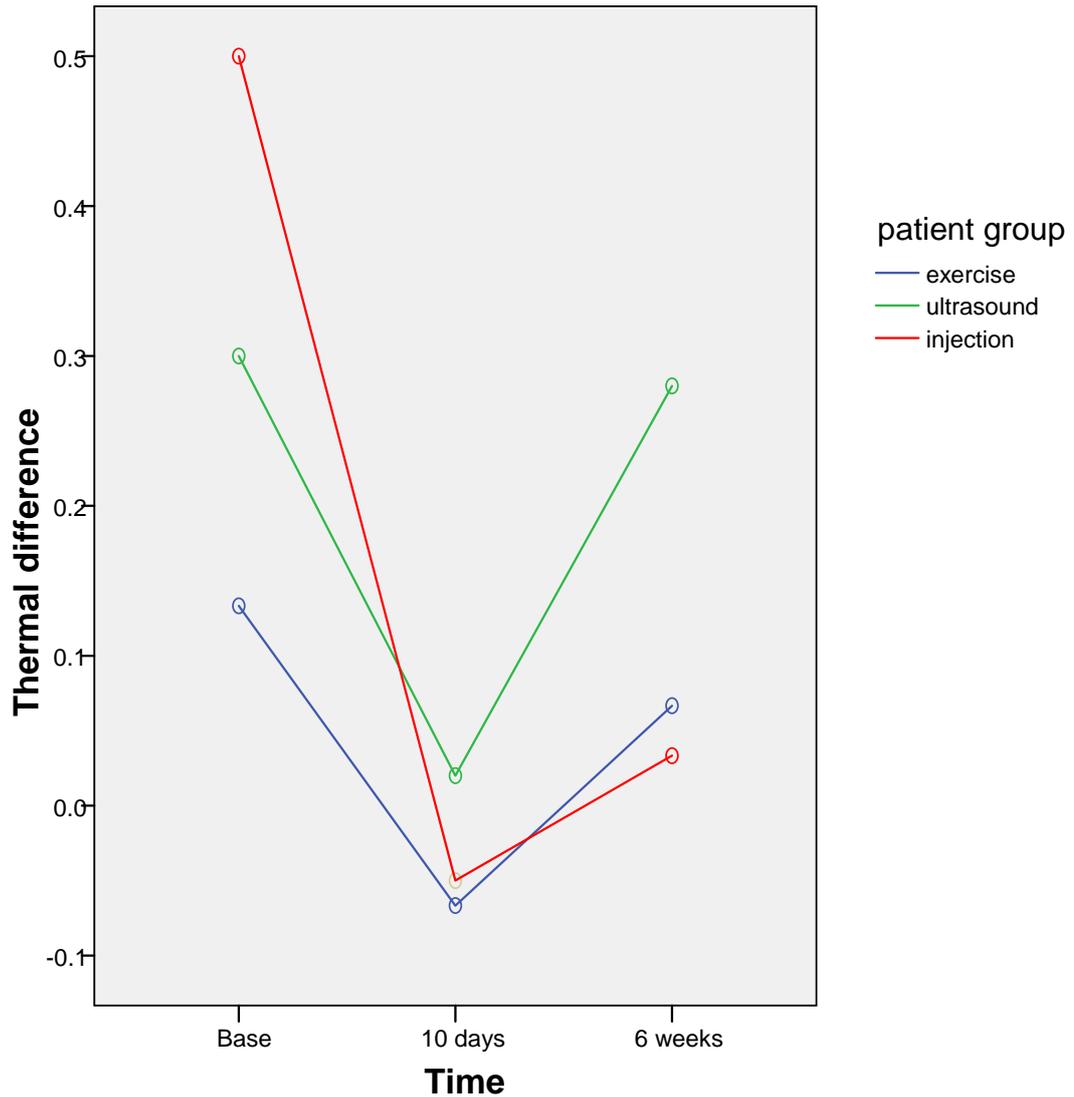
This analysis of the patient study population demonstrates a statistically significant reduction in pain and disability at the 6 week endpoint with treatment of either injection, ultrasound or exercise. A MCIC (10) was found at 6 weeks only.

#### **6.4.5 Treatment group analysis**

Treatment group analysis of the pilot data was undertaken to refine the data analysis and presentation of data plans for the clinical trial. A repeated measures ANOVA comparing all groups found no statistically significant differences between the 3 treatment groups for any of the outcome measures for either the affected or unaffected elbows. This result in the affected elbow was expected due to the small study population and subsequent lack of power of the internal pilot.

However, it is interesting to consider the means profiles of the affected elbow to identify any early trends demonstrable within the internal pilot. Obviously, any conclusions must be regarded with caution due to the small numbers involved and subsequently may not be comparable to the tennis elbow population as a whole.

### 6.4.5.1 Thermal difference



Graph 6.1: Means profile plot for thermal difference ( $^{\circ}\text{C}$ ).

The thermal difference profile plot (Graph 6.1) demonstrates that all 3 treatments have an effect of reducing the  $T_{sk}$  by a MCIC ( $0.2^{\circ}\text{C}$ ) in the ROI at 10 days which is most marked in the injection group and which is maintained in this group through to the 6 week endpoint. With both the ultrasound and exercise groups despite the initial reduction in  $T_{sk}$  at 10 days both rise to approach near pre-treatment levels at 6 weeks.

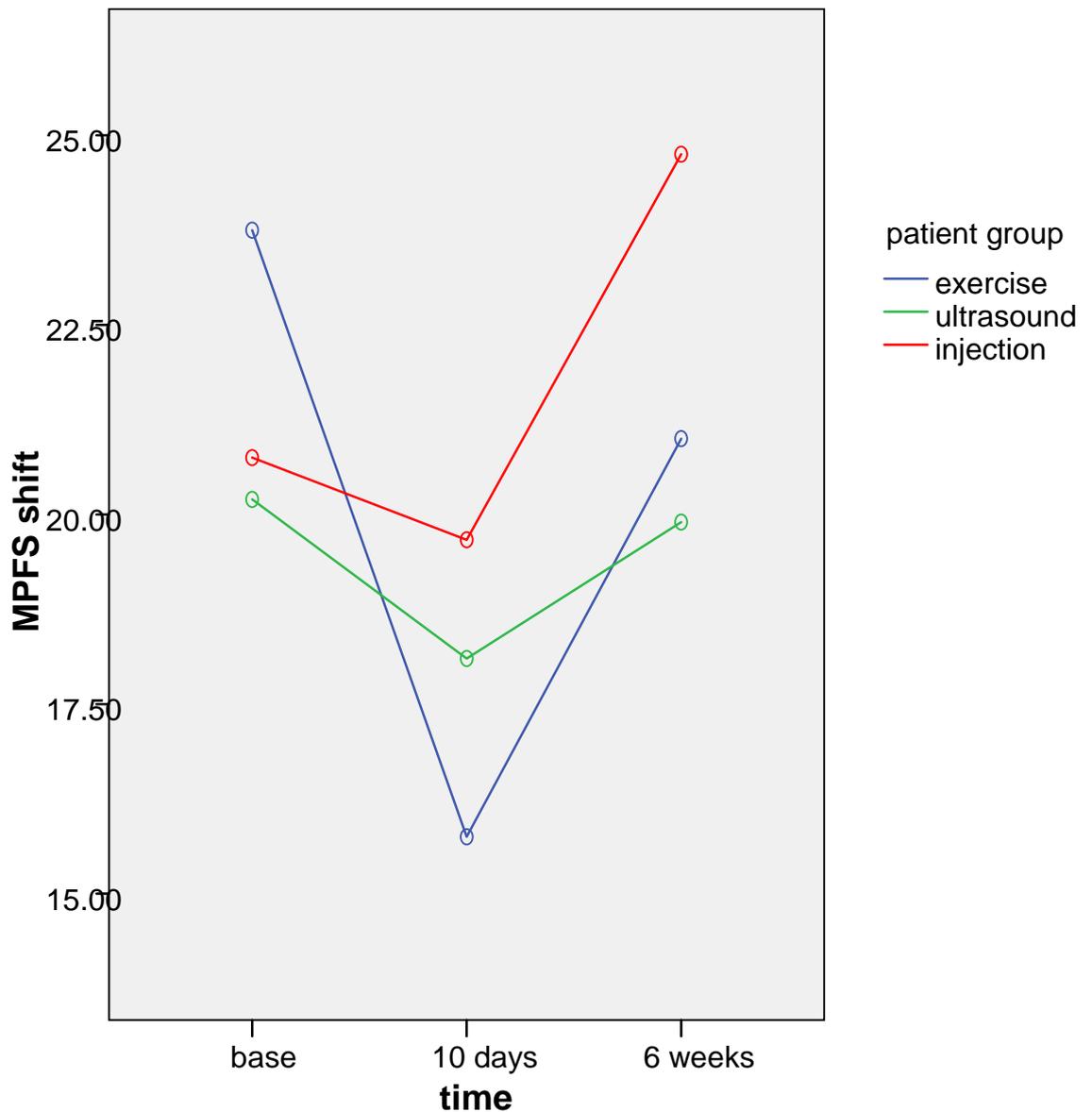
On statistical analysis of the injection group alone by a repeated measures ANOVA.

The mean change between baseline and 10 days was  $-0.7^{\circ}\text{C}$   $p = 0.005$  with a 95% CI (0.35- 1.05)

The mean change between baseline and 6 weeks was  $-0.64^{\circ}\text{C}$   $p = 0.007$  with a 95% CI (0.29- 0.99)

This demonstrates that the MCIC and statistically significant immediate reduction in *Tsk* of the ROI at 10 days is maintained through to the 6 week endpoint in the injection therapy group.

#### 6.4.5.2 Median frequency shift

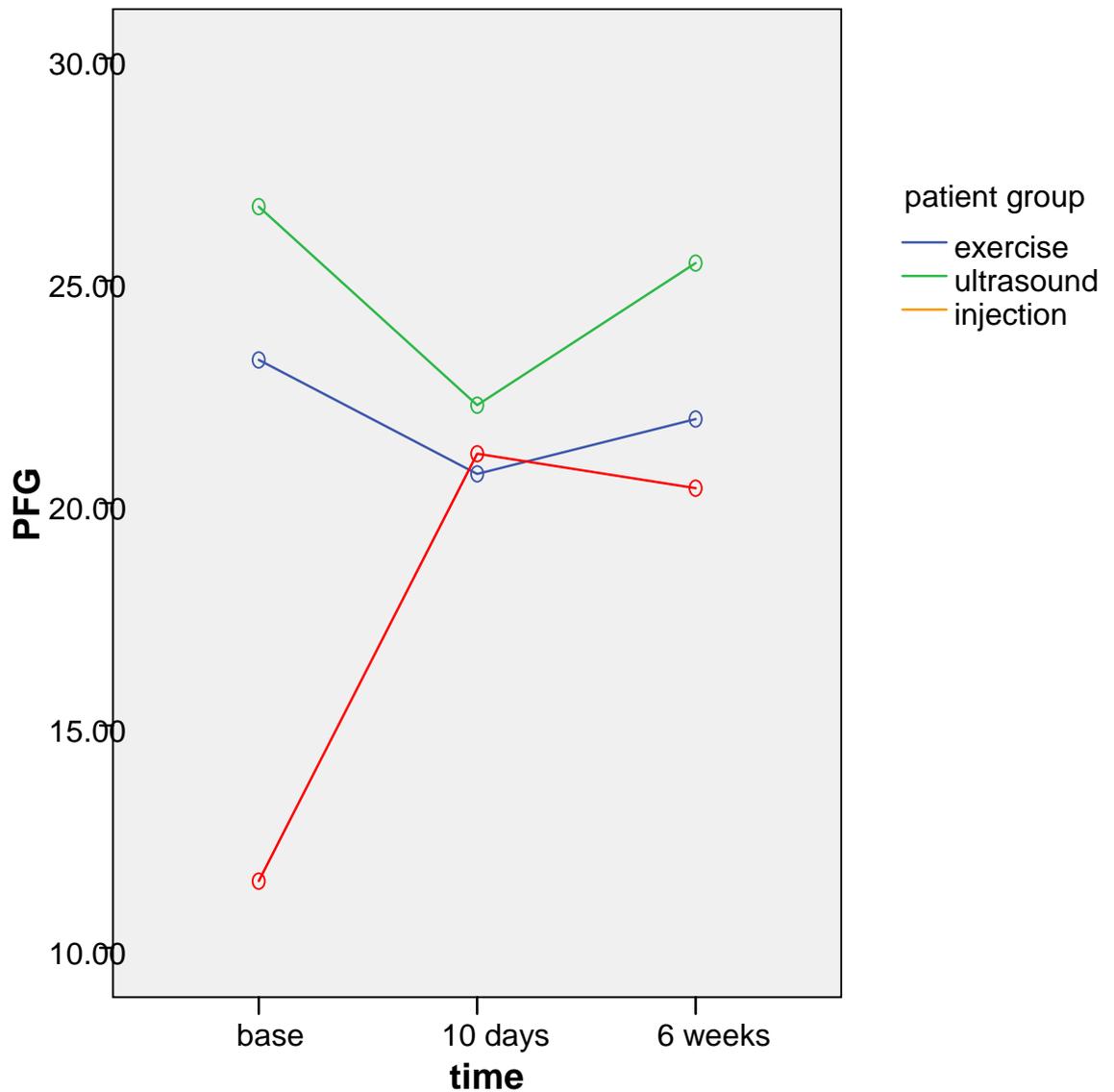


Graph 6.2: Means profile plot for median frequency.

The MDF shift profile plot (graph 6.2) demonstrates that all 3 treatments have an effect on reducing the ECRBr fatigue at 10 days which is most marked in the exercise group where a MCIC (3Hz) is found. The fatigue increases at the 6 week endpoint in all treatment groups to varying degrees and although to a markedly lesser extent in the exercise group a MCIC is no longer evident. The fatigue in the ultrasound group returns

to near baseline levels and returns to a markedly greater than baseline level in the injection group.

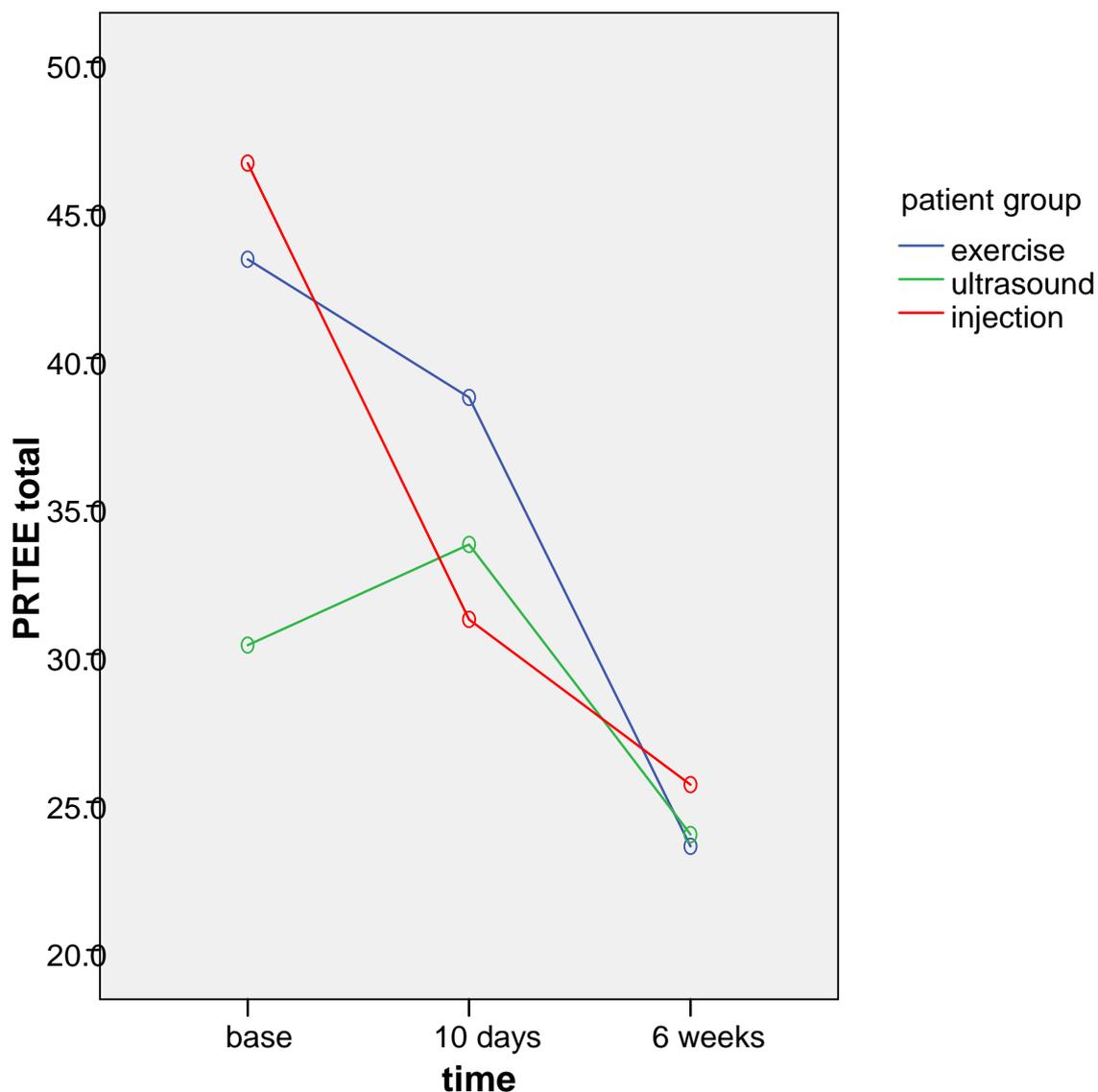
### 6.4.5.3 Pain free grip strength



Graph 6.3: Means profile plot for pain free grip strength.

The PFG profile plot (Graph 6.3) demonstrates that there was a MCIC (3.4kg) increase in PFG for the injection group only which was maintained through to the 6 week endpoint. The PFG reduced for the ultrasound group by a MCIC and by less for the exercise group at 10 days prior to returning to near baseline levels at the 6 week endpoint.

#### 6.4.5.4 Patient rated tennis elbow evaluation total



Graph 6.4: Means profile plot for patient rated tennis elbow evaluation total.

The PRTEE total profile plot (Graph 6.4) demonstrates a reduction in pain and disability in all treatment groups with a MCIC (10) found in the injection group at 10 days and both the injection and exercise group at the 6 week endpoint.

#### **6.5 Stability of grouped data**

To confirm that a sufficient sample size had been recruited the stability of data was analysed throughout the clinical trial on an ongoing basis. The stability of the data was

determined by calculating the cumulative means and the cumulative standard deviations of the change. The change in SD for each consecutive patient was calculated and described as a percentage change of the cumulative mean:

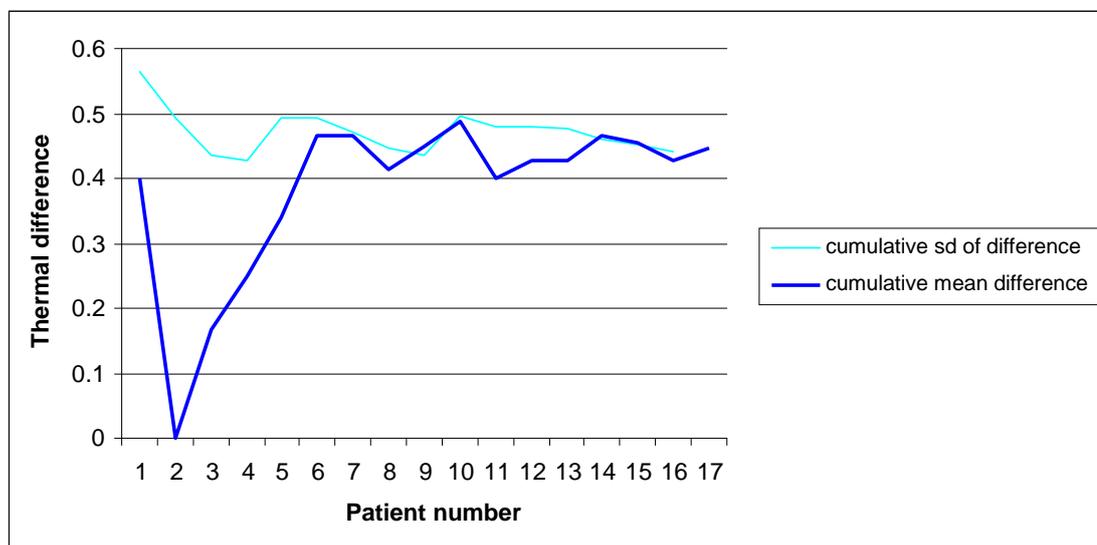
$$\text{Percentage change in SD} = \frac{\text{SD}_{(n+1)} - \text{SD}_{(n)} \times 100}{\text{Cumulative mean}_{(n+1)}}$$

When the SD varied in absolute terms by less than 5% of the cumulative means values for at least 3 consecutive patients it was accepted that the data had stabilised and a sufficient number of patients had been recruited (Selfe et al., 2006). If the sample size is too small the variability may be too large for an, albeit subtle, MCIC to be detected.

### 6.5.1 Methods

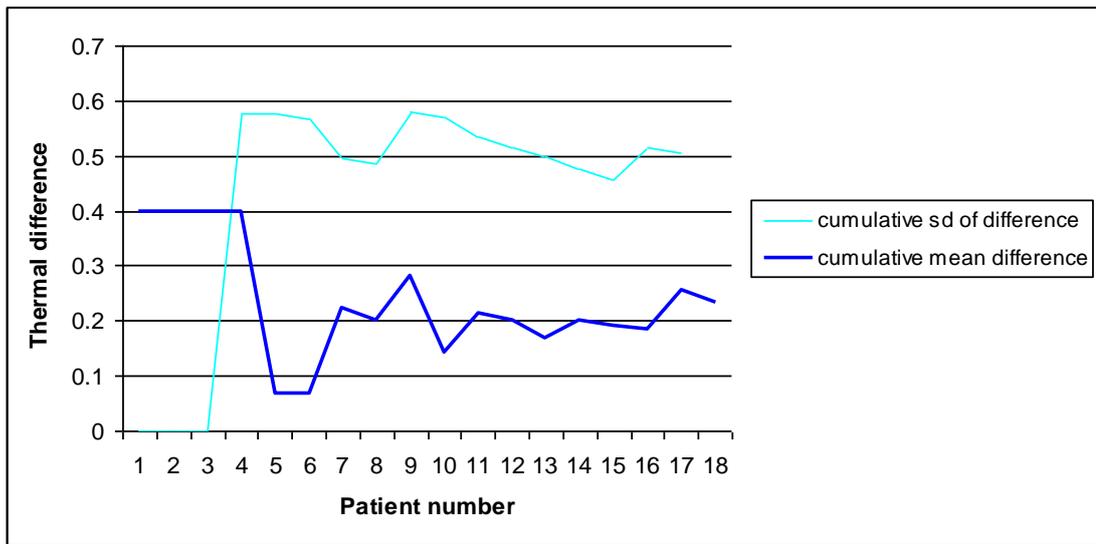
Both the thermal difference primary outcome measure and MDF shift at baseline and the 6 week endpoint was considered for each of the 3 treatment arms. The cumulative means and SDs of the change were plotted against patient number for visual analysis.

### 6.5.2 Results



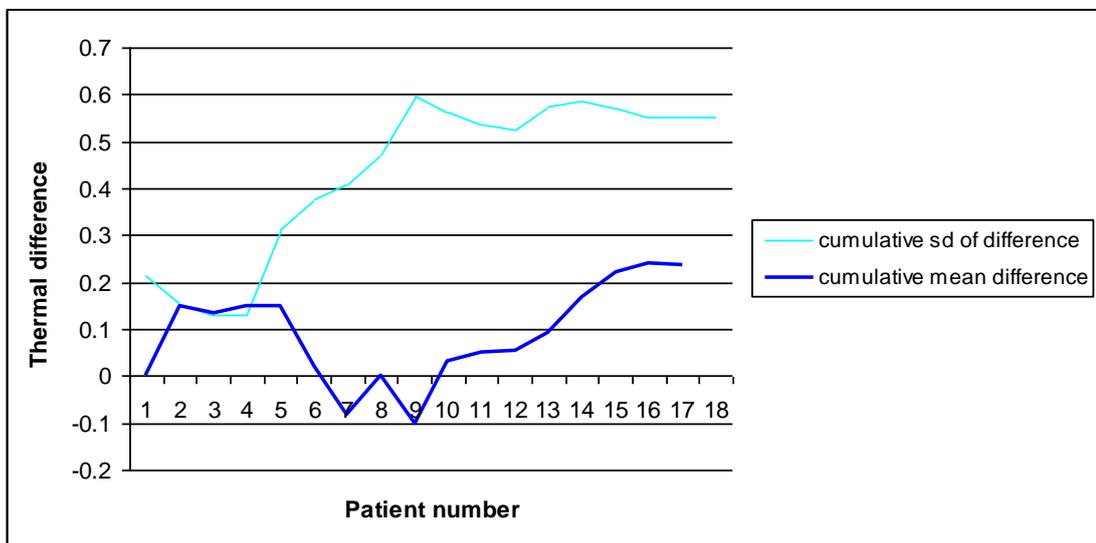
Graph 6.5 Thermal difference cumulative mean and SD of thermal difference for the injection group.

As can be seen in graph 6.5 the injection group data has stabilised as the changes of the cumulative SD of difference and cumulative mean difference show a trend around the parallel over the last 11 consecutive patients with < 0.05 °C difference.



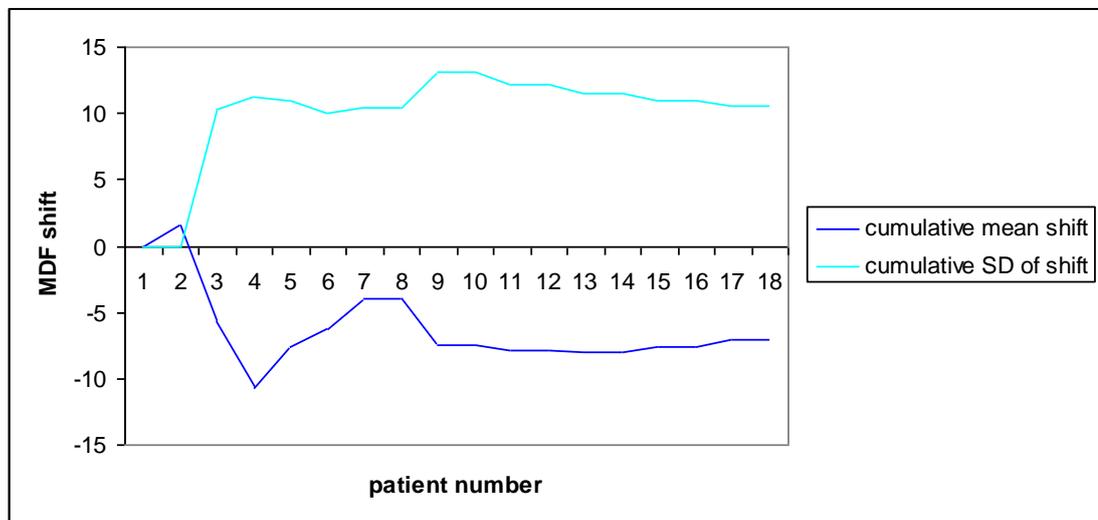
Graph 6.6 Thermal difference cumulative mean and SD of difference for the exercise group.

