Three-dimensional analysis of shoulder movement patterns in shoulders with anterior instability: A comparison of kinematics with normal shoulders and the influence of stabilization surgery.

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For Archita, my better half

and

Arushi & Anika, my little princesses.

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PM
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Declaration

This is to confirm that the present work has not been submitted for another award. This is also to confirm that I have been awarded a second award of Master of Science (MSc) from the University of Central Lancashire with my current registration.

Abstract

Introduction: Movement analysis of the shoulder joint requires a system capable of analysing a complex interplay of movements in six degrees of freedom. This study was conducted to investigate the three dimensional kinematics of asymptomatic shoulders, shoulders with anterior instability and influence of surgical stabilization on kinematics.

Materials and Methods: Kinematic data and clinical scores were obtained from nine asymptomatic individuals who served as the control group. Data was also obtained from five patients with recurrent anterior instability who were awaiting stabilization surgery before and at least six months after arthroscopic stabilization and rehabilitation. Abduction in coronal plane, abduction in the scapular plane, forward flexion and circumduction movements were assessed.

Results: Unstable shoulders demonstrate a significant decrease in the range of movement when the shoulder is abducted in the coronal plane (p=0.002). There is a significant decrease in the area covered by the circumducting arm in instability when the movements are referenced to the trunk (p=0.002). Forward flexion (p=0.33) and scaption (p=0.075) remain unaffected in instability. Surgical stabilization failed to influence a significant change in any of the pre operative kinematic parameters [Abduction in the coronal plane (p=0.673), abduction in the scapular plane (p=0.733), forward flexion (p=0.992) or circumduction (p=0.214)]. There was a significant difference in the clinical scores between the control group and the patients with anterior instability (Constant score; p=0.03, Oxford instability score p=0.001). The Oxford instability scores demonstrated a significant improvement after surgical intervention (p=0.011), whereas the Constant score did not change (p=0.58).

Conclusions: This study describes shoulder motion patterns using a non-invasive motion tracking system, which is capable of dynamic movement data capture in six degrees of freedom. There are significant differences in the kinematic characteristics and clinical scores between patients with anterior instability as compared to shoulders in healthy volunteers and the kinematic characteristics are not restored to normal after surgical stabilization and rehabilitation.

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Chapter 1. Introduction

The primary function of the shoulder joint is to place the hand optimally within a three-dimensional hemisphere centred on the shoulder, with the elbow acting as a calliper, to alter the radius of the sphere. To allow this degree of mobility, the shoulder joint is unique in having a large ball (humeral head) centred over a small socket (the glenoid). This anatomical arrangement predisposes the shoulder to instability, the price it has to pay for being the most mobile joint of the body. The incidence of shoulder dislocation at 11.2 per 100,000 population per year is the highest for any major joint of the body {Simonet et al., 1984}. Even though the onset of shoulder instability could be without any antecedent trauma (atraumatic instability), most of the time shoulder instability follows trauma. Further, instability may be voluntary or involuntary{Robinson and Dobson, 2004}. Traumatic anterior shoulder instability accounts for 96% of dislocations and is the most common form of instability operated upon{Goss, 1988}. Following such an episode of traumatic shoulder dislocation, soft tissue lesions (e.g. Bankart's lesion; tear of the rim or lining of the glenoid) and bony defects (e.g. Hill Sachs lesion; a bony defect in the posterior part of the humeral head), commonly predispose the affected shoulder to recurrent episodes of dislocation{Handoll et al., 2004}. It has been suggested that there is a 50 to 80% chance of developing recurrent instability after a single episode of traumatic anterior dislocation under the age of 20 years{Pulavarti et al., 2009}. The "anatomic" approach to treatment of traumatic anterior dislocation is focused on reconstructing the damaged glenoid rim antero-inferiorly (the capsulo-labral Bankart's lesion) {Millett et al., 2005}. With modern arthroscopic techniques, it is possible to perform this reconstruction using minimally invasive keyhole surgery, with comparable outcomes to open repair {Pulavarti et al., 2009}.

Recurrent instability of the shoulder is predominantly a disease of the young and economically active members of the society. The mean age of primary presentation is 15-40 years with a bimodal peak in the 2nd and the 6th decade{Rowe, 1956}. This coincides with the peak of lifetime relative wealth{Scambler, 2010}. This problem is therefore of significant socio-economic importance. In a Swedish study, the prevalence of shoulder instability was 1.7% between the ages of 18 to 70 years. The male to female ratio was three to one overall, rising to nine to one in the age group to 21 to 30 years{Hovelius, 1982}. A 10 year follow-up evaluation found that 66% of those aged between 12 and 22 years at the time of their first dislocation had one or more recurrences; whereas 24% had a recurrence in those aged between 30 and 40 years{Hovelius et al., 1996}. Each episode of dislocation leads to not only pain and disability but also loss of productivity due to time off work and chronic instability may prevent the individual from gaining employment{Pulavarti et al., 2009}.

Amongst the various methods that have been used to study shoulder kinematics, one of the earliest attempts was by using multiple radiographs{Howell et al., 1988}. This technique provided data in only two dimensions and multiple static radiographs were used. Following on from this, the use of dynamic fluoroscopy has been used to produce a continuous image capture {Burkhart, 1992}, but this involves the use of radiation, and produces positional artefacts. Topography, a technique used in studying spinal deformities where a grid of horizontal shadows is cast from a standard light source on the subjects back, does not produce quantitative data and the images are a reflection of data in two dimensions in shoulder pathologies {Warner et al., 1992}. Electromagnetic tracking devices have also been used to capture shoulder motion, producing data in three dimensions{Vermeulen et al., 2002}. A scapula locator has been used to track the position of the scapula, however due to the shear produced by skin movement, the device had to be relocated on the scapula in varying degrees of arm elevation, producing multiple static images. With the use of an open MRI, no radiation is used, however the technique involves capturing multiple static images of the joint rather than dynamic data {Graichen et al., 2001}. Invasive tantalum markers inserted into bones accurately investigate the dynamic interplay of the shoulder subcomponents, but present significant ethical issues due to its invasive nature and use of radiography{Hallstrom and Karrholm, 2009}. With the use of the Calibrated Anatomical Systems Technique (CAST) {Cappozzo et al., 1995} it is possible to capture and analyse dynamic motion data of body segments in six degrees of freedom using a non-invasive technique. This technique has been used to assess the shoulder movement during golf swing in male amateur golfers to produce dynamic data in three dimensions{Mitchell et al., 2003}. Reflective markers are placed on body segments and motion data are captured using infrared cameras. With this technique, it is possible to capture dynamic three-dimensional data using a non-invasive technique, avoiding the use of radiographs with a possibility of extension of this technique into routine clinical practice and decision making in the future.

Although kinematics in unstable shoulders has been investigated using an electromagnetic tracking device applied over the scapula, the use of multiple static recordings meant that this did not represent a truly dynamic data {Matias and Pascoal, 2006}{Ogston and Ludewig, 2007}. It is also important to note that all these studies concentrated on simple movements like arm elevation, which are rarely ever used in such a pure form outside the laboratory. To date, no study has investigated a complex shoulder movement like circumduction using a dynamic technique capable of data capture in six degrees of freedom and compared it with unstable shoulders. Even though an attempt has been made to understand the kinematics of a more functional task like the throwing action, the use of multiple static helical CT images used meant that the data obtained was not dynamic{Baeyens et al., 2001}. The effect of surgical treatment and rehabilitation on kinematics of instability remains undescribed. The relationship between clinical scores and kinematic data has also never been reported.

Kinematics already plays a significant role routinely in decision making for complex clinical problems such as the orthopaedic management of childhood cerebral palsy{Gough and Shortland, 2008}. Similarly, pathologies affecting the shoulder joint, such as instability, have a complex interplay of disturbed anatomy and altered physiology. There is a need to explore biomechanical markers using the non-invasive technique, which can then be applied to routine clinical practice, eventually in aid of patient management related decision-making. There is scope for improving patient outcomes by providing focussed rehabilitative efforts if deficiencies are identified in kinematics following surgical stabilization.

This study has been conducted to investigate the kinematics of asymptomatic shoulders, shoulders with anterior instability and influence of surgical stabilization on kinematics. By identifying the interplay of kinematics with the clinical picture, kinematic markers relevant in clinical practice can be potentially identified. It is envisioned that eventually a better understanding of shoulder kinematics is likely to influence clinical decision making, especially for complex clinical problems.

Chapter 2. Background

2.1 Evolution and Embryology of the shoulder

There are similarities in the structure of the shoulder girdle across the Vertebrates which can be explained in evolutionary terms. The upper limb in humans corresponds to the longitudinal lateral fold of epidermis in the fish. These folds extend caudal just distal from the gills to the anus. The pectoral and pelvic fins developed from the proximal and distal portions respectively {Neal and Rand, 2010}. Muscle buds, along with spinal nerves, migrated into the pectoral fins allowing for movement. Cartilage rays called radials arose between muscle buds to form a support structure. The proximal portion of these called the basilia formed the pectoral girdle. The ventral portion migrated towards the midline forming the clavicles and dorsally to form the precursors of the scapula. Articulations formed between the basilia and the remainder of the pectoral fin, corresponding to the glenohumeral joint. As amphibians evolved, the head freed from it's attachment and in the reptiles, the pectoral girdle, migrated further distally {Rockwood and Matsen, 2010}.

The mammalian shoulder was characterized by a well-developed clavicle and a flat wide scapula laterally. Humans developed a strong clavicle, a large coracoid and a widened strong scapula {Bechtol, 1980}. The primate shoulder joint and consequently the human shoulder are completely unique in the entire animal kingdom. The simian-anthropoid joint achieves unique bipolarity in that the lines of force are now away from the body in the hanging position but toward the body when quadruped stance is assumed. Although the human no longer lives in the trees he still has a bipolar shoulder, as indicated by complete reversal of force lines when shifting from pushing to pulling. The term "shoulder girdle" is in fact a complete misnomer in that the scapulae are not linked to each other as they are in birds. They are, in fact, entirely without direct bony attachment to the costal cage except for a freely movable sternoclavicular joint. Therefore, the sole attachments to the costal cage are muscular. The acromion process of the scapula is linked to the clavicle by a synostosis in which there is normally complete fixation. Although usually described as a "ball and socket" joint, the rounded humeral head is actually attached to a very flat glenoid fossa of the scapula, all in the interest of a wide range of motion {Jones, 1956}.

The shape of the scapula has evolved over time with human scapula migrating caudally away from the head and neck to serve as a platform for the arm to move. It has also developed a rather large infraspinous fossa, helping in altering the vector of muscles to act as more effective depressors and external rotators {Inman et al., 1996}. The insertion of deltoid on the humerus has moved more distally with evolution increasing its lever arm. The retroversion of the humeral head has been an adaptation response to the dorsal movement of the scapula along a relatively flattened ribcage in humans {Inman et al., 1996}. The clavicle has evolved to suspend the pectoral girdle and allow the scapula and the humerus to be held away from the axial skeleton, and hence allow free movement {Rockwood and Matsen, 2010}.

The limb buds appear as small elevations on the ventrolateral body wall at the end of the fourth week of gestation. The upper limb buds appear before the lower limb buds and maintain the growth advantage throughout development. The lining cells of the limb bud, the ectoderm forms the nervous tissue, epidermis and its appendages. The limb buds also contain the mesodermal tissue, which forms cartilage, bone, connective tissue and muscle {Rockwood and Matsen, 2010}. Only the clavicle and the scapula are ossified in the foetal shoulder. The comparative size ratio of the humeral head and glenoid are consistent except for the coracoid process being more prominent. The inferior glenohumeral ligament, which is key structure preventing glenohumeral instability, is identifiable as a distinct structure at 14 weeks of gestation. The anatomy of this structure in fetal life is consistent with the adult Inferior Glenohumeral Ligament Complex (IGHLC) anatomy. The rotator interval defect has been identified in fetal specimens, suggesting that this aspect of the capsular anatomy is congenital. Surgical closure of the rotator interval has been shown to be an effective treatment for glenohumeral instability {Fealy et al., 2000}.

2.2 Anatomy

One of the earliest descriptions of the human shoulder anatomy was by Susruta in the 6th century BC when he accurately described the two shoulder bones. Hippocrates was the first physician whose ideas regarding shoulder anatomy were widely perpetuated. His work was carried out in the 5th century BC and was based on cadaver dissections. He described the position of nerves of the axilla while describing the burning technique for treatment of anterior dislocation of the shoulder. Herophilus, who is regarded as the father of anatomy, dissected 600 cadavers in the 3rd century BC and started an osteology collection. For many centuries further progress of anatomical knowledge was hindered by religious and philosophical beliefs and it was in the renaissance period that anatomical descriptions recorded by the likes of Leonardo daVinci resulted in great leaps in the anatomical knowledge {Rockwood and Matsen, 2010} (Figure 1). Following this, the scientific study of the human shoulder anatomy progressed rapidly with wider understanding of the muscles and neural anatomy.

Figure 1: Leonardo da vinci's illustrations

The shoulder complex comprises of articulations between the clavicle, the scapula, the humerus and the chest wall (Figure2, 3) . There are three di-arthrodial joints; the gleno-humeral, the sterno-clavicular and the acromio-clavicular joint. Although the space between the scapula and the chest wall is not a true joint, this articulation is commonly regarded as the scapulo-thoracic joint. The stability of the di-arthrodial joints is dependent primarily on ligamentous structures.

Figure 2: The bony anatomy of the shoulder complex: anterior view

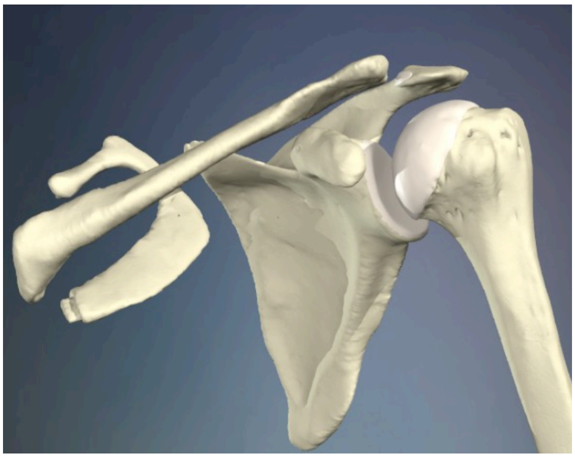


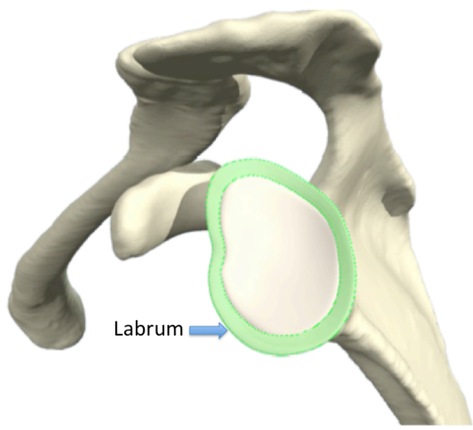
Figure 3: The bony anatomy of the shoulder complex: posterior view

The sternoclavicular joint is formed between the sternum and the medial end of the clavicle. This is the only articulation, which suspends the upper limb to the axial skeleton. It allows rotation, antero-posterior translation, elevation and depression {Inman et al., 1996} and it is reported that fusion of this joint limits abduction by up to 90 degrees {Lockhart, 1930}.

The acromio-clavicular joint is formed between the lateral end of the clavicle and the acromion laterally. The predominant movement is rotation between the clavicle and the acromion, which occurs at the first 20 degrees and the last 40 degrees of elevation {Inman et al., 1996}. It has much less movement than the sternoclavicular joint as even after fusion of this joint, there is no restriction of motion in some patients {Rockwood and Matsen, 2010}.

The glenohumeral joint comprises a relatively large humeral head resting against a shallow glenoid fossa. This arrangement allows for a large range of movement at the cost of bony stability. Stability at this joint is provided by a variety of static and dynamic restraints. The glenoid labrum is a rim of fibrous tissue, which is triangular in cross-section and lines the edge of the glenoid (Figure 3a). Unless it is attached to the gleno-humeral ligaments, it provides very little stability to the joint by itself {Rockwood and Matsen, 2010}. Conventionally, any defect or tear in this labral tissue, which is attached circumferentially, along the edge of the glenoid is described by its location on an imaginary clock face. For example, a common anterior lesion for a right shoulder would be between 2 to 6 o'clock on this clock face as viewed by an observor standing to the right side of the patient looking at this clock in the sagittal plane. Hence a similar anterior labral lesion in the left shoulder would be described as between 10 to 6 o'clock. This description is used in reporting scans and describing surgical findings. The capsule of the glenohumeral joint is large and baggy and it is the distinct thickening of the capsule in the form of ligaments, that are the primary static stabilizers of this joint. The inferior glenohumeral ligament, which is a hammock like structure extending from the glenoid to the humeral neck, is the primary static stabilizer of the abducted arm {Rockwood and Matsen, 2010}. The rotator cuff group of muscles surrounding and blending into the glenohumeral capsule, including the subscapularis, the supraspinatus, the infraspinatus and the teres minor serve as dynamic stabilizers of this joint.

Figure 3a: The glenoid labrum



The muscles controlling the shoulder movements are divided into various broad groups. The glenohumeral muscles produce a compressive force directing the humeral head towards the glenoid. This is an important factor in producing "dynamic" stability of the glenohumeral joint. The deltoid produces the force, which is modulated or "fine-tuned" by the rotator cuff muscles to produce gleno-humeral movement. The scapulothoracic muscles position the scapula, placing it in the optimal position and also contributing to the overall mobility of the shoulder joint complex.

Surgical restoration of stability in cases of traumatic instability is primarily focussed on recontructing the capsulo-labral complex and reattaching it to the glenoid rim. The torn labrum along with part of the glenohumeral joint capsule are attached to the glenoid using suture anchors. This inturn re-tensions the inferior gleno-humeral ligament and restores it's hammock-like function. Modern arthroscopic surgery allow this reconstruction to be performed using minimally invasive techniques.

2.3 Clinical Evaluation

Clinical evaluation of a shoulder disorder begins with a thorough history and proceeds to a structured clinical examination. Patients with a history of recurrent dislocation of the shoulder may have an episode of injury preceding the first dislocation. A progressively lower force of injury heralds each subsequent episode of dislocation. Patients commonly develop a reluctance or apprehensiveness to use the arm in overhead activities. It is also common to have developed muscle pattern behaviours secondary to recurrent episodes of dislocation. Some patients can dislocate their shoulder voluntarily and it is important to ascertain this.

Clinical examination of the shoulder proceeds in the logical sequence of look, feel and move. Inspection of the shoulder anteriorly, laterally and posteriorly picks up signs of wasting of muscles, deformities, swelling, scars and postural abnormalities. Tenderness is elicited in various subcomponents of the shoulder working schematically from one part of the shoulder to the other. Temperature difference, evaluation of swellings and relationship of various structures should be palpated. Clinically, movements are measured both actively and passively using either visual estimation or using goniometry. During clinical examination it is routine to examine forward flexion from the arm by the side to the overhead position moving along the sagittal plane. Abduction of the arm in the coronal plane is compared with the contra lateral side. It is important to note the quality or rhythm of the movement, especially in abduction, as subcomponents of the shoulder joint complex may cross-compensate for deficiencies in one component. It is therefore not uncommon to see an abnormal scapular rhythm during this motion in various shoulder pathologies. Any deviation from the usual smooth gliding movement of the scapula over the thorax is an indirect indicator of shoulder complex pathology. Asking the patient to bring up their hand behind their back checks internal rotation. It is also important to check for loss of external rotation, which is a sensitive indicator of loss of movements.

Special tests commonly used for shoulder instability include the apprehension test, which aims to reproduce a sensation of symptomatic translation. The sulcus sign is a measure of inferior translation of the humeral head on axial traction. In the load and shift test, the humeral head is manually translated anteriorly or posteriorly from a neutral or “loaded” position. It is possible to grade this degree of translation clinically to quantify this movement within the glenoid fossa. Translation of the humeral head anteriorly or posteriorly in a loaded position has been described as a measure of gleno-humeral instability{Hawkins et al., 1996}. The research committee of the American Shoulder and Elbow Surgeons (ASES) have graded instability as Grade 0, if absent; 1, if mild (0 to 1 cm translation); 2, if moderate (1 to 2 cm translation or translates to the glenoid rim); 3, if severe (>2 cm translation or over the rim of the glenoid) {Rockwood and Matsen, 2010}. The load and shift test has a high predictive value for instability when positive (Likelehood ratio>80) although poor at ruling out instability when absent. The apprehension sign has a reasonable inter-observer reliability (interclass corrolation coefficient 0.5 to 0.7) and is highly predictive for anterior instability (likelihood ratio 8 to 100). {Tzannes and Murrell, 2002}

The radiographic evaluation of the shoulder should consist of the antero-posterior, axillary and lateral view. The characteristic signs visualized in traumatic recurrent dislocation of the shoulder include a posterior humeral head compression fracture (the Hill Sachs lesion) {Handoll et al., 2004}, which is best visualized in either the axillary or the Stryker notch view {Rockwood and Matsen, 2010}. The antero-inferior glenoid lesion, commonly called the Bankart’s lesion {Bankart and Cantab, 1993} is best demonstrated using special views like the West Point axillary lateral view {Rockwood and Matsen, 2010}. Magnetic Resonance Imaging (MRI) (Figure 4a,b) combined with the use of intra-articular injection of contrast (MR Arthrogram) provides excellent imaging of the capsulo-labral lesion and has recently substituted the routine use of special radiographic views. The contrast injected in the joint is seen to seep through the defect in the labrum, which is helpful in demonstrating the lesion. In cases of atraumatic instability, the volume of the gleno-humeral joint is expanded, and can be seen on this scan. In case a large bony defect is seen or suspected, a Computerised Tomogram (CT scan) is also obtained to assess the defect in detail.