As can be seen in graph 6.6 the exercise group data has stabilised as the changes of the cumulative SD of difference and cumulative mean difference have become parallel over the last 3 consecutive patients. The cumulative SD of difference is significantly larger (0.3<sup>0</sup>C) than the cumulative mean difference.



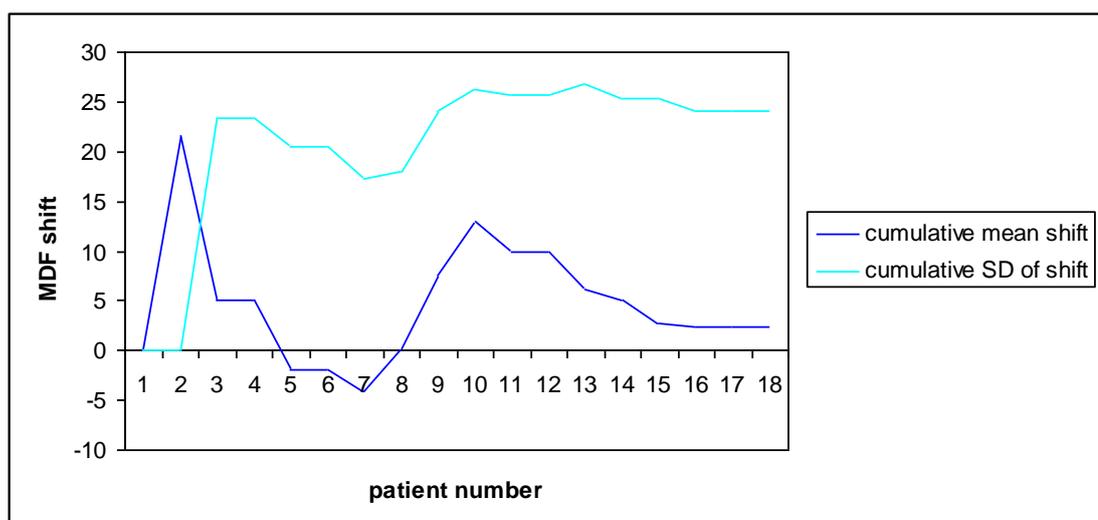
Graph 6.7 Thermal difference cumulative mean and SD of difference for the ultrasound group.

As can be seen in graph 6.7 the ultrasound group shows greater variability and the cumulative SD of difference and cumulative mean difference did not show any convincing trend towards stabilisation in the ultrasound group until the last 2 patients.



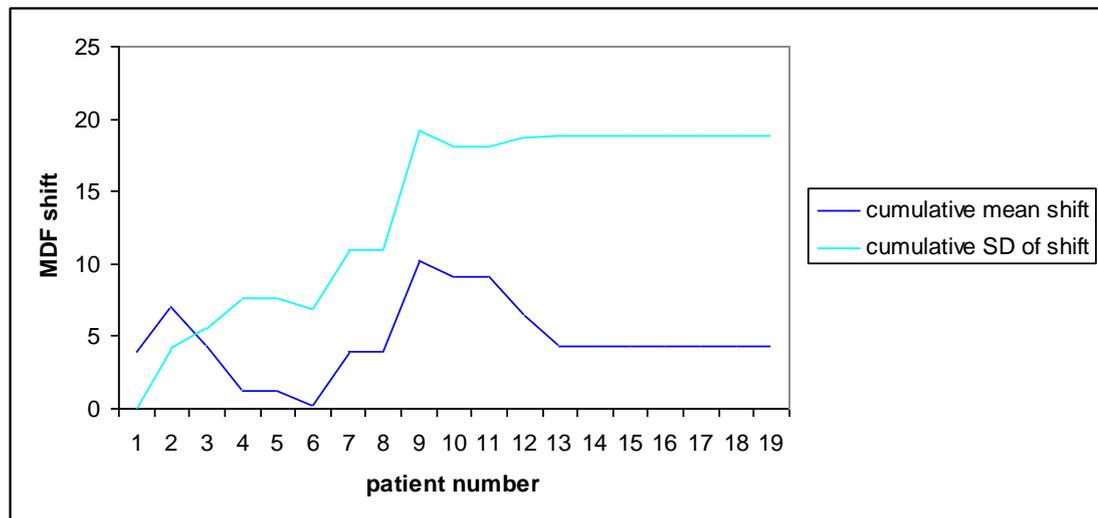
Graph 6.8 Median frequency shift cumulative mean and SD of shift for the injection group.

If the secondary outcome measure MDF shift is considered. As can be seen in graph 6.8 the injection group data has stabilised as the changes of the cumulative SD of shift and cumulative mean shift have become parallel over the last 11 consecutive patients. The cumulative SD of shift is significantly larger (15Hz) than the cumulative mean shift.



Graph 6.9 Median frequency shift cumulative mean and SD of shift for the exercise group.

As can be seen in graph 6.9 the exercise group data has stabilised as the changes of the cumulative SD of shift and cumulative mean shift show a trend around the parallel over the last 6 consecutive patients. The cumulative SD of shift is significantly larger (20Hz) than the cumulative mean shift.



Graph 6.10 Median frequency shift cumulative mean and SD of shift for the ultrasound group.

Again as can be seen in graph 6.10 the ultrasound group data shows a trend towards stabilisation over the last 7 consecutive patients. The cumulative SD of shift is significantly larger (15Hz) than the cumulative mean shift.

### 6.5.3 Discussion

Of the 3 groups, the injection group demonstrates the greatest stability of data. For the primary outcome measure of thermal difference, as the cumulative SD of difference equals the cumulative mean difference ( $< 0.05^{\circ}\text{C}$ ) there is likely to be a significant clinical difference evident. In the exercise group, although the data has stabilised, there is likely to be no clinical difference evident as the cumulative SD of difference is significantly larger ( $0.3^{\circ}\text{C}$ ) than the cumulative mean difference. The ultrasound group is the only group to not demonstrate a convincing stabilisation of data and this could be attributed to the fact that we are applying energy into this patient group through the use of the therapeutic ultrasound which is a proinflammatory modality.

When the MDF shift is considered all 3 groups demonstrate stability of data. However, as the cumulative SD of shift is significantly larger, in the region of 15 to 20Hz, than the cumulative mean shift there is likely to be no clinically significant MDF shift evident.

#### 6.5.4 Conclusion

One can conclude that the data has stabilised in both the injection and exercise groups and is showing a trend towards stabilisation over the last 2 to 3 consecutive patients in the ultrasound group which would indicate that a sufficient sample size has been recruited to detect a clinically important within group change.

However, if the between group differences are considered; the cumulative mean thermal difference was 0.45 °C for the injection group and 0.2 °C for both the ultrasound and exercise groups. Therefore, there is a maximum of 0.25 °C difference between groups which is greater than the a priori defined 0.2 °C MCIC. As the SD is in the region of 0.4- 0.5 for all groups this would give a moderate ES of 0.5 for the clinical trial. To detect this minimum clinically important between group difference a sample size of 60 patients in each group would be required, which was unfortunately beyond the scope of this clinical trial and has contributed to a lack of power with respect to this aspect of this clinical trial.

### 6.6 Single case history

A left-handed 38 year old female in the normative study 1 developed tennis elbow in her non dominant elbow 3 months after testing and was willing to be retested at 8 weeks post onset when she claimed to be 70% improved with NSAID and exercise.

#### 6.6.1 Results

	Normal elbow			Symptomatic elbow		
	AR02	AR03	Diff	AR02	AR03	Diff
<b>Pre</b>	31.1	31.6	-0.5	31.1	32	-0.9
<b>Retest</b>	31.6	31.9	-0.3	31.7	31.9	-0.2

Table 6.6: Maximum temperature (°C) for single case study participant

If one considers her thermal data in table 6.6 it can be seen that pre symptoms there was a difference of  $-0.9^{\circ}\text{C}$  whereas on retesting the difference was reduced to  $-0.2^{\circ}\text{C}$ . In comparison when her normal elbow is considered less change was evident:  $-0.5$  to  $-0.3^{\circ}\text{C}$  although this was classed as a MCIC.

If the grip strength data of the symptomatic elbow was considered:

Pre mean grip strength      36.5kg  
Retest                              18kg

This demonstrates in the region of a 50% reduction (18.2kg) which supports the use of 50% maximum grip strength for both the normative and unaffected elbow of the tennis elbow population.

In comparison when the normal side was considered little change was evident:

Pre mean grip strength      26.5kg  
Retest                              28kg

Table 6.7 details her EMG data:

Normal elbow				Symptomatic elbow			
	10sec	35 sec	MDF shift		10sec	35sec	MDF shift
<b>Pre</b>	116	101	-15	Pre	117.5	108.5	-9
<b>Retest</b>	140.5	123	-17.5	Post	118.5	101	-17.5

Table 6.7: Dominant versus nondominant median frequency shift overtime for single case study participant

For the symptomatic elbow the MDF shift between 10 sec and 35 sec increased with a MCIC from 9Hz pre to 17.5Hz on retest with a marked increase in fatigue apparent.

However, in comparison there was little change and no MCIC evident overtime in the normal elbow with the MDF shift between 10 sec and 35 sec 15Hz pre and 17.5Hz on retest.

## 6.6.2 Discussion

When the single case study participant's thermal data was considered the thermal difference of the presymptomatic elbow was  $-0.9^{\circ}\text{C}$ , the reason for which remains in question. Garagiola and Giani (1990) stated that a hypothermic image demonstrated a degenerative process. The MCIC apparent when the unaffected elbow was considered may be due to increased use so as to protect the symptomatic elbow.

It is also of interest to note that presymptoms her grip strength was greater on her nondominant arm which is generally thought to be atypical. If the grip strength was reconsidered for all left handed participants in the normative study 1, all had greater grip strength on their nondominant (right) arm. In comparison when right dominance was considered only 2 participants (12.5%) had greater grip strength on their nondominant arm with a further 2 participants recorded with equal grip strength bilaterally. Strizac et al (1983) proposed that the inability to acquire the typically greater wrist extensor strength in the dominant arm was associated with tennis elbow.

The variation in the magnitude of the fatigue pre symptoms when compared to the dominant arm is again atypical as the fatigue is generally considered to be less in the dominant and generally accepted stronger arm. Although with this case there was greater grip strength in the nondominant arm evident. However, in contrast, when the normative study 1 data is reconsidered there is little difference in MDF shift, between dominant and nondominant elbows. DeLuca et al. (1986) found that with sustained activity of the 1<sup>st</sup> dorsal interosseous the MDF reduced faster in the nondominant hands of right hand dominant subjects. In contrast no statistically significant difference was found in left hand dominant which was attributed to the fact that the subjects were ambidextrous.

It is also interesting to note that the MDF shift was identical to the normal elbow on retesting. There is a high probability that this as a chance finding because the symptomatic elbow would have performed a PFG and been able to reduce their grip strength if pain was elicited whereas with the unaffected elbow they had visual feedback to maintain 50% maximum. Furthermore, the internal pilot found a reduction in MDF with exercise from baseline at both 10 days and 6 weeks and baseline measurements are

not available for this participant who already claims 50% improvement 8 weeks after onset.

## ***6.7 Internal pilot study summary of recommendations for the clinical trial***

Minimal clinically important changes:

- 33% change in thermal difference of 0.2 °C
- 38% change in MDF shift of 3Hz
- 22% change from baseline for PFG of 3kg
- 25% change from baseline for PRTEE pain of 5
- 25% change from baseline for PRTEE function of 5
- 25% change from baseline for PRTEE total of 10

The MCIC is assumed to be an acceptable estimate for the difference in change between groups (MCID)

Data analysis:

- For the sample population as a whole no statistical differences were found at any time interval for the patient's unaffected arm and are not to be reported on further.
- For the sample population as a whole no statistical difference was found between baseline 1 and baseline 2 for any outcome measure which demonstrates stability of the patient's condition and that there is no evidence of spontaneous healing and is not to be reported on further.
- A repeated measures ANOVA for treatment group analysis and ANOVA for between group analyses with presentation of means profile plots.
- Analysis of the stability of data confirmed that sufficient patients were recruited to the clinical trial when a minimum of 21 patients were in each group to detect a MCIC, i.e.: a within group change. However, in the region of 60 patients in each group would be required to detect a MCID, i.e.: a between group difference with a moderate ES of 0.5.

## **CHAPTER 7: CLINICAL TRIAL**

As the methods (6.1), ethics (6.2) and statistical methods (6.3) apply to the clinical trial and have been previously described in chapter 6: internal pilot, this chapter focuses on the results of the clinical trial. The flow of patients through the trial is presented with the sample descriptives. Both the within group and between group changes are presented in the short and long terms. Treatment preference analysis is also described.

### **7.1 Results**

#### **7.1.1 Sample**

64 tennis elbow patients were randomised by a third party prior to the onset of the clinical trial into the 3 treatment arms in equal numbers: injection (n= 21), exercise rehabilitation (n=22) and ultrasound (n=21).

As can be seen from the flowchart (Figure 7.3) 9% of patients (n=6) had withdrawn prior to the 6 week endpoint: 2 patients from the injection group, 3 from the exercise group and 1 from the ultrasound group. Both patients from the injection group declined injection and 1 patient from the exercise group all withdrew, stating that they were better prior to treatment. The other 2 complained that the exercises aggravated their pain. The ultrasound patient was unable to attend (UTA) for regular treatment appointments. A further 6% of patients (n=4) DNA their 6 week review: 2 patients from the injection group and 1 from both the exercise and ultrasound groups. Subsequently at the 6 week endpoint, 36% of patients (n=23) required further treatment: 6 in the injection group, 5 in the exercise group and 12 in the ultrasound group, not as per protocol, which included braces, ice massage, laser, acupuncture, deep transverse frictions, lateral glides, stretches, exercise, ultrasound or injection.

The remaining 55% of the patient population (n=35) were offered a 6 month review, as per protocol: 13 in the injection group, 14 in the exercise group and 8 in the ultrasound group. Unfortunately, 46% of these patients (n=16) DNA their 6 month review: 2 patients from the injection group and 7 from both the exercise and ultrasound groups. Of those patients who attended their 6 month review all 7 patients in the exercise group and the patient in the ultrasound group did not require further treatment. However, 38%

of patients (n=5) in the injection group required further treatment with 1 patient referred for repeat injection and 4 referred for physiotherapy.

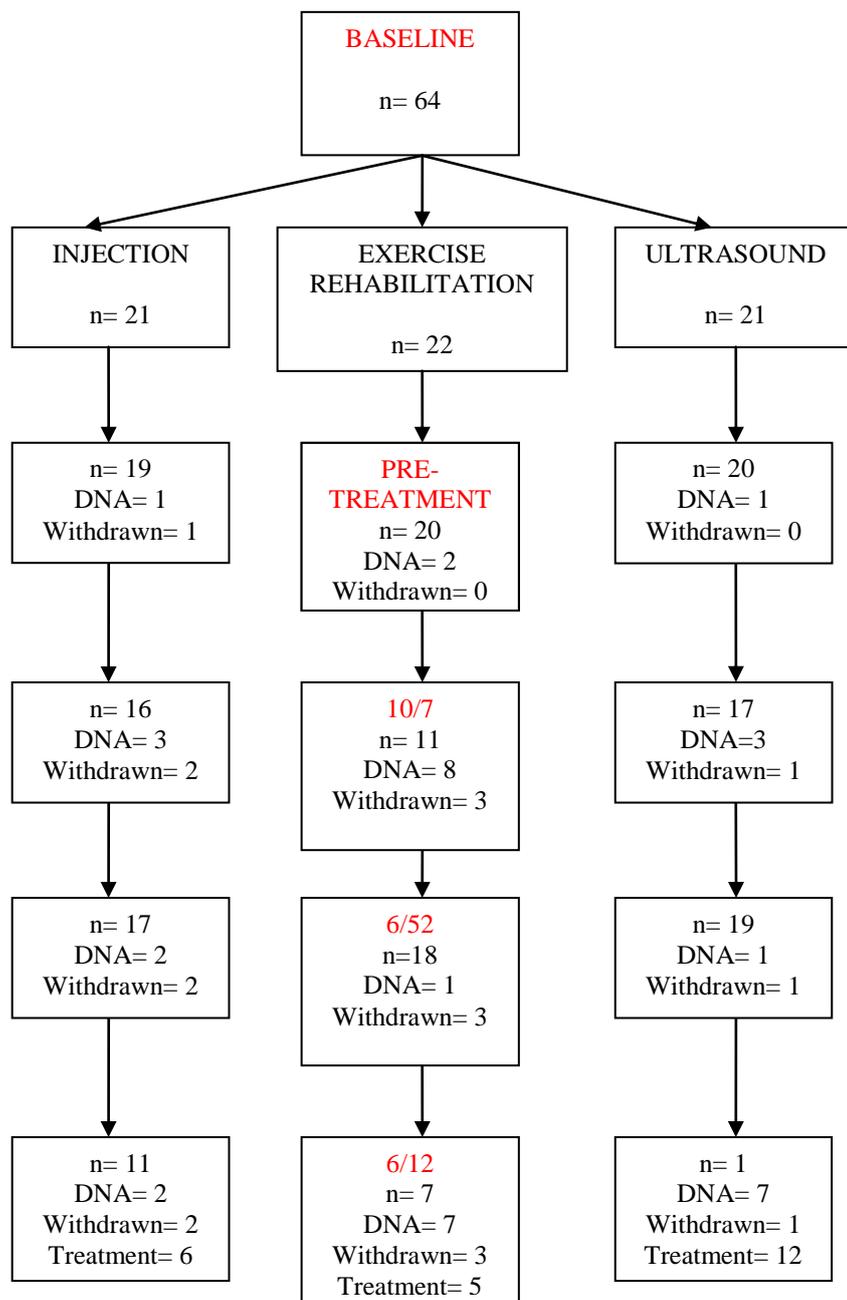


Figure 7.1: Patient flowchart through the study up to the 6 month endpoint.

### 7.1.2 Descriptives

Table 7.1 illustrates the baseline characteristics according to group. Mean (SD) are given for thermal difference, lateral elbow skin fold and body fat percentage. Mean (range) for age and median (range) for duration. Percentages are given for all other

categorical data. Vascular co morbidities included diabetes, high cholesterol, high blood pressure, transient ischaemic attacks and Raynauds.

	<b>Injection</b>	<b>Ultrasound</b>	<b>Exercise</b>
<b>Age (years)</b>	45.6 (30-61)	45.2 (37-56)	45.6 (23-64)
<b>Gender M:F</b>	42.9%: 57.1%	47.6%: 52.4%	45.5%: 54.5%
<b>Dominant elbow affected</b>	80.9%	52.4%	68.2%
<b>Duration (weeks)</b>	16 (2-104)	16 (4-86)	18 (6-104)
<b>Aggravating occupation</b>	90.5%	85.7%	77.3%
<b>Aggravating sport/ hobby</b>	76.2%	71.4%	81.8%
<b>Previous episode(s)</b>	9.6%	9.6%	13.6%
<b>Previous treatment for present episode</b>	4.8%	4.8%	9.1%
<b>Vascular co morbidity</b>	19%	14.3%	18.2%
<b>Unrelated cervical spine problem</b>	28.6%	9.5%	27.3%
<b>Lateral epicondyle skin fold</b>	7.3 (2.1)	6.0 (1.9)	6.3 (3.1)
<b>Body fat %</b>	24 (4.7)	21.2 (4.2)	22.8 (4.3)
<b>Smoke</b>	14.3%	14.3%	18.2%
<b>Past smoker</b>	19%	9.5%	9.1%
<b>Analgesic use</b>	19%	19%	13.6%
<b>Tubigrip use</b>	33.3%	47.6%	31.8%
<b>NSAID gel</b>	19%	38.1%	31.8%
<b>Thermal difference</b>	0.35 (0.4)	0.1 (0.4)	0.02 (0.4)

Table 7.1: Baseline characteristics.

As can be seen randomisation was to a fair effect, given the sample size, and the 3 groups were fairly well matched at baseline, although a fairly large mean difference for the primary outcome measure was evident between the injection and both the ultrasound and exercise groups. The mean age was 45 years with an equal male: female ratio and a median duration of 4-5 months with a range of 2 weeks to 2 years. It is interesting to note that the dominant elbow was not characteristically symptomatic in either the exercise or even more so in the ultrasound group in this population. Between 70-90% of patients presented for treatment due to their symptoms being aggravated markedly by

their occupation or sporting/ hobby activities. In the region of 10% had at least one recurrence of symptoms and between 5-10% had received treatment, greater than 6 months ago, for their presenting condition, from which they had not gained significant improvement. It can, therefore, be concluded that the sample population included both acute and chronic cases and the results can be generalised to the tennis elbow population as a whole. No adverse reactions were reported for any of the treatment groups.

### 7.1.3 Statistical analysis

A repeated measures ANOVA was used with alpha set at  $p < 0.05$  with 95% confidence levels for each of the treatment groups. All reported data is of the primary ITT analysis using LOCF. The sensitivity was as per protocol with similar differences between groups and p values evident. So as not to compromise the power due to loss to follow up, the long term 6 month data was analysed separately, thereby reducing the standard error and increasing the precision in the short term, at 6 weeks.

#### 7.1.3.1 Injection Group

Table 7.2 shows the outcome measures means and standard deviations overtime for the injection group.

	Mean (SD)			
	Baseline	10 days	6 weeks	6 months
<b>Thermal difference (<math>^{\circ}</math>C)</b>	0.4 (0.4)	0.01 (0.6)	-0.005 (0.6)	-0.1 (0.6)
<b>MPFS shift 10s-35s (Hz)</b>	-16.8 (9.2)	-17.3 (10.7)	-20.7 (10.5)	-19.8 (14.1)

<b>Change from baseline to:</b>	<b>10 days</b>	<b>6 weeks</b>	<b>6 months</b>
<b>PFG (kg)</b>	10.3 (10.8)	12.0 (14.6)	4.0 (13.0)
<b>PRTEE pain</b>	-9.2 (13.5)	-13.3 (12.3)	0.2 (12.9)
<b>PRTEE function</b>	-9.6 (14.8)	-13.1 (11.9)	-2.6 (14.3)
<b>PRTEE total</b>	-18.8 (27.7)	-26.4 (23.6)	-2.4 (26.5)

Table 7.2: Outcome measures means (SD) overtime for the injection group.

### Thermal difference

Mean change between baseline and 10 days was  $-0.3^{\circ}\text{C}$   $p= 0.01$  with a 95% CI (-0.6 to -0.1)

Mean change between baseline and 6 weeks was  $-0.4^{\circ}\text{C}$   $p= 0.005$  with a 95% CI (-0.6 to -0.1)

Mean change between baseline and 6 months was  $-0.3^{\circ}\text{C}$   $p= 0.01$  with a 95% CI (-0.6 to -0.1)

This analysis demonstrates a MCIC ( $0.2^{\circ}\text{C}$ ) and a statistically significant reduction in *Tsk* of the ROI at 10 days which was maintained through 6 weeks to the 6 month endpoint.

### Median frequency shift

No statistical difference was found for median frequency shift at any time intervals. A MCIC was found at 6 weeks which was sustained through to 6 months.

### Pain free grip strength

A MCIC (3kg) and statistically significant increase in PFG from baseline at 10 days was maintained through to the 6 week endpoint but not to 6 months.

### PRTEE pain

A MCIC (5) and a statistically significant reduction in pain from baseline at 10 days was maintained through to the 6 week endpoint but not to 6 months.

### PRTEE function

A MCIC (5) and a statistically significant increase in function from baseline was maintained through to the 6 week endpoint but not to 6 months.

### PRTEE total

A MCIC (10) and a statistically significant reduction in pain and disability from baseline at 10 days was maintained through to the 6 week endpoint but not to 6 months.

## **7.1.3.2 Ultrasound Group**

Table 7.3 shows the outcome measures means and SD overtime for the ultrasound group.

	Mean (SD)			
	Baseline	10 days	6 weeks	6 months
<b>Thermal difference (<sup>0</sup>C)</b>	0.1 (0.4)	-0.2 (0.6)	-0.1 (0.6)	-0.2 (0.5)
<b>MPFS shift 10s-35s (Hz)</b>	-15.6 (17.3)	-20.9 (15.4)	-20.9 (17.2)	-28.1 (17.1)

Change from baseline to:	10 days	6 weeks	6 months
<b>PFG (kg)</b>	-1.2 (5.6)	0.8 (6)	4.0 (7.5)
<b>PRTEE pain</b>	0.9 (5.6)	-2.0 (7.5)	-3.4 (8.2)
<b>PRTEE function</b>	1.7 (7.8)	-2.0 (10.2)	-5.2 (12.3)
<b>PRTEE total</b>	2.6 (11.4)	-4.0 (15.5)	-8.6 (17.3)

Table 7.3: Outcome measures means (SD) overtime for the ultrasound group.

#### Thermal difference

Mean change between baseline and 10 days was  $-0.3^{\circ}\text{C}$   $p= 0.02$  with a 95% CI (-0.6 to -0.05)

Mean change between baseline and 6 weeks was  $-0.25^{\circ}\text{C}$   $p= 0.03$  with a 95% CI (-0.5 to -0.03)

Mean change between baseline and 6 months was  $-0.2^{\circ}\text{C}$   $p= 0.2$  with a 95% CI (-0.5 to 0.1)

This analysis demonstrates a MCIC ( $0.2^{\circ}\text{C}$ ) and a statistically significant reduction in *Tsk* of the ROI at 10 days which was maintained through to 6 weeks. However, only the MCIC, not the statistical difference was sustained through to the 6 months endpoint.

#### Median frequency shift

No statistical difference was found for median frequency shift at any time intervals. A MCIC (3Hz) was found at 10 days which was maintained through 6 weeks to 6 months.

#### Pain free grip strength

A statistically significant increase in PFG from baseline at 6 weeks was sustained through to the 6 month endpoint. A MCIC (3kg) was only found at 6 months.

### PRTEE pain

A statistically significant reduction in pain from baseline to 6 weeks was sustained through to the 6 month endpoint. A MCIC (5) was only found at 6 months.

### PRTEE function

A MCIC and a statistically significant increase in function from baseline to 6 weeks was sustained through to the 6 month endpoint.

### PRTEE total

A statistically significant reduction in pain and disability from baseline to 6 weeks was sustained through to the 6 month endpoint. A MCIC (5) was only found at 6 months.

## 7.1.3.3 Exercise Group

Table 7.4 shows the outcome measures means and SD overtime for the exercise group.

	Mean (SD)			
	Baseline	10 days	6 weeks	6 months
<b>Thermal difference (<sup>0</sup>C)</b>	0.02 (0.4)	-0.06 (0.5)	-0.2 (0.5)	-0.2 (0.5)
<b>MPFS shift 10s-35s (Hz)</b>	-17.3 (18.4)	-16.8 (10.1)	-21.3 (10.7)	-23.6 (11.9)

<b>Change from baseline to:</b>	<b>10 days</b>	<b>6 weeks</b>	<b>6 months</b>
<b>PFG (kg)</b>	1.3 (4.4)	2.7 (6.4)	5.7 (9.9)
<b>PRTEE pain</b>	-1.1 (7.5)	-5.6 (10.7)	-9.1 (10.9)
<b>PRTEE function</b>	-1.9 (8.6)	-4.7 (11.2)	-8.4 (10.7)
<b>PRTEE total</b>	-3.2 (14.9)	-8.9 (21.4)	-17.5 (20.3)

Table 7.4: Outcome measures means (SD) overtime for the exercise group.

### Thermal difference

Mean change between baseline and 10 days was  $-0.08^{\circ}\text{C}$   $p=0.5$  with a 95% CI (-0.3 to 0.1)

Mean change between baseline and 6 weeks was  $-0.2^{\circ}\text{C}$   $p=0.095$  with a 95% CI

(-0.4 to -0.04)

Mean change between baseline and 6 months was  $-0.1^{\circ}\text{C}$   $p=0.4$  with a 95% CI

(-0.3 to 0.1)

This analysis demonstrates no statistically significant reduction in Tsk of the ROI at any time intervals. A MCIC ( $0.2^{\circ}\text{C}$ ) was evident at 6 weeks only.

#### Median frequency shift

No statistical difference was found for median frequency shift at any time intervals. A MCIC (3Hz) was found at 6 weeks which was sustained through to 6 months.

#### Pain free grip strength

A statistically significant increase in PFG from baseline at 10 days was maintained through 6 weeks to the 6 month endpoint. A MCIC (3kg) was evident at 6 weeks which was sustained through to 6 months.

#### PRTEE pain

A MCIC and a statistically significant reduction in pain from baseline through 6 weeks to the 6 month endpoint.

#### PRTEE function

A MCIC (5) and a statistically significant increase in function from baseline to the 6 month endpoint only.

#### PRTEE total

A MCIC (10) and a statistically significant reduction in pain and disability from baseline to the 6 month endpoint only.

### **7.1.3.4 Short term between group analysis**

For the primary outcome measure thermal difference, due to the fairly large mean and MCID between the injection and ultrasound and exercise groups at baseline, a univariate analysis of variance with thermal difference at baseline as a covariate was used to reduce the standard error and increase the precision. This analysis was also used for MDF. For all other outcome measures, which were analysed using change from

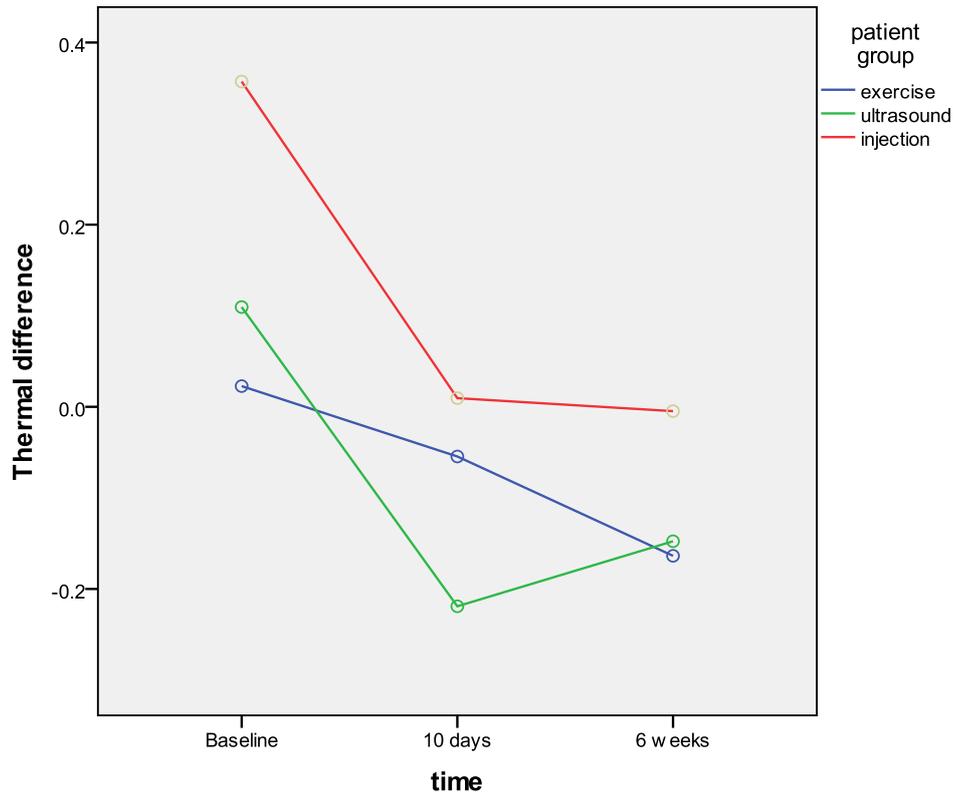
baseline, an ANOVA was used with alpha set at  $p < 0.05$  with 95% confidence levels and the Scheffe post hoc test for the between group analysis.

The mean differences between groups and the significance level with 95% confidence intervals are given for the primary outcome measure thermal difference over time in Table 7.5 with the profile plot in Graph 7.1.

<b>Thermal diff</b>	<b>Groups</b>	<b>Mean difference</b>	<b>Significance level</b>	<b>95% CI</b>
<b>10 days</b>	Ex: U/S	0.2 <sup>0</sup> C	0.2	-0.1 to 0.5
	Ex: Inj	0.1 <sup>0</sup> C	0.5	-0.2 to 0.5
	U/S: Inj	-0.1 <sup>0</sup> C	0.6	-0.4 to 0.2
<b>6 weeks</b>	Ex: U/S	-0.04 <sup>0</sup> C	0.8	-0.3 to 0.3
	Ex: Inj	-0.07 <sup>0</sup> C	0.7	-0.2 to 0.4
	U/S: Inj	-0.03 <sup>0</sup> C	0.9	-0.3 to 0.3

Table 7.5: Mean differences, significance and 95% CI for thermal difference.

No statistically significant differences for thermal difference between groups were found. A MCID (0.2<sup>0</sup>C) was found between the exercise and ultrasound group at 10 days only.



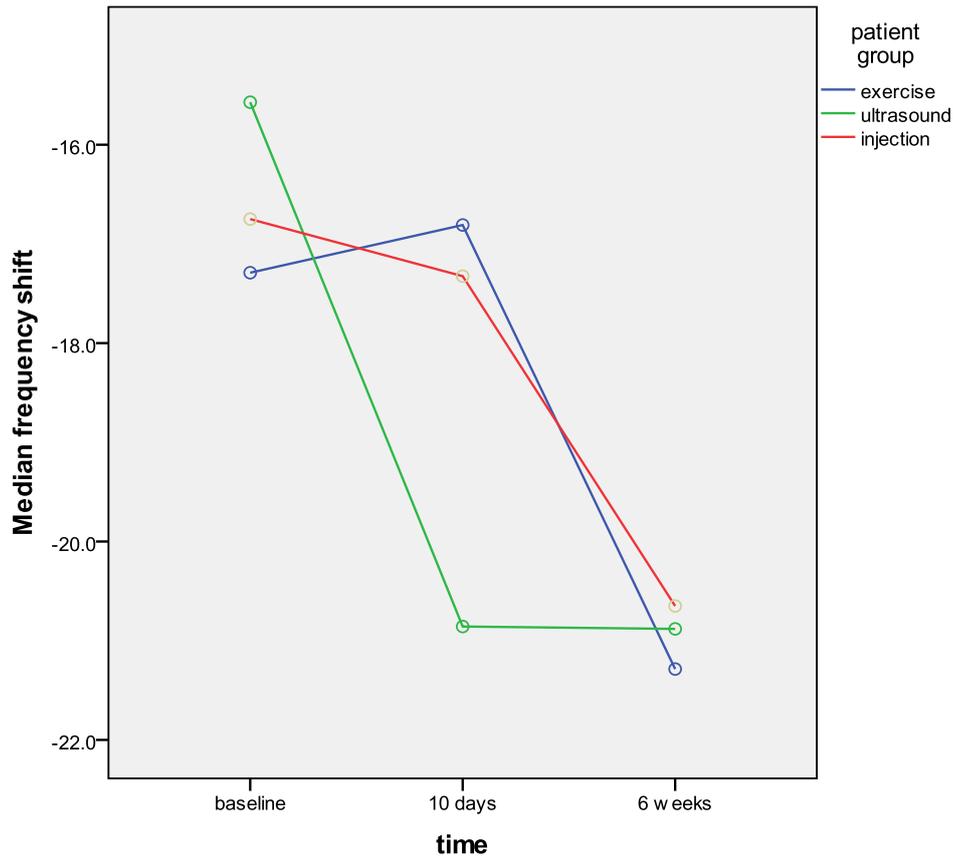
Graph 7.1 Profile plot for thermal difference.

The mean differences between groups and the significance level with 95% confidence intervals are given for median frequency over time in Table 7.6 with the profile plot in Graph 7.2.

<b>MDF</b>	<b>Groups</b>	<b>Mean difference</b>	<b>Significance level</b>	<b>95% CI</b>
<b>10 days</b>	Ex: U/S	4.5 Hz	0.2	-2.8 to 11.8
	Ex: Inj	0.7 Hz	0.9	-6.7 to 8
	U/S: Inj	-3.8 Hz	0.3	-11.2 to 3.5
<b>6 weeks</b>	Ex: U/S	0.004 Hz	1	-10.7 to 9.9
	Ex: Inj	-0.5 Hz	0.9	-11 to 9.8
	U/S: Inj	-0.5 Hz	0.9	-10.6 to 10.2

Table 7.6: Mean differences, significance and 95% CI for median frequency shift.

No statistically significant differences were found for the secondary outcome measure median frequency shift at any time interval. A MCID (3Hz) was found between the ultrasound and both the exercise and injection groups at 10 days only.



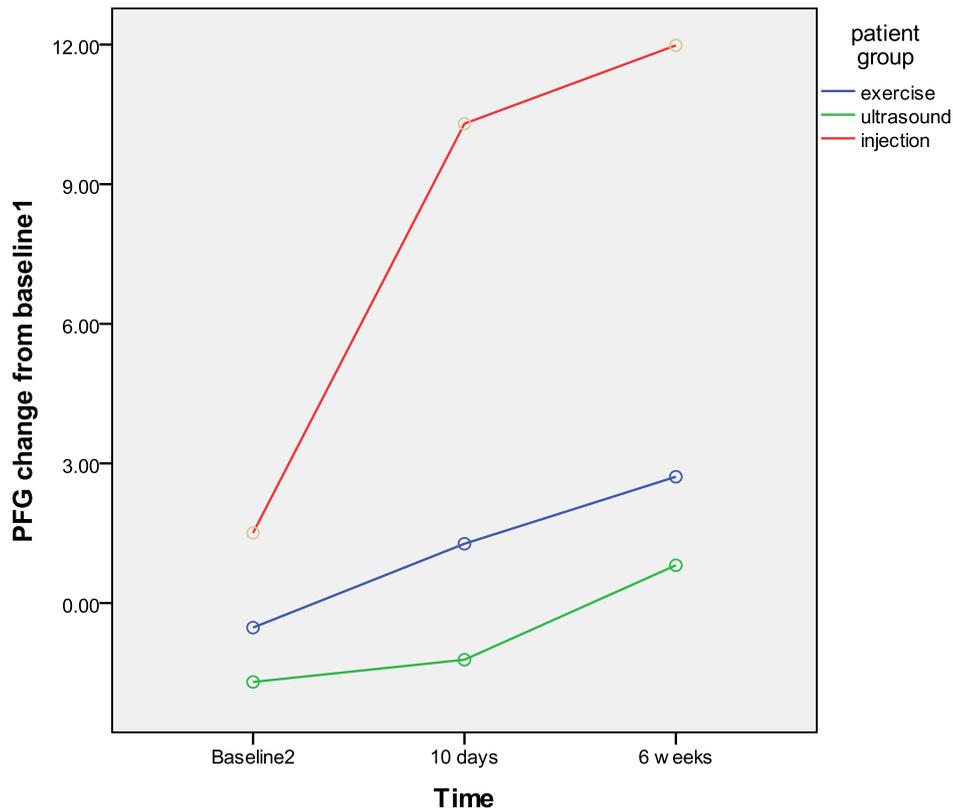
Graph 7.2 Profile plot for median frequency shift.

Table 7.7 shows the mean differences between groups and the significance level with 95% confidence intervals for the PFG over time with the profile plot shown in Graph 7.3.

<b>PFG change from baseline</b>	<b>Groups</b>	<b>Mean difference</b>	<b>Significance level</b>	<b>95% CI</b>
<b>10 days</b>	Ex: U/S	2.5 kg	0.6	-3.2 to 8.2
	Ex: Inj	-9.0 kg	0.001	-14.7 to -3.3
	U/S: Inj	-11.5 kg	0.000	-17.3 to -5.8
<b>6 weeks</b>	Ex: U/S	1.9 kg	0.8	-5.6 to 9.4
	Ex: Inj	-9.3 kg	0.01	-16.8 to -1.8
	U/S: Inj	-11.2 kg	0.002	-18.8 to -3.6

Table 7.7: Mean differences, significance and 95% CI for pain free grip strength.

A MCID (3kg) and a statistically significant difference was found for PFG change from baseline between the injection group and both the exercise and ultrasound groups at 10 days and this was maintained through to the 6 week endpoint.



Graph 7.3 Profile plot for pain free grip strength.

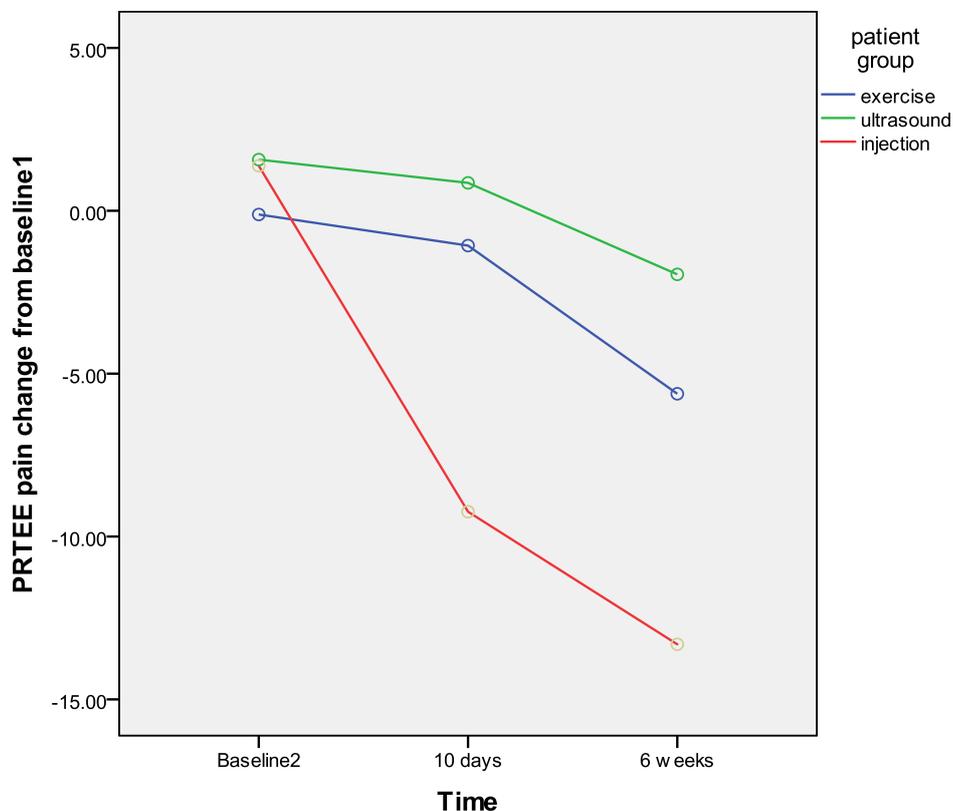
Table 7.8 shows the mean differences between groups and the significance level with 95% confidence intervals for the PRTEE pain over time with the profile plot shown in Graph 7.4.

PRTEE pain change from baseline	Groups	Mean difference	Significance level	95% CI
<b>10 days</b>	Ex: U/S	-1.9	0.8	-9.15 to 5.3
	Ex: Inj	8.2	0.02	0.9 to 15.4
	U/S: Inj	10.1	0.004	2.8 to 17.4
<b>6 weeks</b>	Ex: U/S	-3.7	0.5	-11.6 to 4.2
	Ex: Inj	7.7	0.059	-0.2 to 15.6
	U/S: Inj	11.4	0.003	3.4 to 19.4

Table 7.8: Mean differences, significance and 95% CI for patient rated tennis elbow evaluation pain.

A MCID (5) and a statistically significant difference was found for PRTEE pain change from baseline between the injection group and both the exercise and ultrasound groups

at 10 days which was only maintained between the injection group and the ultrasound group at the 6 week endpoint. However, although a MCID was also maintained through to the 6 week endpoint between the injection and exercise group it was not statistically significant.



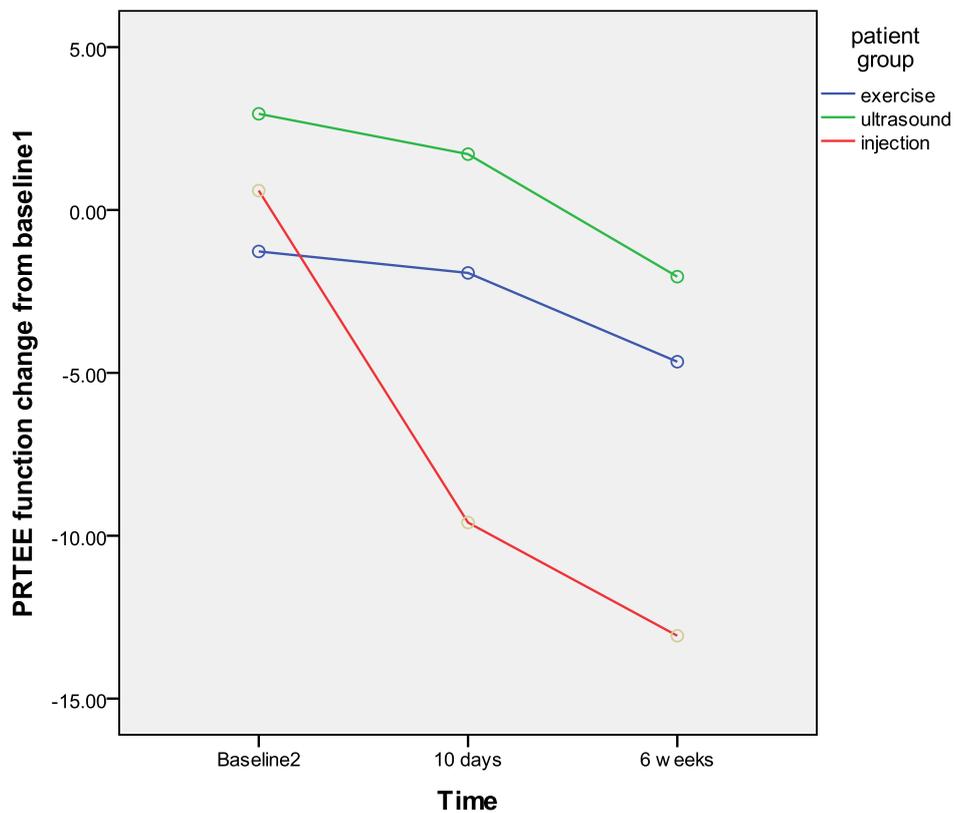
Graph 7.4 Profile plot for patient rated tennis elbow evaluation pain.

Table 7.9 shows the mean differences between groups and the significance level with 95% confidence intervals for the PRTEE function over time with the profile plot shown in Graph 7.5.

PRTEE function change from baseline	Groups	Mean difference	Significance level	95% CI
<b>10 days</b>	Ex: U/S	-3.6	0.5	-11.9 to 4.6
	Ex: Inj	7.7	0.08	-0.6 to 15.9
	U/S: Inj	11.3	0.005	2.9 to 19.7
<b>6 weeks</b>	Ex: U/S	-2.6	0.7	-11.1 to 5.9
	Ex: Inj	8.4	0.054	-0.1 to 16.9
	U/S: Inj	11.0	0.009	2.4 to 19.7

Table 7.9: Mean differences, significance and 95% CI for patient rated tennis elbow evaluation function.

A MCID (5) and a statistically significant difference was found for PRTEE function change from baseline between the injection group and the ultrasound group at 10 days which was maintained through to the 6 week endpoint. A MCID was also found between the injection and exercise group at both 10 days and 6 weeks although not statistically significant.



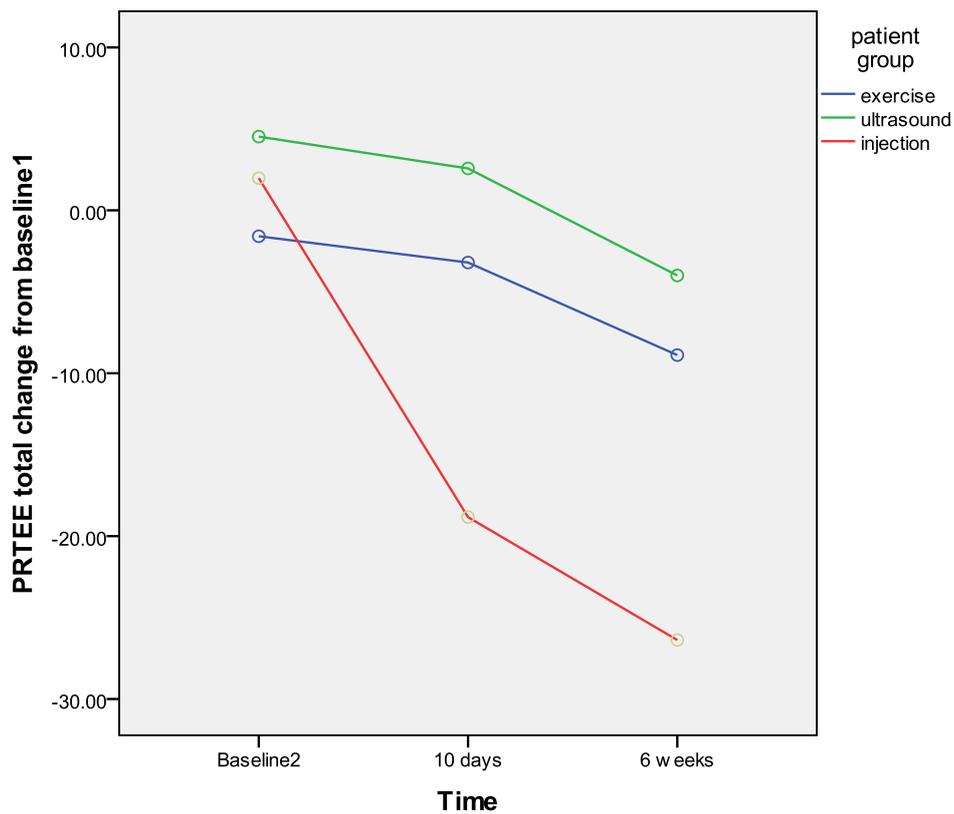
Graph 7.5 Profile plot for patient rated tennis elbow evaluation function.

Table 7.10 shows the mean differences between groups and the significance level with 95% confidence intervals for the PRTEE total over time with the profile plot shown in Graph 7.6.

PRTEE total change from baseline	Groups	Mean difference	Significance level	95% CI
10 days	Ex: U/S	-5.8	0.6	-20.5 to 9
	Ex: Inj	15.6	0.04	0.9 to 30.4
	U/S: Inj	21.4	0.003	6.5 to 36.3
6 weeks	Ex: U/S	-4.9	0.7	-20.6 to 10.8
	Ex: Inj	17.5	0.03	1.8 to 33.2
	U/S: Inj	22.4	0.003	6.5 to 38.2

Table 7.10: Mean differences, significance and 95% CI for patient rated tennis elbow evaluation total.

A MCID (10) and a statistically significant difference were found for PRTEE total change from baseline between the injection group and both the exercise and ultrasound groups at 10 days which was maintained through to the 6 week endpoint.



Graph 7.6 Profile plot for patient rated tennis elbow evaluation total.

### 7.1.3.5 Long term between group analysis

The mean differences for the sample population as a whole and the significance level with 95% confidence intervals are given for the primary outcome measure thermal difference over time in Table 7.11.

<b>Thermal difference</b>	<b>Mean difference</b>	<b>Significance level</b>	<b>95% CI</b>
<b>10 days</b>	0.2 <sup>0</sup> C	0.06	-0.006 to 0.3
<b>6 weeks</b>	0.2 <sup>0</sup> C	0.01	0.05 to 0.4
<b>6 months</b>	0.2 <sup>0</sup> C	0.007	0.06 to 0.4

Table 7.11: Mean differences, significance and 95% CI for thermal difference for all groups.

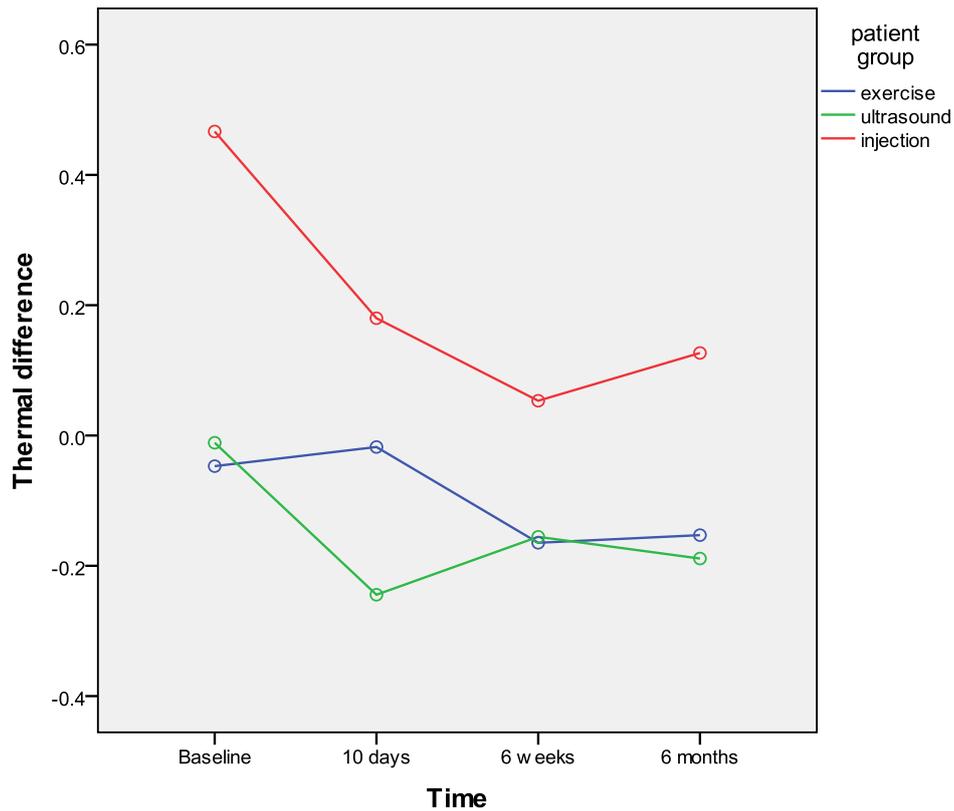
For all groups, at 10 days a MCIC (0.2<sup>0</sup>C) was evident, although not statistically significant, which was maintained through 6 weeks to the 6 month endpoint. A statistically significant change for thermal difference was found only at 6 weeks which was sustained through to 6 months.

The mean differences between groups and the significance level with 95% confidence intervals are given for the primary outcome measure thermal difference at 6 months in Table 7.12 with the profile plot in Graph 7.7.