Figure 4a: MRI scan of the shoulder: Coronal section

Figure 4b: MRI Scan of the Shoulder: Axial section

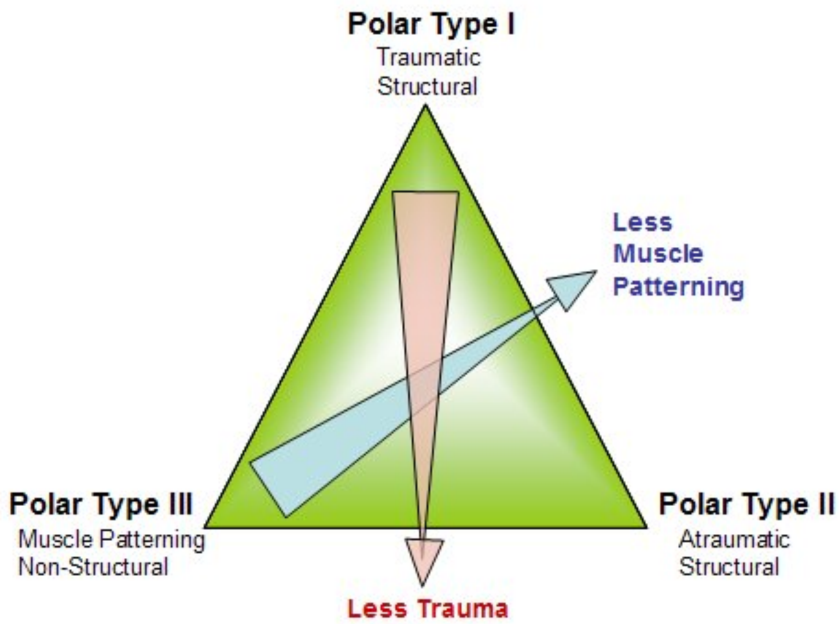
Chapter 3. Review of literature

3.1 Shoulder instability

Clinically, glenohumeral instability can be defined as "a condition in which unwanted translation of the humeral head on the glenoid compromises comfort and function of the shoulder" {Matsen et al., 1991}. Even though this simple definition of shoulder instability has been contested, the two common themes in all definitions have been the presence of symptoms and abnormal movement of the humeral head {Kuhn, 2010}. Glenohumeral stability is partly maintained by static stabilizers, which include the glenoid labrum, the glenohumeral ligaments and the elastic tension of the rotator cuff muscles. The rotator cuff muscles acting in co-ordination with the peri-scapular and shoulder girdle muscles on the other hand provide dynamic stability {Lippitt and Matsen, 1993}.

Rockwood proposed a classification system dividing instability on traumatic aetiology with or without previous dislocation (Types I and II) or atraumatic voluntary (Type IIIa with psychiatric problems and Type IIIb without) and involuntary (Type IV) subluxation {Rockwood and Matsen, 2010}. Thomas and Matsen {Thomas and Matsen, 1989} used a classification which was simple and proposed a management algorithm with two subdivisions of TUBS (Traumatic Unidirectional Bankart lesion treated with Surgery) and AMBRI (Atraumatic Multidirectional Bilateral treated with Rehabilitation and Inferior capsular shift). Gerber described three classes of instability; static, defined by the absence of classic symptoms, yet characterised by humeral head displacement, dynamic, in which a subjective loss of normal glenohumeral stability and momentary, but restorable loss of articular congruity occurs, and voluntary, reserved for those who may dislocate at will {Gerber and Nyffeler, 2002} More recently the Stanmore classification {Lewis et al., 2010} has been described, which recognises the continuity between the various groups. Instability presentation is grouped into 3 polar groups: Type I (Traumatic), Type II (Atraumatic) or Type III (Muscle patterning or habitual non-structural disorders). Each of these represent the corner of a triangle and each patient can be spatially located in a different part of the triangle depending on the degree of polarity present (Figure 5) {Funk, 2011}. Although this classification system is useful in describing all types of instabilities, there are concerns regarding the inter- and intra- observer variability.

Figure 5: The Stanmore classification of instability



It is apparent from the above discussion that the presentation of patients with instability can vary significantly and hence for the purposes of this study only patients with recurrent anterior glenohumeral dislocations following a traumatic episode were included.

Treatment of traumatic anterior shoulder dislocation may range from initial immobilization followed by rehabilitation to early operative stabilization. The patient's age, previous dislocations, joint laxity, co-morbidities, compliance and activity level guide the choice of treatment. It is common practice to reserve surgical treatment for patients having recurrent dislocations. Non-operative management generally involves an initial reduction of the dislocation followed by immobilization of the shoulder for a period of three to six weeks. This is followed by physiotherapy focusing initially on regaining the range of motion and then subscapularis strengthening exercises {O'Brien et al., 1987}. However, 66% of those between 12 to 22 years of age have a recurrence of dislocation {Hovelius et al., 1996}.

In the past, tendon or muscle units were shortened to stabilize the shoulder. For example, the Putti-Platt procedure involved surgical shortening of the subscapularis to achieve stability. This however led to a loss of movement, especially external rotation, on the operated shoulder. Operative techniques for treatment of shoulder instability should ideally achieve stability without loss of mobility {Montgomery and Jobe, 1994}. Modern stabilization techniques aim to stabilize the shoulder by restoring normal anatomy such as the Bankart's procedure {Bankart and Cantab, 1993}, and its modifications {Montgomery and Jobe, 1994} {Wirth et al., 1996} which aim to repair the Bankart's lesion. The underlying surgical principle here to reattach the torn labrum to the glenoid rim. The labrum is firstly released from the scarring. The glenoid neck is prepared and the labrum is attached onto the glenoid rim using suture anchors. Part of the capsule is incorporated within the reconstructed labrum. This helps restore stability by restoring the anatomical "bumper" effect of the labrum, retensioning the inferior glenohumeral ligament which provides a hammock like effect to the humeral head and improving proprioceptive sensations from the joint capsule. The non-anatomical techniques such as the Latarjet or Bristow procedure involve transfer of the coracoid to the glenoid and are used either in cases of failed Bankart's repair or as a primary choice in a high demand patient.

The common practice in the United Kingdom has been to wait for multiple dislocations prior to stabilizing the shoulder. Early surgery in younger active male patients significantly reduces the risk of recurrence. The long term outcome following early surgical intervention in relation to development of osteoarthritis and other shoulder pathologies remains unknown {Handoll et al., 2004}. There is no published literature on the kinematic changes, which are associated with recurrent shoulder dislocations. There is also no available data on the influence of the clinical practice of waiting for multiple dislocations prior to stabilization on shoulder kinematics.

Arthroscopic techniques work on the principle of stabilization with the aim of repairing the Bankart's lesion, using keyhole techniques {Budoff and Wolf, 2006}. The limited evidence available suggests that there is no difference in the outcomes of arthroscopic versus open stabilization in terms of recurrence of dislocation or re-operation rates. The studies which have looked at this difference are small in size and the evidence weak {Pulavarti et al., 2009}. Arthroscopic surgery, with the advantages of quicker rehabilitation, minimal scarring and higher patient acceptance is fast becoming popular and common practice.

3.2 Kinematics of the shoulder

3.2.1 Historical work on shoulder kinematics

3.2.1.1 Introduction

There has been a vast amount of literature generated owing to the complexity of shoulder movements. In 1732 Winslow had found this region complicated enough to warrant his declaring that a treatise might be written on the numerous phenomena to be observed in the movement of the shoulder by the action of serratus itself {Lockhart, 1930}. Motion analysis of the shoulder requires a system, which can measure in three dimensions {Vermeulen et al., 2002}. Movement of the shoulder and arm is extremely complex. For example reaching for an object on a shelf requires linear movement in all three directions and rotations about each of these directions. An ideal system would measure dynamic movements in three dimensions using non-invasive techniques and without the use of radiation. It should be able to produce data, which can be understood by clinicians

In the late 19th century, Eadweard Muybridge published photographic studies of a horse in motion and later human motion using rapid sequence photography which laid the foundation of modern day functional anatomy and motion analysis {Muybridge, 2010}. Early descriptions of shoulder joint complex movement were based on observations on the cadaveric material. Charles Cathcart {Cathcart, 1884} published his careful and exhaustive observations on the movement of the shoulder joint complex on normal living subjects, challenging the commonly accepted wisdom of deriving kinematic inferences from anatomy. Even though his studies were purely observational and on a few individuals, this in fact generated much interest in shoulder motion analysis.

3.2.1.2 Radiography and topography

In 1930, Lockhart {Lockhart, 1930} published his assessment of shoulder movement by using multiple radiographs taken in various degrees of arm elevation. Such two-dimensional studies confirmed the evolving anatomical belief that the shoulder joint movement occurred in various subcomponents, and not only at the glenohumeral joint. His study provided sound evidence to Cathcart's observations regarding the role of the scapula in varying degrees of arm movements. In his landmark work, Codman (1934) described the integrated, coupled and independent motion of the humerus, scapula and the clavicle as the “scapulohumeral rhythm” {Codman, 1934}. Inman proposed that in fact there was a proportional relationship between the scapulothoracic and the glenohumeral rotation over the complete abduction range {Inman et al., 1996}.

The use of multiple static radiographic images was indeed a big advancement for the time; however interpolating this into continuous data invariably risked introducing significant bias. This technique was hence advanced further by the use of continuous data capture using cineradiography, which provides continuous data in vivo. Cineradiography was performed in 38 healthy subjects and the ratio of the gleno-humeral and the scapulothoracic components of the motion were determined. It was using this technique that it was observed that even though there is a great deal of variation between subjects, there is no influence of abduction speed and external load on the scapulohumeral rhythm of an individual subject {Michiels and Grevenstein, 1995}. This technique remains limited in its use due to the need for radiation exposure and the fact that the data is obtained in two dimensions, hence introducing projection artifacts.

An open configured MRI scanner has been used to assess three-dimensional shoulder girdle and supraspinatus muscle motion in patients with impingement syndrome using the contra lateral shoulder and healthy volunteers as control {Graichen et al., 2001}. Examination was performed at 30, 90 and 120 degrees of abduction in the scapular plane with the muscles relaxed. The three dimensional orientation of the clavicle, scapula, spine, supraspinatus and the humerus was isolated in the various positions of arm abduction. These values were interpolated to obtain the scapulothoracic and glenohumeral movements. The purpose of the study was to assess alterations in the scapulohumeral rhythm and glenoid rotation patterns. The images obtained in the study were indeed impressive, although combining multiple static images to obtain a dynamic rhythm introduces a significant bias. The cost and resources needed for such a modality to be used in routine clinical decision-making are presently prohibitive.

Moiré topography is a form of biostereometry, which has been used historically to depict the three-dimensional shape of the human body. Originally designed for evaluating scoliosis patients, a pattern of shadows projected from a horizontal grid is projected on the subject's back. Photographs taken are then compared with a calibrated grid to check for asymmetry. 64% of patients with instability had abnormal topography {Warner et al., 1992}. Even though this method is useful in demonstrating scapular dysfunction, it is difficult to quantify the difference and apply the results of this study to routine clinical practice. This remained an experimental/ research tool for shoulder kinematics.

3.2.1.3 Movement analysis

Sugamoto et al {Sugamoto et al., 2002} analyzed 19 shoulders in 10 healthy volunteers using a combination of a video system and image intensifier. The motions of the bony skeleton are captured using the image intensifier and linked to the subjects video images providing dynamic motion data, albeit in two dimensions. Abduction in the scapular plane was recorded in two dimensions at various speeds, primarily to assess the affect of motion velocity on scapulo-humeral rhythm. This method has merit in defining the scapular rhythm but provides only two-dimensional data. Hence, for example, by changing the plane of the abduction of the limb, the data will change significantly and hence a source of significant bias will be introduced.

Studies investigating the firing pattern of the shoulder muscles (electromyography) have been performed using electrodes either inserted into various muscles around the shoulder {McMahon et al., 1996} or using surface electrodes {Matias and Pascoal, 2006}. These studies are generally combined with continuous video data capture and firing patterns of various muscles are studied at various stages of movement. The primary aim of these studies is to elicit abnormal muscle activity in health and disease. Even though there is no doubt that EMG data is imperitive in understanding kinetics and muscle firing during various stages of movement, they do not provide information regarding the movements of body segments and their inter-relationships.

Electromagnetic sensors have also been used for motion analysis. These are applied to body segments, which are then tracked in a magnetic field, producing data in three dimensions using a non-invasive technique. The use of electromagnetic tracking has greatly facilitated the tracking of individual bones and this technique has been used in assessing range of motion in shoulder, cervical spine {Jordan et al., 2000} and lumbar spine {Van et al., 2000}. The range of motion of the shoulder has been studied using electromagnetic tracking devices {Johnson et al., 1991} and this technique has also been used to assess scapular positions in healthy subjects {Meskers et al., 1998}, shoulder instability {Matias and Pascoal, 2006} and in frozen shoulder {Vermeulen et al., 2002}. Measurement of scapular position has been facilitated using a clamp-like device applied on the scapula. The position of this scapular marker has to be readjusted after every few degrees of movement to clear the skin movements. The multiple static movements are then "joined-up" to produce a representation of dynamic movement. Also, the need for constantly repositioning the scapular clamp, rules out its use in routine clinical use, as it is time consuming and is likely to be uncomfortable to the subjects.

Dynamic radiostereometry has been used to study relative glenohumeral motions during active and passive abduction of the arm in volunteers {Hogfors et al., 1991} {Hallstrom and Karrholm, 2008} {Hallstrom and Karrholm, 2006} and in patients with impingement syndrome {Hallstrom and Karrholm, 2009}. This technique involves implantation of 4-6 tantalum markers inserted under local anaesthesia into the scapula (acromion) and the humeral head. Two film exchangers at right angles were used to record simultaneous exposure and multiple radiographic pictures are taken as the subject actively and passively abducts the arm. This is an important advance in studying scapulo-humeral rhythm as it minimizes errors due to projection and uses truly dynamic data. The methodology involves use of an invasive technique against which there may be significant ethical concerns and rules out its routine use in clinical decision making for individual patients. The experimental movement protocol is very restrictive to ensure the subject stays within the "radiographic field", and may be a source of error, as it does not reflect "physiological" movements. Indeed, it is difficult to capture the thoracic component accurately and makes usage of the thoracic coordinate system impossible. The use of radiation is also a significant drawback. The use of two simultaneous radiographs does produce better quality of data but obtaining motion data in 6 degrees of freedom would be challenging.

Mitchell et al {Mitchell et al., 2003} used a three dimensional motion analysis system for analyzing the golf swing in 65 male recreational golfers of various ages. Reflective markers taped to skin were placed on various body segments and movement data was captured using a 6-camera motion analysis system. They illustrated the age related changes during the golf swing in healthy individuals. This study demonstrates the use of a non-invasive technique of dynamic three-dimensional data capture without using radiation. A significant methodological drawback in this study was the use of markers placed over joints (acromion for shoulder and lateral epicondyle for the elbow) for defining body segments. This introduces potential error due to skin movement as using only two markers to define the humeral segment is inadequate to capture the movement in 6 degrees of freedom. The study however represented an important advance in demonstrating the use of such systems, which can be used in studying shoulder kinematics in a way that can influence individual patient's decision making. Recently, Healy et al have published their investigation into the kinematic factors contributing to a greater hitting distance when using a 5 iron club during a the golf swing {Healy, A. et al 2011}. Using three dimensional motion analysis into functional tasks such as a golf swing marks to onset of a phase where practical application of motion analysis of the shoulder leads to better understanding of these tasks, hence translating into improved performance for athletes and better outcomes for patients.

3.2.2 Concepts of Kinematics and modelling

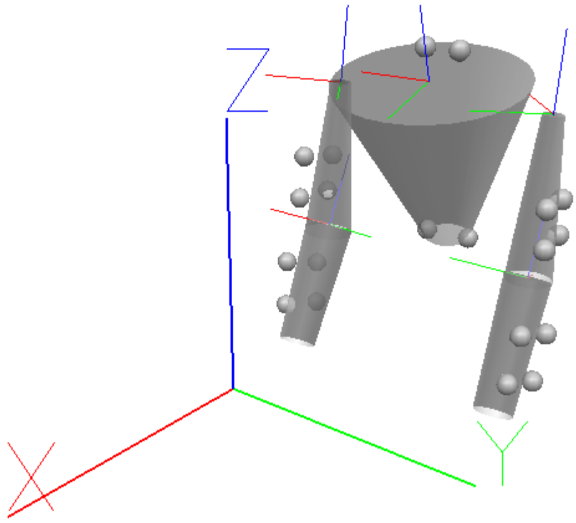
Kinematics is defined as "The study of motion of the body without regards to the forces acting to produce the motion" {Richards, 2008}. There are certain key concepts of physics, which are important to understand kinematics. Some of them, like the Pythagorean theorem, co-ordinate systems, Codman's paradox and Cardan sequences, are discussed here. Pythagoras discovered that in a right-angled triangle, the square of the hypotenuse is equal to the sum of the squares of the other two sides. If the dimensions of two sides of the triangle are known, the third can be hence calculated.

The coordinate system is a reference system against which the position of a rigid body can be defined in three dimensions. Any change with respect to translation or angular displacement of a rigid body can be described in terms of difference between the initial and final position with reference to the coordinate system. The coordinate system for example may be reference to the laboratory, patient or even a body segment. In the present study, the trunk co-ordinates were used for the reference coordinate system. X-axis defining medial/lateral direction, Y-axis defining anterior / posterior direction and Z-axis defining the vertical direction (Figure 6). The body is often divided into three planes, which are set at 90 degrees to each other (the sagittal, coronal and transverse plane) {Richards, 2008}. The position of the end of a body segment (e.g. distal end of humerus) can be defined with its reference to the trunk coordinate system and mapped in relation to these orthogonal planes. Further resolution of this position into the subcomponent x, y and z-axis allows complex calculations like segment length, translation and angular displacement to be calculated.

Codman's paradox is the apparent rotation of a body segment during motion following a sequence of angular movements, even though no rotation is primarily performed. To demonstrate the Codman's paradox, the arm is first placed in the anatomical position with the open palm facing forwards and the medial epicondyle of the humerus pointing to the midline of the body. The arm is then flexed forwards to 90 degrees. The arm is then abducted by 90 degrees, which brings the epicondyle facing forwards. As the arm is brought back to the side to its original apparent position, the medial epicondyle is pointing forwards rather than medially even though the humerus was never rotated axially. For many years the Codman's paradox was much debated, as the sequence dependent nature of rotation about the orthogonal axes was not fully appreciated. This paradox has been a source of much frustration and contention although algebraically complex may help understand many axial rotations during the daily movements of the shoulder {Wolf et al., 2009}. A simple explanation for this observation is that the serial angular rotations are not additive and are sequence dependent. Thus rotation along the Y-axis followed by rotation along the Z-axis results in a different final position than the rotation along the Z-axis followed by rotation along the Y-axis. Indeed, if the sequence of arm movement in the above example is reversed, with the arm laterally elevated, adducted and then brought back down, the final position of the medial epicondyle is posterior. Hence the sequence of rotations along various axis is crucial and these rotations form the basis of "Eulerian angles" and "Cardan sequences".

In description of movements of the shoulder joint it is important that the "sequence" of rotations about various axes is specified. The International Society for Biomechanics (ISB) has produced recommendations on definitions of joint co-ordinate systems and of the Cardan sequences to facilitate and encourage communication among researchers and clinicians {Wu et al., 2005} (Figure 6).

Figure 6: The joint co-ordinate system



The joint kinematics may be studied as either two-dimensional planar movement or three-dimensional spatial movement. As one describes the planar joint movement, three type of movements are commonly described {An and Chao, 1984}. Sliding motion occurs when there is pure translation of a moving segment against the surface of a fixed segment. The point of contact of the moving segment does not change although the contact point of the fixed surface constantly changes. Spinning movement occurs when the point of contact of the moving surface changes continuously but the contact point of the fixed surface remains static. This is indeed the opposite of the sliding motion. The third type of motion is the rolling movement where the point of contact of both the surfaces constantly changes, however the arc length of the moving surfaces matches to that of the fixed surface, ensuring no slippage occurs.

An unconstrained rigid body can not only displace in any of the three axes (X, Y, Z) but also rotate along any of these axes. Three-dimensional analysis of a rigid body motion therefore requires three linear and three angular coordinates to specify its position in space. In other words a rigid body has 6 degrees of freedom in space.

Description of three-dimensional movement can be in terms of "Eulerian angles", when spinning is the predominant movement and the sliding and rolling movements are negligible, thereby the joint can be considered as a ball and socket joint. An individual movement can hence be split into its subcomponent X, Y and Z parts. In using Eulerian angles, however it is paramount to specify the sequence of the axis of rotation as the resultant position will vary significantly as per the Codman's paradox. The other method for describing three-dimensional motion is using the Screw Displacement Axis (SDA) or the Helical Angle**.** This is a composite measurement of a rigid body describing the rotation around and translation along an imaginary "screw axis" {Rockwood and Matsen, 2010}.

The advantage of using a Screw Displacement Axis is that it incorporates the translation (i.e. rolling and sliding) component of a joint and it's orientation remains the same independent of the reference coordinate system used and sequence of the axis of rotation used. It is however a difficult measurement to grasp conceptually and even more difficult to apply in a clinical setting. On the other hand, even though the description along Eulerian angles does presume absence of translational movement occurring at the joint, the data obtained can be more readily interpreted and applied onto clinical situations.

Usage of Eurelian angles may also be associated with the Gimbal lock phenomenon. A gimbal is a ring that is suspended so it can rotate about an axis. Gimbal lock might occur with three gimbals rotating within the other, where there is a loss of one degree of freedom in three dimensional space that occurs when the axes of two of the three gimbals are driven into a parallel configuration. This locks the system in a two dimensional space. Even though the three gimbals continue to rotate individually, the innermost gimbal's motion is restricted to a two dimensional movement. Eulerian angles behave as if they were real gimbles used to measure the angles. One needs to be aware of this phenomenon when using Eulerian angles as may lead to mis-interpretation of three dimensional data.

As one understands the limitations posed by the use of Eulerian angles, it is important to realise that this is an almost exclusive method of assessing and reporting clinical work on shoulder kinematics {Vermeulen et al., 2002} {Ogston and Ludewig, 2007} {Michiels and Grevenstein, 1995} {Sugamoto et al., 2002} {Karduna et al., 2001} {de Groot et al., 1998}{Johnson et al., 1991}{Graichen et al., 2001}{Hallstrom and Karrholm, 2009}.

The concepts described in this section allow defining the postion of an object in space in relation to a reference frame. Any movement of this object within the refernce frame can be defined in relation to displacement and rotation along it's subcomponent X, Y or Z axes. The sequence of these movements has a significant effect on the resultant because of the Codman's paradox and hence appropriate Cardan sequences need to be used during motion analysis. One can appreciate the limitation of describing complex rotational and translation movments using currently available descriptors, such as screw displacement axis.

3.2.3 Kinematics of shoulder instability: Techniques used

Abnormal muscle firing patterns have been studied in patients with anterior glenohumeral instability versus controls {McMahon et al., 1996}. Fine wire electrodes were inserted into various muscles around the shoulder joint. The serratus anterior had significantly less electromyographic activity in patients with instability. The supraspinatus also exhibited significantly less activity from 30 to 60 degrees of abduction. This work helps focus rehabilitative efforts directing strengthening and coordination of muscles in glenohumeral instability. It is important to emphasise that electro-myography does not produce movement data. In fact it produces data related to muscle activity during motion. Study of electromyographic activity during motion in important in identifying abnomal firing patterns and are hence supplement the information obtained using kinematic studies.

Matias et al have investigated the three dimensional kinematics of glenohumeral instability {Matias and Pascoal, 2006}. They described the scapulohumeral rhythm and the shoulder muscular activation in patients with gleno-humeral instability. An electromagnetic tracking system was used with sensors placed on the thorax, scapula, arm and a stylus (a long pointer). Multiple static recordings were taken with the arm in varying degrees of elevation and the scapular marker repositioned after every successive position. Surface electrodes were used to record EMG activity from the trapezius, deltoid and the serratus anterior. Of the six patients in the study three had traumatic and three had atraumatic causes of instability. There was also a mixture of unidirectional anterior (3), unidirectional posterior/ inferior (1) and multidirectional instability (2). This study group was too heterogeneous, and the authors admit there was a significant difference between the subjects. An individual approach was used to identify the differences between the subjects and literature controls. They found a difference in the spinal-scapular tilt in 5 of the 6 patients suggestive of an altered scapulo-thoracic rhythm in a majority of patients with glenohumeral instability. The scapular protraction showed changes in a couple of subjects and none showed a difference in the scapular rotation. It is likely that the lack of a consensus result is due to wide selection criteria although this hasn't been a subject of further analyses. It is also speculative to translate the results of this study to a clinical scenario as the methodology involved the use of multiple static readings.

An electromagnetic motion capture system has also been used to investigate kinematic differences between patients with multidirectional instability against controls {Ogston and Ludewig, 2007}. An electromagnetic motion capture system evaluated the 3-dimensional position of the trunk, scapula, and humerus during frontal and scapular plane elevation. They found a significant decrease in upward scapular rotation during abduction in patients of multidirectional instability but no significant difference in the gleno-humeral translations. They identified the need for evaluating the effect of treatment, both surgical and rehabilitative on shoulder kinematics.

A helical CT has also been used to investigate shoulders with anterior glenohumeral instability who have had frank dislocation {Baeyens et al., 2001}. Patients with glenohumeral instability were compared with controls with images taken in 90 degrees of abduction-external rotation and in late cocking (maximum external rotation). Differences were observed in the amount of external rotation of the humerus and also in the amount of translation of the geometric centre of the humeral head in these two positions. This study provides evidence that symptomatic minor instability can exist in the absence of a history of frank dislocation. Despite the excellent visual images obtained with this type of study, this method of assessment however has limitations due to its static nature and the need for radiation. This method isn't generalisable either, as subjecting patients with frank instability to extremes of shoulder position may precipitate a dislocation.

Paletta et al {Paletta et al., 1997} studied the relationship of the glenohumeral and scapulo-thoracic kinematics in controls and unstable shoulders using a bi-planar radiographic series. They included 6 healthy adults as controls and 18 patients with recurrent (2 or more) anterior shoulder instability. They also took a third group of 15 patients with full thickness rotator cuff tear. The methodology involved obtaining 5 serial X rays in the AP plane in successive degrees of abduction. Another 3 modified axillary views were obtained with the arm in varying degrees of flexion and extension to study the changes in the axial plane. They demonstrated a tendency of superior displacement of the humeral head during abduction in patients with shoulder instability. It was also noted that there was abnormal motion in the antero-posterior plane in shoulder instability. It is interesting that they looked at kinematics after shoulder stabilization surgery and found that the abnormal glenohumeral-scapulothoracic motion relationship persisted after surgery even thought the anterior humeral translation came to normal. They suggested that the abnormal motion pattern might be a contributory rather than a compensatory factor. This study is commendable because it looks at the effect of intervention on shoulder instability and rotator pathology. The methodology used to arrive at these conclusions is however a static screening process and even though they studied the motion in two planes, the images obtained are not simultaneous and are in fact two different movements. The use of multiple X-rays and the use of radiation prompt significant ethical concerns for this to be used as a routine tool for clinical assessment. They recommended further studies to investigate the effect of surgery on these kinematic changes.

Illyes et al {Illyes and Kiss, 2006} reported the kinematics of scapular plane elevation in 15 healthy subjects and 15 patients with multidirectional instability using an ultrasound-based motion analyser and simultaneous surface electromyography. The system uses three transmitters located in front of the patient with active markers located on the patient. The scapula was tracked using a cluster of markers taped on to the acromion. They demonstrated significant kinetic abnormalities in multidirectional instability compared to the contralateral shoulder and also compared to controls. They calculated the significance of movement of centre of rotation of the scapula and the humeral head contributing to the abnormal translation in this condition. Abnormal firing patterns of various shoulder muscles have also been described. They found significant alteration in firing patterns of pectoralis major, deltoid, supraspinatus, biceps and infraspinatus in patients with mutidirectional instability. They describe a non invasive method of dynamic kinematic analysis, which can be potentially used in a variety of clinical settings although it remains to be seen if its reliability is confirmed by other investigators. There is particular concern about the reliability of the scapular cluster as significant skin movement in the overhead position may produce significant errors.

3.2.4 Movement Tasks investigated

The movement most commonly studied in various kinematics studies is the simple task of abduction in the coronal plane {Vermeulen et al., 2002} {McMahon et al., 1996} {Hallstrom and Karrholm, 2009} {Matias and Pascoal, 2006} {Karduna et al., 2001}. The scapula is however placed at roughly 30 degrees to the coronal plane. It is felt that a distinction must be made between abduction in coronal plane and that of advanced abduction where the humerus moves in the plane of the body of the scapula (scaption), which may be a much less complicated movement {Lockhart, 1930}. Whereas the movement in the coronal plane has an element of extension (with reference to the glenohumeral joint), scaption is a purer form of abduction. Many studies have therefore included scaption in their protocol {Vermeulen et al., 2002} {McMahon et al., 1996} {Ogston and Ludewig, 2007} {Michiels and Grevenstein, 1995} {Sugamoto et al., 2002} {Karduna et al., 2001} {de Groot et al., 1998}. Although, difference between the frontal and scapular plane movement was not specifically investigated in most studies {Vermeulen et al., 2002}{McMahon et al., 1996}{Michiels and Grevenstein, 1995}{Sugamoto et al., 2002}{Karduna et al., 2001}{de Groot et al., 1998}, no difference between these tasks has been reported by some authors {Ogston and Ludewig, 2007}. Forward elevation has also been commonly investigated {Vermeulen et al., 2002} {McMahon et al., 1996} {Ogston and Ludewig, 2007} {Karduna et al., 2001} in kinematic studies as it represents a common functional task of reaching for an object placed at a height. With previous methods of motion analyses, it has only been possible to investigate simple tasks. It is hence difficult to carry over the results of these studies into the clinical setting, where the movement of the shoulder during performance of an average task is significantly more complex. The interest in studying movements during physiological movements has inspired the investigation of three dimensional motion patterns during golf swing {Mitchell et al., 2003} using non-invasive techniques. Circumduction of the shoulder is a composite movement, successful performance of which requires a combination of flexion-extension, abduction-adduction and external-internal rotation. A pathology affecting any of these movements is likely to influence performance of this task. It has so far not been possible to investigate this task due to its complexity and limitation of motion capture systems.

To summarise, most studies have investigated shoulder kinematics during abduction in the coronal plane, abduction in the scapular plane and forward elevation. It is therefore important that any new study evaluates these tasks to be able to compare outcomes. However, it is rare for the shoulder joint to be involved in such a pure movement in everyday life and hence there is a need to explore a more complex task, such as circumduction. Such a movement would involve a combination of angulation, torsion and displacement in all three planes and is likely to be sensitive to changes in shoulder pathologies. It would also be more representative of the multidirectional nature of the shoulder joint and may serve as a possible biomechanical marker to identify pathology and response to treatment.

Recurrent anterior instability is particularly likely to be symptomatic especially with the arm in abduction and external rotation. Activities which involve this action, like throwing are likely to be effected in subjects with recurrent instability. The kinematic sequence of the throwing action has been investigated in handball players. The proximal to distal sequence in throwing has been described using three dimensional motion kinematics. This task has been investigated to specifically look at trunk movements, ball velocity and the influence of varying skills and experience {Wagner et al, 2012}. Similarly, the influence of ball weight on the throwing action{Tillaar van der, et al, 2011} and influence of different arm position {Wagner et al, 2010} in handball have been investigated using three dimensional motion analysis. These recent studies demonstrate the usage of the throwing action as a task, which can be potentially used to motion analysis. Significant variation in outceomes have however been noted which are influenced by the experience of the sportsperson, ball weight and the arm position. These therefore imply the challenges in standardisation of this particular task when used in movement analysis.

3.3 Effect of Surgical Intervention on instability

3.3.1 Clinical effect of Surgical intervention

Every episode of dislocation of the shoulder is associated with pain, discomfort, time off work and loss of economic productivity. The main reason why patients with recurrent dislocation of the shoulder undergo surgery is to prevent re-dislocation. Overall, surgery is quite successful in this regard. A systematic review of surgical intervention confirmed that risk of re-dislocation following open (5 /85) or arthroscopic (7/92) stabilization of recurrent instability of the shoulder is very low{Pulavarti et al., 2009}. A majority of patients are able to return to their pre-injury level of activity and demonstrate an improvement in the outcome scores post-operatively. Various surgical techniques have been described to achieve this aim with the primary objective of reconstructing the anterior capsulo-labral complex {Pulavarti et al., 2009} {Massoud et al., 2002}. The outcome measures used for assessing the clinical affect of surgery are the absence of dislocation and clinical scores. Optimal results from surgery are dependent on adequate post-operative physiotherapy and rehabilitation. Although the individual details of rehabilitation would vary to a certain extent between therapists, there is a broad consensus that regaining range of motion, and then strengthening exercises follow an initial period of immobilization. The American Society of Shoulder and Elbow Therapists' consensus rehabilitation guideline recommend a period of absolute immobilization for 0 to 4 weeks, a staged recovery of full range of motion over a 3 month period, strengthening program beginning at postoperative week 6, and a functional progression for return to athletic or demanding work activities between the postoperative months 4 and 6 {Gaunt et al., 2010}. It is envisaged that most people will recover their optimal shoulder function by 6 months postoperatively. It is therefore important to wait for at least 6 months after surgical intervention before reassessing shoulder function or kinematics to minimise the residual effects of the surgery.

3.3.2 Effect of surgical intervention on kinematics

Kinematics has been infrequently used in quantifying the effect of intervention (surgical or non-surgical) in shoulder disorders. Vermeulen et al {Vermeulen et al., 2002} used an electromagnetic tracking system to compare movement patterns in affected and non affected shoulders in patients with frozen shoulder before and after physical therapy. They noticed an improvement in range of motion and Visual Analogue Scale (VAS) in all subjects. They found that the system was significantly sensitive to detect clinical improvements. They suggested exploring the use of kinematics in detecting change following intervention in other shoulder disorders.

Moving on from just describing the changes following intervention, Yang et al have used the 3D electromagnetic tracking system to define a subset of patients with frozen shoulder who will respond favourably to physical therapy {Yang et al., 2008}. They have identified two kinematic variables, the presence of which increased the probability of improvement following physical therapy in frozen shoulder from 41% to 92%. These two variables were scapular tipping >8.4 degrees during arm elevation and external rotation >38.9 degrees during hand to neck movement. This marks a move from identifying kinematic differences in shoulder pathologies to studying the effect of intervention and finally to a phase where in the near future kinematics can be used to help guide treatment. It is therefore possible to identify kinematic markers for individual shoulder pathologies, which could potentially influence clinical decision-making.

The research into the effect of intervention on shoulder instability hasn't developed much. Despite a large variety of presentation and subgroups of patients bundled into the category of "shoulder instability" very little work has been done on instability kinematics and even less on the effect of intervention. There is only one report in the literature which has investigated the effect of intervention for shoulder instability on kinematics {Paletta et al., 1997}. They studied the effect of surgical intervention on the kinematics of instability and rotator cuff tears using radiographs. They suggested that kinematic differences persisted even after shoulder stabilization surgery. Although this is no doubt an important step forwards, the use of this methodology in clinical decision-making is fairly limited because of the need for using multiple X-rays. Conversion of such two-dimensional data to three-dimensional kinematic data remains challenging. There is a need to study kinematic changes following surgical intervention for instability and also a need to identify potential kinematic markers, which are responsive to change after treatment of shoulder instability. This would eventually help in identifying markers linked to adverse outcome and influence clinical decisions.

3.4 Clinical scores

3.4.1 Introduction

Outcome following shoulder injuries and surgery have been investigated using various outcome scores. More than 30 shoulder outcome measures have been described. The outcome measures designed are sometimes disease specific (e.g. the Oxford Shoulder Instability Score, West Ontario Shoulder Instability index) or joint specific (e.g. the Constant score, The American Shoulder and Elbow Surgeons Shoulder outcome score) {Wright and Baumgarten, 2010}. An assessment tool should satisfy various parameters before being accepted for use in a particular condition. *Internal consistency* deals with checking if the items within the tool measure a single underlying concept. *Reproducibility* checks whether the tool yields similar results on repeated trials under the same condition. *Validity* determines whether it does what it proposes to; Content validity shows whether the intended topics are covered clearly and Construct validity compares whether a set of relationships with other variables is as expected. *Sensitivity to change or responsiveness* of a tool is an ability to detect changes in the clinical condition over time {Dawson et al., 1999}.

3.4.2 The Constant shoulder score

The Constant Score {Constant and Murley, 1987} was proposed by the European Society for Surgery of the Shoulder and the Elbow (ESSSE-SECEC) as an outcome measure for comparing shoulder function before and after treatment. This score has been recommended by the SECEC and the Journal of shoulder and Elbow surgery as the minimal dataset needed for presentation and publication {Constant et al., 2008}. The Constant score has 4 components with scores assigned to each component totalling 100 (Appendix e). [Pain; 15 points, activities of daily living; 20, range of motion; 40 and power; 25] It therefore has patient based and physician assessment domains.

The Constant score was one of the original shoulder scores and was a significant milestone in using outcome scores for functional assessment of the shoulder. This score was obtained using a combination of patient description, clinical examination and measurement using simple instruments. Although in the original description the authors suggested the use of a Cybex apparatus for testing power, they clearly admitted that using a spring balance instead was acceptable and comparable. This score was not validated against other instruments at the time of its launch, as there were none available. To overcome this the authors asked a random selection of a 100 patients to give an appropriate score for the function of their affected shoulder in comparison with their asymptomatic shoulder. It is from this part of the study, that they concluded that the use of 35 points for subjective and 65 points for objective assessment is the best differential distribution between these parts of the score. In the original description, inter-observer error was assessed and described at 3% (range 0 to 8%) {Constant and Murley, 1987}. It was for the first time that quantification of shoulder function, including definition of what's normal and what constitutes disability was possible. The first validation study for the Constant score used a heterogeneous group of patients, which included patients with arthritis, dislocation and impingement. It has been suggested that the Constant score is not appropriate for assessing instability {Conboy et al., 1996}. It is also notable that although it has not been specifically validated for shoulder instability, it continues to be commonly used for reporting shoulder function {Wright and Baumgarten, 2010}.The Constant score has been criticized for inclusion of a section scored by an examiner, which increases the risk of bias. The original paper lacked precise details for application of the measure and interpretation of the result. There have been different ways of describing the measurement of strength and range of motion {Wright and Baumgarten, 2010} {Bankes et al., 1998}. It has been suggested that the reliability and sensitivity of the Constant score significantly reduced over time {Kirkley et al., 2003}. There is good to excellent inter rater reliability of the Constant score between therapists with a Kappa statistic ranging between 1.0 and 0.7 {Thompson, 2001}

3.4.3 The Oxford Shoulder Instability Score

The Oxford Shoulder Instability score {Dawson et al., 1999} is a disease specific assessment tool developed specifically for patients with shoulder instability and has been a recommended tool for evaluating results of shoulder instability treatment {Wright and Baumgarten, 2010}. The Oxford Shoulder score {Dawson et al., 1996}, which is a non-disease specific tool for shoulder pathologies, was found to be insensitive to instability problems and this was the primary reason driving the development of the instability score. The group of patients with shoulder instability were characterized not by the presence of pain, but by the anticipation of problems arising from specific activities. An understanding that the patients with shoulder instability were a distinct group with very little pain but significant apprehension related to certain activities drove the development of this tool. Scores developed for a single condition are likely to be more sensitive to the outcome in narrowly defined groups. It was based on the patient’s perception of the condition and is in the form of a 12-item questionnaire with multiple choice answers (appendix d). Each response on the score is given a numerical value ranging from 1 (good) to 5 (poor), thus giving a range of possible scores from 12 (best possible score) to 60 (worst possible score). This forms an easy to use patient based tool, which can be potentially delivered by post. A short questionnaire with 12 items is also likely to yield higher response rates. The development of this tool used rigorous scientific validation to ensure it was reliable, reproducible, valid and sensitive to change {Dawson et al., 1999}. The questions used in this score were developed using exploratory patient interviews rather than clinical assumptions. Draft versions of the questionnaire were tested on patients and final content was agreed when patients understood it and felt that no important themes had been left out. Correlation with existing Constant, Rowe and SF36 scores were tested to ensure the expected direction of scores were obtained. It has been found to be more sensitive to change after change in the clinical condition as compared to the Constant score {Dawson et al., 1999}.

This tool has been used successfully in assessing function following surgical stabilization and found to be a useful tool as a measure of function although relatively poor in assessing dislocation rates {Loughead and Williams, 2005}. It is hence important to ask specifically about re-dislocation after therapy along with administering the score. It has also been shown to correlate consistently with the patients' subjective score {Moser et al., 2008}, even though some authors disagree {Plancher and Lipnick, 2009}. The development and testing of this score is relatively rigorous and likely to produce reliable, valid and responsive information {Kirkley et al., 2003}.

3.5 Correlation of clinical scores with kinematics

There have been a few attempts at investigating the relationship between shoulder kinematics and outcomes. Fayad et al {Fayad et al., 2008} assessed the relationship between kinematic variables related to shoulder function as assessed by the Disability of the Arm, Shoulder and Hand (DASH) scale. They conducted a prospective study in 88 patients comprising of four common shoulder disorders including frozen shoulder, proximal humeral fracture, rotator cuff disease and glenohumeral arthritis. Active arm elevation, forward flexion and two activities of daily living were performed and assessed using an electromagnetic tracking system. They suggested that the glenohumeral elevation and lateral rotation of the scapula explain almost 40% of the variability in the DASH score. This is a good attempt at linking function to kinematics. Even though skin artifacts continue to remain a source of error, the importance of this study remains in bringing together the lab data and clinical scores. Similar studies have previously looked at correlating changes in kinematic variables with loss of function {Rundquist and Ludewig, 2005} {Lin et al., 2006}. There has been no study, which has attempted to investigate the relationship between kinematic changes and outcome scores in patients with shoulder instability.

3.6 Summary

There is a need to describe differences in kinematics between asymptomatic shoulders and shoulders with anterior instability using a motion capture system capable of recording movement in 6 degrees of freedom in a truly dynamic way using a non-invasive technique. Such a study has not been performed previously.

There is also no report in the literature of the effect of surgery and rehabilitation on three-dimensional kinematics. The recovery of individuals pre and post shoulder instability surgery has also never been fully documented using movement analysis. Even though Palletta et al {Paletta et al., 1997} studied the affect of surgery for shoulder instability on kinematics using sequential X-rays, their study however was essentially a two dimensional study with possible errors due to parallax and perspective.

Changes in range of motion, strength and clinical scores following surgery have been well documented following such surgeries {Rowe et al., 1978}. However the relationship between kinematics and shoulder outcome scores has never been investigated before in individuals who are pain and pathology free and those with shoulder instability. The change in these parameters following surgical intervention and rehabilitation remains unknown as well.