<b>Thermal difference</b>	<b>Groups</b>	<b>Mean difference</b>	<b>Significance level</b>	<b>95% CI</b>
<b>6 months</b>	Ex: U/S	-0.06 <sup>0</sup> C	0.7	-0.3 to 0.4
	Ex: Inj	-0.07 <sup>0</sup> C	0.7	-0.3 to 0.4
	U/S: Inj	-0.01 <sup>0</sup> C	0.95	-0.4 to 0.4

Table 7.12: Mean differences, significance and 95% CI for thermal difference.

Neither a MCID nor a statistically significant difference for thermal difference between groups was found.



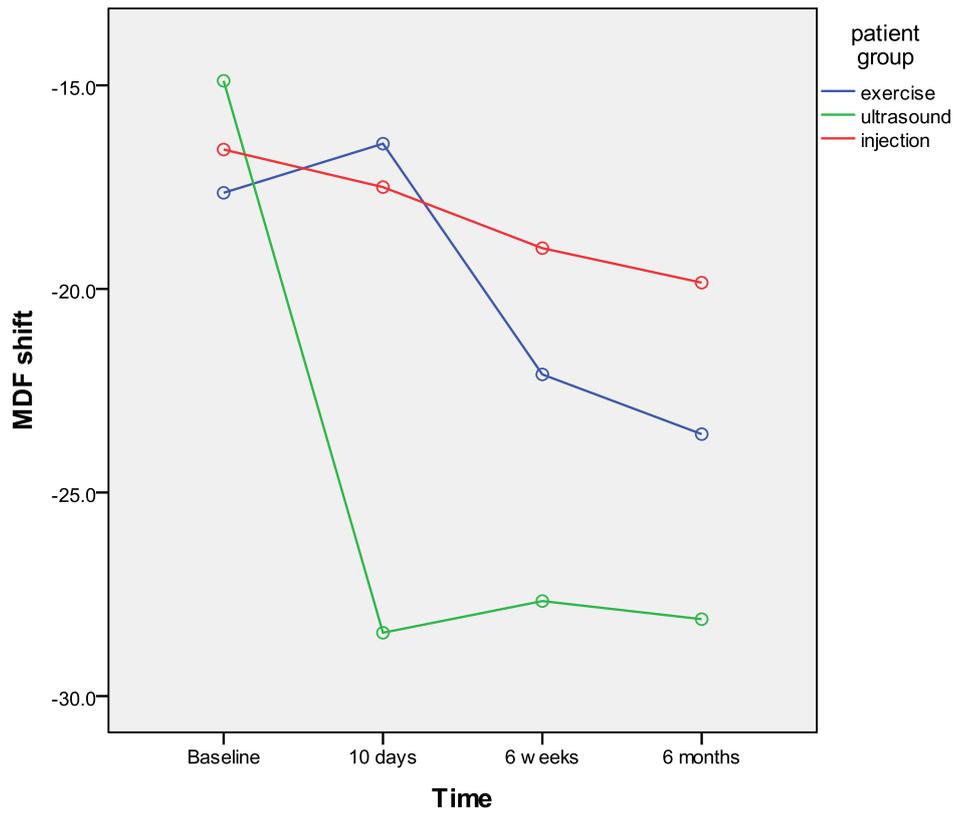
Graph 7.7 Profile plot for thermal difference.

The mean differences between groups and the significance level with 95% confidence intervals are given for median frequency over time in Table 7.13 with the profile plot in Graph 7.8.

MDF	Groups	Mean difference	Significance level	95% CI
6 months	Ex: U/S	4.7 Hz	0.4	-7.6 to 16.9
	Ex: Inj	-3.7 Hz	0.5	-14.7 to 7.3
	U/S: Inj	-8.3 Hz	0.2	-20.9 to 4.3

Table 7.13: Mean differences, significance and 95% CI for median frequency shift.

Although no statistically significant differences for median frequency between groups were found a MCID (3Hz) was found between ultrasound and both the exercise and injection groups and between the exercise and injection groups.



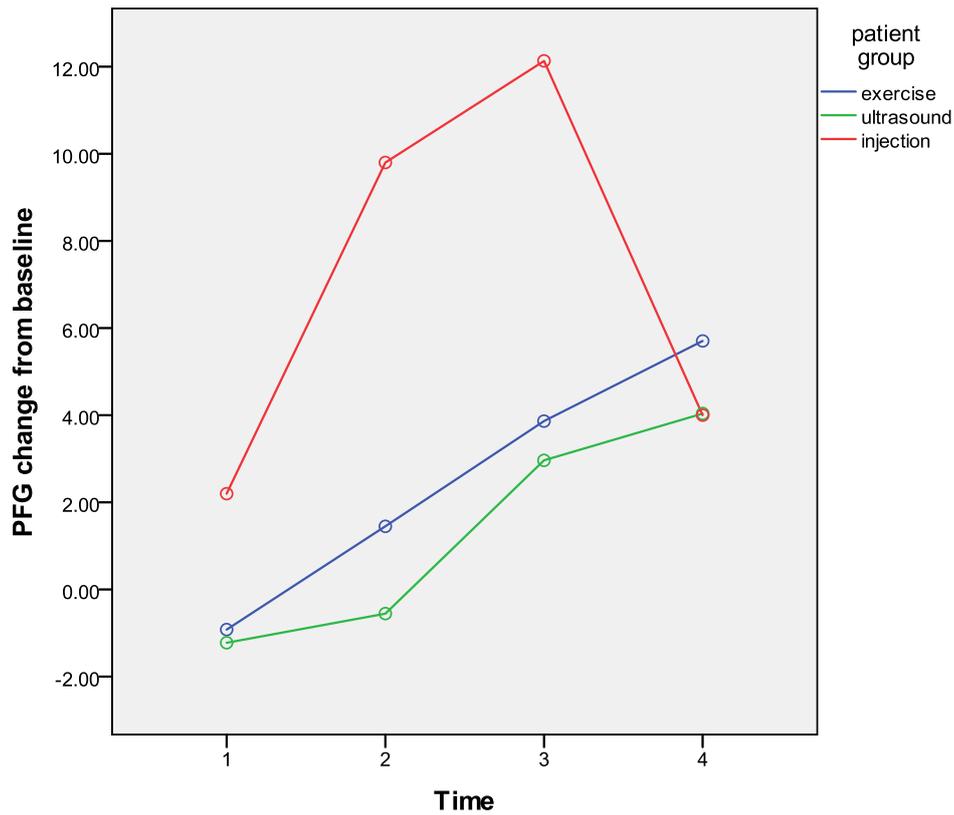
Graph 7.8 Profile plot for median frequency.

Table 7.14 shows the mean differences between groups and the significance level with 95% confidence intervals for the PFG over time with the profile plot shown in Graph 7.9.

PFG change from baseline	Groups	Mean difference	Significance	95% CI
6 months	Ex: U/S	1.7kg	0.9	-9.6 to 12.9
	Ex: Inj	1.7kg	0.9	-8 to 11.4
	U/S: Inj	0.04kg	1	-11.5 to 11.6

Table 7.14: Mean differences, significance and 95% CI for pain free grip strength.

No MCID or statistically significant difference for PFG between groups was found.



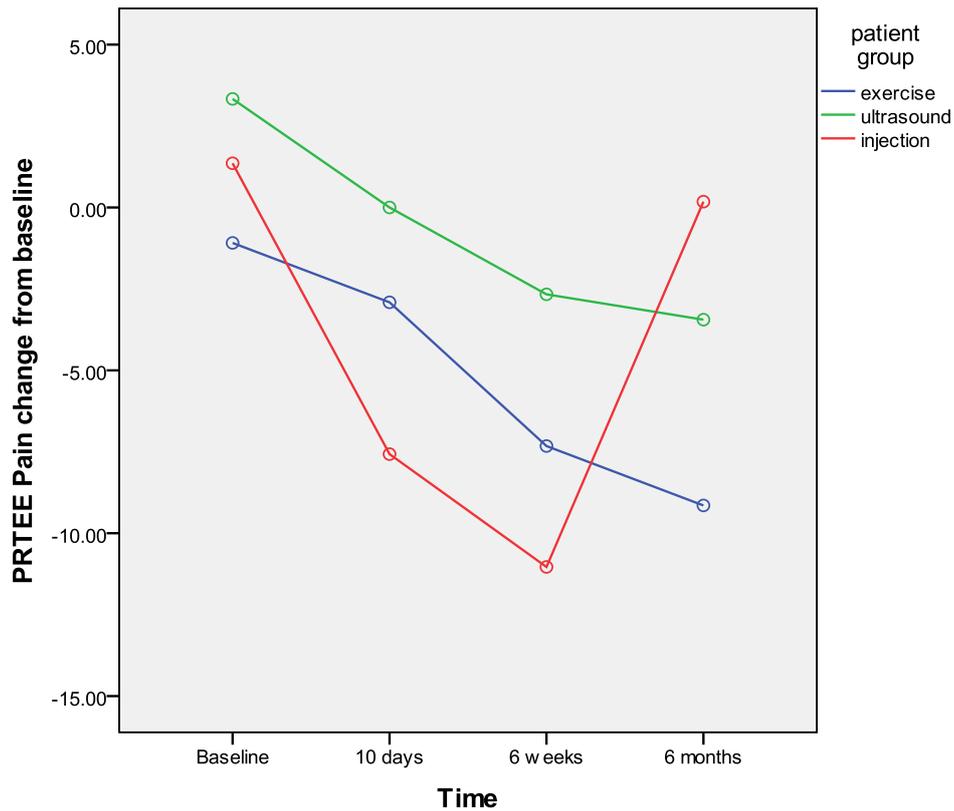
Graph 7.9 Profile plot for pain free grip strength.

Table 7.15 shows the mean differences between groups and the significance level with 95% confidence intervals for the PRTEE pain over time with the profile plot shown in Graph 7.10.

PRTEE pain change from baseline	Groups	Mean difference	Significance	95% CI
6 months	Ex: U/S	-5.7	0.5	-17.4 to 6
	Ex: Inj	-9.3	0.08	-19.6 to 0.9
	U/S: Inj	-3.6	0.75	-15.8 to 8.5

Table 7.15: Mean differences, significance and 95% CI for patient rated tennis elbow evaluation pain.

No statistically significant differences for PRTEE pain between groups were found. A MCID (5) was evident between the exercise group and both the ultrasound and injection groups.



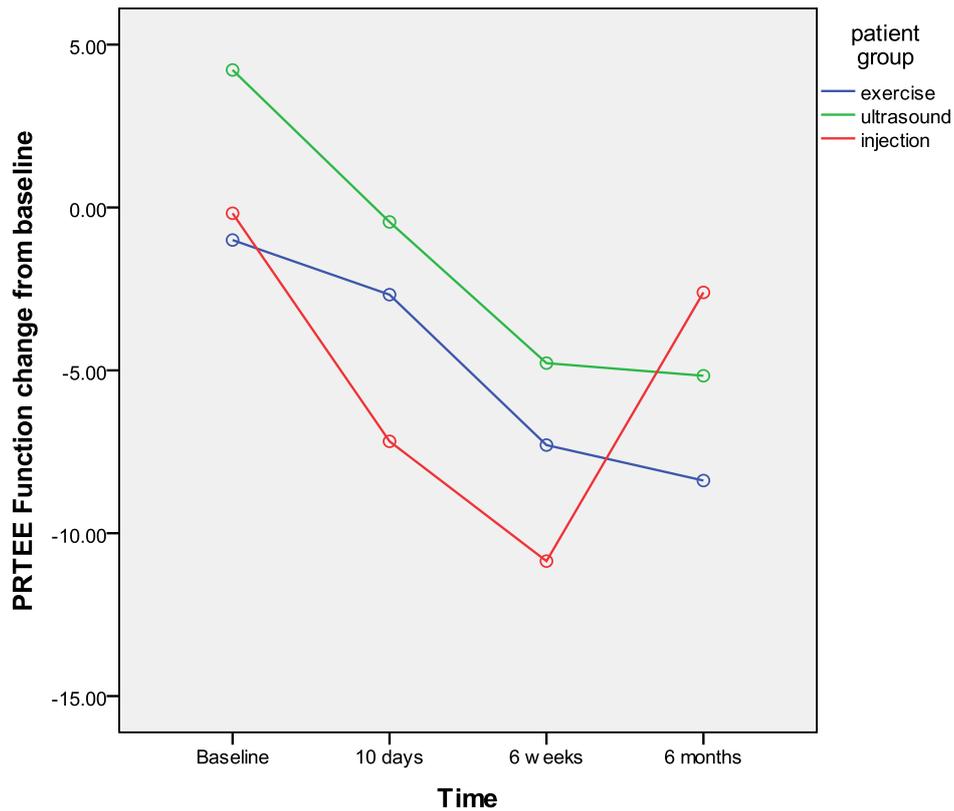
Graph 7.10: Profile plot for patient rated tennis elbow evaluation pain.

Table 7.16 shows the mean differences between groups and the significance level with 95% confidence intervals for the PRTEE function over time with the profile plot shown in Graph 7.11.

PRTEE function change from baseline	Groups	Mean difference	Significance	95% CI
6 months	Ex: U/S	-3.2	0.8	-16.3 to 9.8
	Ex: Inj	-5.8	0.4	-17.2 to 5.6
	U/S: Inj	-2.6	0.9	-16.1 to 10.9

Table 7.16: Mean differences, significance and 95% CI for patient rated tennis elbow evaluation function.

No statistically significant differences for PRTEE function between groups were found. A MCID (5) was found between the exercise and injection group only.



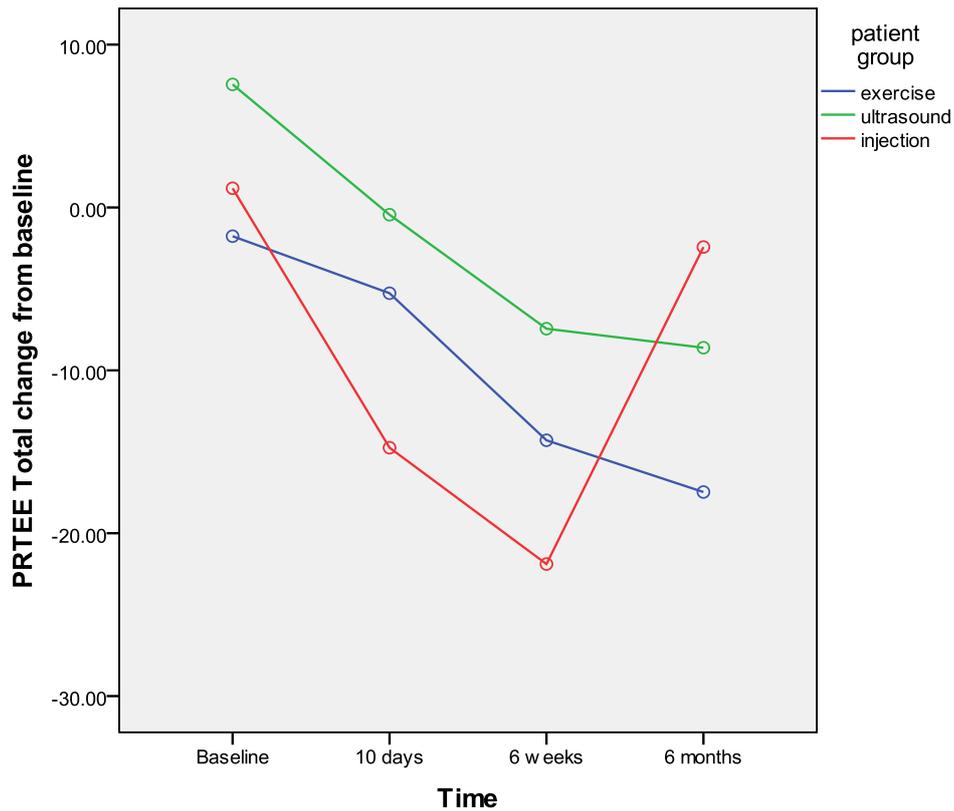
Graph 7.11: Profile plot for patient rated tennis elbow evaluation function.

Table 7.17 shows the mean differences between groups and the significance level with 95% confidence intervals for the PRTEE total over time with the profile plot shown in Graph 7.12.

PRTEE total change from baseline	Groups	Mean difference	Significance	95% CI
6 months	Ex: U/S	-8.9	0.6	-32.1 to 14.4
	Ex: Inj	-15	0.2	-35.4 to 5.3
	U/S: Inj	-6.2	0.8	-30.3 to 17.9

Table 7.17: Mean differences, significance and 95% CI for patient rated tennis elbow evaluation total.

No statistically significant differences for PRTEE total between groups were found. A MCID (10) was found between exercise and injection only.



Graph 7.12: Profile plot for patient rated tennis elbow evaluation total.

### 7.1.4 Treatment preference analysis

The patient preference questionnaires were analysed by group, by identifying themes. As can be seen in table 7.18, apart from all groups having an aversion to exercise, patient preference was unequally distributed across the treatment groups with those in the injection group having a strong preference for injection whilst the majority of patients in both the ultrasound and exercise groups preferred ultrasound.

Preference (%)	Injection group	Ultrasound group	Exercise group
<b>Injection</b>	68	10.5	25
<b>Ultrasound</b>	10	47	56
<b>Exercise</b>	5	5	6
<b>No preference</b>	5	26	12.5

Table 7.18: Patient preference for treatment.

#### **7.1.4.1 Injection group**

At 10 days 68% of patients in the injection group stated a preference for injection, 10% ultrasound and 5% each of exercise, exercise with ultrasound, no preference and surgery. Subsequently, this rose to 84% of patients with a preference for injection with those who initially had a preference for ultrasound or exercise changing their opinion following treatment.

Patients favoured injection therapy as it was perceived as a 'quick fix' giving quick pain relief in 44% and pain relief within a week in a further 33%. The remaining 22% commented that the treatment only required one visit. In comparison, when dislikes were considered, 56% of patients complained of pain or discomfort during the injection, 19% did not like needles, 12.5% found the injection only gave short term relief and the remaining 12.5% had no complaints. Following on from this, 79% of patients had no suggestions for improving the injection therapy they had received. 16% felt that the time taken from first presenting at the GP to treatment could be shorter and 5% suggested reintroduction of the use of local anaesthetic with the steroid injection.

67% of patients would prefer to have a repeat injection if their problem returned and 14% had no preference. 9.5% of patients would like ultrasound or exercise and the remaining 9.5% would prefer surgery.

#### **7.1.4.2 Ultrasound group**

At 10 days 47% of patients in the ultrasound group stated a preference for ultrasound and 26% had no preference. 10.5% would prefer an injection with 5% each preferring exercise, physiotherapy or injection/ surgery. Subsequently, this dropped to 35% of patients with a preference for ultrasound and rose to 35% of patients with no preference. 10% of each would prefer an injection or physiotherapy and only 5% of each would prefer exercise or surgery

Patients favoured ultrasound as it was perceived as a quick pain free treatment in 67% and 22% praised their physiotherapist for their professional, attentive and polite manner. The remaining 11% commented that the treatment felt good. In comparison, when

dislikes were considered, 61% of patients had no complaints, 28% did not think the treatment was effective and 5% each found the treatment only gave short term relief or was momentarily painful during treatment. Following on from this, 85% of patients had no suggestions for improving the ultrasound treatment they had received. 5% each suggested it was combined with an exercise programme, a longer course of ultrasound or treatment sessions were planned in advance.

37% of patients would prefer to have a repeat course of ultrasound if their problem returned and 31.5% had no preference. 10.5% of patients would like an injection with 5% each preferring ultrasound/ injection, exercise, acupuncture or injection/ surgery. Following treatment an increase to 55% of patients would prefer to have a repeat course of ultrasound if their problem returned with only 20% having no preference and with 5% each preferring injection, ultrasound/ injection, exercise, acupuncture or injection/ surgery.

### **7.1.4.3 Exercise group**

At 10 days 56% of patients in the exercise group stated a preference for ultrasound, 25% injection, 12.5% no preference and 6% for exercise and ultrasound. Subsequently, this dropped to 44% of patients with a preference for ultrasound, 17% injection and 17% no preference. A further 11% preferred exercise and 5.5% each preferred injection with ultrasound or 'radiotherapy' following treatment.

Patients favoured exercise therapy as 53% found the exercises helped their problem and 37% stated that they were easy to do/ done at home at anytime. A further 5% each liked 'understanding how it all worked' and trying different exercises. In comparison, when dislikes were considered whilst 43% of patients had no complaints, 14% each found the exercises time consuming or slow/ queried their efficacy and 9.5% complained that the exercises aggravated their pain. 5% each complained that there was not enough variety and specifically wanted massage, found it difficult to remember to do the exercises, the theraband did not smell nice or would prefer for the treatment to last a bit longer. Following on from this, 58% of patients had no suggestions for improving the exercise therapy they had received. 10.5% felt that they would have benefited from treatment earlier and 5% each suggested possible short cuts on repetitions, less amount of

exercise, longer between visits, to include massage and more variety, to include ultrasound initially, or a more strenuous programme.

33% of patients would prefer to have ultrasound if their problem returned and 28% had no preference. 17% would like further exercise and 11% of patients would like an injection. 5.5% each would prefer ultrasound/ injection or 'radiotherapy'.

### **7.1.5 Summary of results**

64 patients were recruited into the clinical trial which sustained a 15% dropout rate, (9% withdrew and 6% DNA). Only 60% of the patient population, (68% injection, 40% ultrasound and 73% exercise), did not require further treatment at the 6 week end point and were offered review at 6 months. Strong preference for the treatment the patient received was found for injection therapy (68%) but not for ultrasound (47%) or exercise (6%).

The data from this RCT assessing the effectiveness of 3 common conservative treatments for tennis elbow: injection, ultrasound and exercise rehabilitation programme through the collective outcome measures of thermal difference, MDF, PFG, PRTEE and patient preference are summarised in the following series of tables:

Table 7.19 summarises the key MCIC and statistically significant changes (SSC) for the injection group overtime.

<b>Injection group time point</b>	<b>Thermal difference</b>	<b>MDF</b>	<b>PFG</b>	<b>PRTEE pain</b>	<b>PRTEE function</b>	<b>PRTEE total</b>
<b>10 days</b>	MCIC SSC	- -	MCIC SSC	MCIC SSC	MCIC SSC	MCIC SSC
<b>6 weeks</b>	MCIC SSC	MCIC -	MCIC SSC	MCIC SSC	MCIC SSC	MCIC SSC
<b>6 months</b>	MCIC SSC	MCIC -	- -	- -	- -	- -

Table 7.19 MCIC and statistically significant changes (SSC) summary for the injection group overtime.

Table 7.20 summarises the key MCIC and SSC for the ultrasound group overtime.

<b>Ultrasound group time point</b>	<b>Thermal difference</b>	<b>MDF</b>	<b>PFG</b>	<b>PRTEE pain</b>	<b>PRTEE function</b>	<b>PRTEE total</b>
<b>10 days</b>	MCIC SSC	MCIC -	- -	- -	- -	- -
<b>6 weeks</b>	MCIC SSC	MCIC -	- SSC	- SSC	MCIC SSC	- SSC
<b>6 months</b>	MCIC -	MCIC -	MCIC SSC	MCIC SSC	MCIC SSC	MCIC SSC

Table 7.20 MCIC and statistically significant changes (SSC) summary for the ultrasound group overtime.

Table 7.21 summarises the key MCIC and SSC for the exercise group overtime.

<b>Exercise group time point</b>	<b>Thermal difference</b>	<b>MDF</b>	<b>PFG</b>	<b>PRTEE pain</b>	<b>PRTEE function</b>	<b>PRTEE total</b>
<b>10 days</b>	- -	- -	- SSC	- -	- -	- -
<b>6 weeks</b>	MCIC -	MCIC -	MCIC SSC	MCIC SSC	- -	- -
<b>6 months</b>	- -	MCIC -	MCIC SSC	MCIC SSC	MCIC SSC	MCIC SSC

Table 7.21 MCID and statistically significant changes (SSC) summary for the exercise group overtime.

Table 7.22 and 7.23 summarise the key MCID and statistically significant differences found between groups in the short term at 10 days and 6 weeks respectively.

<b>Between group analysis</b>	<b>Thermal difference</b>	<b>MDF</b>	<b>PFG</b>	<b>PRTEE pain</b>	<b>PRTEE function</b>	<b>PRTEE total</b>
<b>Exercise: ultrasound</b>	MCID -	MCID -	- -	- -	- -	- -
<b>Exercise: injection</b>	- -	- -	MCID SSD	MCID SSD	MCID -	MCID SSD
<b>Ultrasound: injection</b>	- -	MCID -	MCID SSD	MCID SSD	MCID SSD	MCID SSD
<b>Profile plot trend</b>	Ultrasound and injection ↓	Ultrasound ↓	Injection ↑	Injection ↓	Injection ↓	Injection ↓

Table 7.22 MCID and statistically significant differences (SSD) summary at 10 days.

<b>Between group analysis</b>	<b>Thermal difference</b>	<b>MDF</b>	<b>PFG</b>	<b>PRTEE pain</b>	<b>PRTEE function</b>	<b>PRTEE total</b>
<b>Exercise: ultrasound</b>	- -	- -	- -	- -	- -	- -
<b>Exercise: injection</b>	- -	- -	MCID SSD	MCID -	MCID -	MCID SSD
<b>Ultrasound: injection</b>	- -	- -	MCID SSD	MCID SSD	MCID SSD	MCID SSD
<b>Profile plot trend</b>	-	Injection and exercise ↓	-	-	-	-

Table 7.23 MCID and statistically significant differences (SSD) summary at 6 weeks.

Table 7.24 summarises the key MCID and statistical differences in the long term at 6 months.

<b>Between group analysis</b>	<b>Thermal difference</b>	<b>MDF</b>	<b>PFG</b>	<b>PRTEE pain</b>	<b>PRTEE function</b>	<b>PRTEE total</b>
<b>Exercise: ultrasound</b>	- -	MCID -	- -	MCID -	- -	- -
<b>Exercise: injection</b>	- -	MCID -	- -	MCID -	MCID -	MCID -
<b>Ultrasound: injection</b>	- -	MCID -	- -	- -	- -	- -
<b>Profile plot trend</b>	-	-	Injection ↓	Injection ↑	Injection ↑	Injection ↑

Table 7.24 MCID and statistically significant differences (SSD) summary at 6 months.

Table 7.25 summarises the between group differences overtime with both MCID and statistically significant differences highlighted and the treatment groups also ranked by the size of the difference depicted by a traffic light scheme.

Outcome measure	10 days			6 weeks			6 months		
	Injection	U/S	Ex	Injection	U/S	Ex	Injection	U/S	Ex
Thermal difference	X	MCID							
MDF		MCID					MCID	MCID	MCID
PFG	MCID SSD			MCID SSD					
PRTEE pain	MCID SSD			MCID SSD*					MCID
PRTEE function	MCID SSD*			MCID SSD*				X	MCID
PRTEE total	MCID SSD			MCID SSD				X	MCID
Patient preference									

Table 7.25: MCID, SSD and group ranking summary.

-  Most effect
-  Intermediate effect
-  Least effect

MCID found between the most effective treatment group and the other 2 groups, except for MDF at 6 months when a MCID was also found between the exercise and injection groups.