There is a need to identify a biomechanical model capable of recording three dimensional shoulder motion (in 6 degrees of freedom) that is dynamic, non-invasive, doesn't involve the use of radiation, easy to use, reliable and transferable to the clinical setting. The electromagnetic tracking system has been used extensively in shoulder motion analysis due to it being able to meet some of these criteria, however the scapular data becomes less reliable beyond 120 degrees of elevation {Karduna et al., 2001}. Its use in more complex tasks remains unexplored. There is a need to explore the use of an existing motion capture system, which has been used successfully and extensively in gait analysis and already has an established place in decision making in a variety to disorders such as cerebral palsy {Gough and Shortland, 2008}. Most kinematic studies have focussed on simple movements such as abduction, scapular elevation and forwards flexion. Even though it is important to understand the kinematics of these simple movements, they are not necessarily representative of the complex multi-planar motion of the shoulder joint. There is a need to investigate a more complex movement like circumduction, which encompasses all forms of angular and rotatory movements and is more likely to be sensitive to change in subtle shoulder pathologies. There also remains a need to explore kinematic variables, which can be used reliably in identifying differences in disease and the effect of treatment.

This study aims to describe the movement pattern in patients with glenohumeral joint instability, with a non-invasive three-dimensional tracking system. A comparison with shoulders of healthy volunteers has been made. Changes in these variables following surgical shoulder stabilization have been assessed and compared with changes in clinical scores. The role of this motion analysis system in its usefulness to clinical practice has been explored.

Chapter 4. Aim and Objectives

4.1 Aim

The aim of the study was to investigate the kinematic differences between patients with anterior instability as compared to controls and whether these are altered by surgery?

4.2 Objectives

1. To determine if shoulder movement patterns are significantly different in patients with shoulder instability as compared to controls.
2. To determine if shoulder movement patterns are significantly different in patients with shoulder instability before and after anterior capsulo-labral reconstruction.
3. To determine if standard clinical scores are different in patients with shoulder instability before and after anterior capsulo-labral reconstruction.
4. To investigate the relationship between existing clinical scores and movement data before and after anterior capsulo-labral reconstruction.
5. To determine the usefulness of 3D shoulder kinematic assessment to clinical practice.

Chapter 5. Materials and Methods

5.1 Ethical and Research and Development Approval.

The study has been a collaboration between the Faculty of Health at the University of Central Lancashire, Preston and the Wrightington Hospital, Wigan. Ethical committee approval was obtained from the Wrightington, Wigan and Leigh local research ethics committee [LREC] reference 05/Q1410/22. Salford Royal Hospital was added to the study after being granted Trust Approval from the Salford Royal NHS foundation trust and registration with their R&D office. Ethical Approval was also obtained from the Faculty of Health Research Ethics Committee (FHEC) at the University of Central Lancashire. (Appendix a). None of the patients were operated on or treated clinically by the chief investigator.

The study is registered with the Research and Development Department at Wrightington, Wigan and Leigh NHS Trust. The Wrightington, Wigan and Leigh NHS Trust also act as sponsors of the research. Wrightington Wigan and Leigh NHS Trust provided public liability insurance cover for NHS work and AON corporate division provided Liability cover for the University of Central Lancashire.

Funding for the study (£4000) was successfully bid for and granted by the Research and Development fund of the Wrightington, Wigan and Leigh NHS Trust (Appendix b).

5.2 Recruitment of Control Group

Volunteers were invited to the motion analysis laboratory, University of Central Lancashire by means of posters displayed at the University and the Hospital (Appendix c). All volunteers were screened to ensure they did not have previous shoulder dislocations. They were asked about any previous history of shoulder pain, pathology or surgery. The Oxford shoulder instability score {Dawson et al., 1999}(Appendix d) and the Constant score {Constant and Murley, 1987} (Appendix e) were also obtained. Ten volunteers were recruited. It was attempted that the volunteers were age matched to the patient population with the average age of volunteers being 24 years (average age in patient group 30 years) [Table 1]. Kinematic data from one volunteer could not be used as two of the four trunk markers fell during the recording, making data unsatisfactory for use (Control no. 2). This occurred during the early part of volunteer / patient recruitment. Using a velcro abdominal strap on the trunk with markers stuck onto this strap, avoided any further similar recurrence. There were seven male and two female volunteers, representing the male predominance of recurrent shoulder instability in society. All the volunteers were right hand dominant and movement data were obtained for 5 right shoulders and four left shoulders. As these subjects were all right handed, a variable mix of left and right sided data was obtained to account to any differences which may occur due to hand dominance. Data from only one side (left or right) was obtained to limit the number of comparative groups as with the relatively small number of subjects recruited in the study, having a large number of comparative groups would limit the significance of individual comparisons. The average Oxford shoulder instability score was 12/60 (best possible score 12, worst score 60) and the average constant score was 98.78 (Best possible score 100, Worst score 0). The two female members of the volunteer group scored lower than the males in the group, which is accounted by the gender difference in the Constant score in the normal population {Yian et al., 2005}.

Table 1: The Control Group

S. No	Age	Gender	Dominance	Side Data obtained	Oxford instability Score	Constant Score
1	35	Male	Right	Right	12	100
3	36	Male	Right	Right	12	100
4	23	Male	Right	Right	12	100
5	19	Male	Right	Left	12	100
6	22	Male	Right	Left	12	100
7	18	Female	Right	Left	12	95
8	29	Male	Right	Right	12	100
9	18	Female	Right	Left	13	94
10	19	Male	Right	Right	12	100

5.3 Recruitment of Patient Group

Patients with unidirectional anterior gleno-humeral instability were recruited for the study. Patients who had multidirectional instability, neurological disorders and significant spinal pathology were not included in the study. The Stanmore classification of shoulder instability is commonly used in clinical practice. Type 1 class related to patients who have an anatomical lesion (typically a capsulo-labral lesion) predisposing them to dislocation. The patients belonging to the Type I class from the Stanmore classification are good candidates for surgical repair of this capsulolabral lesion. Some of these patients may also have altered muscle-firing patterns and surgery is performed once their muscle patterning behaviour (Classified as type III in the Stanmore Classification) has been optimised by pre-operative physiotherapy. Prospective candidates were identified from the waiting lists of shoulder surgeons at the Wrightington Hospital and Hope hospital by the chief investigator and medical records reviewed prior to invitation to the study. 17 consecutive patients who were waiting for arthroscopic stabilization were invited using a postal request (Appendix f), which was accompanied with by an information sheet (Appendix g). A second invitation was posted 2 weeks later. 7 patients agreed to participate and visited the motion analysis laboratory for their pre-operative visit. One patient had an associated rotator cuff tear and another did not have a stabilization procedure as per the original plan. This left 5 patients in the shoulder instability group. Most rehabilitation programs aim to restore full active range of motion by 12 weeks after arthroscopic and open anterior stabilization {Hayes et al., 2002}. The post-operative visit to assess the subjects were scheduled at least 6 months after surgery to allow for rehabilitation and minimise the bias of altered kinematics, which might follow shoulder surgery. All these five patients were able to re-attend the movement analysis laboratory for their second visit post-operatively. A summary of key patient characteristics is described in Table 2.

Table 2: Summary of Key Patient characteristics

S No	Age	Gender	Dominance	Affected	Occupation (pre-injury)	Number of dislocations	Interval b/w 1st dislocation & Op
1	21	Male	Left	Right	Manual (lifting)	30	18 months
2	22	Male	Right	Left	Visualizer, Drawing	10	18 months
3	46	Male	Right	Right	Bus Driver	15	11 years
4	40	Male	Right	Left	Manufacturing, desk job	10	21 years
5	19	Male	Right	Right	Auto body repair	3	8 months

Patient 1 was a 21 year old left hand dominant male with recurrent dislocation of his right shoulder. His occupation involved lifting heavy weights. He played football at the recreational level and his shoulder was affecting both his occupation and recreation. From the first dislocation 18 months ago, he had suffered over 30 dislocations. He had arthroscopic stabilization for a Bankart's lesion (2 o'clock to 6 o'clock). [As mentioned earlier, any tear in the labral tissue, which is attached circumferentially, along the edge of the glenoid is described by its location on an imaginary clock face. For example, a common anterior lesion for a right shoulder would be between 2 to 6 o'clock on this clock face and a similar anterior labral lesion in the left shoulder would be described as between 10 to 6 o'clock]. Unfortunately he had a re-dislocation 8 weeks after surgery and underwent redo Bankart repair 5 months later. His postoperative lab visit was 10 months after his repeat surgery. He had no further episodes of dislocations. He was unable to fully perform all activities involving lifting weights, had not started playing contact sports however felt satisfied with the results and felt his main problem was resolved.

Patient 2 was a 22-year-old right-handed male with recurrent dislocations of his left shoulder. He was a building designer and played football at an amateur level. His shoulder prevented him from full participation in sports but did not affect his occupation. From his first dislocation 18 months ago, he had 10 further episodes of dislocation. He had arthroscopic stabilization for a Bankart's lesion (10 o'clock to 6 o'clock position). He was back at work in 3 weeks and had no further episodes of dislocations. His shoulder did not affect him at work although he hadn't started participating in contact sports at the time of his post-op visit at 8 months after surgery. He felt his main problem (for which he had the operation) was resolved. He had recurrent dislocation of the opposite shoulder, which was successfully stabilised operatively 3 years ago.

Patient 3 was a right-handed 46-year-old male bus driver with recurrent dislocation of his right shoulder. He played ten pin bowling at the semi-professional level. His shoulder dislocations affected his sporting activities but not his occupation. Over the last 11 years he had 15 episodes of dislocation. He underwent arthroscopic anterior stabilization for a Bankart's lesion (2 to 6 o'clock) and was back at work and sports 8 weeks after surgery. At his post op assessment at 11 months after surgery, he had no re-dislocations after surgery and the shoulder did not affect his work or sports. He felt his main problem (for which he had surgery) was resolved. He felt some residual pain in his shoulder despite surgery.

Patient 4 was a 40-year-old right-handed male in a desk job with recurrent dislocations of his left shoulder. He was involved in recreational fell walking. His shoulder pathology was affecting his sporting activities but not his job. His first dislocation was 21 years ago and he subsequently had 10 similar episodes since. His Bankart's lesion (10 o'clock to 5 o' clock) was stabilized arthroscopically and he was back at work after a day. He had returned to work and sports and had no further episodes of dislocation. He was seen 9 months after surgery for the postoperative assessment, at which time he was extremely satisfied with the treatment and felt that his main problem was resolved.

Patient 5 was a right-handed 19-year-old male with right recurrent shoulder dislocation. His occupation of auto body repair was affected by his shoulder problem. He had suffered 3 dislocations in the 8 months prior to his first visit to the movement analysis laboratory. He underwent arthroscopic anterior stabilization of his shoulder (2 to 5 o' clock lesion) and was able to return to work in 2 weeks after surgery. He was seen again in the movement laboratory 10 months after his surgery. He had no further episodes of dislocation and was able to return to sports. He felt satisfied with the treatment and also felt that his main problem had been resolved.

Two patients who were initially recruited were excluded, as they did not fit the inclusion criteria as a different pathology was found intra-operatively. They were not called for the post-operative visit. Movement data of one volunteer had to be discarded, as at least 3 of the trunk markers could not be traced in 90% of the movement. Files with missing data, unusable trials and trials which were not synchronous with the rest of the files in the group were also discarded. A detailed log of these was maintained. This log is published in appendix h. One control subject (subject 2) could not be used as two trunk markers fell off during data collection. Only 18 data files had to be discarded from a total of 380 data files for various reasons listed in the appendix, hence representing a high percentage of quality data.

5.4 Data Collection

The volunteers and patients visited the movement analysis laboratory at the University of Central Lancashire, Preston. On attendance, a standard patient questionnaire (Appendix i) was filled and the Oxford instability and Constant scores obtained (Appendix d,e). The Constant score was obtained using a method described by Bankes et al using a spring balance {Bankes et al., 1998}. It is not possible to blind the researchers and participants due to the nature of the intervention. The data for the patients were paired (pre-operative and post-operative) and hence blinding of patient data was not feasible either.

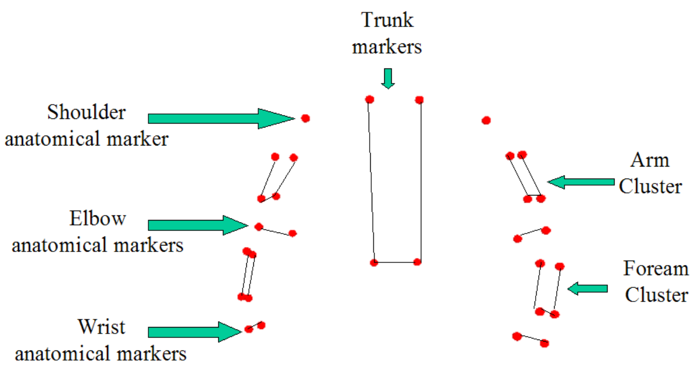
Reflective markers placement was based on the calibrated anatomical system technique (CAST) {Cappozzo et al., 1995}, which has been shown to provide improved kinematic data and location of anatomical reference frames with the use of rigid cluster plates over the segments. This allowed measurement of six degrees of freedom movement between the body segments. The CAST technique involves the use of static calibration markers and the dynamic tracking markers. The static calibration markers are placed on anatomical landmarks to identify the position of joints in the three dimensions. The static calibration marker for the shoulder joint was placed on the acromion. The static calibration marker for the elbow was placed on the medial and lateral epicondyle and for the wrist on the radial and ulnar styloid (Figure 7). The calibration markers defined the proximal and distal ends of body segments. The elbow joint was defined midway between the medial and the lateral epicondyle marker. The shoulder joint center was defined as 0.02m medial to the acromion marker. This has been discussed in detail in section 7.3.5

The dynamic tracking markers were placed on each body segment. The arm and the forearm segments were identified using dynamic tracking markers in the form of rigid clusters. These were applied using elastic bandages with Velcro straps. Each of these rigid clusters had four markers attached on a base plate. There was one rigid cluster applied to each individual body segment. The thorax segment was identified using 4 markers. Two of these markers were placed an inch on either side of the vertebra prominence (C7 spinous process) and two were placed at the renal angle on each side (Figure 7). The position of the dynamic tracking markers on the segment were such that they could be tracked effectively and hence "visible" to the infrared cameras. At least 3 markers on each body segment are needed to measure a segment in 6 degrees of freedom. Clusters of 4 markers were used, so that losing track of one marker during the movement still left the model usable.

Figure 7: Marker placement on a subject

The first recording was a static file. The subject was asked to stand within the semicircular area of the cameras with the shoulders extended and elbows flexed to ensure the surrounding cameras could capture all markers (Figure 8). After capturing this static file, the static calibration markers were removed. Following this the movement tasks were performed sequentially. The motion data was captured using the dynamic tracking markers which represented the thorax, humerus and forearm respectively.

Figure 8: Body segment and joint position markers



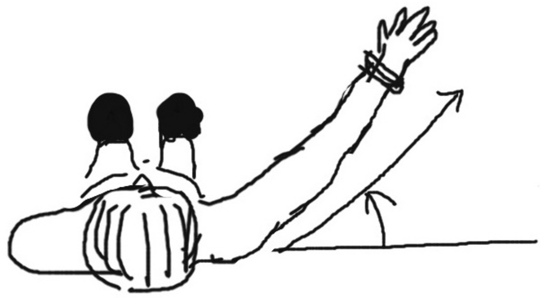
Kinematic data was collected using ProReflex MCU1000 motion analysis system at 240 Hz. At least 8 Cameras were used each time. These cameras were placed in a semi-circle around the subject. The cameras had to be placed on high mounts to capture the full range of upper limb movement (Figure 9). The postion of the cameras was titrated in the initial trials to be far enough to capture the full volume of the shoulder joint movements in full elevation, at the same time near enough to minimise data loss and interference from camera cross-talk.

Figure 9: Camera setup for data capture

5.5 Tasks

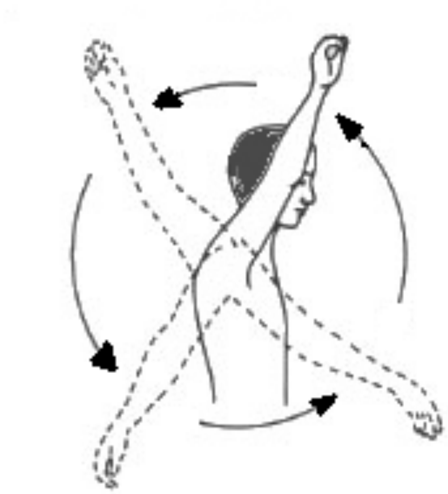
Four movement tasks were investigated for the purposes of this study. Abduction in the coronal plane involved asking the patients to start lateral elevation of their arm from a position by the side of their body to maximal possible elevation in the plane of their body (frontal / coronal plane) followed by bringing it back to the original position, without stopping, in one continuous movement. Range of motion in the coronal plane was investigated during this task. Abduction in the scapular plane involved a similar continuous movement of maximal elevation and back, but in a plane approximately 30 degrees to the coronal plane. This plane of movement is approximately 30 degrees to the coronal plane or 60 degrees to the sagittal plane (Figure 10). It is not desirable to be precise in this measurement as the scapula is located in a variable plane to the coronal plane in different individuals. This plane of movement was instructed to each subject individually based in clinical examination of individual scapular position. Range of motion in the coronal plane was assessed duing this movement.

Figure 10: Scaption



The forward elevation task involved maximal elevation of the arm in the sagittal plane and back to the original position, again in one continuous movement. Range of motion in the sagittal plane was assessed during this movement. The circumduction task involved asking the subject to forward flex the arm and then bringing it around over head into a maximally abducted position and then to extending the arm as far back as possible before bringing it down by the side of the trunk (Figure 11). For all the movements the subject was asked to stand in one place and no restriction of the trunk movement was specified. For each subject an ensemble average was computed from the five replicates of each task. The sequence of movements tested was randomly selected to minimize changes due to either motor learning or fatigue bias. For all movements, the subject was asked to perform tasks within comfort range and not to push him or herself beyond what they feel comfortable with.

Figure 11: The circumduction task

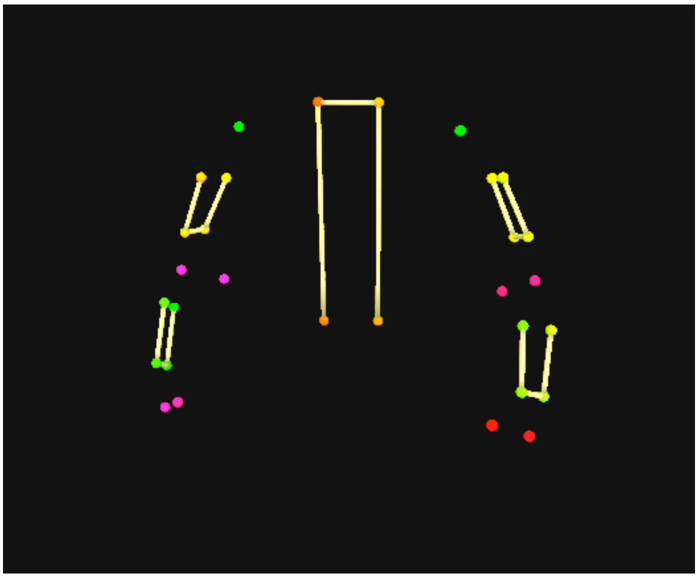


It is evident from the review of exisiting literature that forward flexion, abduction in the coronal plane and scaption have been studied by a majority of the investigators. It is hence important that any further study investigating shoulde kinematics includes these movements, to make the results comparable. These three movements were therefore included to make results of the given study comparable to the existing literature. Circmduction, on the other hand, is a complex movement combining angulations, rotations and translations of the body segment. This dynamic movement is representative of the average complexity of movement occuring at the shoulder joint complex during routine activity. It is therefore important to investigate such a movement, which would have clinical implications as circumduction conceptually represents the "maximum span" of shoulder movements. Hence, it is envisaged that this movement would be responsive to any pathologies affecting shoulder movments.

5.6 Modeling.

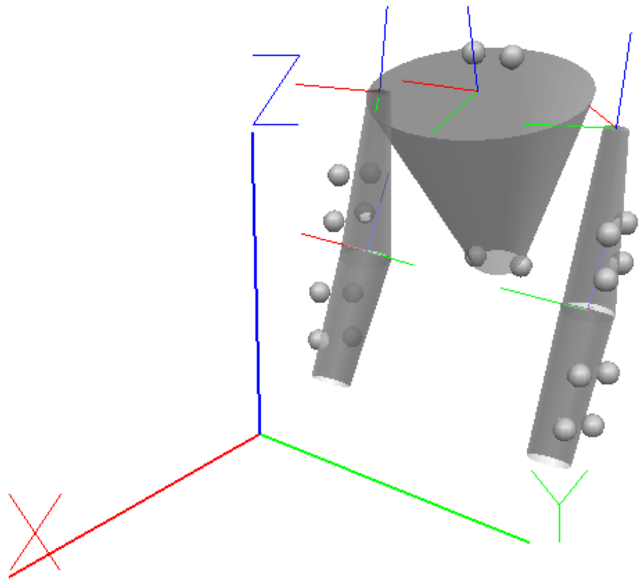
The completed successful trials were digitized and captured initially onto the Qualysis Motion capture system (Qualysis Medical AB, Gothenburg, Sweden). Individual markers were identified, and assigned to the relevant body segment. A segment model was built for every motion file. Hence each marker was assigned to either the trunk, arm or forearm segment (Figure 12).

Figure 12: Captured data onto Qualisys Track Manager Software



The data was then exported as a C3D file to Visual 3D (C-Motion, USA). The motion files were calibrated against the static calibration marker file. The movement data were smoothed by applying a 6Hz low pass filter. Start and end points of each trial were identified to ensure comparability of individual repetitions. The start of the event was defined when the arm movement just started and the end when it had returned to its original position. The trunk co-ordinates were used as the reference coordinate system. In the present study, X-axis was along the medial/lateral direction, Y-axis was along the anterior / posterior direction and Z-axis along the vertical direction. By calibrating the motion files against the static calibration markers, an anatomical model was constructed (Figure 13). This model was the virtual representation of the subject's movements in 6 degrees of freedom.

Figure 13: Model building on Visual 3D software



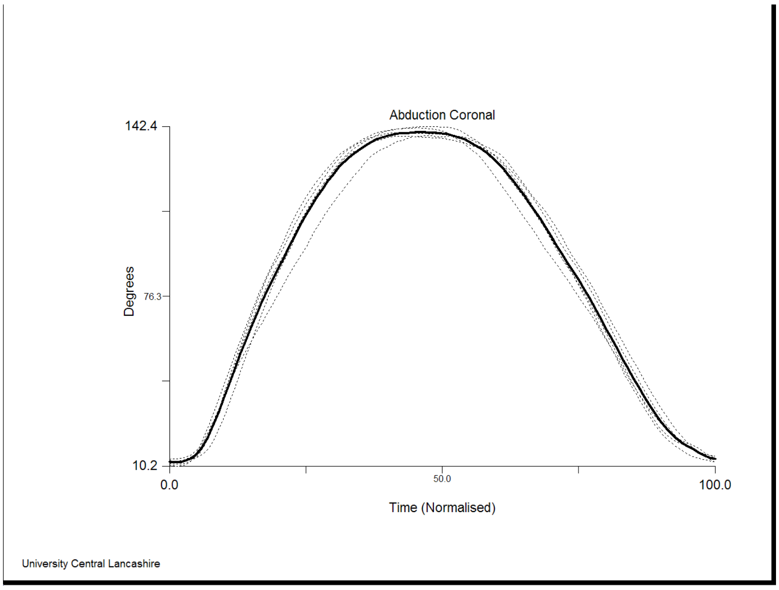
Besides giving a visual representation of the movements, the Visual 3D software was also used to extract graphs and numerical data from the anatomical model. In analyzing the forward flexion movement, the sagittal plane thoraco-humeral angle was assessed. For the abduction movement, the coronal plane joint angle was calculated. Abduction in the coronal plane was also the outcome assessed in the movement where the subject performed abduction in the scapular plane. For the "abduction" and "abduction in scapular plane" movement, the ZYZ Cardan sequence was used as per the International

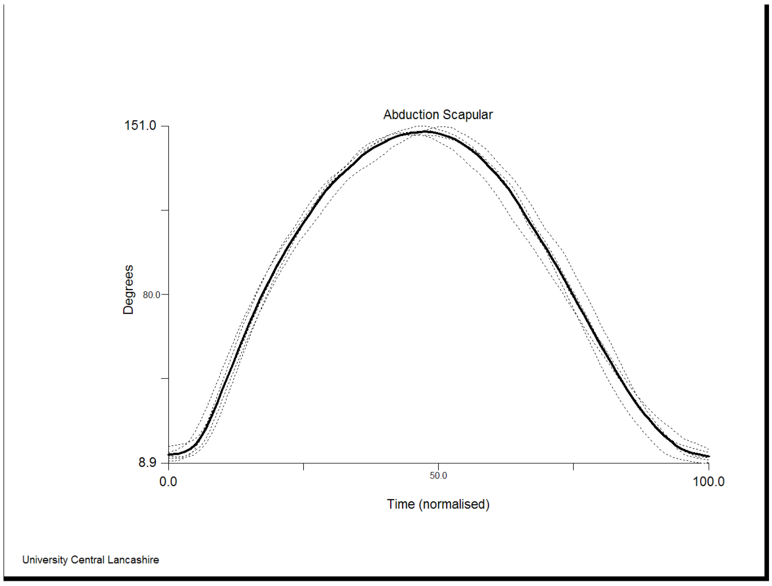
Society of Biomechanics (ISB) recommendations {Wu et al., 2005}. However, the XYZ sequence was used for sagittal plane movement when analysing the "forward flexion" movement. This has been further discussed in detail in section 7.2.2.

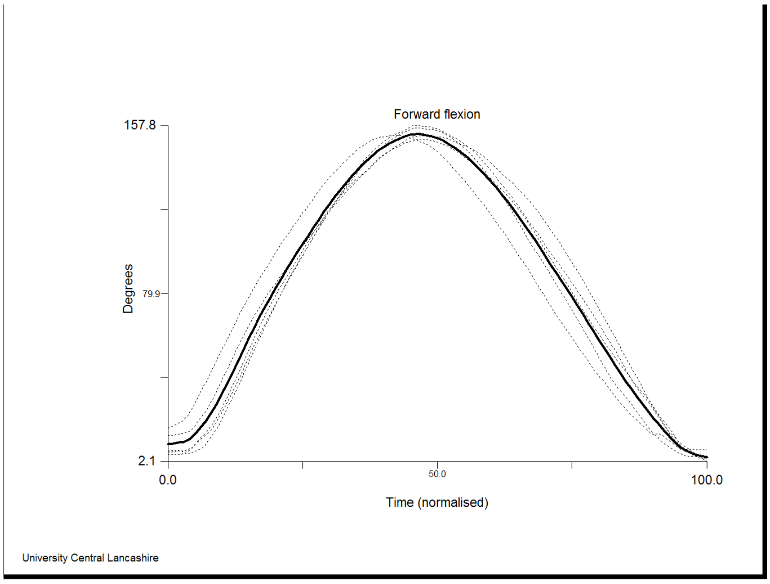
5.7 Method of Analysis

Joint angle (in degrees) was plotted against time for the movements of abduction, abduction in scapular plane and forward flexion. To make individual files comparable, the time between the start and end point of the movement was normalized. Hence each graph of these three movements was plotted using joint angle against a normalized time from 0 to 100. A typical trace of abduction in the coronal plane, abduction in scapular plane and forward flexion is depicted in Figure 14.All the three traces look similar with a smooth dumb-bell shaped plot of joint angle versus time as the arm is taken from a resting position to full elevation and then back to the resting position.

Figure 14: A typical trace of Abduction in the coronal plane, scapular plane and forward flexion.







For analyzing the circumduction movement, the imaginary path traced by the elbow in the Sagittal plane was plotted as the arm performed a circumduction manoeuvre. The area covered within this imaginary "trace" represents the composite measure of the span of the circumduction movement. To make the area comparable between various subjects of differing arm lengths, the trace was described as a normalised proportion to the subject's arm length, rather than metric measures. This trace is referenced to the subjects' trunk. As these are the movements of the arm relative to the trunk, they hence represent the movement occurring at the shoulder joint complex. This graph would be representative of the "maximum span" of the composite shoulder movement as the shoulder moves from flexion through to abduction, followed by extension and back to being by the side of the trunk. A typical trace obtained in a control subject for the right shoulder is shown in Figure 15. On the other hand, a graph obtained using the global coordinate system (e.g. the laboratory axis), as a reference would represent a combination of the shoulder joint movements and the trunk movement (Figure 16). The trace obtain in Figure 16 is composite of not only the movment occuring at the shoulder joint complex but also includes the trunk movements as the trace represents the movments of the arm relative to the laboratory coordinates.

Figure 15: A Typical circumduction trace in a control referenced to the Trunk coordinates.

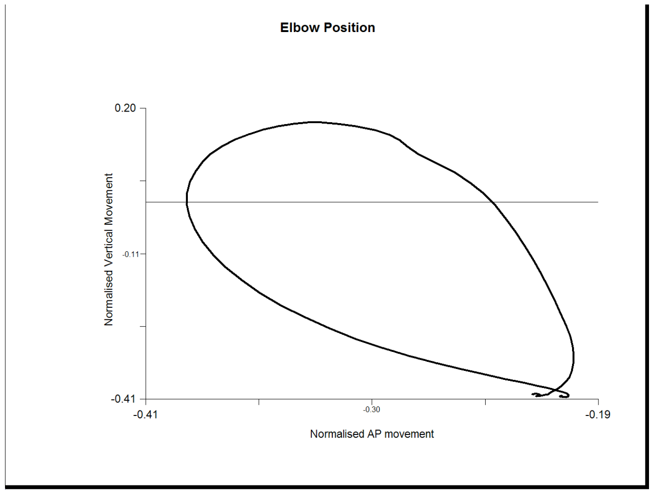
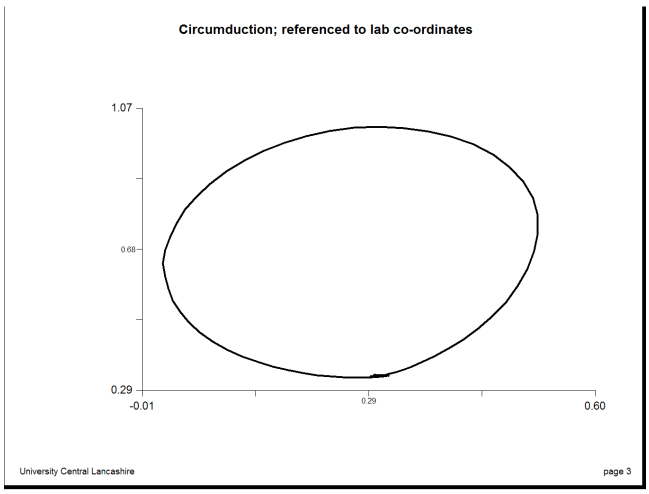


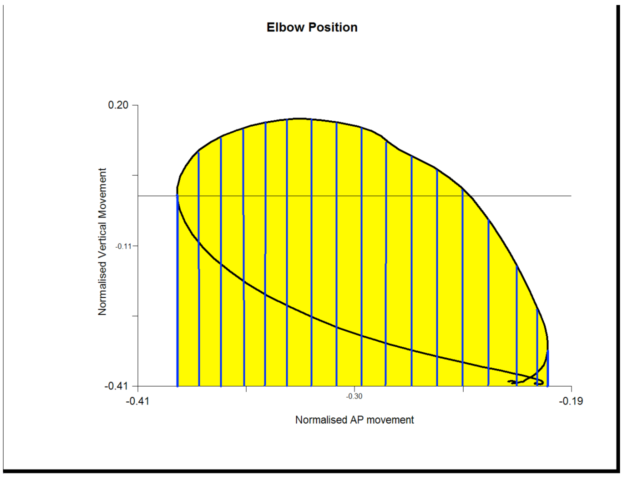
Figure 16: Shape of the circumduction trace referenced to the Lab coordinates.



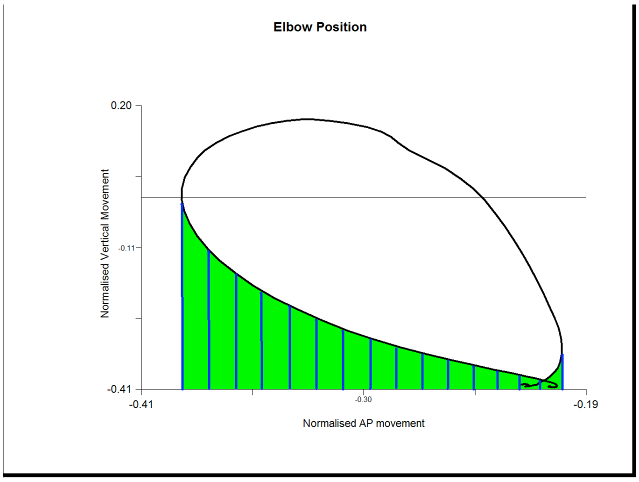
To calculate the area within the trace of a circumduction graph, the trapezium rule was used. The area contained under the superior trace was calculated by dividing it into multiple small trapeziums (Figure 17a). Similarly the area under the inferior trace is calculated by dividing it into multiple trapeziums (Figure 17b). Subtracting the latter from the former provides the area within the trace (Figure 17c). Although this method uses basic mathematical calculations for calculate this area, the concept has previously been used in angle-angle diagrams by Cavanagh and Grieve {Cavanagh and Grieve, 1973}. This calcualtion was performed by exporting the normalised data onto Microsoft Excel. The individual individual data points were squared and then a square root obtained to take away the negative values from the calculation. As the arm length of individual subjects was variable all measurements were normalised with respect to arm lengths. Further calcualtion including calculating the areas of multiple trapeziums were carried out in Excel as well.

Figure 17: Illustration of calculation of the area within the trace using the Trapezium rule.

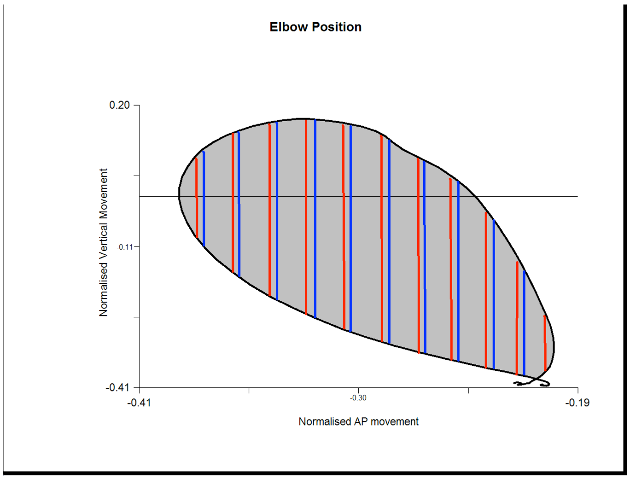
A: Calculate area under the superior trace using multiple Trapeziums.



B: Calculate area under the inferior trace



C: Subtracting B from A gives area within the trace



Key parameters of movement data were exported into Microsoft Excel. For the abduction in coronal plane, abduction in scapular plane and forward flexion, the data extracted was the joint angles in all the three planes versus normalised time. For the circumduction data, the data exported was elbow position referenced to the trunk, for obtaining the trace. The arm length was calculated by subtracting the instantaneous shoulder position from the elbow position. This calcualtion was perfomed in x, y and z axis and a mathematical average was obtained. Also, this measurement was performed throughout the range of motion.

The key comparisons made were difference between controls, pre-operative and post-operative data using an ANOVA with a Tukey posthoc test using SPSS version 17 software, which was used for statistical analysis.

Chapter 6. Results

6.1 Movement Data

6.1.1 Abduction in the coronal plane.

The key parameter investigated during the abduction in the coronal plane task was the range of motion in the coronal plane. The joint angle (in degrees) was plotted against normalised time (0 to 100). The trunk coordinate system was used as the reference segment. A comparison of mean range of motion of the three comparison groups [controls (n=9), pre-operative (n=5) and post-operative (n=5)] is shown in Figure 18. Statistical comparison between subgroups is presented on Table 3.

Figure 18: Range of movement in the Coronal Plane

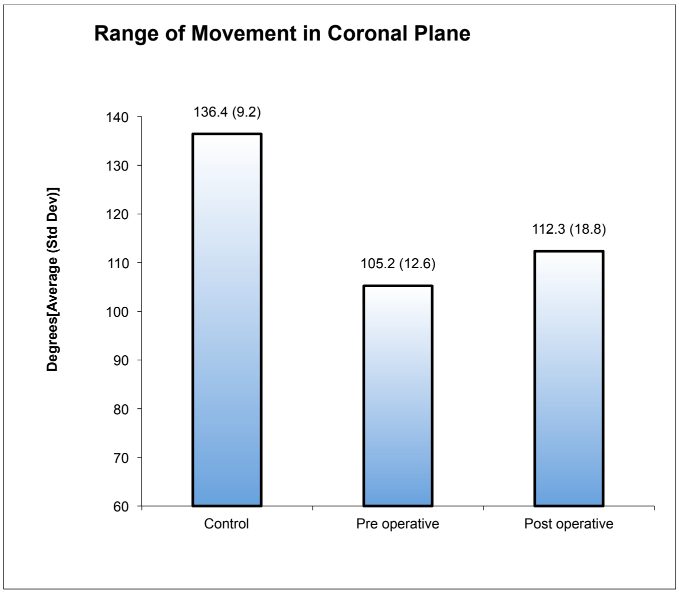


Table 3: Abduction in the coronal plane

	Range of Movement in coronal plane
Controls versus Pre operative	0.002
Controls versus Post operative	0.012
Pre operative versus Post operative	0.673

p values (ANOVA; posthoc Tukey)

6.1.2 Abduction in the scapular plane

Coronal plane range of motion was investigated during the scaption (abduction in the scapular plane) task. Joint angle (in degrees) referenced to the trunk co-ordinate system were plotted against normalised time. A graphical depiction is presented in Figure 19. There was a non significant difference between shoulders with recurrent instability (n=9) as compared to controls (n=5), with no statistically significant difference between the post-operative range of motion (n=5) with either the control group or the pre-operative group (Table 4).

Figure 19: Range of movement during scaption

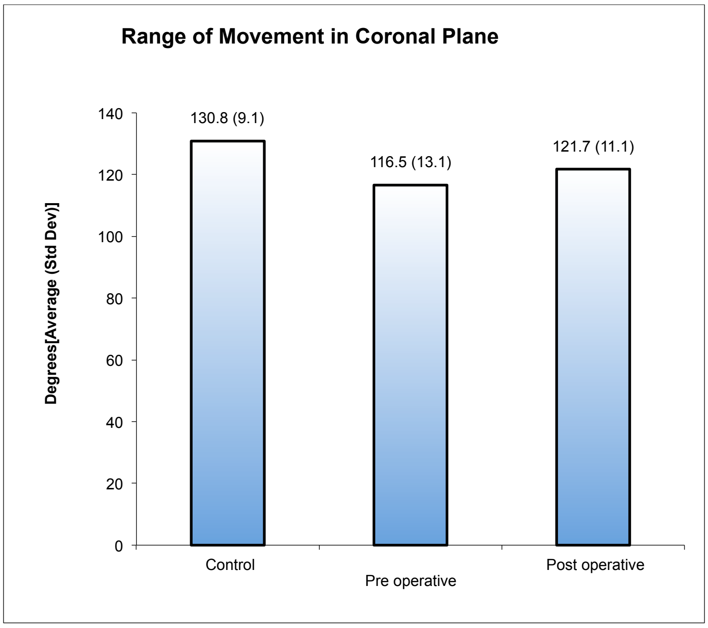


Table 4: Abduction in the scapular plane

	Range of Movement in Coronal plane
Controls versus Pre operative	0.075
Controls versus Post operative	0.313
Pre operative versus Post operative	0.733

p values (ANOVA; Posthoc Tukey)

6.1.3 Forward Flexion

The range of motion in the sagittal plane during the forward flexion task was assessed. This movement was again referenced to the trunk coordinate axis. Joint angle (in degrees) was plotted against normalised time. There was no statistically significant difference in this movement between either the controls (n=9), the pre-operative (n=5) or the post-operative groups (n=5) (Figure 20, Table 5).

Figure 20: Range of movement during forward flexion

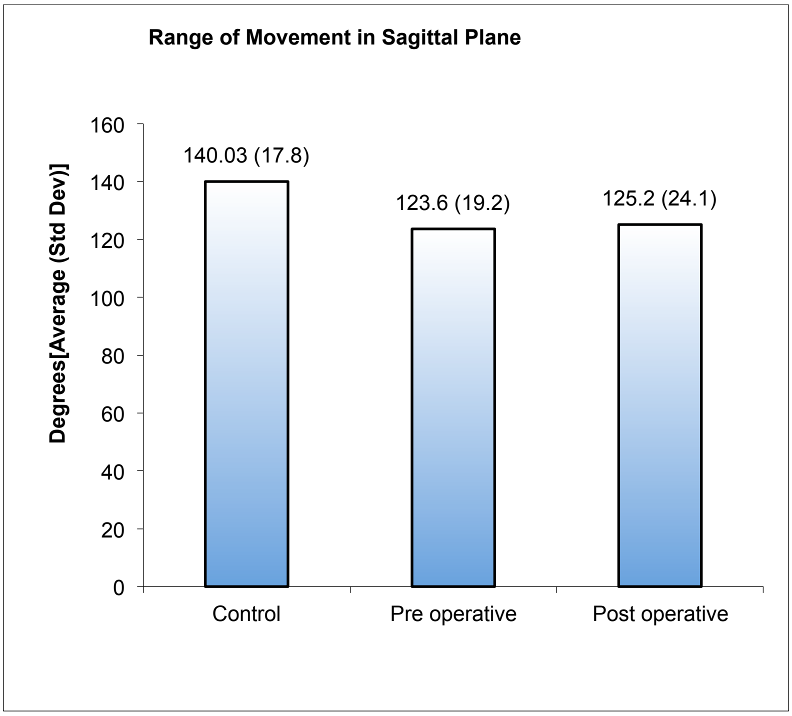


Table 5: Forward Flexion

	Range of Movement in Sagittal plane
Controls versus Pre operative	0.330
Controls versus Post operative	0.396
Pre operative versus Post operative	0.992

p values (ANOVA; Posthoc Tukey)

6.1.4 Circumduction

As subjects' took their arm through a circumduction motion, a graph was plotted depicting the "composite span" of the shoulder joint complex movements in the sagittal plane. There was a statistically signicant reduction in the area contained within this trace in the pre-operative group with instability (n=5) as compared to asymptomatic controls (n=9). There was a non significant trend towards an increase in the area covered after surgical input (n=5) (Figure 21, Table 6). A collection of circumduction graphs obtained in controls and patients appended (Appendix j)

Figure 21: Area within the graph during circumduction.