X no MCID found

\* SSD between injection and ultrasound group only

This table clearly depicts that the overall outcome in the short term at both 10 days and 6 weeks found injection therapy to be the most effective with both a statistically significant and minimum clinically important difference. Exercise therapy was the least effective at 10 days and ultrasound the least effective at 6 weeks and although no statistically significant differences between the 2 groups were found MCIDs were found in favour of ultrasound at 10 days for thermal difference and MDF. In contrast, in the long term at 6 months the converse was found with exercise the most effective and injection the least effective. However, no significant differences between the 3 groups were found. A MCID for PRTEE pain was found in favour of exercise over both the injection and ultrasound groups and a MCID for PRTEE function and total in favour of exercise over the injection group. A MCID was also found between all 3 groups for MDF in favour of ultrasound.

## **CHAPTER 8: DISCUSSION**

This chapter discusses the clinical trial results sequentially as reported in the previous chapter: the sample, within group changes, short term and long term between group analyses and patient preference. The clinical implications, in addition to the limitations of the clinical trial are also highlighted.

### **8.1 Results**

#### **8.1.1 Sample**

From the flow chart for the clinical trial (figure 7.1) it can be seen that at the 6 week endpoint 9% (n=6) of patients had withdrawn and 6% (n=4) of patients DNA which gave a dropout rate of 15%. This was inline with other studies and was successfully reduced from previous work undertaken by Tonks et al. (2007) through the use of a team of treating physiotherapists who could offer a wider range of localities and times more convenient to the patient. This highlights the fact that patient choice is an important factor in treatment compliance, which should be offered, even in the current climate. When the withdrawals are considered it is interesting to note that 3 patients spontaneously settled to a sufficient extent for them to decline any treatment and withdraw from the clinical trial. This supports the self-limiting natural evolution of tennis elbow (Assendelft et al., 2003).

Only 60% (n=35) of the patient population did not require further treatment at the 6 week endpoint and were offered a 6 month review. This implies that for in the region of 1 in 2 of patients the individual treatment has failed to address all the problems the patient was presenting with, which is most markedly evident in the ultrasound group with 60% requiring further treatment at 6 weeks. Whether this is due to the patients not receiving the optimum duration of treatment or that the treatment is inadequate at addressing all of the problems remains in question. The latter suggests that success is more likely with a comprehensive treatment programme which includes a variety of modalities given simultaneously to address all aspects of the problems a patient presents with which is the norm in clinical practice. Alternatively, it may be due to the higher expectations from patients to achieve 100% improvement, due to the advances in medicine, and remaining unsatisfied with an occasional minor discomfort.

In retrospect, on consideration of the design of the 6 month follow up it would have been more advantageous to have continued with the ITT analysis from the short term into the long term with detailed analysis of co interventions. As the 6 month analysis was undertaken on a per protocol analysis, this limited the long term follow up to a much smaller sample and selective subgroup of the patient population. Consequently, this has led to a reduction in power, in addition, to an increased risk of bias of the long term follow up at 6 months.

If the injection group is considered, it can be seen that 32% of those patients who received a steroid injection required further treatment at 6 weeks. This implies that 2/3rds of patients who received an injection became asymptomatic by 6 weeks. Of those patients who remained in the trial through to the long term of 6 months 38% complained of recurrence of symptoms and sought further treatment. Again, this implies that nearly 2/3rds of those patients who received an injection remained asymptomatic through to 6 months. This is supported by a survey of the prevalence of humeral epicondylitis in 77 patients over a 2 year period. Hamilton (1986) reported that the majority received a steroid injection and only a third (36%) complained of a recurrence of symptoms within 6 months. This is in contrast to the reported high recurrence rates following steroid injection (Smidt et al., 2002). Indeed, Bisset et al. (2006) reported a 72% recurrence rate with 47/ 65 successes regressing. However, it could be explained through the dependency on the definition of recurrence used. If the profile plots for PFG, (graph 7.9), and PRTEE, (graphs 7.10- 7.12), are reviewed it would appear that there is a prominent fall back in the injection group at 6 months which could be construed as a very large recurrence rate until the sample data is evaluated. Of course it may be attributable to the selective subgroup of the sample analysed at the 6 month long term follow up.

In addition, in contrast to tennis elbow being generally described as almost invariably affecting the dominant arm, in this research the dominant arm was affected in only 67% of patients. Indeed, this is comparable to the 67%, 78% and 63% reported by Bisset et al. (2006), Smidt et al. (2002) and Hay et al. (1999) respectively.

The mean age was 45 years and would comply with the histological view that tennis elbow is a degenerative process. However, this peak incidence questions why the incidence of tennis elbow does not continue to increase into older age past 50-60 years when a degenerative process would continue to increase with age, as supported by the cadaveric findings of Milz et al. (2004). Although barely plausible, a vast reduction in activity levels after 45 years could account for a reduction in the stresses placed on ECRBr and subsequently reduce the incidence of tennis elbow. It would be hard to comprehend how the age related changes of stiffer and more load resistant tendons with a reduced collagen turnover rate could preclude one from tennis elbow.

### **8.1.2 Injection group**

There was a MCIC and a statistically significant reduction in thermal difference and all aspects of PRTEE and a significant increase in PFG in the short term, between baseline and both 10 days and 6 weeks, but this was only sustained for thermal difference through to the long term at 6 months. A MCIC was found for MDF in the short term of 6 weeks which was sustained through to the long term of 6 months (Table 7.19, p.131). This supports the superiority of injection in the short term which is not extended into the long term as reported in the systematic review of Smidt et al. (2002).

Pizzeti et al. (1984) proposed that thermography can detect subclinical involvement. As the significant reduction in thermal difference was sustained through to the long term follow up of 6 months this implies that the underlying biochemical processes which have modified the pathological process are still evident although a fall back in PFG and pain and disability is noted. However, this may be due to the lack of power evident at 6 months due to the reduction in patient population through only those patients who remained as per protocol being offered an appointment at 6 months and subsequently being reduced further due to a high DNA rate. Even so, sustainable thermal change has been found which supports Thomas et al. (1992) who reported thermography as a sensitive and objective measure for tennis elbow assessment.

So in summary, injection therapy has an immediate effect in reducing temperature, pain and disability and increasing PFG within 10 days which is maintained in the short term for a minimum of 6 weeks. However, by the long term follow up of 6 months, in the

selective subgroup, although the reduction in temperature is sustained this is albeit at a subclinical level (Pizzeti et al., 1984). These results highlighted that 2 out of 3 remained sufficiently improved not to require further treatment due to a recurrence of symptoms.

### **8.1.3 Ultrasound group**

There was a MCIC and a statistically significant reduction in thermal difference in the short term at both 10 days and 6 weeks but only the MCIC was sustained into the long term of 6 months. A MCIC was also found for MDF shift from 10 days which was maintained through 6 weeks to 6 months, although not statistically significant. In contrast, there was a significant increase in PFG and significant reduction in all aspects of PRTEE in both the short term at 6 weeks and the long term at 6 months but not at 10 days. A MCIC was found for PFG and all aspects of PRTEE only in the long term of 6 months, apart from for PRTEE function where a MCIC was also found at 6 weeks (Table 7.20, p.131).

The heat energy gains during a session of therapeutic ultrasound, versus sham, have demonstrated a clinically important increase in skin temperature of 0.5 °C for 5 to 19 minutes following a single treatment, (as discussed in Chapter 5.3.3), and these thermal effects optimising the healing process are evident through a reduction in temperature from 10 days, during which the patient should have received a minimum of 3 treatment sessions, equivalent to 50% of their course of treatment. This demonstrates that ultrasound is having an immediate therapeutic effect which is sustained in to the long term, albeit sub clinically.

Ultrasound not only appears to increase the efficiency of the normal healing process but also enhances the quality of repair through a reduction in fatigue, as can be seen by the MCIC for MDF shift in the short term at 10 days although not statistically significant, which is sustained through 6 weeks and continues to improve two-fold through to the long term at 6 months. In addition the latter finding supports the accumulative therapeutic effects of ultrasound. This is further supported by both a statistically significant and MCIC found for function at 6 weeks which is sustained through to 6 months.

However, despite the reduction in temperature and fatigue seen at 10 days, albeit surprisingly so early, it is interesting to note the concurrent clinical lack of a reduction in pain and disability and increase in PFG. The author hypothesises that this initial delay in progress is due to the pro inflammatory nature of ultrasound which promotes the tissue healing process which may take a number of weeks to complete. The statistically significant increase in PFG and reduction in pain and disability by the short term of 6 weeks was sustained with a MCIC by the long term of 6 months, although the lack of power and selectivity at the 6 month follow up must be considered. The increase in PFG supports the enhanced quality of repair and return to normal muscle function. This continued improvement following the course of treatment, supports the findings of Davidson et al. (2001) and Williams (2003) of a continuation in functional improvement in the short term with the addition of treatment effects being maintained into the long term of 6 months.

So in summary, within 10 days of the commencement of a course of therapeutic ultrasound a reduction in both temperature and fatigue was evident which was sustained through to the long term of 6 months in the selective subgroup. By 6 weeks, a reduction in pain and increase in PFG and function were evident which were sustained through to 6 months.

#### **8.1.4 Exercise group**

No statistically significant thermal differences or MDF shift were found, although a MCIC was found at 6 weeks only for thermal difference and at both 6 weeks and 6 months for MDF shift. There was a statistically significant increase in PFG in the short term of 10 days through 6 weeks into the long term of 6 months with a MCIC evident in the short term of 6 weeks which was sustained in the long term at 6 months. There was a MCIC and a statistically significant reduction in PRTEE pain from the short term of 6 weeks which was sustained through to long term at 6 months, but not at 10 days. However, for PRTEE function and total a MCIC and statistically significant reduction was only found in the long term of 6 months (Table 7.21, p.132).

The MCIC and statistically significant reduction in PRTEE function and total in the long term at 6 months was expected and supports the findings of Smidt et al. (2002) and Bisset et al. (2005). However, in contrast, it is interesting that PFG was significantly

increased, although not a MCIC, within 10 days of commencing their exercise rehabilitation programme. Although changes in collagen reorganisation and upregulation are generally accepted to take longer than 10 days, neuromotor control has the potential to be established within this time frame through the nature of the exercise programme done slowly under control, without pain, and, furthermore, the first exercise the patient is shown is clenching the fist. In addition to improved neuromotor control, it may also be hypothesised that there is an increase in patient confidence in using their symptomatic elbow and the knowledge that use and exercise does not equate to harm has an effect.

Similarly, to find a MCIC and a statistically significant reduction in PRTEE pain and a MCIC in thermal difference in the short term of 6 weeks, is surprising as pain relief through rebalance of the biochemical milieu, (Khan et al., 2000), would only happen with collagen repair which is generally accepted to take months rather than weeks.

Although not statistically significant, there is greater than a MCIC for the MDF shift in the short term of 6 weeks which is sustained through to the long term at 6 months which demonstrates a reduction in fatigue and a return to normal muscle function as expected following a 6 week course of physiotherapy exercise rehabilitation programme.

So in summary, the increase in PFG was isolated as the only improvement seen in the exercise group by 10 days which was sustained through to the long term of 6 months. A reduction in both temperature and fatigue is only evident from 6 weeks with the reduction in fatigue only being sustained through to the long term of 6 months. A reduction in pain was evident from 6 weeks through to the long term of 6 months with an improvement in function only found in the long term of 6 months. However, the lack of power and selectivity at the 6 month follow up must be considered.

### **8.1.5 Short term group analysis**

Although randomisation was to a fair effect it was surprising to find an isolated MCID for the mean thermal difference between the injection and both the ultrasound and exercise groups at baseline. However, this was overcome through the use of a univariate analysis of variance with thermal difference at baseline as a covariate.

No statistically significant differences for the primary outcome measure thermal difference were found between groups although a MCID was found between the ultrasound and exercise group at 10 days only (Table 7.22 and Table 7.23, p.132-133). When the means profile plot, (Graph 7.1, p.115) is considered alongside with the individual group repeated measures analysis one can see a MCID in thermal difference for both the injection and ultrasound groups at 10 days which continues to improve slightly in the injection group at 6 weeks but decrease slightly in the ultrasound group.

Although no statistically significant differences for the MDF shift were found between groups a MCID was found between the ultrasound and both the injection and exercise groups concurrently to the thermal difference at 10 days, which could be attributable to the power issue. When the ultrasound repeated measures analysis and the means profile plot, (Graph 7.2, p.116), is considered a marked MCID reduction in MDF shift is seen in the ultrasound group at 10 days which is mirrored in both the injection and more markedly in the exercise group by 6 weeks. Again, this challenges the theory of the need for exercise rehabilitation as a prerequisite for a reduction in fatigue and a return to normal muscle function. It appears that the therapeutic effects of ultrasound, and to an extent with injection, so that the patient can subsequently resume normal activities, can have an impact on reducing fatigue and prompt a return to normal muscle function.

A MCID and statistically significant difference for PFG was found between the injection group and both the ultrasound and exercise groups in the short term at 10 days with maintenance through to 6 weeks. No MCID or statistical differences were found between the ultrasound and exercise groups in the short term at either 10 days or 6 weeks. The means profile plot, (Graph 7.3, p.117), highlights the marked increase in PFG in the injection group which again supports that due to injection therapy giving immediate pain relief this treatment subsequently enables greater grip strength to be employed.

This theory is supported by the MCID in PRTEE pain found between the injection group and both the ultrasound and exercise groups in the short term at 10 days which is sustained through to 6 weeks. Although a statistically significant difference was found in the short term of 10 days this was only maintained between the injection and ultrasound group at 6 weeks. No MCID or statistically significant differences were found between the ultrasound and exercise groups in the short term at either 10 days or

6 weeks. The means profile, (Graph 7.4, p.118), highlights the marked reduction in pain in the injection group at 10 days which continues to improve through to 6 weeks. The exercise group reduces pain from 10 days through to 6 weeks by a similar degree, over this time interval, to the injection group.

A MCID in PRTEE function was found between the injection group and both the exercise and ultrasound groups in the short term at both 10 days and 6 weeks although only the difference between the injection and ultrasound groups was statistically significant. No MCID or statistically significant difference was found between the exercise group and ultrasound groups in the short term of 10 days or 6 weeks. The marked increase in function in the injection group at 10 days is highlighted in the means profile plot, (Graph 7.5, p.119), and continues to improve through to 6 weeks albeit at a slower rate. This corroborates the findings of increased PFG and reduced pain seen in the injection group in the short term.

A MCID and statistically significant difference for PRTEE total was found between the injection group and both the ultrasound and exercise groups in the short term at 10 days with maintenance through to 6 weeks. No MCID or statistical differences were found between the ultrasound and exercise groups in the short term at either 10 days or 6 weeks. The means profile plot, (Graph 7.6, p.120), again highlights the marked increase in function and reduction in pain seen in the injection group at 10 days which is continued through to 6 weeks, albeit at a slower rate.

So in summary, both a MCID and a statistically significant difference is evident for PFG and PRTEE total which demonstrates superior effectiveness for injection therapy immediately within 10 days which is sustained and continues to improve albeit by a lesser degree through to the short term of 6 weeks. However, no differences were found for thermal difference or MDF outcome measures. The only differences found between the ultrasound and exercise groups was a MCID for thermal difference at 10 days and a MCID for MDF between the ultrasound group and both the injection and exercise groups at 10 days in favour of ultrasound.

These results for the superior effectiveness of injection therapy in the short term support the findings of Smidt et al. (2002) and Bisset et al. (2005). With respect to the lack of difference between groups for thermal difference, when the profile plots, (Graph 7.1,

p.115), are considered both injection and ultrasound have a marked and an immediate MCID at 10 days. Subsequently, one can hypothesise that both the anti inflammatory effect of injection and the proinflammatory effect of ultrasound, utilising an additional thermal effect, both promote healing through contrasting methods which is demonstrated through a reduction in thermal difference which monitors, in at least a subgroup of the tennis elbow population, the potential underlying inflammatory processes through temperature change. This profile questions the current research which proposes, that in all cases, tennis elbow is an angiofibroblastic tendinosis which is distinctly non-inflammatory and supports Kjaer (2004) who could not completely exclude an inflammatory component. It also promotes the practice of injection therapy for tennis elbow patients with superior effectiveness in the short term.

With respect to the lack of difference for MDF shift it appears from the means profile plots, (Graph 7.2, p.116), that all treatment groups have an effect on reducing fatigue but again work by contrasting actions. Ultrasound has an immediate effect whilst in contrast both injection and exercise have an effect between 10 days and 6 weeks. The author hypothesises that the lack of a reduction in ECRBr fatigue in the injection group by 10 days may be explained by the fact that as pain was relieved immediately by virtue of the injection the patient's PFG increased markedly but the resulting deconditioned musculature still presented with fatigue. This could be due to the advice given following injection for relative rest for a week, which presuming the patient had been compliant, would mean that on retesting at 10 days this could be the first time that a patient had 'tried out' their renewed grip function. However, through resumption of normal activities fatigue was reduced markedly by 6 weeks. This would imply that fatigue changes are fully reversible through injection therapy or ultrasound alone and physiotherapy rehabilitation is not a prerequisite to return to normal muscle function.

Apart from the marked reduction in MDF at 6 weeks, (Graph 7.2, p.116), the profiles demonstrate that exercise therapy has a gradual reduction in thermal difference and a gradual increase in PFG with more reduction in pain and disability from 10 days to 6 weeks. The therapeutic effects of exercise take time, as was expected, but even so to find a change within 6 weeks is surprising and highlights the benefit that can be achieved through the use of this particular exercise regime.

### 8.1.6 Long term group analysis

Due to the use of an as per protocol analysis at 6 months, there was a large loss of patients to alternative treatment at 6 weeks which was exacerbated by the high DNA rate in both the exercise and ultrasound groups in particular, the use of LOCF in the analysis highlighted the little difference found between 6 weeks and 6 months, excluding the injection group for whom 38% required further treatment due to recurrence which was highlighted in the analysis as an increase in pain and disability and a poorer outcome. Consequently, as previously discussed, the long term follow up at 6 months was limited to a much smaller sample and selective subgroup of the patient population which not only generated a power issue in addition to an increased risk of bias but also caused difficulty with interpretation and brought the value of the long term analysis into question.

For all groups, for the primary outcome measure thermal difference a MCIC was found in the short term from 10 days and was maintained through 6 weeks and sustained into the long term at 6 months. A statistically significant change was only found in the short term at 6 weeks which was sustained through to the long term at 6 months. This supports that thermal difference is a sensitive and objective measure for both the diagnosis and assessment of tennis elbow (Haake et al., 2002 and Thomas et al., 1992). However, no MCID or statistically significant difference was found between groups in the long term at 6 months (Table 7.24, p.133). If the profile plot, (Graph 7.7, p.122), is considered no significant change from the short term at 6 weeks to the long term at 6 months is evident. This would imply that the temperature changes evident through thermal difference have been sustained even despite the increase in pain and decrease in function seen which subsequently means a subclinical temperature change persists. Consequently, it leads one to question why the injection group's effectiveness deteriorated so markedly after the short term. One theory to be proposed is that ad cortyl has a duration of action in the region of 6 weeks (Saunders, 2002) and that as not all aspects of the cause of the problem have been addressed it has recurred due to a potential predisposition to tendinopathy. However, if the drugs therapeutic action was only for 6 weeks one would question why the subclinical thermal difference persists through to 6 months. This implies that injection only temporarily treats part of a complex problem and unless all components are addressed resistance to treatment may persist.

No statistically significant differences were found between any groups for MDF in the long term at 6 months. However, a MCID was found between all groups. If the profile plot, (Graph 7.8, p.123), is considered no significant change from the short term at 6 weeks to the long term at 6 months is evident apart from a slight reduction in the exercise group which has led to a MCID at 6 months to be evident again.

No statistically significant differences were found between any groups for PFG in the long term at 6 months. However, when the means profile plot, (Graph 7.9, p.124), is considered it highlights the marked decrease in PFG for the injection group in the long term of 6 months back to near baseline levels, whereas for both the ultrasound and exercise groups an increase in PFG continues, albeit small.

No statistically significant differences were found between any groups for PRTEE pain although a MCID was found between the exercise group and both the ultrasound and injection groups in the long term at 6 months. This MCID was also found between the exercise and injection groups only for PRTEE function and total scores. However, when the means profile plots, (Graph 7.10, 7.11 and 7.12, p.125-7), are considered they highlight the marked increase in pain and decrease in function for the injection group from the long term at 6 months back to near baseline levels. This supports the findings of Hay et al. (1999), Smidt et al. (2002) and Bisset et al. (2006) who all reported that the superior effectiveness of injection therapy in the short term was not maintained into the long term and there were more favourable outcomes for pain relief and grip strength with physiotherapy.

### **8.1.7 Patient preference**

From clinical experience patients tend to fall into 2 categories: those with definite strong preference, with respect to injection in particular, and those who just want their problem resolved by 'whatever' following your 'expert' advice on best practice. Although on evaluation of preference with this research strong preference was found with injection therapy at 68%, this was not the case with either of the ultrasound or exercise groups with 47% and 6% respectively having a strong preference for the treatment they were receiving. This was further highlighted by 1 in 4 and 1 in 8 respectively having no preference for any particular treatment. This is in contrast to Smidt et al. (2002) who found a large preference for physiotherapy.

At 10 days following treatment 68% of the injection group had a strong preference for injection which rose to 84%. This was surprising when 19% of patients reported a dislike towards needles, 12.5% found only short term relief and 56% complained of pain or discomfort during treatment. However, with respect to the latter, as only 5% suggested reintroduction of the local anaesthetic and the strong preference for injection rose one can hypothesise that the pain was potentially only minor in nature. This is supported by Lewis et al. (2005) who reported 62% of patients in the injection group recorded higher pain scores on day 1 of follow-up and that any post injection pain was perceived as acceptable. Injection was perceived as a 'quick fix' with 77% claiming pain relief within a week and 22% commenting that treatment only required one visit. This, again, is supported by Lewis et al. (2005) who reported significantly greater pain reduction within 3 days when compared to placebo and within 4 days when compared to naproxen. Globally, this suggests that patients were highly satisfied with injection treatment.

In comparison, at 10 days following treatment only 47% of the ultrasound group stated a preference for ultrasound with 26% having no preference which subsequently changed to 35% of patients having a preference for ultrasound and 35% no preference. In contrast ultrasound was perceived as a quick, pain free treatment by 67% of patients, although 28% did not think the treatment to be effective. 85% had no suggestions for improving their treatment whilst 10% suggested either a longer course of ultrasound or a combination of ultrasound and exercise.

However in distinction, at 10 days following treatment only 6% of the exercise group stated a preference for exercise which rose to only 11% following treatment. This was further highlighted by 56% dropping to 44% preferring ultrasound and 25% dropping to 17% injection. This is surprising considering that 53% of patients found the exercises helped and 37% found them easy to do and furthermore 58% had no suggestions for improving their treatment.

When preference for further treatment on hypothetical recurrence is considered: whilst 67% of patients would prefer to have a repeat injection and 55% of patients would prefer to have a repeat course of ultrasound only 17% of patients would prefer further exercise if their pain recurred.

This evaluation not only supports clinical experience that patients have a very strong preference with respect to injection but that patients also have a surprisingly strong aversion towards exercise. It strongly suggests that patients are more satisfied with either injection or, albeit to a smaller extent, ultrasound treatment and that the general preference of patients for passive and quick fix treatments persists.

### **8.1.8 Summary of findings**

Table 7.25 (p.134) summarises the overall findings for between group differences overtime. The main findings of this research were that in the short term at 10 days the injection group was the most effective and the exercise group the least effective. The superior effectiveness of the injection group was maintained through to 6 weeks with the ultrasound group now the least effective. The short term superior effectiveness of injection therapy was highlighted with both statistically significant and minimum clinically important differences found between the injection group and both the ultrasound and exercise groups. However, no statistically significant or minimum clinically important differences were found between the ultrasound and exercise groups. In contrast in the long term at 6 months, the exercise group was now the most effective followed closely by the ultrasound group, although no statistically significant differences were found and only MCIDs were found in favour of exercise compared with injection. However, as previously discussed, due to the loss of power these long term findings must be regarded with caution.

## **8.2 Clinical implications**

Consequently in conclusion, the results from this trial found that all 3 treatment groups showed improvement overtime for different aspects of the clinical picture at different time intervals. The results for injection therapy support the previous conclusions of Bisset et al. (2006) and Smidt et al. (2002) that injection has superior effectiveness in the short term with both statistically significant and minimum clinically important differences when compared with physiotherapy and exercise. However, although Bisset et al. (2006) and Smidt et al. (2002) found injection to be significantly worse than physiotherapy and wait and see in the long term, and although in this trial, exercise was

ranked most effective no statistically significant differences between groups were found just a MCID for the exercise group over injection for PRTEE. Although, these conclusions should be regarded with caution due to the power issue and potential risk of bias, this supports the findings of the pooled analysis of Smidt et al. (2002), Bisset et al. (2006) and Tonks et al. (2006) by Coombes et al., (2010) who reported no group being favoured in either the intermediate or long term.

Bisset et al. (2007) and Smidt et al. (2005) found marked similarities for the course of pain for patients who received injection between the studies of Smidt et al. (2002) with Bisset et al. (2006) and Hay et al. (1999) respectively which mirror this research; an immediate marked reduction in pain with recurrence after 6 months although in contrast they reported high recurrence rates in comparison to this trial's lower rates with PFG, pain and disability relapsed in only a 1/3<sup>rd</sup> of patients by the long term of 6 months supporting Hamilton (1986). This may simply be due to a loss of power at 6 months although evidence has suggested that single injections are more effective (Coombes et al., 2010) and all conservative treatment should be fully exhausted prior to repeat injection which is supported by this trial and is a potential reason for less recurrence found in this trial which utilised only a single injection compared with Smidt et al. (2002) and Bisset et al. (2006) who allowed repeat injections up to 3 or 2 injections respectively.

They query the reason for recurrence suggesting that steroids may be potentially harmful in the long term or that patients simply overuse their elbows too quickly due to the immediate resolution of symptoms. However, with respect to the former, if steroids were detrimental one would surely expect to at least see a reported higher incidence of adverse effects following injection for tennis elbow whereas steroid injections are well tolerated with minor and infrequent side effects (Gaujoux-Viala et al., 2009). The preference analysis could support the latter as a potential cause of recurrence as the injection group preferred the quick fix and more passive treatment wishing their pain and disability to be resolved without inconvenience to them and this could potentially cause return to previous activities without consideration of the consequences. If patients are informed about the superiority of injection therapy in the short term and the chance of 2 in 3 remaining symptom free into the long term, as found in this trial and supported by Hamilton (1986), one can postulate a large percentage of patients would be willing to take those odds.

From this trial continuous 3 MHz therapeutic ultrasound at  $2\text{W}/\text{cm}^2$  for 5 minutes has demonstrated a clinically important increase in skin temperature of  $0.5^{\circ}\text{C}$  for 5 to 19 minutes following a single treatment and these thermal effects have optimised the healing process which is evident through a reduction in thermal difference from 10 days. The accumulative effect of ultrasound has been demonstrated with a continuous improvement in all outcome measures by 6 weeks which are sustained into the long term. The results also suggest that exercise is not necessarily a prerequisite to resolution of symptoms which is highlighted by a MCID for reduction in fatigue by 10 days and an increase in function by 6 weeks. From the findings of this trial these parameters for ultrasound need to be evaluated further and advocated in clinical practice as an alternative treatment, in particular for those patients who are unable or unwilling to be treated with injection therapy.

From this trial, the exercise group demonstrated general slow improvement overtime with changes in fatigue at only 6 weeks and changes in function at 6 months when ranked as the most effective. In comparison to Smidt et al. (2002), it was surprising to find such a strong aversion to exercise and the difficulties of exercising with tennis elbow in the short term were highlighted by 2 patients withdrawing at 10 days and 10% complaining of aggravation of symptoms.

Figure 8.1 (Haynes and Haines, 1998) puts the implementation of clinical findings in to context. The application of research findings is as important as the conduct of the research itself. The aim is to transform findings into clinical policies which can be applied at the right place in the right way and at the right time. There is a need to develop evidence based practice to ensure that the patient receives optimal treatment improving both the quality and efficiency of our services.

As can be seen the 3 important factors to be considered when making clinical decisions are not only the evidence but equally the individual patients' needs and their wishes. Consequently, patient preference needs to be taken into account which from this research was a strong preference for injection or, but to a lesser degree, ultrasound over exercise.

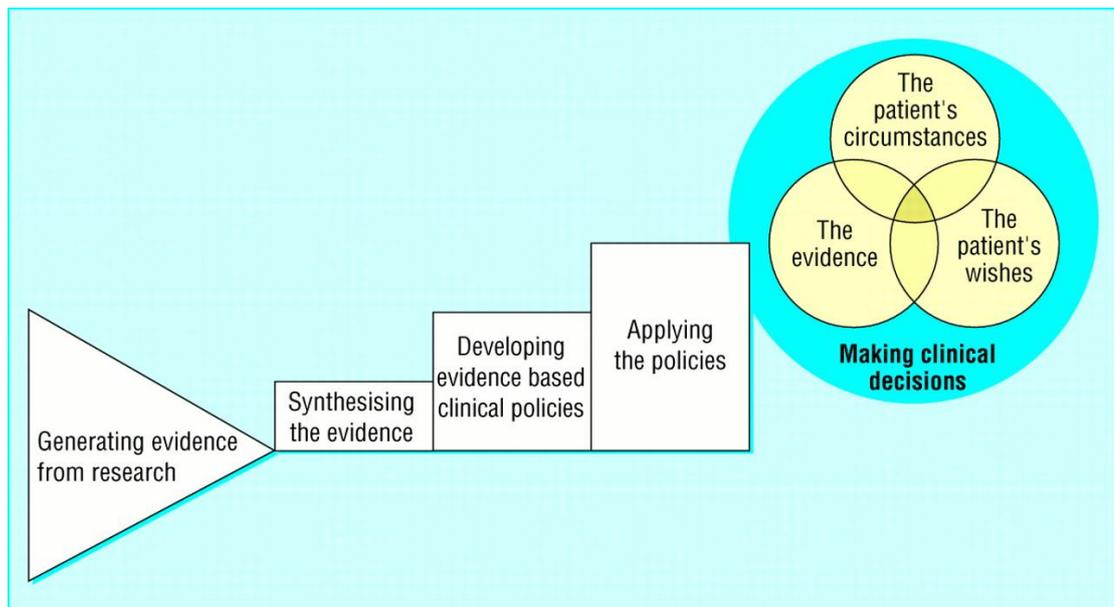


Figure 8.1: Application of research findings (Haynes and Haines, 1998).

Similarly, the patient's individual circumstances need to be taken into account so that if a patient's short term outcome is more important than their long term outcome, such as loss of their job or suffering financial hardship through extended sick leave for example, injection treatment may be offered even if it is for only an interim period (Orchard, 2011). This is supported from the findings of Bisset et al. (2007) who reported that for patients with high baseline pain severity, physiotherapy was not found to be significantly better than wait and see in the short term. Indeed, Smidt et al. (2006) reported high baseline pain severity as a poor prognostic indicator at 1 month. Furthermore, Gaujoux-Viala et al. (2009) reported that steroid injections were more effective in acute or subacute tendonitis, (< 12 weeks), and concluded that the optimum timing for injection may be in the early weeks of symptoms where the potential benefit appears clearer when compared with chronic tendinopathy.

Patient collaboration in treatment choice is of paramount importance and the pros and cons with respect to treatment options need to be discussed with the individual patient. An area for further research in tennis elbow is the identification of effect modifiers for tennis elbow patients to be able to identify best practice for different subgroups of patients through linear regression of a large, highly powered trial or further evaluation of the pooled data from a number of robust homogeneous trials to substantiate the reported assertions, although the latter would be difficult due to the large variability in physiotherapeutic interventions.

Further research is also needed to investigate the effectiveness of continuous ultrasound with exercise and advice versus injection with exercise and advice to identify whether the short term superior effectiveness of injection therapy is sustained in to the long term with the use of exercise as an adjunct or whether ultrasound and exercise has greater effectiveness to inform the debate on best practice for this notoriously difficult condition to treat. The inclusion of injection with exercise therapy is important because, although PFG has reduced and pain and disability recurred in the long term, thermal difference remained markedly improved, albeit subclinically, and MDF shift had a downward trend which implies that the underlying biochemical processes which have modified the pathological process are still evident. Similarly, it may further inform the debate on the reasoning for recurrence. Only 2 trials, Newcomer et al. (2001) and Tonks et al. (2007), have assessed a combination of injection and exercise and both trials were underpowered. Currently 2 study protocols, Coombes et al. (2009) and Olausson et al. (2009), have been published to assess the benefits of a combination of physiotherapy and injection.

In addition, the effects of ultrasound given over a longer time period or less frequently, for example in the region of once a week for 6 weeks, as such is the availability for treatment in some Trusts due to high patient loads and limited appointment availability in the current climate of financial constraints is needed to investigate the optimum parameters of ultrasound treatment.

Also of clinical importance, when patient preference is considered 1 in 2 patients complained of pain or discomfort during the injection. From clinical experience this was surprising as the majority of patients usually comment that the injection was not as bad as they had expected. In contrast, when the local anaesthetic is given for other injections, in a bolus form, this is when the patient generally would report pain. Due to the peppering technique involved with the injection for tennis elbow one would expect the actual peppering of the local anaesthetic to be more painful not only due to the chemical itself but also due to the injection taking twice as long. Lewis et al. (2005) evaluated post injection pain and reported it to be of an insignificant magnitude. However, the patients' comments need to be taken into consideration and patient preference to include local anaesthetic will need to be investigated further.

Even though Hamilton (1986) reported that patients suffered tennis elbow symptoms for a mean of 41 days before presentation, another ongoing issue is that 16% of injection and 10.5% of exercise patients felt that the time taken from first seeing their GP to treatment could have been shorter. The importance of this wait was highlighted by Bot et al. (2005) and Smidt et al. (2006) who reported longer duration of symptoms before consultation with the GP, due to patients often only presenting after having waited a while to see if their elbow settles spontaneously, increased the likelihood of an unfavourable outcome and potentially an increased risk for the development of a chronic condition. If the model proposed by Coombes et al. (2009) is considered this would lead to not only motor system dysfunction but also pain system impairments, including central sensitisation, which would lead to a more difficult condition to treat. There are a number of potential reasons for delay in referral, including interpretation of the robust trial of Smidt et al. (2002) that wait and see combined with naproxen is probably the most cost effective treatment for tennis elbow in the long term when compared to injection and pulsed ultrasound with exercise. However, in the short term there were both SSDs and MCIDs in favour of injection and the success rates of physiotherapy, even using only pulsed ultrasound, were 15% more than the wait and see group. Together with the patient preference data one can surmise that patients both expect and prefer a quick fix to enable them to both continue with their work and function without limitation of their activities of daily living rather than them potentially having to 'put their life on hold' for 6 to 12 months. Furthermore, the self-limiting nature of tennis elbow remains in contention with Bot et al. (2005) reporting poor recovery at 12 months. They also suggest that treatment could be an important predictor of outcome due to clinical decisions to treat based on prognostic indicators such as duration and pain severity, as recommended by the Dutch general practice guidelines to only offer injection or physiotherapy to patients with severe and persistent pain and disability. Also, the issues surrounding the potential adverse reactions following long term use of NSAIDs with potential gastrointestinal bleeds and associated costs need to be taken into consideration in addition to the potential deleterious effects of these drugs on tendon healing (Orchard, 2011). However, these effects have not materialised and in contrast wait and see with the use of NSAIDs has been found to be of superior effectiveness in the long term (Smidt et al., 2002).

The clinical utility of the 6 outcome measures employed in this clinical trial varied. The PRTEE pain, function and total used in conjunction with PFG are sensitive outcome

measures which can monitor treatment effects for tennis elbow patients. They are readily available in most clinical settings and only require a minimum of time for completion. In contrast, both the thermal and EMG outcome measures are more time consuming, with respect to the data collection, processing and analysis, in addition to the equipment required which is both highly technical and expensive with limited availability in the clinical setting. Even so, for the purposes of this clinical trial and research on tennis elbow they revealed some interesting, novel and useful data. It has not only confirmed and contested the findings of previous research on tennis elbow but has given greater weight to the use of thermal imaging in the clinical setting to monitor the progress of tennis elbow patients and their response to treatment through the development of a novel protocol for this trial. Thermography has also identified the utilisation of the thermal effects of continuous ultrasound which warrants further research in tendinopathy. The protocol developed for the MDF shift outcome measure has demonstrated that isolated ECRBr fatigue can be evaluated through surface EMG although EMG utility as an outcome measure in clinical practice is questionable.

The analysis of the physiological data from this clinical trial could be taken further through identification of any relationships between thermal difference or MDF shift and PFG and PRTEE to explore the mechanisms through which injection and ultrasound work. Also of importance would be further analysis of the data to identify the extent that thermal difference or MDF changes mediate treatment effects.

### ***8.3 Limitations of the clinical trial***

A major issue was the sample size calculation for this clinical trial which was challenging as there was no existing data for the primary outcome measure of thermal difference. From the literature there was only scarce data in the field of the secondary outcome measure of MDF and even so this was mainly on a normal population and not based on between group differences. From this data the sample size required was in the region of 21 patients in each group with an effect size of larger than 0.9. When the internal pilot and the stabilisation of data was considered the data had stabilised which confirmed that a sufficient sample size of 21 patients per group had been recruited to detect a MCIC. However, when the between group differences were considered there was a maximum of 0.25 °C difference between groups which was greater than the a

priori defined 0.2 °C MCIC. As the SD was in the region of 0.4- 0.5 for all groups this gave a moderate ES of 0.5 which would require a sample size of 60 patients to detect this MCID, which was unfortunately beyond the scope of this clinical trial. Consequently, this clinical trial has a lack of power to detect difference between groups. However, due to the robust methods that have been utilised and the consistency of the short term results had the clinical trial been sufficiently powered where only a MCID was detected a statistically significant difference probably would also have been found.

As previously discussed, as the 6 month analysis was undertaken on a per protocol analysis, this limited the long term follow up to a much smaller sample and selective subgroup of the patient population. Consequently, in addition to the high DNA rate at 6 months this led to a further reduction in power and an increased risk of bias in the long term. Only 50% of the exercise group attended and all 7 who attended were satisfied with their outcomes and did not wish further treatment. Only 1 out of 8 patients attended at 6 months in the ultrasound group and they were satisfied with their outcome and declined further treatment. Although a lower DNA rate was apparent for the injection group 38% required further treatment.

Another challenge, with respect to the data for the MDF shift outcome measure, was the finding of interference on the tennis elbow patient data which highlights the obstacles that need to be overcome when undertaking research within the clinical setting.

The inability to blind patients to their allocated treatment is an ongoing issue of potential bias within randomised trials, although this is not so relevant in pragmatic trials where you compare treatments as carried out as in normal clinical practice. Patient treatment preference could influence both their response to treatment and their scoring of subjective outcome measures such as the PRTEE. This was overcome to an extent through the use of a select group of both objective and subjective outcome measures undertaken by a single researcher who was blind to randomisation and through the evaluation of preference for the treatments. As can be seen in table 7.18 preference was unequally distributed across treatment groups which increased the risk of biased estimation of subjective outcome.

Unfortunately preference was first evaluated at 10 days after commencement of treatment, and not as suggested by van der Windt et al. (2000) prior to randomisation,

so potentially the actual treatment that the patient received may have influenced their decision and already raised potential bias. Smidt et al. (2002) found that the large preference for physiotherapy in their trial showed little effect on outcome, whereas from subgroup analysis of frozen shoulder patients van der Windt et al. (2000) reported that only for patients in the injection group, allocation to the preferred treatment had some influence on success rates. If one considers the change in preference after 10 days of treatment and after completion of treatment at 6 weeks it can be postulated that due to the good outcome of injection although 68% had a strong preference initially this rose to 84% following treatment. Subsequently one would expect better success rates for the injection group in the long term within this trial which were evident in comparison to previous research. However, this was not the case when the ultrasound and exercise groups are considered: 47% of the ultrasound group had a preference for ultrasound which subsequently dropped to 35% after completion of treatment and only a minimal 6% of the exercise group had a preference for exercise which subsequently increased by twofold to 11% after completion of treatment.

Two other suggestions by van der Windt et al. (2000) to reduce bias from patient preference were to exclude patients who have previously received any treatments included in the trial which would have reduced this population by in the region of 9% or by excluding patients with a treatment preference which was acknowledged and would have been unacceptable through depletion of the patient population.

Blinding of the researcher was successful in the most part with the researcher having only 25 correct guesses, 18 incorrect guesses and no idea about a further 7 patients at review. Only 2 patients' treatment group was unmasked through a slip of the tongue by the patient or administration staff. The rationale for the guess was based on clinical reasoning of the outcome measures as a whole after assessment and matching with an expected outcome overtime following a particular intervention, most notably the quick resolution of pain and increase in function following injection. This implies that as the guess was formulated after outcome measure assessment it was unlikely to have influenced the actual assessment of the outcome measure itself.

## CHAPTER 9: CONCLUSIONS

In conclusion this trial supports previous findings that injection is superior in the short term of 6 weeks. Despite the power and selectivity issues discussed and the consequent questionable value of the long term findings through to 6 months, the trends observed in this trial found recurrence following injection but to a lesser magnitude than previously reported. This trial supports previous findings that outcomes are better with exercise rehabilitation and physiotherapy when compared to injection in the long term, although not of a magnitude which is statistically significant or clinically relevant.

Thermal difference using the protocol developed in this trial is a sensitive outcome measure for tennis elbow and has been shown to track temperature changes within both the injection and ultrasound groups overtime. On analysis of the injection group thermal difference tracks the changes of both the PFG and PRTEE outcome measures in the short term up to 6 weeks but not at 6 months. These results support the theory that thermography can detect subclinical changes which implies that the underlying biochemical processes which have modified the pathological process are still evident although pain and disability have recurred.

The heat energy gains during a session of continuous therapeutic ultrasound have demonstrated a clinically important increase in skin temperature of  $0.5^{\circ}\text{C}$  for 5 to 19 minutes following a single treatment and that these thermal effects optimise the healing process which is evident through a reduction in thermal difference from 10 days. Furthermore, the theory of an accumulative effect of ultrasound has been supported by a continuation of improvement in to the long term of 6 months.

The results also support that exercise is not necessarily a prerequisite to resolution and is highlighted by ultrasound treatment demonstrating a MCID for reduction in fatigue by 10 days and an increase in function by 6 weeks in contrast to the exercise group who demonstrated changes at only 6 weeks and 6 months respectively.

Patient preference demonstrated strong preference for injection and to a lesser degree ultrasound as the modalities of choice and a strong aversion towards exercise. These findings need to be considered in clinical practice. The patient's individual circumstances also need to be taken into account and patient collaboration in treatment

choice is of paramount importance; the pros and cons with respect to treatment options need to be discussed with the individual patient to be matched with their priority goals. If a patient presents with non severe pain and can cope with their current limitations physiotherapy or exercise may be the treatment of choice. However, conversely if a patient presents with severe pain and their short term outcome is of more importance then injection may be the treatment of choice for early resumption of activity either with an exercise programme or acknowledgement that 1/3<sup>rd</sup> of patients will suffer a recurrence of symptoms with a potentially poorer prognosis.

This research can be taken forward through further translational research exploring the associations of the physiological data of thermal difference and MDF with PFG and PRTEE and exploring to what extent thermal and MDF changes mediate treatment effects. It would also be of value to analyse the combination of treatments as is the norm in clinical practice: injection with exercise to see if the superior effectiveness is extended into the long term and any additional value of ultrasound with exercise. The benefit of continuous ultrasound utilising the thermal effects in the treatment of tennis elbow is also a notable area for further investigation. Another important area for further research is identification of effect modifiers for tennis elbow patients and identification of best practice for different subgroups of patients through linear regression of a large, highly powered trial to substantiate the reported assertions.

In summary this randomised clinical trial found:

in the short term of 10 days and 6 weeks

- injection therapy is the most effective treatment demonstrating both statistically significant and minimum clinically important differences for PFG and PRTEE in comparison to ultrasound and exercise.
- patients had a strong preference for injection.
- no statistically significant differences were found between ultrasound and exercise although a MCID was found in favour of ultrasound for thermal difference and MDF at 10 days.

in the long term of 6 months

- no statistically significant differences were found between injection, ultrasound or exercise. A MCID was found in favour of ultrasound for MDF and a MCID

was found in favour of exercise over injection for all aspects of PRTEE and over ultrasound for PRTEE pain only.

This research supports the superior effectiveness of injection in the short term of 6 weeks and should be advocated for patients who present early with severe limiting pain and have important short term goals, although patients need to be warned that a 1/3<sup>rd</sup> of patients will suffer a recurrence of symptoms associated with a potentially poorer prognosis. Evidence has suggested that single injections are more effective and all conservative treatment should be fully exhausted prior to repeat injection (Coombes et al., 2010).

In contrast for those patients who present with moderate to low pain physiotherapy including exercise and/ or ultrasound should be advocated. Further research on the efficacy of a combination of injection with physiotherapy is required.

Continuous 3 MHz therapeutic ultrasound at  $2\text{W}/\text{cm}^2$  for 5 minutes utilises thermal effects which optimise the healing process and demonstrate an accumulative effect of ultrasound in to the long term. These parameters should be advocated in clinical practice.

Exercise is not necessarily a prerequisite to resolution.

Thermal difference using the protocol developed in this trial is a sensitive outcome measure for tennis elbow overtime and can detect subclinical involvement.

## CHAPTER 10: REFERENCES

Abbott, J., Patla, C., Jensen, R. (2001) The initial effects of an elbow mobilisation with movement technique on grip strength in subjects with lateral epicondylalgia. *Manual Therapy* 6 (3), p. 163-169

ACPOM (1999) *A clinical guideline for the use of injection therapy by physiotherapists*

Albrecht, A., Kleihues, H., Cordis, R. and Noack, W. (1997) Diagnostic and therapeutic strategies for the operative treatment of radiohumeral epicondylopathy. *Arch Orthop Trauma Surg* 116, p. 164-172

Alizadehkhayat, O., Fisher, A., Kemp, G., Frostick, S. (2007) Strength and fatigability of selected muscles in upper limb: Assessing muscle imbalance relevant to tennis elbow *Journal of Electromyography and kinesiology* 17, p. 428-436

Alizadehkhayat, O., Fisher, A., Kemp, G., Vishwanathan, K., Frostick, S. (2007) Upper limb muscle imbalance in tennis elbow: A functional and electromyographic assessment *Journal of Orthopaedic Research* Dec, p. 1651-1657

Alizadehkhayat, O., Fisher, A., Kemp, G., Vishwanathan, K., Frostick, S. (2008) Assessment of functional recovery in tennis elbow *J Electromyogr Kinesiol* doi:10.1016/j.jelekin

Ammer, K. (1995) Thermal evaluation of tennis elbow *The thermal image in medicine and biology* Eds. Ammer and Ring Uhlen Verlag: Wein

Ammer, K. (2006) Repeatability of the identification of hotspots in thermal images *Thermology International* 16 (3), p.105

Ammer, K. (2008) Thermal imaging: a diagnostic aid for fibromyalgia? *Thermology International* 18 (2), p.45-50

Ashton, Leigh and Wigan Community Healthcare Patient Group Direction for the administration of triamcinolone acetonide (version 1/2008)

Assendelft, W., Green, S., Buchbinder, R., Struijs, P., Smidt, N. (2003) *Clinical Evidence: concise*: London: BMJ publishing group

Barr, S., Cerisola, F., Blanchard, V. (2009) Effectiveness of corticosteroid injections compared with physiotherapeutic interventions for lateral epicondylitis: a systematic review *Physiotherapy* 95, p.251-265

Bauer, J., Murray, R. (1999) Electromyographic patterns of individuals suffering from lateral tennis elbow *Journal of Electromyography and kinesiology* 9, p. 245-252

BenEliyahu, B. (1990) Infrared thermography in the diagnosis and management of sports injuries: a clinical study and literature review *Chiropractic Sports Medicine* 4 (2), p. 46-53

Binder, A., Hodge, G., Greenwood, A.M., Hazleman, B.L., Page-Thomas, D.P., (1985) Is therapeutic ultrasound effective in treating soft tissue lesions *Br Med J* 290, p.512-514

Binder, A., Parr, G., Page Thomas, P., Hazleman, B. (1983) A clinical and thermographic study of lateral epicondylitis *British Journal of Rheumatology* 22, p.77-81

Bishop, S., Draper, D., Knight, K., Feland, B. and Eggett, D. (2004) Human tissue-temperature rise during ultrasound treatments with the aquaflex gel pad. *Journal of Athletic Training* 39 (2), p126-131

Bisset, L., Paungmali, A., Vicenzino, B., Beller, E. (2005) A systematic review and meta-analysis of clinical trials on physical interventions for lateral epicondylalgia *Br J Sports Med* 39, p.411-422

Bisset, L., Beller, E., Jull, G., Brooks, P., Darnell, R., Vincenzino, B. (2006) Mobilisation with movement and exercise, corticosteroid injection or wait and see for tennis elbow: randomised trial *BMJ* 333, p.939-945

Bisset, L., Smidt, N., van der Windt, D., Bouter, L., Jull, G., Brooks, P., Vicenzino, B. (2007) Conservative treatments for tennis elbow- do subgroups of patients respond differently? *Rheumatology* 46, p.1601-1605

Bot, S., van der Waal, J., Terwee, C., van der Windt, D., Bouter, L., Dekker, J. (2005) Course and prognosis of elbow complaints: a cohort study in general practice *Ann Rheum Dis* 64, p.1331-1336

Burgess, R. (1990) Tennis elbow *J Ky Med Assoc* 88 (7), p.349-354

Chan, A., Myrer, J.W., Measom, G. and Draper, D. (1998) Temperature changes in human patellar tendon in response to therapeutic ultrasound. *Journal of Athletic Training* 33 (2), p. 130-135

Chard, M. and Hazleman, L. (1989) Tennis elbow- a reappraisal. Editorial. *Br. J. Rheumatology* 28, p.186-189

Coombes, B., Bisset, L., Vicenzino, B. (2010) Efficacy and safety of corticosteroid injections and other injections for the management of tendinopathy; a systematic review of randomised controlled trials *The Lancet* 376, p. 1751-1767

Coombes, B., Bisset, L., Connelly, L., Brooks, P., Vicenzino, B. (2009) Optimising corticosteroid injection for lateral epicondylalgia with the addition of physiotherapy: a protocol for a randomised control trial with placebo comparison *BMC Musculoskelet Disord* 10, 76

Coombes, B., Bisset, L., Vicenzino, B. (2008) A new integrative model of lateral epicondylalgia *Br J Sports Med* 43, p. 252-258

Copay, A., Subach, B., Glassman, S., Polly, D., Schuler, T. (2007) Understanding the minimum clinically important difference: a review of concepts and methods. *The Spine Journal* 7, p.541-546

Cowan, J., Lozano-Calderon, S., Ring, D. (2007) Quality of prospective controlled randomised trials Analysis of trials of treatment for lateral epicondylitis as an example *J Bone Joint Surg Am* 89, p. 1693-99

Croisier, J., Forthomme, B., Foidart-Dessalle, M., Godon, B., Crielaard, J. (2001) Treatment of recurrent tendonitis by isokinetic eccentric exercises. *Isokinetics and Exercise Science* 9, p.133-141

Cyriax, J. (1984) *Textbook of orthopaedic medicine: Treatment by manipulation, massage and injection. Vol. 2.* 11<sup>th</sup> ed. London: Bailliere Tindall

Cyriax, J. (1982) *Textbook of orthopaedic medicine: Diagnosis of soft tissue lesions Vol. 1.* 8<sup>th</sup> ed. London: Bailliere Tindall

Davidson, J., Vandervoort, A., Lessard, L. and Miller, L. (2001) The effect of acupuncture versus ultrasound on pain level, grip strength and disability in individuals with lateral epicondylitis: a pilot study *Physiotherapy Canada* p.195-202

De Luca, C. J. (1984) Myoelectrical manifestations of localised muscular fatigue in humans *Crit Rev Biomed Eng* 11, p. 251-279

De Luca, C. J. (1997) The use of surface electromyography in biomechanics *Journal of Applied Biomechanics* 13 (2), p. 135-163

De Luca, G. (2003) *DELSYS Fundamental concepts in EMG signal acquisition Rev.2.1* DelSys Inc.