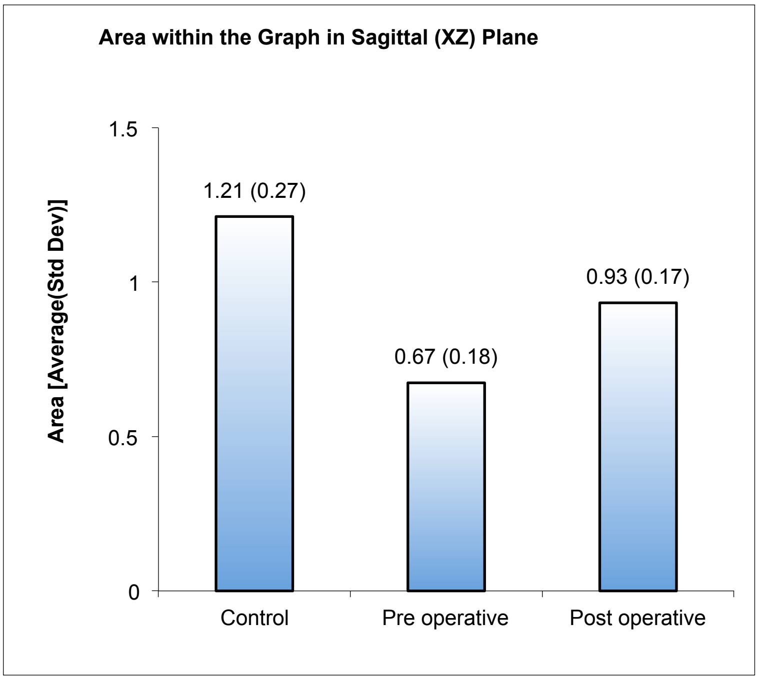


Table 6: Circumduction

	Area within the graph in Sagittal (XZ) plane
Controls versus Pre operative	0.002
Controls versus Post operative	0.110
Pre operative versus Post operative	0.214

p values; ANOVA; posthoc tukey

6.2 Comparisons between tasks

A comparison was made between the average ranges of motion achieved during abduction in the frontal plane versus those achieved during abduction in the scapular plane. There was no statistically significant difference between the average range of motion achieved either during abduction in the frontal plane or during the scapular plane in controls (n=9). However, in patients with recurrent instability of the shoulder (n=5) there was a statistically significant reduction in the overall range of motion during the abduction in the frontal plane as compared to the scapular abduction (Figure 22, Table 7).

Figure 22: Comparison of abduction during arm movement in frontal versus scapular plane (Controls and patients)

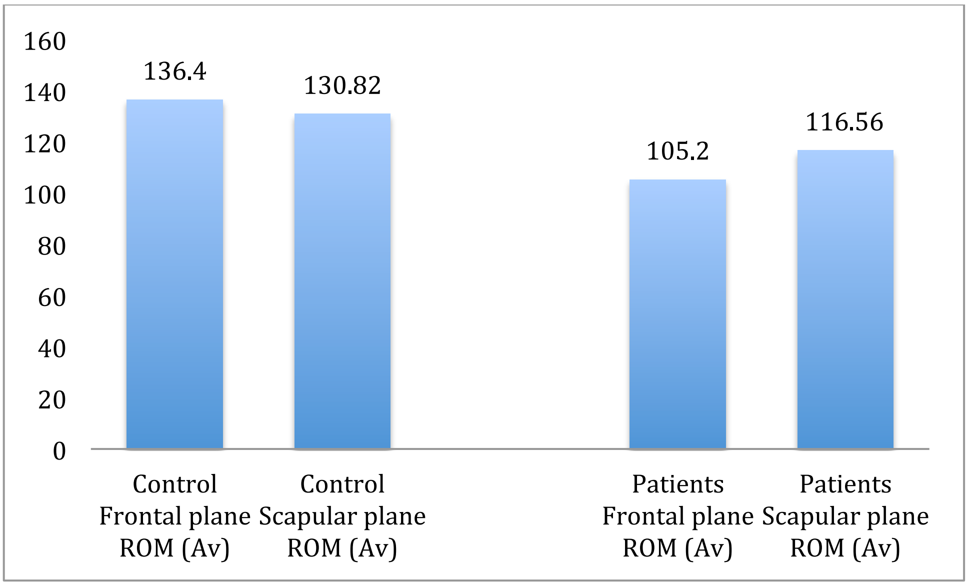


Table 7: Comparison of ROM between frontal plane abduction and scaption

Frontal vs Scaption (Controls)	0.14
Frontal vs Scaption (Patients Preoperative)	0.02

p values (paired t-test)

6.3 Clinical Scores

Oxford instability score and Constant score were obtained in all controls (n=9) and in patients on their pre-operative (n=5) and post-operative visits (n=5). The Oxford instability scores obtained in individual subjects and the individual subcomponent scores are presented in the Appendix k. There was an overall improvement in the Oxford instability score following surgical stabilization and rehabilitation, suggesting that this score was responsive to change following surgical stabilization. (Figure 23, Table 8).

Figure 23: Changes in the Oxford Shoulder Instability Score

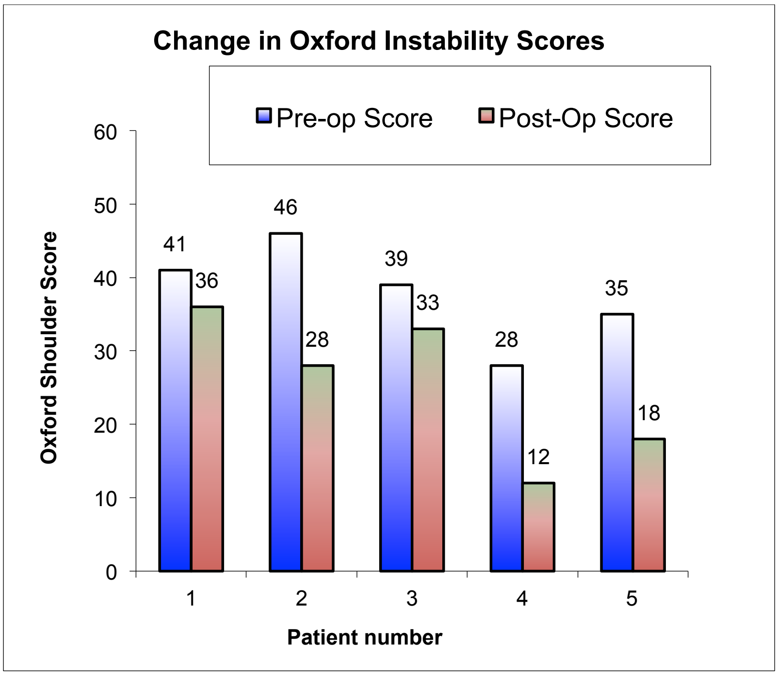


Table 8: Changes in the Oxford instability score

Oxford instability Shoulder score Pre operative versus Post operative	0.011

Paired test; p value

The Constant score is a popular score used in shoulder conditions and research and has patient reported and clinician assessed domains. Individual scores obtained by the subject are provided in the appendix k. Even though, there was a trend towards improvement in the Constant scores after surgical stabilization, there was no statistically significant difference in the scores before and after surgery, suggesting that the Constant score was not sensitive enough to pick up the differences between the two groups (Figure 24, Table 9). Constant scores of individual subjects and the subcomponents are listed in Appendix k

Figure 24: Changes in the Constant Score

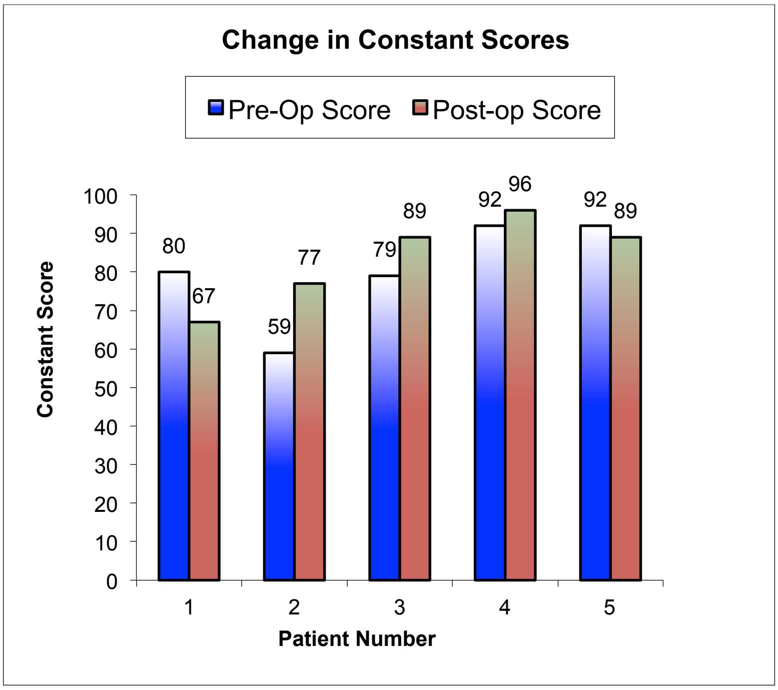


Table 9: Changes in the Constant score

Constant score Pre operative versus Post operative	0.58

Paired test; p value

6.4 Summary of results

Table 10: Summary of changes as compared to controls.

Red indicates a significant changes from control, whereas blue indicated a non-significant change with respect to controls.

	Control (n=9)	Pre-operative (n=5)	Post-operative (n=5)
Abduction coronal (Jt Angle)	136.4	105.2	112.3
Abduction scapular(Jt Angle)	130.8	116.5	121.7
Forward flexion (Jt Angle)	140.03	123.6	125.2
Circumduction (area within the graph)	1.21	0.67	0.93

In patients with anterior instability, the range of movement of the shoulder during abduction in the coronal plane and the area covered by the circumduction graph showed a significant reduction compared to controls. There was no significant difference in the range of motion when the arm was abducted in the scapular plane or during forward flexion. Surgical stabilization failed to influence a significant change in range of motion in the postoperative group (versus the preoperative group) in any of the kinematic parameters tested. There was a significant difference in the clinical scores between the control group and the patients with anterior instability. The Oxford instability scores demonstrated a significant improvement after surgical intervention, whereas the Constant score did not.

Chapter 7. Discussion

7.1 Objectives of the study.

7.1.1 Kinematics of unstable shoulder complex versus controls.

The first objective of this present study was to describe the kinematic characteristics of the shoulder joint complex in patients with recurrent anterior instability of the shoulder and compare it with controls. Despite the existence of a difference between individual patients, there were differences noted between the two groups as a whole. On average, the range of abduction as the shoulder was abducted in the frontal plane was limited in the patients with anterior instability (p=0.002). No statistically significant restriction of abduction was seen when the shoulder is abducted in the scapular plane(p=0.075). It has been proposed that the abduction in the scapular plane is a pure of movement as the scapula lies at approximately a 30-degree angle to the frontal plane of the body{Lockhart, 1930}. Hence abduction in the frontal plane really represents a combination of abduction (in scapular plane) and extension (in the scapular plane). Anterior instability of the shoulder typically manifests during abduction and extension of the shoulder. In fact apprehension in abduction and extension forms the basis of the commonly used "apprehension sign" for shoulder instability{Rockwood and Matsen, 2010}. This current study revealed more significant restriction of abduction in frontal plane versus scapular plane (105 vs. 117 degrees; p=0.02) in patients with instability. This can be explained by the apprehension experienced by the patients during the terminal range of movements. It was notable that there is no such difference between frontal versus scapular plane abduction in controls (136 degrees vs. 131 degrees; p=0.138). It is reasonable to suggest that it is therefore important to study the movement of abduction in both the scapular and the frontal plane. It is likely that the size of this difference in these two movements could serve as a sensitive biomechanical marker in further studies.

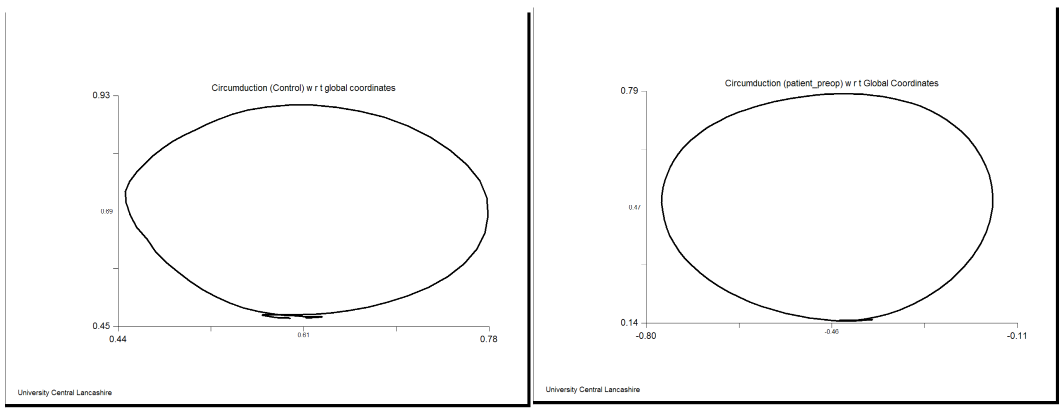
It was also found that there is no statistically significant difference in the sagittal plane range of motion during forward elevation in patients with shoulder instability as compared to controls (124 degrees vs. 140 degrees respectively; p value 0.13). Forward elevation does not place the humeral head in a position of instability hence avoiding apprehension and this could explain the small difference in range of motion during forward flexion. Any kinematic study or clinical test looking at forward flexion, as a possible task to investigate shoulder instability is unlikely to detect any significant differences.

The above three tasks have been commonly used commonly in various kinematic studies investigating a range of shoulder disorders, including frozen shoulder, instability and impingement{Vermeulen et al., 2002}{McMahon et al., 1996}{Hallstrom and Karrholm, 2009}{Matias and Pascoal, 2006}{Ogston and Ludewig, 2007}{Michiels and Grevenstein, 1995}{Sugamoto et al., 2002}{Karduna et al., 2001}{de Groot et al., 1998}. Most of these studies have not specifically looked at differences between individual movments {Vermeulen et al., 2002}{McMahon et al., 1996{Michiels and Grevenstein, 1995}{Sugamoto et al., 2002}{Karduna et al., 2001}{de Groot et al., 1998}, and only one study has reported that there is no difference between these individual tasks {Ogston and Ludewig, 2007}. Although these simple movements form the basis for understanding the more complex task, they do not represent the average complexity of the tasks the shoulder joint has to perform every day. Only with the advent of advanced motion analysis systems, has it been possible to study such complex movements as a golf swing{Mitchell et al., 2003}. One would be able to integrate movement analysis in clinical decision-making only when complex tasks performed in real life can be assessed and analysed. Hence, the circumduction movement was used as a task in the present study as it is likely to be sensitive to change in pathology, given its composite nature, with components of angulations and rotations in various planes combining to produce the resultant.

The kinematic interpretation of the circumduction movement is complex. The possibility of using joint angles to describe this movement was explored but the changes in the Cardan sequences during the task made any useful interpretation difficult. One could also consider using the helical angle or screw displacement axis to describe this movement but it is difficult to interpret its clinical significance and is hence unlikely to be taken up by the clinicians. Clinically the movement in circumduction is often used and observed in the same plane. A scientific interpretation of this observation could be the path traced by the elbow in the sagittal plane, thereby producing an area described by the circumduction movement. The area covered within this imaginary "trace" represents the composite measure of the span of the circumduction movement. As different subjects naturally would have different arm lengths, the dimensions of this trace was normalised by describing it as a proportion of arm length rather than using metric measures. It is important to appreciate that this trace is referenced to the subjects' trunk coordinate system rather the global co-ordinate system. Using this measure avoids the use of multiple complex Cardan sequences for one task and provides a tangible concept of area, which is representative of the span of shoulder range of movement.

When the circumduction movement trace is obtained with reference to the global coordinate system (Laboratory coordinates), an almost circular pattern is observed. This trace looks very similar, both in patients and controls (Figure 25). This trace represents movements not only at the shoulder complex but also the torsion of the trunk. This graph represents what would be apparent to an observer on casual examination of the circumduction movement. A movement analysis system, which would reference to the global coordinate system, would be unable to pick up any perceptible difference in the shape of these traces.

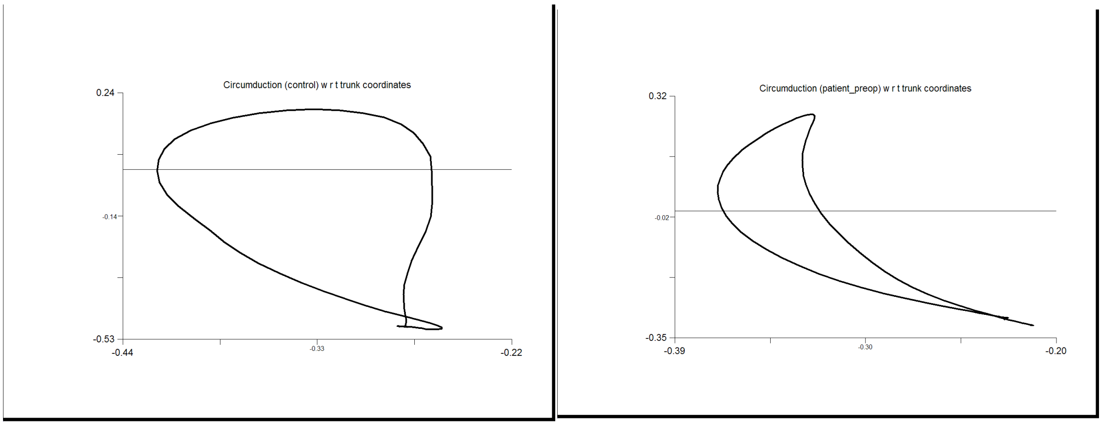
Figure 25: Shape of the circumduction trace referenced to the global coordinates.



a) Control b) Patient

When the circumduction trace was obtained referenced to the trunk coordinate system, the shape of the graph was different (Figure 26). In this figure both the control and the patient are performing a right arm circumduction with the left part of the trace being anterior, and the right side of the trace being posterior. It is interesting to note that the shape of the trace was significantly different between the controls and the instability group. The typical trace in a control was an oval shape, with hardly any extension noted. On the other hand, patients with shoulder instability produced a trace, which covered a much smaller area, producing a "squashed" shape. It was found that the area within the graph in the patient group was only 55.37% of the control group (1.21 vs. 0.67; p value 0.002). This indicates a reduced overall span of the circumduction which is likely to be part apprehension to extreme abduction / external rotation and part physical restriction of range of motion. It is evident from the shape of the trace that the abduction and extension is affected the most in this form of instability. It is interesting to note that even in the controls there is hardly any extension at the shoulder (with reference to the trunk) during the circumduction movement. The change in the shape and loss of area of this graph in shoulder instability can be explained by the apprehension experienced by patients in the extremes of external rotation, extension and abduction, thereby “shaving off” the postero-superior part of the trace. Although individual traces varied in quality between patients, the loss of postero-superior part of the trace was consistent. Controls consistently produced a similar looking trace. A collection of all the circumduction traces obtained in the subjects and controls is presented in Appendix j.

Figure 26: Shape of the right shoulder circumduction trace referenced to the trunk coordinates.



a) Control b) Patient

The function of the shoulder joint is to place the arm in a functional hemisphere so that the hand can reach appropriately, with the elbow acting as a caliper. The circumduction task is a representation of this function of the shoulder joint complex. A combination of shoulder and trunk movements produces the resultant circumduction. When trunk torsion is isolated the movements occurring at the shoulder complex are evident. The trace obtained is clearly not a complete circle (Figure 26). One of the striking features of the trace in controls is the lack of any significant extension beyond the starting position (This starting position is represented by the most inferior point of the graph). There is very little active extension of the thoracohumeral joint during functional tasks. This was seen in all the traces of the subjects in the control group.

The other striking feature was the change in shape seen in the circumduction trace in patients with anterior instability (Figure 26). The change can be explained based on the understanding of anterior instability. One of the clinical tests of assessing patients with anterior instability is the “apprehension test”. This involves placing the shoulder in abduction, extension and external rotation. If the test is positive, the subject actively resists this position due to apprehension, which is a natural reaction to prevent the shoulder from dislocating. The loss of extension and abduction seen in circumduction traces with anterior instability is therefore a “dynamic equivalent of the apprehension test”. This also explains the decreased area covered by the trace, which is seen in cases of shoulder instability. One might consider using the apprehension test itself as a kinematic task in further studies assessing instability. It is however a measure which would be difficult to standardise as the degree of abduction and external rotation and subject positioning (supine versus standing) when performing this test varies significantly between individuals and clinicians.

The circumduction movement is a composite movement encompassing all elements of movements at the shoulder joint complex including abduction-adduction, flexion-extension and external-internal rotation. Whereas on one hand it represents a single movement, which is sensitive to picking up pathologies, on the other hand changes in the shape of the circumduction graph would not be specific to the lack of a certain type of movement. Hence, even though one can deduce that the change in the shape of the circumduction graph is likely to represent a lack of external rotation / abduction in the “apprehension position” (as discussed above), this is not confirmatory of the cause. Lack of specificity is hence a price, the circumduction movement graph has to pay for being sensitive. Further work to assess this compensation could look at assessing trunk rotation with respect to the laboratory coordinates during circumduction. Increased trunk torsion in unstable shoulders during circumduction would indirectly indicate the change of the circumduction trace is due to a lack of abduction / external rotation at the shoulder joint complex, especially with the circumduction traces appearing similar in controls and afffected shoulder when referenced to the lab coordinates (Figure 25).