Demmink, J. (2007) The net temperature increase in the context of ultrasound-induced heat *Thermology International* 17 (4), p.156

De Smet, L. and Fabry, G. (1997) Grip force reduction in patients with tennis elbow: influence of elbow position. *J Hand Ther* 10 (3), p.229-231

Draper, D., Castel, J. and Castel, D. (1995) Rate of temperature increase in human muscle during 1MHz and 3MHz continuous ultrasound. *JOSPT* 22 (4), p.142-149

- Draper, D. and Ricard, M. (1995) Rate of decay in human muscle following 3MHz ultrasound: the stretching window revealed. *Journal of Athletic Training* 30 (4), p. 304-307
- Duque, J., Masset, D., Malchaire, J. (1995) Evaluation of hand grip force from EMG measurements *Appl Ergon* 26, p. 61-66
- Dyson, M. and Suckling, J. (1978) Stimulation of tissue repair by ultrasound: a survey of the mechanisms involved. *Physiotherapy* 64, p.105-108
- Enwemeka, C. (1989) The effects of therapeutic ultrasound on tendon healing a biomechanical study *Am J Phys Med Rehabil* 68, (6), p. 283-287
- Farrar, J., Young, P., LaMoreaux, L., Werth, J., Poole, M. (2001) Clinical importance of changes in chronic pain intensity measured on an 11-point numerical pain rating scale *Pain* 94, p. 149-158
- Firrell, J (1996) Which setting of the dynamometer provides the maximum grip strength? *J of Hand Surgery* 21A, p.397-401
- Fugl-Myer, A., Eriksson, A., Sjostrom, M., Soderstrom, G. (1982) Is muscle structure influenced by genetical or functional factors? *Acta Physiol. Scand.* 114, p. 227-281
- Gallo, J., Draper, D., Brody, L., Fellingham, G. (2004) A comparison of human muscle temperature increases during 3MHz continuous and pulsed ultrasound with equivalent temporal intensities *J Orthop Sports Phys Ther* 34 (7), p. 395-401
- Garagiola, U., Giani, E. (1990) Use of telethermography in the management of sports injuries *Sports Medicine* 10 (4), p. 267-272
- Garrett, C., Draper, D., Knight, K. (2000) Heat distribution in the lower leg from pulsed short-wave diathermy and ultrasound treatments *Journal of Athletic Training* 35 (1), p. 50-55

Gaujoux-Viala, C., Dougados, M., Gossec, L. (2009) Efficacy and safety of steroid injections for shoulder and elbow tendonitis: a meta-analysis of randomised controlled trials *Ann Rheum Dis* 68, p. 1843-1849

Greenfield, C. and Webster, V. (2002) Chronic lateral epicondylitis: survey of current practice in the physiotherapy departments in Scotland. *Physiotherapy* 80 (10), p. 578-594

Hagg, G. and Milerad, E. (1997) Forearm extensor and flexor muscle exertion during simulated gripping work- an electromyographic study. *Clinical Biomechanics* 12 (1), p. 39-43

Haake, M., Willenberg, T., Sauer, F., Griss, P. (2002) Effect of extracorporeal shockwave therapy on vascular regulation. Infrared thermography in epicondylitis humeral radialis *Swiss Surg* 8 (4), p.176-180

Haker, E. and Lundeberg T., (1991) Pulsed ultrasound treatment in lateral epicondylalgia *Scand J Rehab Med* 23, p. 115-118

Hamilton, P. (1986) The prevalence of humeral epicondylitis: a survey in general practice *Journal of the Royal College of General Practitioners* 36, p.464-465

Haslock, I., Macfarlane, D., Speed, C. (1995) Intra-articular and soft tissue injections: a survey of current practice *Br J Rheumatology* 34, p.449-452

Hay, E., Paterson, S., Lewis, M., Hosie, G., Croft, P. (1999) Pragmatic randomised controlled trial of local corticosteroid injection and naproxen for treatment of lateral epicondylitis of tennis elbow in primary care. *BMJ* 319, p. 964-968

Hayes, B., Merrick, M., Sandrey, M. and Cordova, M. (2004) Three-MHz ultrasound heats deeper into the tissues than originally theorized. *Journal of Athletic Training* 39 (3), p. 230-234

Haynes, B. and Haines, A. (1998) Barriers and bridges to evidence based clinical practice *BMJ* 317, p.273-276

Karki, A., Karppi, P., Ekberg, J., Selfe, J (2004) A thermographic investigation of skin temperature changes in response to a thermal washout of the knee in healthy young adults *Thermology Int* 14, p. 137-141

Kirtley, C. (2006) *Clinical gait analysis, theory and practice* London: Churchill Livingstone, Elsevier

Kjaer, M. (2004) Role of extracellular matrix in adaptation of tendon and skeletal muscle to mechanical loading *Physiol Rev* 84, p.649-698

Khan, K., Cook, J., Maffulli, N., Kannus, P. (2000) Where is the pain coming from in tendinopathy? It may be biochemical, not only structural, in origin. *Br J Sports Med* 34, p.81-83

Kitchen, S. (2002) *Electrotherapy- Evidence Based Practice* 11<sup>th</sup> Ed. Edinburgh Churchill Livingstone p.213

Knebel, P., Avery, D., Gebhardt, T., Koppenhaver, S., Allison, S., Bryan, J. and Kelly, A. (1999) Effects of the forearm support band on wrist extensor muscle fatigue. *JOSPT* 29 (11), p. 677-685

Korthals-de-Bos, I., Smidt, N., van Tulder, M., Rutten-van-Molken, M., Ader, H., van der Windt, D., Assendelft, W., Bouter, L. (2004) Cost effectiveness of interventions for lateral epicondylitis Results from a randomised controlled trial in primary care *Pharmoeconomics* 22 (3), p.185-195

Kraushaar, B. and Nirschl, R. (1999) Tendinosis of the elbow (tennis elbow) *J Bone Joint Surg* 81-A (2), p.259-278

Lewis, M., Hay, E., Paterson, S., Croft, P. (2005) Local steroid injections for tennis elbow: does the pain get worse before it gets better?: results from a randomised controlled trial *The Clinical Journal of Pain* 21 (4), p. 330-334

Lundeberg, T., Abrahamsson, P., Haker, E. (1988) A comparative study of continuous ultrasound, placebo ultrasound and rest in epicondylalgia *Scand J Rehabil Med* 20, p.99-101

MacDermid, J. (2005) Update: The Patient-rated Forearm Evaluation Questionnaire is now the Patient-rated Tennis Elbow Evaluation *Journal of Hand Therapy* 18, p.407-410

Magdeburg, H., Herrgoss, G., Hans-Joerg, K. (1986) Measurement of skin surface temperature by dynamic properties of contact thermometer *Fourth International Congress of the European Association of Thermology Proceedings* p.80

Malliaras, P. (2008) Aetiology of tendon injury *Upper limb tendinopathy course* October 2008 Birmingham

Mayr, H. (1995) Thermographic evaluation after knee surgery *Proceedings of the meeting of the royal photographic society imaging science and technology group* October 1994 Bath

Michlovitz, S. (1986) *Thermal Agents in Rehabilitation* 2<sup>nd</sup> Ed. Philadelphia FA Davis Co p.144-5

Milz, S., Tischer, T., Buettner, A., Schieker, M., Redman, S., Emery, P., McGonagle, D., Benjamin, M. (2004) Molecular composition and pathology of entheses on the medial and lateral epicondyles of the humerus: a structural basis for epicondylitis *Ann Rheum Dis* 63, p.1015-1021

Mogk, J., Keir, P. (2003) The effects of posture on forearm muscle loading during gripping *Ergonomics* 46, p. 956-975

Newcomer, K., Laskowski, E., Idank, D., McLean, T., Eagan, K. (2001) Corticosteroid injection in early treatment of lateral epicondylitis *Clinical Journal of Sport Medicine* 11, p.214-222

- Newcomer, K., Martinez- Silvestrini, J., Schaefer, M., Gay, R., Arendt, K. (2005) Sensitivity of the patient- rated forearm evaluation questionnaire in lateral epicondylitis *Journal of Hand Therapy* 18 (4), p.400-405
- Ng, Y. and Fan, A. (2001) Does elbow position affect strength and reproducibility of power grip measurements? *Physiotherapy* 87 (2), p.68-72
- Nirschl, R. (1992) Elbow tendinosis/ tennis elbow. *Clinics in sports medicine* 11 (4), p.851-869
- Noteboom, T., Cruver, R., Keller, J., Kellogg, B., Nitz, A. (1994) Tennis elbow: a review. *JOSPT* 19 (2), p. 357-366
- Olaussen, M., Holmedal, O., Lindbaek, M., Brage, S. (2009) Physiotherapy alone or in combination with corticosteroid injection for acute lateral epicondylitis in general practice: a protocol for a randomised, placebo- controlled study *BMC Musculoskelet Disord* 10, 152
- Orchard, J., Kountouris, A. (2011) The management of tennis elbow *BMJ* 342, doi:1136/bmj.d2687
- Overend, T., Wouri-Fearn, J., Kramer, J., MacDermid, J. (1999) Reliability of a patient-rated forearm evaluation questionnaire for patients with lateral epicondylitis. *J Hand Therapy* 12, p.31-37
- Paavola, M., Kannus, P., JaRvinen, T., Jozsa, L., Jarvinen, M. (2202) Treatment of tendon disorders. Is there a role for corticosteroid injection? *Foot Ankle Clin* 7, (3), p.501-513
- Pienimaki, T., Tarvainen, T., Siira, P., Vanharanta, H. (1996) Progressive strengthening and stretching exercises and ultrasound for chronic lateral epicondylitis. *Physiotherapy* 82 (9), p. 522-530

- Pienimäki, T., Karinen, P., Kemila, T., Koivukangas, P., Vanharanta, H. (1998) Long-term follow-up of conservatively treated chronic tennis elbow patients: a prospective and retrospective analysis. *Scand. J. Rehab. Med.* 30, p. 159-166
- Pizzetti, M., Fredella, D., Allegro, A. (1984) La laserterapia nell'epicondilita. Controllo mediante teletermografia *I. J. Sports Traumatology* 6 (2), p. 133-141
- Richards, J. (2008) *Biomechanics in clinic and research* Edinburgh: Churchill Livingstone, Elsevier
- Riek, S., Carson, R., Wright, A. (2000) A new technique for the selective recording of extensor carpi radialis longus and brevis EMG *Journal of Electromyography and kinesiology* 10, p. 249-253
- Riley, G. (2010) The biology of tendinopathy *Conference on tendon biology and healing* January 2010 Cambridge
- Ring, E., Plassmann, P., Ammer, K., Jung, A., Zuber, J., Wiececk, B. (2005) Aspects of standardisation in the recording of thermal images- the anglo-polish project *Thermology International* 15 (4), p.147-148
- Ring, E. (2002) Protocol and sources of error in thermal imaging *Thermology International* 12 (2), p.59-60
- Rompe, J., Overend, T., MacDermid, J. (2007) Validation of the patient-rated tennis elbow evaluation questionnaire *Journal of Hand Therapy* 20, p.3-11
- Saunders, S. (2002) *Injection techniques in orthopaedic and sports medicine*. 2<sup>nd</sup> ed. Edinburgh: W B Saunders
- Scudds, R., Helewa, A., Scudds, R. (1995) The effects of transcutaneous electrical nerve stimulation on skin temperature in asymptomatic subjects *Physical Therapy* 75 (7), p.621-628

Selfe, J., Whitaker, J., Hardaker, N. (2008) A narrative literature review identifying the minimum clinically important differences for skin temperature asymmetry at the knee. *Thermology international* 18 (2), p.51-54

Selfe, J., Hardaker, N., Thewlis, D., Karki, A. (2006) An accurate and reliable method of thermal data analysis in thermal imaging of the anterior knee for use in cryotherapy research *Arch Phys Med Rehabil* 87, p.1630-1635

Selfe, J., Callaghan, M., McHenry, A., Richards, J., Oldham, J. (2006) An investigation into the effect of the number of trials during proprioceptive testing in patients with patellofemoral pain syndrome. *Journal of Orthopaedic Research* June, p.1218-1224

Smidt, N., van der Windt, D., Assendelft, W., Deville, W., Korthais - de Bos, I., Bouter, L. (2002) Corticosteroid injections, physiotherapy, or a wait-and-see policy for lateral epicondylitis : a randomised controlled trial. *The Lancet* 359, p.657-662

Smidt, N., Assendelft, W., van der Windt, D., Hay, E., Buchbinder, R., Bouter, L. (2002) Corticosteroid injections for lateral epicondylitis: a systematic review. *Pain* 96, p. 23-40

Smidt, N., van der Windt, D., Assendelft, W., Mourits, A., Deville, W., de Winter, A., Bouter, L. (2002) Interobserver reproducibility of the assessment of severity of complaints, grip strength and pressure pain threshold in patients with lateral epicondylitis. *Arch Phys Med Rehabil* 83, p.1145-1150

Smidt, N., Assendelft, W., Arola, H., Malmivaara, A., Green, S., Buchbinder, R., van der Windt, D., Bouter, L. (2003) Effectiveness of physiotherapy for lateral epicondylitis: a systematic review *Annals of Medicine* 35, p. 51-62

Smidt, N., Lewis, M., Hay, E., van der Windt, D., Bouter, L., Croft, P. (2005) A comparison of two primary care trials on tennis elbow: issues of external validity *Ann Rheum Dis* 64, p.1406-1409

Smidt, N. and van der Windt, D. (2006) Tennis elbow in primary care- corticosteroid injections provide only short term pain relief *BMJ* 333, p.927-928

- Smidt, N., Lewis, M., van der Windt, D., Hay, E., Bouter, L., Croft, P. (2006) Lateral epicondylitis in general practice: course and prognostic indicators of outcome *The Journal of Rheumatology* 33 (10), p.2053-2059
- Smith, B., Bandler, M., Goodman, P. (1986) Dominant forearm hyperthermia: a study of fifteen athletes *Thermology International* 2 (1), p.25-28
- Solveborn, S. and Olerud, C. (1996) Radial epicondylalgia (tennis elbow): Measurement of range of motion of the wrist and the elbow *JOSPT* 23 (4), p.251-257
- Speed, C. (2001) Corticosteroid injections in tendon lesions. *BMJ* 323, p.382-386
- Stoeckart, R., Vleeming, A., Snijders, C. (1989) Anatomy of the extensor carpi radialis brevis muscle related to tennis elbow. *Clinical Biomechanics* 4 (4), p.210-212
- Stratford, P., Levy, D., Gowland, C. (1993) Evaluative properties of measures used to assess patients with lateral epicondylitis at the elbow. *Physiotherapy Canada* 45 (3), p.160-164
- Stratford, P., Norman, G., McIntosh, J. (1989) Generalisability of grip strength measurements in patients with tennis elbow. *Physical Therapy* 69 (4), p.276-281
- Stratford, P., Levy, D., Gauldie, S., Levy, K., Miseferi, D. (1987) Extensor carpi radialis tendonitis: a validation of selected outcome measures. *Physiotherapy Canada* 39 (4), p. 250-255
- Thomas, D. and Savage, J. (1989) Persistent tennis elbow: evaluation by infrared thermography and nuclear medicine isotope scanning. *Thermology* 3 (2), p.132-136
- Thomas, D., Siahhamis, G., Millicent, M., Boyle, C. (1992) Computerised infrared thermography and isotopic bone scanning in tennis elbow *Annals of the Rheumatic Diseases* 51, p103-107

Tonks, J., Pai, S., Murali, S. (2007) Steroid injection therapy is the best conservative treatment for lateral epicondylitis: a prospective randomised controlled trial. *Int J Clin Pract* 61 (2), p. 240-246

Turchin, D., Beaton, D., Richards, R. (1998) Validity of observer-based aggregate scoring systems as descriptors of elbow pain, function and disability *JBJS* 80-A (2), p.154-162

Uematsu, S., Edwin, D., Jankel, W., Kozikowski, J., Trattner, M. (1988) Quantification of thermal asymmetry *J Neurosurg* 69, p.552-555

Uzunca, K., Birtane, M., Tastekin, N. (2007) Effectiveness of pulsed electromagnetic field therapy in lateral epicondylitis *Clin Rheumatol* 26, p.69-74

van der Windt, D., Koes, B., van Aarst, M., Heemskerk, M., Bouter, L. (2000) Practical aspects of conducting a pragmatic randomised trial in primary care: patient recruitment and outcome assessment *British Journal of General Practice* 50, p.371-374

van der Windt, D., van der Heijden, G., van der Berg, S., ter Reit, G., de Winter, A., Bouter, L. (1999) Ultrasound therapy for musculoskeletal disorders: a systematic review. *Pain* 81, p.257-271

Vardasca, R., Ring, F., Plassman, P., Jones, C. (2007) Thermal symmetry on extremities of normal subjects *Thermology International* 17 (3), p.114

Verhaar, J. (1994) Tennis elbow. Anatomical, epidemiological and therapeutic aspects. *Int. Orthop.* 18 (5), p.263-267

Verhaar, J., Walenkamp, G., van Mameren, H., Kester, A., Linden, A. (1996) Local corticosteroid injection versus Cyriax- type physiotherapy for tennis elbow *J Bone Joint Surg Am* 77, p.128-132

Vicenzino, B. (2003) Lateral epicondylalgia: a musculoskeletal physiotherapy perspective. *Manual Therapy* 8 (2), p.66-79

Vicenzino, B. and Wright, A. (1996) Lateral epicondylalgia I: epidemiology, pathophysiology, aetiology and natural history. *Phys. Ther. Rev.* 1, p. 23-24

Watson, T (2006) Electrotherapy and tissue repair. *Sportex-Medicine* 29, p.7-13

Watson, T. (2008) Ultrasound in contemporary physiotherapy practice. *Ultrasonics* 48, p.321-329

Williams, P. and Warwick, R. (1980) *Gray's anatomy 36<sup>th</sup> Ed.* Edinburgh: Churchill Livingstone

Williams, J. (2003) The effects of the variation of ultrasound intensity on tennis elbow  
Single case research MSc poster presentation, MRI Manchester

Woodley, B., Newsham-West, R., Baxter, G. (2007) Chronic tendinopathy: effectiveness of eccentric exercise *Br J Sports Med* 41, p. 188-199

**CHAPTER 11: APPENDICES**

**11.1 Normative study consent form**

**CONSENT FORM**

Subject Identification Number for this trial:

Title of Project: EMG and thermographic analysis of the lateral elbow in a pain and pathology free sample

Name of Researchers: Jeanette Tonks

Please initial box

I confirm that I have read and understood the information sheet dated 7/10/05 (version 1) for the above study and have had the opportunity to ask questions.

I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, without my legal rights being affected.

I agree to take part of the above study

\_\_\_\_\_  
Name

\_\_\_\_\_  
Date

\_\_\_\_\_  
Signature

\_\_\_\_\_  
Researcher

\_\_\_\_\_  
Date

\_\_\_\_\_  
Signature

## **11.2 Normative study information sheet**

**INFORMATION SHEET**

Version No 2 Date: 20/2/07

**TITLE OF STUDY:** EMG and thermographic analysis of the lateral elbow in a pain and pathology free sample

**NAME OF RESEARCHER:** Jeanette Tonks

You are being invited to take part in a research study. Before you decide it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with me if you wish. Ask me if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part. Thank you for reading this.

### **What is the purpose of the study?**

We would like to invite you to take part in a research study investigating the thermal imaging of the outside part of the elbow and the muscle function of a group of muscles on the back of the forearm

### **Why have I been chosen?**

All staff and students at UCLAN who do not have any pain or problems with either of their elbows are eligible for inclusion in this study. Request for volunteers will initial be to AHP's via email. Those who are suitable with respect to age and gender of patients who complain of tennis elbow will be invited.

### **Do I have to take part?**

It is up to you to decide whether or not to take part. If you do decide to take part you will be given this information sheet to keep and asked to sign a consent form. If you decide to take part you are still free to withdraw at any time.

### **What will happen to me if I take part?**

If you agree to participate in the study a picture of both your elbows will be taken using a special camera that measures heat.

Sticky electrodes will be placed on both your forearms to tell us how your muscles are working whilst your grip strength will be taken three times.

4 skin fold measurements will be taken on your arm, leg and abdomen. You may wish to bring some shorts and a short sleeve top.

You will be asked not to drink alcohol from the night before and not to apply any creams to the area on the day of the assessment. You will be asked to avoid food consumption, strenuous exercise, drugs, caffeine and nicotine for 2 hours prior to the assessment if possible.

**What are the disadvantages/ risks of taking part?**

There are no known risks to you from your inclusion in the study.

**What are the benefits of taking part?**

As an individual probably none, however you will be helping us to understand more about the thermal imaging and muscle function of the outside of the elbow. This in turn will help us to understand more about tennis elbow which will lead to better treatment of this condition in the future.

**Will my taking part in this study be kept confidential?**

All information, which is collected, about you during the course of this research will be kept strictly confidential. If a scientific paper is written about the results your name and details will be removed completely so that you cannot be recognized from it.

**Who has reviewed this study?**

The Faculty of Health University (UCLAN) Ethics committee have reviewed this study.

**Contact for further information.**

Jeanette Tonks, Orthopaedic Physiotherapy Practitioner on 01942 774605

**You will be given a copy of this information sheet as well as the consent form for taking part in the study.**

### 11.3 Normative study data collection sheet

#### NORMAL DATA COLLECTION SHEET

NUMBER	AGE	GENDER
DOMINANCE	TENNIS	
SMOKE	DIABETES	CIRCULATION
UPPER QUADRANT PROBLEM (6/12)		
PH UPPER QUADRANT PROBLEM		

#### SKIN FOLD TEST

	1	2	3	MEAN
TRICEPS				
ABDOMINAL				
SUPRAILIAC				
THIGH				
LATERAL EPICONDYLE				

$$\%Bf - \text{female} = 0.29669(\sum 4sf) - 0.00043(\sum 4sf)^2 + 0.02963(\text{age}) + 1.4072$$

$$\%Bf - \text{male} = 0.29288(\sum 4sf) - 0.0005(\sum 4sf)^2 + 0.1584(\text{age}) - 5.76377$$

%Bf =

ROOM TEMP		TIME	
CAMERA DIST			

#### ELECTRODE PLACEMENT

A=Radius length (lat epicondyle-radial styloid)	R		L	
B=0.078 x A (up lat humerus to ECRL origin)				
C=ECRL origin to radial styloid length				
D=0.476 x C =ECRBr belly				

#### GRIP STRENGTH

MAX 1	R		L	
MAX 2				
MEAN				
50%				
ACTUAL				
+30SEC				

## ***11.4 Normative study faculty of health ethics committee approval***

19 October 2005

Jeanette Tonks  
Allied Health Professions  
University of Central Lancashire

Dear

**Re: Faculty of Health Ethics Committee (FHEC) Application - (Proposal Number 105 )**

The FHEC has approved your 'normal population' study application and will then take Chair's Action on the proposal once it has received approval from LREC.

Yours sincerely

Bernie Carter  
Acting Chair  
**Faculty of Health Ethics Committee**

Cfi: Jim Richards

**11.5 Standardised subjective and objective assessment proforma**

ADDRESS:  
Telephone No.

**TENNIS ELBOW ASSESSMENT**

Patient No.....

Group  
Injection  
U/S  
Physiotherapy

HPC

P.C.

X-RAY

EYES/EARS

24HRS

SLEEP

DIZZY

OW

BLOODS

H.A.

OR

P & N

BLACKOUTS

DAY

AN

PH – Upper Quadrant

PM.S.H. General Health

Major Surgery

H Bp D A

Ep TB RA

weight loss

medical problems

DH A/c

ST

SH Occupation

Leisure

**Baseline Data**

Age

Previous physiotherapy

Smoker

Gender

Previous Injection

Occupation

N.S.A.I.D

Symptom Duration

Analgesia

Dominant Hand

Brace use



## **11.6 Patient information sheet**

**PATIENT INFORMATION SHEET**

Version No 2 Date: 2/12/05

**TITLE OF STUDY: Evaluation of short-term conservative treatment in patients with tennis elbow (lateral epicondylitis): A prospective randomised, assessor-blinded trial.**

**NAME OF RESEARCHER:** Jeanette Tonks

You are being invited to take part in a research study. Before you decide it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with me if you wish. Ask me if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part. Thank you for reading this.

### **What is the purpose of the study?**

We would like to invite you to take part in a research study investigating tennis elbow which forms part of the researcher's PhD at UCLAN. Many patients are referred to physiotherapy or orthopaedics for treatment, which may incorporate a wide range of treatments including: ultrasound, injection or exercise. To date we do not know which is the best treatment for this condition. This study will provide us with valuable information about the efficacy of your treatment.

### **Why have I been chosen?**

All patients referred to physiotherapy or Orthopaedics here, with this type of problem, who are suitable, are being invited.

### **Do I have to take part?**

It is up to you to decide whether or not to take part. If you do decide to take part you will be given this information sheet to keep and asked to sign a consent form. If you decide to take part you are still free to withdraw at any time. Any decision to withdraw or not to take part will not affect the standard of care you receive.

### **What will happen to me if I take part?**

If you agree to participate in the study you will be allocated to a treatment group at random. All these treatments are common treatments provided by the physiotherapy department here:

1, Injection group: This is a single injection of local anaesthetic and steroid which is injected around the tender area on the outside of your elbow.

2, Ultrasound group: Gel will be placed on the tender area on the outside of your elbow and the ultrasound head will be gently applied for 5 minutes. You should not feel any discomfort.

3, Physiotherapy exercise group: This is a progressive series of strengthening and stretching exercises you need to do on a regular basis.

For the review appointment you will be asked not to drink alcohol from the night before the review and not to apply any creams to the area on the day of the review.

Any brace will need to be removed and food consumption, strenuous exercise, drugs, caffeine and nicotine avoided for 2 hours prior to the review if possible.

At each review you will be asked to fill in a short questionnaire, (which should take 3-5 minutes to fill in), that asks you about your pain and what kind of problems you have with your elbow. At the 10 day, 6 week and 6 month review you will be asked to fill in a short additional questionnaire, (which should take less than 5 minutes to fill in), about your treatment preferences. A picture of both your elbows will be taken using a special camera that measures heat. 4 skin fold measurements will be taken on your arm, leg and abdomen on the first appointment only. Sticky electrodes will be placed on both your forearms to tell us how your muscles are working whilst your pain free grip strength will be taken three times.

Once the tests have finished you will receive your allocated treatment as per your group. These tests are taken at baseline, your 1<sup>st</sup> appointment and then at 10 days and 6 weeks. You may need to attend more regularly for your treatment. If you still require treatment at 6 weeks you will receive further treatment as required. You will be asked to return at 6 months for retesting to tell us how effective your treatment was. If you are not receiving treatment at your 6 months review you will be given the opportunity to claim reimbursement for your travel expenses in order to attend your 6 month review appointment.

**What are the disadvantages/ risks of taking part?**

All treatments are as per normal care for any patient being referred with tennis elbow. Any small risks of treatment will be explained to you fully prior to treatment. There are no additional risks to you from your inclusion in the study.

**What are the benefits of taking part?**

As an individual probably none, however you will be helping us to understand more about tennis elbow which will lead to better treatment of this condition in the future.

**Will my taking part in this study be kept confidential?**

All information, which is collected, about you during the course of this research will be kept strictly confidential. Any information about you, which leaves the hospital, will have your name and address removed so that you cannot be recognized from it. If a scientific paper is written about the results your name and details will be removed completely.

**Who has reviewed this study?**

The Wrightington, Wigan and Leigh local research and ethics committee and the Faculty of Health University (UCLAN) Ethics committee have reviewed this study.

**Contact for further information.**

Jeanette Tonks, Orthopaedic Physiotherapy Practitioner on 01942 774605

**Thank you for taking the time to read about this study, if you have any questions please do not hesitate to ask. If you agree to take part you will be given a copy of this information sheet as well as the consent form for taking part in the study.**

## 11.7 Informed consent sheet

### PATIENT CONSENT FORM

Version No 2 Date 2.12.05

**Title of Project: Evaluation of short term conservative treatment in patients with tennis elbow (lateral epicondylitis): a prospective randomised, assessor blinded trial.**

**Name of Researchers: Jeanette Tonks**

PLEASE INITIAL BOX

I confirm that I have read and understood the information sheet dated 2.12.05 (Version 2) for the above study and have had the opportunity to ask questions.

I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, without my medical care or legal rights being affected.

I understand that sections of any of my medical notes may be looked at by responsible individuals from Wrightington Hospital or from regulatory authorities where it is relevant to my taking part in research. I give permission for these individuals to have access to my records.

I agree to take part in the above study

.....  
Name of Patient

.....  
Date

.....  
Signature

.....  
Name or person  
Taking consent  
(if different from  
Researcher)

.....  
Date

.....  
Signature

.....  
Researcher

.....  
Date

.....  
Signature

I for patient, 1 for researcher, 1 to be kept with hospital notes

# 11.8 Patient rated tennis elbow evaluation

## PATIENT-RATED TENNIS ELBOW EVALUATION

Name \_\_\_\_\_ Date \_\_\_\_\_

The questions below will help us understand the amount of difficulty you have had with your arm in the past week. You will be describing your average arm symptoms over the past week on a scale 0-10. Please provide an answer for all questions. If you did not perform an activity because of pain or because you were unable, then you should circle a "10". If you are unsure please estimate to the best of your ability. Only leave items blank if you never perform that activity. Please indicate this by drawing a line completely through the question.