Patients with instability have apprehension during the terminal degree of abduction and external rotation. Throwing athletes are particularly predisposed to instability as they frequently place their arm in this position. The throwing action itself, has never been investigated during any kinematic study, although Mitchell et al studied the kinemtics of the golf swing which a "physiological movement" {Mitchell et al, 2003}. For the purposes of this study, the throwing action was considered as a possible task to assess, expecially because it is likely to be affected in instability. The throwing action is difficult to standardize, as different subjects would place their arms in varying degrees of abduction and achieve varying degrees of trunk torsion during the cockup stage of throwing. The velocity of the throwing action is likely to be variable across subjects. All there factors would be to a large extent individual preferences (of subjects) and difficult to control. Finally, the cardan sequence changes occuring suring the throwing action make interpretation / analysis of this action challenging. For these reasons, the throwing movments was not investigated inthis study.

7.1.2 Effect of surgical stabilization on kinematics

The second objective of the study was to determine if surgical stabilization and post-operative rehabilitation has an influence on the kinematics of an unstable shoulder. Effect of intervention on kinematics has been investigated by Vermeulen et al {Vermeulen et al., 2002}, where they assessed patients with frozen shoulder before and after physical therapy and noticed that three dimensional kinematic recording was sensitive enough to detect improvement. It has also been possible to define kinematic markers which can predict the successful outcome following physical therapy in frozen shoulder {Yang et al., 2008}. They identified two kinematic variables which could be used to predict a higher chance of success following physiotherapy for frozen shoulder. Scapular tipping and humeral rotation measured in their study were found to be significant factors in frozen shoulder. They demonstrated that scapular tipping >8.4 degrees during arm elevation and external rotation >38.9 degrees during hand to neck movement could predict a higher chance of success of therapy. The only study investigating the kinematic changes after surgical stabilization was reported by Paletta et al {Paletta et al., 1997}. They used radiographs to investigate changes following surgical stabilization in instability. They concluded that even two years following open stabilization, abnormal glenohumeral-scapulothoracic kinematics persisted. This relates to the findings in the present study where despite surgical stabilization and formal rehabilitation, kinematics were not comparable to the control group. The present work did not aim to identify kinematic markers influencing treatment of shoulder instability. However, future research could be directed towards investigating circumduction and abduction in the coronal plane as possible markers which would potentially influence success of treatment, given the findings of this study.

Rehabilitation after surgical stabilization plays an extremely important role in restoring function. Athletes are allowed to return to contact sports after a period of 3 to 6 months after stabilization surgery. At least 6 months (average 10.2 months; Range 7 to 14 months) of rehabilitation were therefore allowed following surgery before the repeat measure was taken to allow full recovery. Even though the abduction in the coronal plane had changed from 105 degrees to 112 degrees, it was not statistically significant (p= 0.673). If was therefore unsurprising that there remains a significant difference between this measure and that in the control group (p=0.012). Similarly no significant difference in the range of movement in the preoperative and post-operative period when abducting the arm in the scapular plane (p=0.733) was seen. It is however interesting to note that there is no significant difference in the range of motion in the postoperative period as compared to the controls (p=0.313). This apparent discrepancy between changes in range of motion in the scapular versus the coronal plane movement is possibly because the abduction movement in the frontal plane is a relatively more sensitive marker for this condition. Abduction in the frontal plane does involve an element of "extension" relative to the plane of the scapula. This extension in terminal abduction would be the apprehension position in shoulders with instability. Therefore, abduction in the coronal plane is lost in instability, even when abduction in the scapular plane remains unchanged.

The range of motion during forward elevation i.e. abduction in the sagittal plane did not change significantly after surgery (p value= 0.992), nor did it differ in value from the control group (p value=0.396). This lends support to the earlier argument about forward flexion being an insensitive marker for picking up kinematic changes in shoulder instability. The likely explanation for this finding is that during forward flexion, the gleno-humeral joint is not placed in the position of instability; hence there is no secondary apprehension or restriction of movement. As there is no significant loss of forward elevation in instability per se, any effect of surgery and rehabilitation is clearly not seen in this movement.

It is interesting to note that the circumduction trace obtained in patients after stabilization surgery is barely distinguishable from controls and the pre-operative traces, when referenced against the global coordinate system (Figure 27). The trace is the resultant of trunk torsion along with shoulder movements. Clearly trunk torsion compensates for the restriction in circumduction due to shoulder pathology. However, when the humeral circumduction is traced against the trunk co ordinates, the shape of the graph appears different from controls (Figure 28). This confirms the sensitivity of the circumduction movement relative to the trunk coordinate system in picking up the difference. This emphasizes the importance of taking into consideration trunk movements rather than just humeral movements for measuring such motion. The second feature observed at this stage is that although individual traces in the post-operative group do differ from each other, none of the traces were restored to the "D" shape of the controls. The area contained within the graph for the circumduction movement had not changed significantly in the post-operative assessment (p value= 0.214). These observations imply inability of current therapy to restore shoulder kinematics.

Figure 27: Shape of the postop circumduction trace in a patient with right shoulder instability using Global co-ordinates as reference

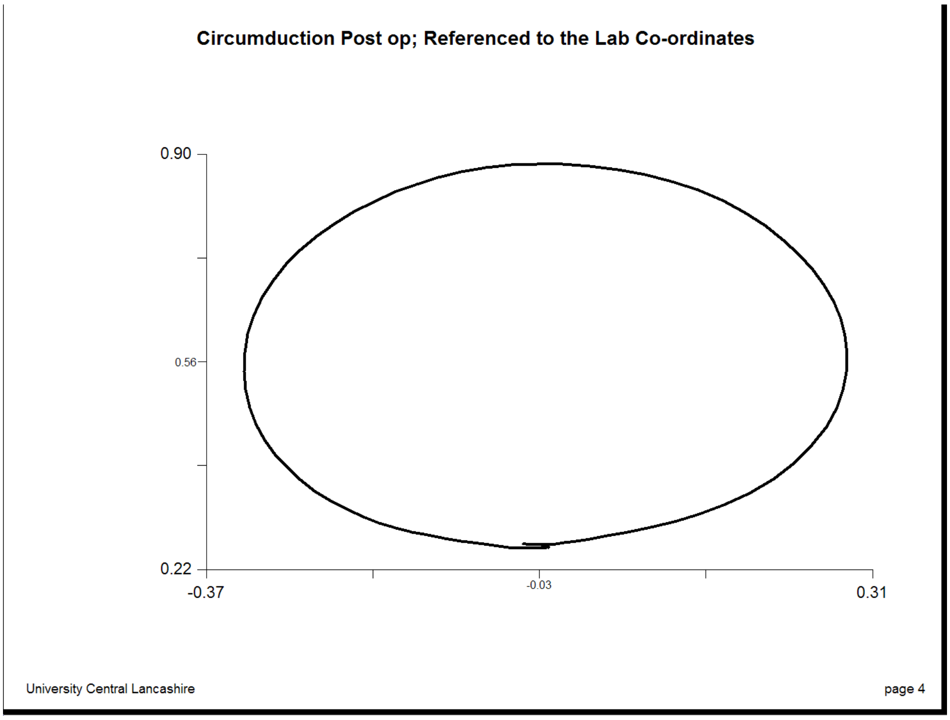
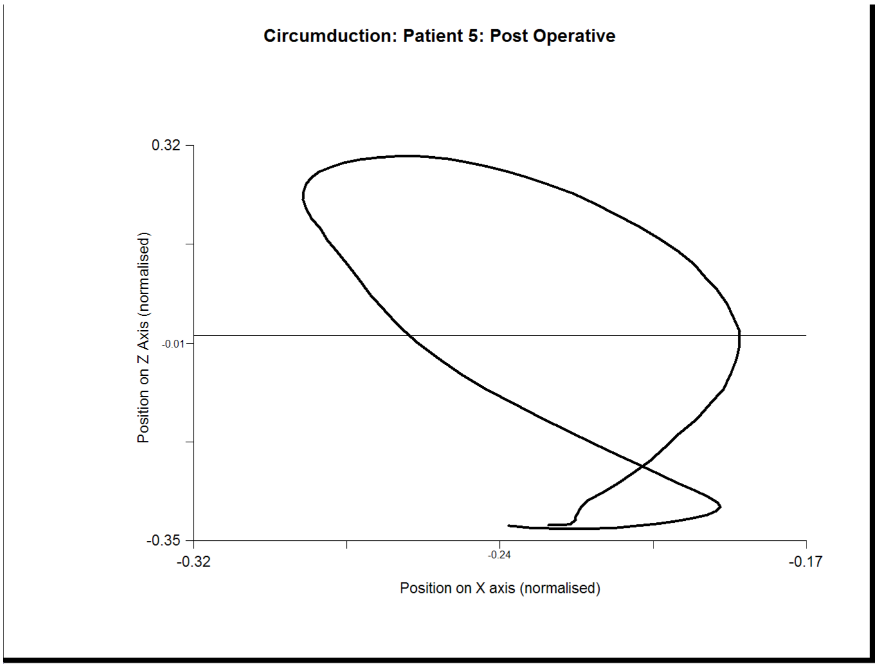


Figure 28: Shape of the circumduction trace in a patient with right shoulder instability after surgery



In summary, surgery does not restore kinematics. Even though the kinematics change in the post-operative period, it was not possible for it to be restored after surgery and rehabilitation. Recent work on classification of shoulder instability has suggested that patients fall into various locations within the polar groups of structural defect, atraumatic dislocations and muscle patterning{Lewis et al., 2010}. Their study bears from the observation that patients with shoulder instability do not always fall in strictly defined brackets of anatomical defects or hyper laxity or muscle patterning but are usually a combination of a varying degree of each of these three elements (Figure 5). Interestingly compensatory muscle patterning occurring over a period of time in a structurally unstable shoulder may possibly shift the position of a particular patient within the triangle. The present study adds evidence to understanding of the natural history of traumatic shoulder instability, based on the background of this classification. Hence, the inability to restore kinematics following therapy despite absence of re-dislocation (and correction of the structural defect) is likely to be explained by development of abnormal muscle patterning as a compensatory mechanism. Whether early stabilization of the shoulder{Handoll et al., 2004} following a single episode of dislocation, as is practiced by some surgeons, would prevent development of compensatory muscle patterning and restore kinematics would be a subject of a very interesting future study. The second observation from the present study is that there was no significant loss of range of motion following modern arthroscopic techniques for shoulder stabilization. This is clearly an important advance as compared to the non-anatomical techniques of shoulder stabilization like the Putti Platt procedure where the subscapularis was double breasted, resulting in significant loss of external rotation after surgery.

7.1.3 Effect of surgery on clinical scores.

The primary outcome used by a majority of shoulder surgeons after stabilization remains absence of re-dislocation. This is obviously the most important reason for which patients with recurrent dislocation undergo surgery and clearly would be of paramount significance. There was one re-dislocation in the five patients in the series, who underwent further revision stabilization. Following the revision surgery, he had no further episodes of dislocation. All patients felt that the main problem they were having before surgery was resolved (A question posed to subjects; Appendix i). Despite the absence of re-dislocation two patients expressed that they were satisfied with reservations. There is no direct relationship between patient reported satisfaction and absence of dislocation. It is therefore common practice to use outcome scores to compare and evaluate results following intervention.

The Oxford instability score demonstrated a significant change following surgical stabilization ($p = 0.011$) although the Constant score failed to pick up any significant difference ($p = 0.58$). The Oxford instability score was designed to be used specifically for patients with shoulder instability{Dawson et al., 1999} and has been recommended for use as such following rigorous scientific testing{Wright and Baumgarten, 2010}. The present study confirms its responsiveness to change. On the other hand, even though the Constant score{Constant and Murley, 1987}{Constant et al., 2008} continues to be used for shoulder instability{Wright and Baumgarten, 2010}, this study does not support its continued use in shoulder instability due to the absence of responsiveness to change in this study. The findings of this study are in agreement with various other previous studies in this respect{Conboy et al., 1996}{Bankes et al., 1998} who found this tool inappropriate for assessing shoulder instability.

Both the Oxord score and the Constant score were satisfacory for detecting the minimal clinically important difference (MICD) for shoulder pain related to the rheumatological desease before and after surgery {Christie et al., 2011}. The DASH score has been used to successfully investigate the change following treatment of anterior instability an MICD has been recorded following intervention{Brennan et al., 2010}. The MICD relevant to shoulder instability in context of the Constant score and the Oxford instability score has not been described. Future studies need to be directed towards investigating this.

Preventing further dislocations of the shoulder is the most important reason why patients would have surgery for recurrent instability. Re-dislocation would imply failure of treatment and hence enquiring about re-dislocation is important. Overall patient satisfaction following therapy is an important measure and although all the patients in the present series were generally satisfied, this tool remains a guide for assessing the overall experience of the patient. The present study demonstrated the superiority of the Oxford instability score over the Constant score in being more responsive to change. It is best to use a combination of patient satisfaction, re-dislocation and the Oxford instability score for evaluating the results of shoulder instability treatment.

7.1.4 Relation between clinical scores and kinematics.

There was a significant difference in the clinical scores between the control group and the patients with anterior instability (Constant score; p=0.03, Oxford instability score p=0.001; t-test, 2 tails; unpaired with unequal variance). This related well to the kinematic data in this study, which found a significant difference between range of motion while performing abduction in the frontal plane and also during circumduction. Both the Constant and the Oxford instability score seem to be valid to demonstrate this difference between asymptomatic shoulders and shoulders with recurrent dislocation.

There was a significant improvement demonstrated by the Oxford instability score following shoulder stabilization (p=0.011) although the Constant score failed to register any significant change (p=0.58). There was no significant difference between the pre-operative and post-operative kinematic data in all the tasks investigated. This could either imply that shoulder stabilization surgery does not significantly change kinematics, but could also mean that assessing tasks using this methodology is not sensitive enough to pick up the change.

Despite shoulder stabilization surgery, patients continued to demonstrate significant differences compared to the control group in terms of their Oxford score (p=0.042, t-test, 2 tails, unpaired unequal variance) or the Constant score (p=0.041, t-test, 2 tails, unpaired unequal variance). This remains consistent with the kinematics, as there remains significant difference in some tasks when values after stabilization surgery were compared with the control group. Both the clinical scores mirrored the differences in the kinematic data when used to compare difference between the control and the patients (whether pre-operative or post- operative). The Oxford instability score, however, was the most responsive to change following surgical input.

There has been no prior study comparing the changes in the outcome scores and kinematics in patients with shoulder instability. Fayad et al{Fayad et al., 2008} reported the relationship between kinematics in four shoulder pathologies (frozen shoulder, proximal humeral fractures, rotator cuff disease and arthritis) and an outcome score (DASH –Disability of Arm, Shoulder and Hand Scale). This study attempts to link kinematics with outcome scores and identified kinematic variables which have a significant affect on the variation of the outcome score. In the present study, both the kinematic and outcome scores have been investigated and the corresponding changes following treatment have been investigated. Along with other studies which have looked at correlating changes in kinematic variables with loss of function {Rundquist and Ludewig, 2005} {Lin et al., 2006}, the present study confirms that shoulder kinematics are sensitive enough to detect changes and variability in outcome scores.

There are four broad subcomponents of the constant score; Pain, activities of daily living, range of motion and strength. Maximum weightage is given to range of motion (40 points) followed by strength (25 points), activity of daily living (20 points) and pain (15 points). Individual subcomponent scores of the participants in the present study are detailed in Appendix k. Within the range of motion subdomain, 10 points each are given to forward flexion, abduction, external rotation and internal rotation. Three subjects with instability scored 10 points in the lateral elevation subcomponent and four scored 10 points in external rotation subcomponent (all controls scored 10 points each in these subcomponents). These subcomponent scores remained unchanged at 10 in three of these subjects after stabilization surgery. This failure to pick up a difference between controls and instability subjects represents failure to appreciate loss of abduction and external rotation even during formal clinical examination. Kinematics investigated in this study, especially abduction in the coronal plane and circumduction, however clearly demonstrate a significant difference. Clinical range of motion assessment is very similar to kinematic range of motion assessment with reference to the lab coordinates and the insensitivity of both has been demonstrated in this study.

7.1.5 Usefulness to clinical practice

In this study, the method of analyzing motion allows assessment of data in six degrees of freedom and reflects the dynamic nature of motion data. The movement of the shoulder joint complex was chosen because it is the composite movement rather than it's subcomponents, which is of primary concern to the patient. Also, it is presently not possible to capture the dynamic scapular movements using any noninvasive methods due to anatomical constraints and skin movement artifact. Even though implanted markers have previously been used to capture scapular movements{Hallstrom and Karrholm, 2009} the invasive nature of these studies essentially precludes them from being used in a clinical setting. This method of assessment has the potential of being used routinely in the clinical setting for decision-making in complex shoulder pathologies, as it is presently used (already) for gait analysis in cerebral palsy and stroke. It is therefore, hoped that this study may help inform new methods of analysis of shoulder motion, which may be useful in clinical decision-making.

The kinematic differences between patients with recurrent anterior dislocations versus volunteers with no shoulder pathology have been demonstrated. This difference is almost expected intuitively and the study describes the actual difference. What is interesting to note from this study is that despite surgery and rehabilitation, there continues to remain kinematic differences between the operated shoulder and asymptomatic volunteers. From previous work on shoulder instability{Lewis et al., 2010}, it is known that patients with anatomical deficits caused by shoulder dislocation develop muscle patterning behavior with time. It seems that it is this muscle patterning that prevents restoration of the kinematics. Although, it would in itself be insufficient reason to be operating on people earlier, these persistent kinematic differences do question the present clinical practice of allowing shoulders to develop recurrent instability prior to surgery. The subject of early versus late shoulder stabilization continues to be a subject of debate amongst shoulder surgeons presently. A study to assess kinematics following stabilization after the very first dislocation would be the logical next step to investigate this further.

7.2 Methodological considerations

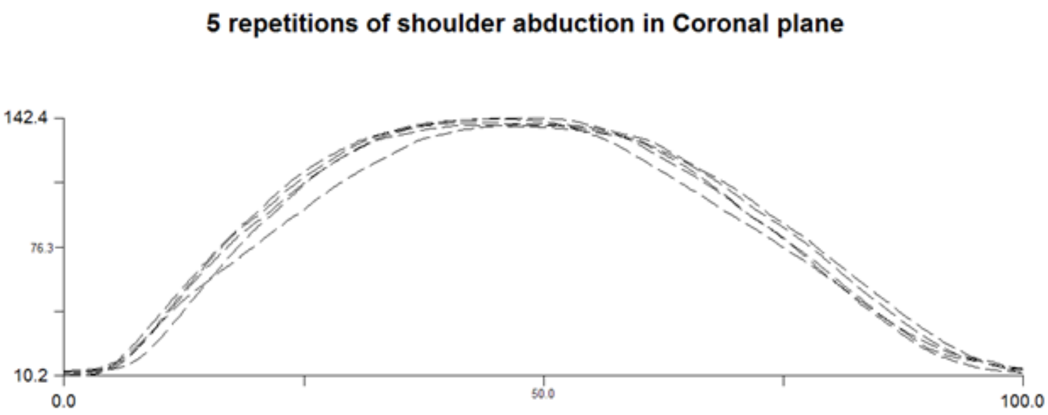
To the authors knowledge, there have been no other studies which have used a three dimensional motion analysis system for motion analysis of the shoulder complex, comparing it with patients with shoulder instability and investigating the effect of therapy. This system is commonly used in gait analysis and motion capture in lower limb pathologies{Gough and Shortland, 2008}. Mitchell et al{Mitchell et al., 2003} have demonstrated the use of a similar system in capturing the shoulder joint complex motion during a golf swing in amateur golfers. They used single markers on body segments rather than a cluster of markers, which decreases the quality of the data. Their work however remains an excellent demonstration of the usefulness of this system for large-scale clinical application as they used motion analysis on 65 golfers to assess the quality of their golf swing. It is important to subject a new method of shoulder motion capture to rigorous scientific testing prior to routine use in clinical decision making. The present study demonstrates the use of a non-invasive motion tracking system, which can record dynamic motion in six degrees of freedom and can potentially be used routinely for motion analysis of the shoulder joint complex.

7.2.1 Assessment of methodology

One of the measures which is used to assess the validity of a tool is internal consistency. This checks if the items within the tool measure a single underlying concept. The items, or tasks, used in this study were a combination of simple and complex tasks, all of which aim to measure the concept of “range of motion”. Simple tasks of abduction, abduction in the scapular plane and flexion are commonly used measures in clinical practice to assess range of motion of the shoulder. Circumduction is a composite movement that measures a combination of flexion, abduction, extension and rotations of the shoulder joint complex. Although is not possible to describe a single “range of motion” figure for the circumduction, the concept of measuring the area with the circumduction manoeuver does conceptually signify a range. In fact, the graph clearly demonstrates the effect of shoulder pathology in “shrinking” the area within the graph, thereby implying a reduced range of motion. All tasks used in the method of analysis therefore attempt to measure a single underlying concept of range of motion of the shoulder joint.

The other measure used in checking the validity of an outcome tool is reproducibility. This is the ability of the tool to yield similar results in repeated trials. Each movement was recorded using a set of 5 repetitions each. It was found that very similar graphs on each successive trial were obtained. Figure 29 demonstrates the typical graph obtained during shoulder abduction in the coronal plane with each dotted line representing a single trial. A "tight" graph with each line falling close to each other represents high reproducibility implying that similar traces are obtained in successive trials. It seems therefore that this method of motion capture and analysis is reproducible.

Figure 29: Comparison of traces during multiple repetitions



Validity of a tool determines whether it does what it proposes to. The motion analysis system hereby used aims to detect differences in shoulder kinematics. It has been demonstrated that it can be used to detect differences and changes in the range of motion. A difference between the kinematics and range of motion in certain tasks is demonstrable between the unstable shoulders and asymptomatic shoulders.