1. PAIN in your affected arm											
Rate the average amount of pain in your arm over the past week by circling the number that best describes your pain on a scale from 0-10. A zero (0) means that you did not have any pain and a ten (10) means that you had the worst pain imaginable.											
RATE YOUR PAIN:										Worst	
	No Pain									Imaginable	
When you are at rest	0	1	2	3	4	5	6	7	8	9	10
When doing a task with repeated arm movement	0	1	2	3	4	5	6	7	8	9	10
When carrying a plastic bag of groceries	0	1	2	3	4	5	6	7	8	9	10
When your pain was at its least	0	1	2	3	4	5	6	7	8	9	10
When your pain was at its worst	0	1	2	3	4	5	6	7	8	9	10

Please turn the page.....

2. FUNCTIONAL DISABILITY											
A. SPECIFIC ACTIVITIES											
Rate the amount of difficulty you experienced performing each of the tasks listed below, over the past week, by circling the number that best describes your difficulty on a scale of 0-10. A zero (0) means you did not experience any difficulty and a ten (10) means it was so difficult you were unable to do it at all.											
	No Difficulty									Unable To Do	
Turn a doorknob or key	0	1	2	3	4	5	6	7	8	9	10
Carry a grocery bag or briefcase by the handle	0	1	2	3	4	5	6	7	8	9	10
Lift a full coffee cup or glass of milk to your mouth	0	1	2	3	4	5	6	7	8	9	10
Open a jar	0	1	2	3	4	5	6	7	8	9	10
Pull up pants	0	1	2	3	4	5	6	7	8	9	10
Wring out a washcloth or wet towel	0	1	2	3	4	5	6	7	8	9	10
B. USUAL ACTIVITIES											
Rate the amount of difficulty you experienced performing your usual activities in each of the areas listed below, over the past week, by circling the number that best describes your difficulty on a scale of 0-10. By "usual activities", we mean the activities that you performed before you started having a problem with your arm. A zero (0) means you did not experience any difficulty and a ten (10) means it was so difficult you were unable to do any of your usual activities.											
1. Personal activities (dressing, washing)	0	1	2	3	4	5	6	7	8	9	10
2. Household work (cleaning, maintenance)	0	1	2	3	4	5	6	7	8	9	10
3. Work (your job or everyday work)	0	1	2	3	4	5	6	7	8	9	10
4. Recreational or sporting activities	0	1	2	3	4	5	6	7	8	9	10
Comments:											

© MacDermid 2005

## **11.9 Patient preference questionnaire**

23/05/05 V1

### **PATIENT QUESTIONNAIRE**

<b>Patient number</b>	<b>Review</b>	<b>Patient group</b>
-----------------------	---------------	----------------------

Which treatment would you prefer to have?

What did you like about the treatment you received?

What did you not like about the treatment you received?

Can you suggest anyway the treatment you received could have been improved?

If you had this problem again which treatment would you prefer to have?

Thank you for your comments

**11.10 Treatment diary**

**TREATMENT DIARY**

<b>Patient number</b>	<b>Group</b>
<b>Pre study Treatment</b>	

<b>Week</b>	<b>Rx</b>	<b>Change to protocol</b>	<b>Pre study Rx change</b>	<b>Adverse/ side effects</b>
1				
2				
3				
4				
5				
6				

**Rx summary 6 weeks – 6 months**

## 11.11 Data collection sheet

### DATA COLLECTION SHEET

Patient Number.....

#### SKIN FOLD TEST

	1	2	3	MEAN
TRICEPS				
ABDOMINAL				
SUPRAILIAC				
THIGH				

#### LATERAL EPICONDYLE

$$\%Bf - \text{female} = 0.29669(\sum 4sf) - 0.00043(\sum 4sf)^2 + 0.02963(\text{age}) + 1.4072$$

$$\%Bf - \text{male} = 0.29288(\sum 4sf) - 0.0005(\sum 4sf)^2 + 0.1584(\text{age}) - 5.76377$$

%Bf =

#### ELECTRODE PLACEMENT

A=Radius length R L  
(lat epicondyle-radial styloid)  
B=0.078 x A  
(up lat humerus to ECRL origin)  
C=ECRL origin to radial styloid length  
D=0.476 x C =ECRBr belly

BASELINE.....

ROOM TEMP TIME  
CAMERA DIST

#### GRIP STRENGTH

PFGS 1	R	L
PFGS 2		
PFGS 3		
+15 SEC		
+30 SEC		

**PRETREATMENT.....**

<b>ROOM TEMP</b>		<b>TIME</b>	
<b>CAMERA DIST</b>			

**GRIP STRENGTH**

<b>PFGS 1</b>	<b>R</b>		<b>L</b>	
<b>PFGS 2</b>				
<b>PFGS 3</b>				
<b>+15 SEC</b>				
<b>+30 SEC</b>				

**10 DAYS.....**

<b>ROOM TEMP</b>		<b>TIME</b>	
<b>CAMERA DIST</b>			

**GRIP STRENGTH**

<b>PFGS 1</b>	<b>R</b>		<b>L</b>	
<b>PFGS 2</b>				
<b>PFGS 3</b>				
<b>+15 SEC</b>				
<b>+30 SEC</b>				

**6 WEEKS.....**

<b>ROOM TEMP</b>		<b>TIME</b>	
<b>CAMERA DIST</b>			

**GRIP STRENGTH**

<b>PFGS 1</b>	<b>R</b>		<b>L</b>	
<b>PFGS 2</b>				
<b>PFGS 3</b>				
<b>+15 SEC</b>				
<b>+30 SEC</b>				

**6 MONTHS.....**

<b>ROOM TEMP</b>		<b>TIME</b>	
<b>CAMERA DIST</b>			

**GRIP STRENGTH**

<b>PFGS 1</b>	<b>R</b>		<b>L</b>	
<b>PFGS 2</b>				
<b>PFGS 3</b>				
<b>+15 SEC</b>				
<b>+30 SEC</b>				

## 11.12 Accumulative data collection sheet

### ACCUMULATIVE DATA COLLECTION

Patient No.	GROUP	AGE smoker	MALE/FEMALE OCCUPATION	D. Left/right	Affected left/right
-------------	-------	---------------	---------------------------	------------------	------------------------

Symptom duration	Previous treatment	N.S.A.I.D. f pre	N.S.A.I.D f post	ANALGESIA	BRACE
---------------------	-----------------------	---------------------	---------------------	-----------	-------

Affected/unaffected	Baseline	Pre- treatment	10 days	6 weeks	6 months
MPFS					
Thermography					
PFG 1					
PFG 2					
PFG 3					
Mean					
PRFEQ pain					
PRFEQ Function					
PRFEQ Total					
Additional Treatment					
Researchers opinion on treatment received.					

## **11.13 Local regional ethics committee approval**

### **Wrightington, Wigan & Leigh Local Research Ethics Committee**

Room 181, Gateway House  
Piccadilly South  
Manchester  
M60 7LP

Telephone: 01612372585  
Facsimile: 01612372383

6 January 2006

#### **Private & Confidential**

Mrs J H Tonks, Orthopaedic Physiotherapy Practitioner  
Ashton, Leigh and Wigan PCT  
Physiotherapy Dept,  
Royal Albert Edward Infirmary  
Wigan Lane  
WIGAN  
WN1 2NN

Dear Mrs Tonks

**Full title of study:** Evaluation of long-term conservative treatment in patients with tennis elbow (lateral epicondylitis): A randomised, assessor- blinded controlled trial.  
**REC reference number:** 05/Q1410/122

Thank you for your response to the Committee's request for further information on the above research and for submitting revised documentation.

The further information has been considered on behalf of the Committee by the Chair.

#### **Confirmation of ethical opinion**

On behalf of the Committee, I am pleased to confirm a favourable ethical opinion for the above research on the basis described in the application form, protocol and supporting documentation as revised.

#### **Ethical review of research sites**

The Committee agreed that all sites in this study should be exempt from site-specific assessment (SSA). There is no need to complete Part C of the application form or to inform Local Research Ethics Committees (LRECs) about the research. The favourable opinion for the study applies to all sites involved in the research.

#### **Conditions of approval**

The favourable opinion is given provided that you comply with the conditions set out in the attached document. You are advised to study the conditions carefully. **Please note in particular the requirements relating to the submission of progress and other reports in point 4.**

#### **Approved documents**

The final list of documents reviewed and approved by the Committee is as follows:

<i>Document</i>	<i>Version</i>	<i>Date</i>
Application	5.0	10 October 2005
Investigator CV Jeanette Tonks		01 July 2005
Investigator CV Prof J Richards		01 October 2004
Protocol	6	14 September 2005
Summary/Synopsis	2	08 August 2005
Letter from Sponsor		28 October 2005
Peer Review		27 September 2005
Questionnaire Patient Rated Forearm Evaluation		
Questionnaire Patient Questionnaire		23 May 2005
Questionnaire Tennis Elbow Assessment		10 October 2005
Questionnaire Accumulative Data Collection		10 October 2005
Participant Information Sheet	2	02 December 2005
Participant Consent Form	2	02 December 2005
Letter from Faculty of Health Ethics Committee		19 October 2005
Physio Rehab: Exercise Programme		01 January 1996
Treatment Diary		10 October 2005
Letter of support from PCT		12 October 2004
Letter of authorisation from PCT		12 October 2004

### **Research governance approval**

The study should not commence at any NHS site until the local Principal Investigator has obtained final research governance approval from the R&D Department for the relevant NHS care organisation.

### **Statement of compliance**

The Committee is constituted in accordance with the Governance Arrangements for Research Ethics Committees (July 2001) and complies fully with the Standard Operating Procedures for Research Ethics Committees in the UK.

<b>05/Q1410/122</b>
---------------------

<b>Please quote this number on all correspondence</b>
---

With the Committee's best wishes for the success of this project

Yours sincerely

**Chair**

## **11.14 Faculty of health ethics committee approval**

6<sup>th</sup> April 2006

Jeanette Tonks  
Department of Allied Health Professions  
University of Central Lancashire

Dear Jeanette

**Re: Faculty of Health Ethics Committee (FHEC) Application - (Proposal Number 105 V2 – Chair’s Action on Proposal)**

As your proposal has now received LREC approval, the FHEC hereby approves your proposal application by way of Chair’s Action having met the conditions set by the Committee and on the basis described in its ‘Notes for Applicants’.

Yours sincerely

Bernie Carter  
Vice Chair  
**Faculty of Health Ethics Committee**

Cfi: Jim Richards

# 11.15 Exercise programme (Pienimaki et al. 1996)

Exercises	Figures
<b>Step 1</b>	1
Clench fist strongly	2
Resisted wrist extension	3
Resisted wrist flexion	4
Wrist rotation with a stick	5
Towards the little finger	6
Towards the thumb	7
End: stretching at least 30 seconds to flexion and extension	8
<b>Step 2</b>	
Exercises against an elastic band for:	
Wrist extension	9
Wrist flexion	10
Wrist radial deviation	
Wrist ulnar deviation	
End: stretching 30 seconds (as in step 1) 10 x 3 series, several repetitions daily	
<b>Step 3</b>	
Combined wrist rotary movements using eg table top as a support	
Upwards, resisted from below	
Towards the little finger	
Towards the thumb	
Downwards, resisted from above	
Towards the little finger	
Towards the thumb	
Pressing hand against a wall	
End: stretching 30 seconds 10 x 3 series, several repetitions daily	
<b>Step 4</b>	
An occupational training programme, including:	
Soft ball compressing exercises	
Transferring button from cup into another	
Rolling paper for a table, in both directions, etc	
End: stretching 30 seconds	
This program can be performed together with one of steps 1-3	
Each separate movement and exercise in each step must be done while slowly counting to eight.	



Fig 1: Clenching fist strongly

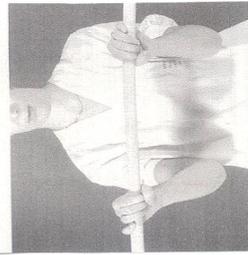


Fig 2: Resisted wrist extension exercises



Fig 3: Wrist rotation with a stick towards the little finger (pronation) or towards the thumb (supination). The movement should be resisted to break the stick between the wrists



Fig 4: Wrist rotation with a stick towards the little finger (pronation) or towards the thumb (supination). The movement should be resisted to break the stick between the wrists

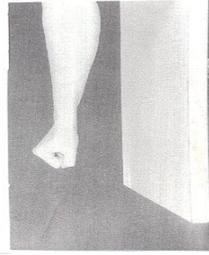


Fig 5: Stretching to flexion



Fig 6: Resisted wrist extension exercises

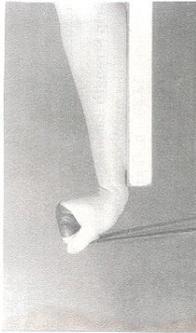


Fig 6: Wrist extension exercises against an elastic band



Fig 7: Wrist flexion exercises against an elastic band



Fig 8: Exercises for radial deviation



Fig 8: Exercises for ulnar deviation

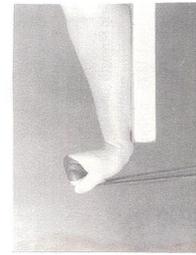


Fig 6: Wrist extension exercises against an elastic band



Fig 7: Wrist flexion exercises against an elastic band

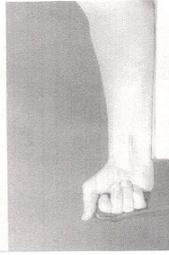


Fig 8: Exercises for radial deviation



Fig 8: Exercises for ulnar deviation

Fig 8 (below left): A table top or the patient's knee, with the patient sitting on a chair, may be used as a support. B(i) shows the movement resisted from below; B(ii) shows the wrists resisted from above. The movement is resisted from the thumb side to side - first towards the thumb and then towards the little finger

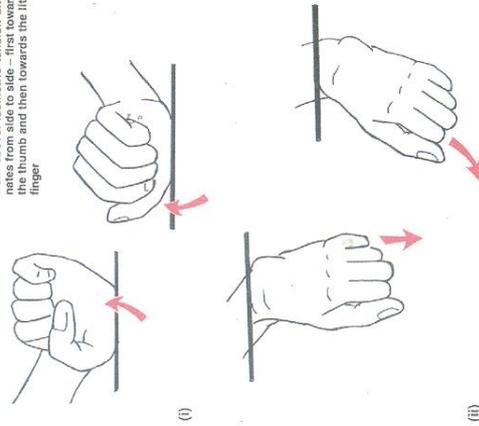


Fig 9: Pressing hands against a wall



Fig 10: Twisting a towel into a roll

# 11.16 Poster presentation Chartered Society of Physiotherapy Congress

Liverpool 16-17/10/09

## NOVEL PROTOCOL FOR THE THERMOGRAPHIC ANALYSIS OF TENNIS ELBOW



ILLUSTRATIVE NORMATIVE DATA, SINGLE CASE HISTORY AND THERMAL EFFECTS OF ULTRASOUND

Jeanette Tonks<sup>1</sup>, James Selfe<sup>2</sup>, Jim Richards<sup>2</sup>

<sup>1</sup>Ashton, Leigh and Wigan Community Healthcare, Wigan; PhD student University of Central Lancashire; <sup>2</sup>School of Public Health and Clinical Sciences, University of Central Lancashire, Preston, UK

### INTRODUCTION

Infrared thermography is a valuable technique for the diagnosis of tennis elbow and is reported as a 'sensitive, objective investigational procedure for the assessment of tennis elbow' (Haake et al. 2002). Thermal image data collection is inherently difficult to standardise due to potential intrinsic and extrinsic variables which affect vasomotor regulation. A novel scientifically robust model for the thermographic analysis of tennis elbow has been developed which negates some of these issues and is being used clinically to analyse the effects of current treatment on tennis elbow.

### PROTOCOL

A FLIR A40M thermovision infra-red thermal imaging camera was focused on the lateral epicondyle and aligned parallel with the skin overlying the area at a distance of 80cm. The concept of the use of thermally inert wooden anatomical markers (Selfe et al. 2006) was applied in a unique manner for tennis elbow: midpoint of the olecranon and in the same plane in the cubital crease with the elbow flexed to 90° and in full supination. This procedure enabled a reliable and accurate method for the thermal image data collection and subsequently analysis through the development of a novel scientifically robust model.

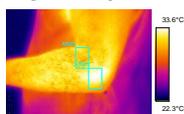


Fig 1: AR02 and AR03

A unique method of measuring the skin temperature (Tsk) of the insertion of extensor carpi radialis brevis (ECRBr) was developed in a standardised procedure which was both easy and reproducible in a consistent manner. The region of interest (ROI) quadrant (AR02) was compared with the unaffected quadrant (AR03) which acts as a control. The thermal difference between the maximum Tsk (AR02 – AR03) for the ROI was then recorded.

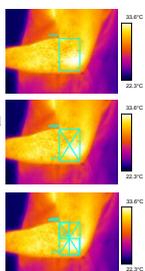


Fig 2: Protocol method

### NORMATIVE DATA

Normative data was collected, using this method, from 20 asymptomatic subjects who were age and gender matched to a typical tennis elbow population. The ROI was found to be a mean of 0.35°C cooler when compared to the control; i.e.: a negative thermal difference. This was supported by previous research (Binder et al. 1983) who found a similar thermal gradient was often present in the 120 elbows of 60 normal subjects they examined.

	Dominant AR02	Dominant AR03	Dominant Thermal Difference	Non Dominant AR02	Non Dominant AR03	Non dominant Thermal Difference
Mean °C	32.5	32.8	-0.3	32.1	32.5	-0.4
(SD)			(0.51)			(0.43)

Fig 3: Table of normative data

**REFERENCES**  
 Binder, A., Parr, G., Page Thomas, P., Hazleman, B. (1983) A clinical and thermographic study of lateral epicondylitis *British Journal of Rheumatology* 22, p.77-81  
 Garagiola, U., Giani, E. (1990) Use of telethermography in the management of sports injuries *Sports Medicine* 10 (4), p.267-272  
 Haake, M., Willenberg, T., Sauer, F., Griss, P. (2002) Effect of extracorporeal shockwave therapy on vascular regulation. Infrared thermography in epicondylitis humeral radialis *Swiss Surg* 8 (4), p.176-180  
 Selfe, J., Hardaker, N., Thewlis, D., Kirk, A. (2006) An accurate and reliable method of thermal data analysis in thermal imaging of the anterior knee for use in cryotherapy research. *Arch Phys Med Rehabil* 87, p.1630-1635

### SINGLE CASE HISTORY

A left-handed 38 year old female in the normative study developed tennis elbow in her, non dominant, right elbow 3 months after testing and was retested at 8 weeks post onset when she claimed, subjectively, to be 70% improved with NSAID and exercise. Applying the method described her thermal data was compared pre and post symptoms demonstrating an increase in Tsk. It has been proposed that the original -0.9°C hypothemic image in the presymptomatic elbow demonstrates a degenerative process (Garagiola and Giani 1992). In comparison when her unaffected elbow was considered little change was evident: -0.5 to -0.3 °C.

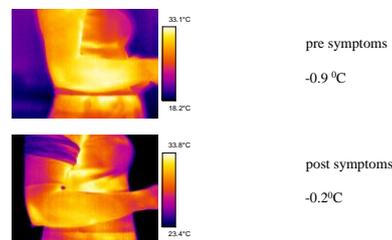


Fig 4: Thermal image pre and post symptoms

### THERMAL EFFECTS OF ULTRASOUND

The immediate thermal effects following a treatment session of ultrasound (continuous 3 MHz using a 0.5 transducer with gel at 2W/cm<sup>2</sup> for 5 minutes) to the tenoperiosteal junction of ECRBr was explored on a 'healthy subject' using this method and was repeated on a separate occasion without the ultrasound switched on. A thermal image was taken immediately prior to ultrasound, within 1 minute post ultrasound and then at 1 minute intervals until 20 minutes inclusive. Then at 25 and 30 minutes post ultrasound. This graph shows the thermal difference overtime with a clinically important change of 0.5°C from baseline highlighted by the 2 pink lines.

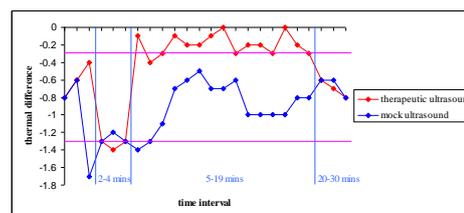


Fig 5: Thermal difference overtime

With therapeutic ultrasound (red) after 5 minutes through to 19 minutes a clinically important change of 0.5°C can be seen with a marked reduction in thermal difference, i.e. a clinically important increase in Tsk. This can be attributed to the therapeutic effects of ultrasound. This is validated as no clinically important increase in Tsk is evident with mock ultrasound (blue). It is interesting to note the 5 minutes delay for the effects of ultrasound and the vascular response to become apparent, which may be explained as a result of the initial masking cooling effects of the application of gel and metal transducer.

# 11.17 Poster presentation British Elbow and Shoulder Society

## 20th annual scientific meeting UCL, London 24-26/6/09

### EVALUATION OF THE SHORT-TERM CONSERVATIVE TREATMENT IN PATIENTS WITH TENNIS ELBOW: INTERNAL PILOT OF A PROSPECTIVE RANDOMISED, ASSESSOR-BLINDED TRIAL

Ashton, Leigh and Wigan NHS Community Healthcare  
The Princess Anne Of, Ashton, Leigh, West Wigan PCT

uclan

Wrightington, Wigan and Leigh NHS Foundation Trust

Jeanette Tonks<sup>1</sup>, Raj Manki<sup>2</sup>, James Selfe<sup>3</sup>, Jim Richards<sup>4</sup>

<sup>1</sup>Ashton, Leigh and Wigan Community Healthcare, Wigan, UK, PhD student University of Central Lancashire; <sup>2</sup>Wrightington, Wigan and Leigh NHS Foundation Trust; <sup>3</sup>School of Public Health and Clinical Sciences, University of Central Lancashire, Preston, UK

#### PURPOSE

The complexity of the underlying pathophysiological processes of tennis elbow remains in contention and although a myriad of therapeutic interventions are available there is little consensus on optimum treatment. This poster presents the preliminary thermographic and EMG findings from the internal pilot of a trial investigating the efficacy of current conservative treatments (ultrasound, steroid injection and exercise rehab) for tennis elbow which was used to validate the sample size.

#### METHODS

The study was a prospective randomised, assessor-blinded trial. 20 patients with tennis elbow referred by their GP to either the physiotherapy, orthopaedic or MSK, CATS services, subject to eligibility criteria, were randomised into one of the 3 treatment arms to which the researcher remained blinded. Thermal, median frequency (MDF), patient-rated tennis elbow evaluation questionnaire (PRTEE) and pain-free grip strength (PFG) data was taken twice at baseline, 10 days and at 6 weeks. A repeated measures ANOVA was used with alpha set at  $p < 0.05$  with 95% confidence levels.

Ethical approval was gained from both Wrightington, Wigan and Leigh Regional Ethics Committee (WWL REC) and PRTEE (UCLans).

A novel scientifically robust model for the thermographic analysis of tennis elbow was developed (Fig 1). The region of interest (ROI) ANOV was compared with the unaffected quadrant (AQO), which acts as a control, and the thermal difference of the maximum skin temperature (TA) recorded.



The MDF of extensor carpi radialis brevis (ECRB) was measured during a sustained PFG which is a sensitive and reliable measure of fatigue. The surface EMG method applied double differential electrodes to remove cross-talk (Fig 2) and a new technique for the selective recording of ECRB (Fig 3).



#### SAMPLE

Patients were randomised into the 3 treatment arms in equal proportions (Fig 4). The descriptors of the sample are comparable to typical population of tennis elbow patients: male: female = 9:11, mean age 47 years, mean symptom duration 7 months, dominant arm affected n=11.



Fig 4 Patient flowchart through study up to 6 week endpoint

#### RESULTS

	Baseline 1 mean (SD)	Baseline 2	10 days	6 weeks
Thermal difference (°C)	0.3 (0.4)	0.2 (0.5)	-0.1 (0.5)	0.1 (0.4)
MDFs (Hz)	22.6 (14.8)	19.8 (9.3)	20 (11.1)	23.9 (12.9)
PFG (N)	200.1 (14.5)	182.5 (12.9)	218.7 (13.8)	227.4 (14.1)
PRTEE pain	21.2 (9.0)	21.5 (9.8)	17.9 (9.9)	12.8 (9.0)
PRTEE function	17.2 (10.2)	18.5 (11.1)	13.6 (9.3)	10.1 (8.9)
PRTEE total	38.4 (18.0)	40.0 (20.0)	31.5 (18.4)	22.9 (17.0)

Fig 5 Outcomes across time (SD) for the affected elbow contrast

For all treatment groups the preliminary analysis of PRTEE demonstrated a statistically significant reduction in pain and disability at the 6 week endpoint with treatment of either injection, ultrasound or exercise.

Mean difference between baseline and 6 weeks was 14.9  $p < 0.003$  with a 95% CI (6.4 to 23.5).

No other statistical differences were found.

2 interesting examples are illustrated below

A clinically important reduction in temperature was found at 10 days following injection (Fig 6).

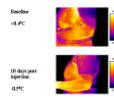


Fig 6 Thermal image pre and 10 days post injection

A clinically important reduction in fatigue was found at 7 weeks following exercise rehab (Fig 7).

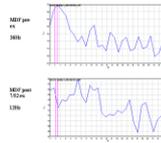


Fig 7 MDF pre and 7 weeks post exercise rehab

#### RESULTS

It was interesting to identify early trends from the estimated marginal means profile plots for each outcome measure for the affected elbow (Fig 8).

On statistical analysis of the thermal difference for the injection group alone by a repeated measures ANOVA: The mean difference between baseline and 10 days was 0.7 °C  $p = 0.005$  with a 95% CI (0.35 - 1.05). The mean difference between baseline and 6 weeks was 0.64 °C  $p = 0.007$  with a 95% CI (0.29 - 0.99).

This demonstrates that the statistically significant immediate reduction in TA of the ROI at 10 days is maintained through to the 6 week endpoint in the injection therapy group.

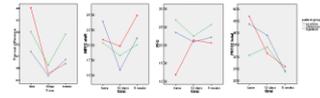


Fig 8 Estimated marginal means profile plots for all outcomes measured for the affected elbow

#### DISCUSSION

Preliminary results demonstrate that injection therapy causes an immediate statistically significant reduction in TA which is maintained through to 6 weeks. This questions both the current research which proposes that tennis elbow is an angiofibrotic tendinosis which is distinctly non-inflammatory and the practice of injection therapy for tennis elbow patients.

Subsequently, due to the increased PFG following an injection a rise in fatigue is evident which would imply that EMG changes are not fully reversible through injection therapy. To add to the debate it is also interesting that the effects on muscle fatigue are evident from as early as 10 days. This further highlights the need for exercise rehabilitation as a prerequisite for a reduction in fatigue and a return to normal muscle function.

The internal pilot has validated the sample size of 21 in each group (allowing for a 15% drop-out rate) to give a robust analysis of the efficacy of the treatment interventions.

#### CONCLUSIONS

Obviously, any conclusions must be regarded with caution due to the small numbers involved and subsequently may not be comparable to the tennis elbow population as a whole.

Preliminary results demonstrate the immediate effect of injection therapy on tennis elbow and highlight the importance of exercise rehabilitation which needs to be undertaken for only 6 weeks before any marked change in pain and disability is apparent.

This study gives greater weight to identifying which specific elements of rehabilitation are important and that success is more likely with a comprehensive treatment programme as is the norm in clinical practice. It will also inform the debate on the pathogenesis of tennis elbow and the actions of steroid injection therapy and therapeutic ultrasound when full power is achieved.