Sensitivity to change of a tool is an ability to detect changes in the clinical condition over time. Shoulder kinematics was measured before and after shoulder stabilization surgery. No statistically significant difference was observed between the pre-operative and post-operative kinematic data. There however remained some difference between the post-operative data as compared to the control. This lack of change following intervention could either be because of ineffectiveness of surgery to restore kinematics or due to the insensitivity of the tool to detect change. The fact that the Oxford instability score had improved significantly in the post-operative group, suggests that the latter may be the case. This remains conjectural and hence it is not possible to conclude regarding this tool's responsiveness.

Assessment of shoulder kinematics presents challenges in setting up the motion analysis laboratory. In contrast to lower limb gait analysis, where the camera cluster can be placed close together covering a relatively small volume in space close to the floor, in assessment of shoulder movements a much larger volume of the laboratory needs to be covered. This area to be covered is to be located higher than the ground level. In defining this space, the cameras capturing the motion have to placed on higher mounts. Also, these have to be placed sufficiently away from each other to be able to capture the full range of shoulder movements. Calibration of this space also needs to be performed using the calibration tools above the ground level covering the upper limb range of motion. The markers placed on the limbs were rigid clusters taped onto limbs. There was no movement between individual markers during limb movements dur to the rigidity of the base plate. The trunk markers, however were placed individually usually double sided tape. During the early stages of the study, one subject's data in the control group had to be discarded as the lower trunk markers dropped off during the trials. Further to this, the individual markers were placed on an elastic belt rather than on the skin directly. This prevented the recurrence on such an error.

As the initial data was captured onto the motion analysis software, the indivdual markers were assigned to their respective places on the body segments. Any marker visible for less than 90 percent of the time was not used in the analysis. The software allows gapfilling of trajectories and if the marker was present for more than 90 percent of the entire duration, this software function was used. All individual marker traces were manually checked at the time of gapfilling to ensure smoothness and appropriateness of the trace for this generally very small proportion of the trajectories. There were a total of five trials used for every task for each subject. Certain movement trials could not be used as the recording started too late or ended too early. These incomplete movement trials were not used for analysis and are listed as a log in Appendix h. Skin Movements can create errors when any skin based markers are used to capture kinematics. As discussed, capturing scapular movements is associated with a high chance of skin movment artefact. This skin movement artefact is of a much smaller magnitude when assessing limb and trunk movements, however does remain a source of error compared to using bone markers. This is a source of error which is an essential trade-off against ethical issues using implanted bone markers.

The use of the area covered by the circumduction movement not only produces an outcome which is a tangible measure of area which is easy to represent in quantitative and graphical terms, but also obviates the need to take into account changes in cardan sequences occuring during these cardan sequences. Screw displacement axis or helical angle is another measure which can be used to describe complex movements such as circumduction. This takes into account angular and rotational components of a movement to produce a single value. It is, however, difficult to infer a clinical siginificance and implication from this measure and hence limts it's application in clinical settings is limited.

7.2.2 Role of ISB recommendations:

The International Society of Biomechanics (ISB) proposed a definition of a joint co-ordinate system (JCS) for the shoulder in 2004, so as to produce a standard for the local axis system{Wu et al., 2005}. They have also provided recommendations on the appropriate Cardan sequences. The International Shoulder Group (ISG) has supported this initiative. The purpose of their proposals is to encourage and facilitate communication among researchers and clinicians. They have proposed that the Y-X-Y Cardan sequence be used when measuring motion for the humerus relative to the thorax. This translates to ZYZ sequence in the motion analysis model used in this study. It was found that when using the ISB recommendations for "abduction" and "abduction in scapular plane" movement, the graphs obtained were representational of functional movements. However, when "forward flexion" was being analysed using the ISB recommended sequence, this produced graphs which were not clinically relevant. By a process of trial and elimination the XYZ (read as ZXY for ISB nomenclature) were found to be the most suitable sequence to be used for forward flexion. ISB proposed this nomenclature and set of Cardan sequences for use in upper limb motion analysis. This is an important step forwards to standardise reporting and analysis. The use of these recommendations should be judicious, though, as in this study the same sequence was not usable for all tasks. These recommendations should therefore be used and interpreted cautiously.

Recently, reference positions of the shoulder joints recommended by ISB were investigated by Jackson et al. They recognised that the reference position for the shoulder were not standardised in the ISB recommendations and could be a source of variation in results. Having investigated arm elevations using skin markers, they have proposed standardized reference configurations for the shoulder joint which produce more clinically relevant results{Jackson et al, 2012}. Future studies investigating shoulder kinematics would benefit form considering these receommendations. The use of circumduction movement in the way decribed in the study presented here, avoids this source of error and would serve as a preferred task to assess shoulder motion.

7.3 Controversies in shoulder kinematics

Movement analysis of the shoulder has been challenging. Significant advancements of shoulder kinematic research has been hampered by various controversies and concepts related to the shoulder complex. This is partly owing to the complex nature of the shoulder joint complex and partly because of the predominant focus on scapular movements.

7.3.1 Scapulohumeral rhythm

Scapulo-humeral rhythm is the complex movement of the humerus, clavicle and the scapula. Scapulo-humeral rhythm has been the focus of much research over the last few decades following Codman's initial description{Codman, 2010}. The predominant focus of much of the research in this area has pertained to the relative contribution between the scapulo-thoracic and scapulo-humeral subcomponents. The ratio of scapulo-thoracic to glenohumeral joint movement during the task of abduction has been reported differently by various authors. Initially it was though that the predominant movement in the first 90 degrees of arm elevation was glenohumeral, followed by scapulo-thoracic{Rockwood and Matsen, 2010}. Later, the overall gleno-humeral to scapulo-thoracic ratio of 2:1 became popular{Inman et al., 1996} More recently, invasive bone markers have been used to suggest that this ratio is closer to 1:1{Hallstrom and Karrholm, 2009}.

It has also been suggested that this ratio is not constant and varies with the degree of arm elevation. Some have suggested a 4:1 glenohumeral to scapulothoracic ratio in the first 25 degree{Poppen and Walker, 1976} while others have reported as 1:7 ratio in the first 25 degrees{Doody et al., 1970}. There is therefore no consensus regarding the pattern of non-linearity. Even though it is clear that the shoulder complex movements are a resultant of a combination of scapulo-thoracic and scapulo-humeral movements, the ratio and relative contribution of these components through the arc of abduction is debatable. Infact there is great disagreement between various authors. The most likely reason for this significant discrepancy between various researchers describing different ratios of scapulo-humeral rhythm is due to difficulty in tracking the scapular movements accurately. Even thought the ratio of 1:1 obtained using bone markers by Hallstrom et al{Hallstrom and Karrholm, 2009} seems to have the most robust methodology and is likely to be the most accurate, ethical concerns of this invasive technique preclude it's widespread use in researching other shoulder disorders.

7.3.2 Tracking Scapular movements

There has been a great deal of interest in studying the motion pattern of the scapula. However, due to its unique shape, position and mobility it has been difficult to study it's motion in vivo. Use of X rays{Poppen and Walker, 1976} and goniometry{Doody et al., 1970} produce motion data in two dimensions. Bone markers{Hallstrom and Karrholm, 2009} produce accurate positioning of the scapula but remain restrictive in use due to it's invasive nature. Open MRI{Graichen et al., 2001} produces static images and demand prohibitive cost and resources. Jigs with electromagnetic sensors allows tracking of the scapula have been used statically using a clamp applied on palpable bony landmarks{Meskers et al., 1998} and dynamically using a sensor directly applied to the acromion using double sided tape{McQuade and Smidt, 1998}. The reliability of these methods have been assessed against simultaneous recording of scapular motion using bone pins in healthy volunteers{Karduna et al., 2001}. Both the scapular jig and the acromial sensor were found to produce accurate data below 120 degrees of elevation. They also found errors when this method was used in (the only patient with) impingement syndrome. They agree that it is not possible to rule out exaggerated skin motion errors in patients with shoulder pathologies. There is also a possibility that data obtained using these scapular markers would be compromised in obese subjects. De Groot et al performed a study to validate the assumption that multiple static recordings can be interpolated to produce a continuous data set. They suggested that using an X-ray video method, the use of multiple static images was reliable at low movement velocities only{de Groot et al., 1998}. Recording accurate scapular movement using tracking devices therefore remains unreliable in overhead movements and shoulder pathologies and untested in subjects who are well covered in adipose tissue.

7.3.3 Concept of the shoulder joint complex

Clinical assessment of the shoulder is primarily an assessment of the humero-thoracic movement and the function of the shoulder requires movement at the sterno-clavicular, acromio-clavicular and the glenohumeral joint components. It was clear even by 1884 that movements occur in various components over its range of motion, and a combination of these movements is seen as the "resultant" {Cathcart, 1884}. With the advent of the radiographs, it was confirmed that in raising the arm from the dependent to the vertical position, there is a continuous movement not only at the gleno-humeral joint, but also at the acromio-clavicular, the scapulo-thoracic and the sterno-clavicular from the very beginning to the very end of the action{Lockhart, 1930}. It is pertinent to understand that the sterno-clavicular, acromio-clavicular, scapulo-thoracic and the glenohumeral joint combine to form one functional unit; the shoulder joint complex.

A vast multitude of research done recently has been designed to capture either the glenohumeral component of this movement or attempted to capture the scapular component. Whilst there is indeed no doubt that understanding the movements occurring in the subcomponents is important, it produces a great degree of difficulty in carrying over the results of such research into clinical practice. Registration of movement of the scapula is difficult using externally applied markers due to skin movements. Scapular movements can only be studied using either invasive markers {Hallstrom and Karrholm, 2006} or multiple static measurements{Vermeulen et al., 2002}{Graichen et al., 2001}. It is hence necessary to design and conduct a research experiment to explore the composite shoulder complex movement, so that results can be correlated with clinical assessment and hence applied to clinical practice. In this study, therefore the clinically relevant shoulder joint complex movements have been investigated rather than concentration on scapular contributions. In cases of shoulder pathology, such as instability, the trunk compensates for the restriction in the shoulder joint complex mobility. This work drives the focus on this trunk compensation. It underlines the importance of dealing with issues related to trunk compensation and core stability when designing physiotherapy and rehabilitation programmes in shoulder instability.

7.3.4 Humeral Rotation

It has been traditionally considered that external rotation of the humerus during abduction is necessary for elevation. External rotation of the humerus clears the greater tuberosity posteriorly; increasing the range of abduction {Rockwood and Matsen, 2010}. The elevation of the humerus and it's relationship to humeral rotation was studied quantitatively using an electromagnetic tracking device{Browne et al., 1990}. The plane of maximal arm elevation was found to be 23 degrees anterior to the scapular plane and at this position was associated with a 35 degree of external rotation of the humerus. When the arm is placed in full internal rotation, the maximal elevation is restricted to 115 degrees and occurs in a plane 20 to 30 degrees posterior to the scapular plane. External rotation of the humerus is coupled with abduction. Pathologies affecting external rotation of the humerus such as frozen shoulder, significantly limit humeral elevation as well. This knowledge regarding the humeral rotation is inherently linked to the findings of the work presented. Patients with anterior shoulder instability are most apprehensive during extremes of external rotation as this position places their shoulder in the position of dislocation. There was a statistically significant difference in the range of motion during abduction in the coronal plane in patients with shoulder instability as compared to controls. This difference is likely to be due to decreased external rotation and adds further evidence to the findings of Browne et al{Browne et al., 1990} that placing the arm in internal rotation restricts abduction. The finding of decreased area covered by the circumduction graph also confirms this coupling of abduction to external rotation of the shoulder.

7.3.5 Centre of rotation

Determining the centre of rotation of the shoulder joint is a complex problem due to the contributions of multiple subcomponents. The centre of rotation of the glenohumeral joint has been defined as a locus of points situated between 6+/- 2 mm of the geometric centre of the humeral head{Poppen and Walker, 1976}. The accuracy of the methodology used has however been questioned{Spiegelman and Woo, 1987} as it doesn't take into account the affect of translation on the centre of rotation. In fact, some authors consider that multiple centre of rotations occur during arm abduction{Rockwood and Matsen, 2010}. Mitchell et al used the centre of rotation 8.25 cms inferior and 3.5 cm lateral to the marker placed at the tip of the acromion, based on shoulder radiographs taken with markers in place{Mitchell et al., 2003}. This method however utilizes the centre of rotation obtained using a two-dimensional radiograph and doesn't consider the antero-posterior location of the centre of rotation. The scapular center of rotation for arm elevation has been described at the tip of the acromion as viewed edge on{Poppen and Walker, 1976}. Determining the centre of rotation of the shoulder joint is a complex task due the multiplanar movements and the multiple subcomponents. Presently there is lack of consensus regarding the accurate location of the glenohumeral and shoulder joint complex centre of rotation. There is not only a lack of consensus regarding the centre of rotation, the methodolgy to ascertain this is controvertial as well. It is also likely that the centre of rotation of the shoulder is not a fixed point but changes during movements. This issue has prevented any significant advances in shoulder kinematics for a long time. As discussed, this study considers the shoulder joint as one composite unit including the thoraco-scapular, glenohumeral, acromio-clavicular joint and the sterno-clavicular joint. This avoids the complexity and bias related to accounting for the constantly changing centre of rotations of the individual subcomponents of the shoulder complex. The circumduction movement used in this study is based on the instantaneous position of the elbow in space. This measure is hence independent of the centre of rotation of the shoulder joint complex. Also, as is referenced to the trunk, the circumduction measure, as used in this study, is independent to the instantanous position of the subcomponents of the shoulder joint as well.

7.4 Future research

Inability to restore kinematics after stabilization surgery and a program of rehabilitation could possibly be because of development of muscle patterning behaviour in a setting of recurrent dislocations. Surgical stabilization following the first shoulder dislocation has been a matter of interest and debate recently. It would be useful to evaluate the kinematic patterns after such a change in management plan for this condition. Restoration of kinematics to normal would be a strong argument in favour of early surgery. This may lead to a change in clinical practice to prevent development of irreversible kinematic changes, and possibly secondary muscle patterning.

Chapter 8. Conclusions

This study describes shoulder motion patterns using a non-invasive system, which is capable of dynamic movement data capture in six degrees of freedom. There are significant differences in the kinematic characteristics between patients with anterior instability as compared to shoulders in healthy volunteers and the kinematic characteristics are not restored to normal after surgical stabilization and rehabilitation.

1. Unstable shoulders demonstrate a significant decrease in the range of movement when the shoulder is abducted in the coronal plane. There is a significant decrease in the area covered by the circumducting arm in instability when the movements are referenced to the trunk. Forward flexion and scaption remains unaffected in instability. Abduction in the coronal plane and circumduction movements are the most sensitive tasks to study kinematics of shoulder instability.

2. Surgery for recurrent shoulder instability does not restore kinematic characteristics to normal. Re-dislocation after surgery is an important outcome measure following surgical stabilization, although by itself, it is not sensitive enough to assess function and patient satisfaction.

3. The Oxford instability score was found to be sensitive to change following surgery, and the Constant score was not.

4. Both the clinical scores mirrored the differences in the kinematic data when used to compare difference between the control and the patients (whether pre-operative or post- operative). The Oxford instability score, however, was the most responsive to change following surgical input.

5. The present study demonstrates the use of a non-invasive motion tracking system, which can record dynamic motion in six degrees of freedom and can be used routinely for motion analysis of the shoulder joint complex

Chapter 9. References

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Chapter 10. Appendices

a. UClan Ethical committee approval

13/02/06

Dr. Puneet Monga
Allied Health Professionals
University of Central Lancashire

Dear Puneet,

Re: Faculty of Health Ethics Committee (FHEC) Application – (CA 033)

The FHEC has granted approval of your proposal application 'Three-dimensional analysis of shoulder movement patterns in shoulders with anterior instability: A comparison of kinematics with normal shoulders and influence of stabilization surgery' on the basis described in its 'Notes for Applicants'.

Recommendation

Whilst there are no ethical issues with the nature of the research project, the planned research is not for an existing validated programme of study. We would therefore advise the research team, if has not already done so, to confirm that suitable indemnity and other governance arrangements exist. In particular, whilst we note that the Wrightington, Wigan and Leigh NHS Trust has agreed to provide indemnity for negligent harm, we recommend that issues surrounding health safety and indemnity are confirmed if the research is planned to commence prior to the student (Puneet Monga) transferring to the MD Clinical and Health Sciences.

Yours sincerely

Dr. Chris Sutton
Chair
Faculty of Health Ethics Committee

Cfi: Jim Richards

b. Funding approval letter

Wrightington, Wigan and Leigh NHS
NHS Trust

Research and Development Department
Wrightington Hospital
Hall Lane
Appley Bridge
Nr Wigan
WN6 9EP

Miss Jillian Martin, B.Sc, M.Sc – Research and Development Co-ordinator
Mrs Sandra Latham – Research and Development Administrative Assistant
Mr Raj Murali, F.R.C.S., Ed. F.R.C.S. (Trauma and Ortho.) – Clinical Director of R&D

Tel: 01257 256465
Fax: 01257 256398

Jillian.Martin@wiganlhs-tr.nwest.nhs.uk
Sandra.Latham@wiganlhs-tr.nwest.nhs.uk

5th November 2005

SRM/SAL

Mr P Monga
Honorary Research Fellow/SPR
Wrightington Hospital

Dear Mr Monga

REF: Three Dimensional Analysis of Shoulder Movement

Thank you for your application for funding for the above mentioned project. I am delighted to inform you that at the R & D Committee Meeting held on the 1st November 2005 your project was approved, subject to us receiving the necessary funding from Clinical Trials Department in January 2006.

Kind Regards

Yours sincerely

Mr Raj Murali
Clinical Director of Research and Development

c. **Volunteer Invitation Advertisement**

Can you spare 1 hour for a good cause?

Volunteers

We request participation of volunteers to attend a short session at the motion analysis lab at University of Central Lancashire, Preston.

You would be only requested to perform certain movements of your arm to help our understanding of shoulder disorders.

Your input would be greatly appreciated.

For more details please contact:

Mr. Puneet Monga
Research Fellow,
Wrightington Hospital.
Tel 07817847512
Email:
mongapuneet@hotmail.com

Prof J Richards
Professor of Biomechanics,
Allied Health Dept,
University of Central
Lancashire
Tel.: 01772 894575

d. Oxford Instability Score

OXFORD INSTABILITY SCORE:
Please tick one correct response for every question

No	Item	Scoring	Response
1	During the last six months, how many times has your shoulder slipped out of joint (dislocated)?	Not at all in 6 months	
		1 or 2 times in 6 months	
		1 or 2 times per month	
		1 or 2 times per week	
		More than 1 or 2 times / week	
2.	During the last three months, have you had any trouble (or worry) dressing because of your shoulder?	No trouble at all	
		Slight trouble or worry	
		Moderate trouble or worry	
		Extreme difficulty	
		Impossible to do	
3	During the last three months, how would you describe the worst pain you have had from your shoulder?	None	
		Mild Ache	
		Moderate	
		Severe	
		Unbearable	
4	During the last three months, how much has the problem with your shoulder interfered with your usual work (including school or college work, or housework)?	Not at all	
		A little bit	
		Moderately	
		Greatly	
		Totally	
5	During the last three months, have you avoided any activities due to worry about your shoulder-feared that it might slip out of joint?	Not at all	
		Very occasionally	
		Some days	
		Most days or more than one activity	
		Every day or many activities	
6	During the last three months, has the problem with your shoulder prevented you from doing things that are important to you?	No, not at all	
		Very occasionally	
		Some days	
		Most days or more than one activity	
		Every day or many activities	
7	During the last three months, how much has the problem with your shoulder interfered with your social life (including sexual activity, if applicable)?	Not at all	
		Occasionally	
		Some days	
		Most days	
		Every day	
8	During the last four weeks, how much has the problem with your shoulder interfered with your sporting activities or hobbies?	Not at all	
		A little / occasionally	
		Some of the time	
		Most of the time	
		All the time	
9	During the last four weeks, how often has your shoulder been 'on your mind'-how often have you thought about it?	Never, or only if someone asks	
		Occasionally	
		Some days	
		Most days	
		Every day	
10	During the last four weeks, how much has the problem with your shoulder interfered with your ability or willingness to lift heavy objects?	Not at all	
		Occasionally	
		Some days	
		Most days	
		Every day	
11	During the last four weeks, how would you describe the pain which you usually had from your shoulder?	None	
		Very mild	
		Mild	
		Moderate	
		Severe	
12	During the last four weeks, have you avoided lying in certain positions, in bed at night, because of your shoulder?	No nights	
		Only 1 or 2 nights	
		Some nights	
		Most nights	
		Every night	

e. Constant Score

MRC GRADES

Normal	5	Full range, antigravity, maximum resistance
Good	4+	Full range, antigravity, moderate resistance
	4	Full range, antigravity – minimal resistance
Fair	3+	Full range, antigravity
	3	Partial range, antigravity
Poor	2	Partial range, gravity eliminated
Trace	1	Contraction, no motion
Absent	0	No evidence of contraction

The Constant Shoulder Assessment Scoring For:-

1) Pain Max = 15

	Points
None	15
Mild	10
Moderate	5
Severe	0

2) Activities of Daily Living Max. = 20

		Points
Activity level:	Full work	4
	Full recreation/sport	4
	Unaffected sleep	2
Positioning:	Up to waist	2
	Up to xiphoid	4
	Up to neck	6
	Up to top of head	8
	Above head	10

3) Forward and Lateral Elevation Max. = 20 (10 each)

Elevation (degrees)	Points
0-30	0
31-60	2
61-90	4
91-120	6
121-150	8
151-180	10

4) External Rotation Max. = 10

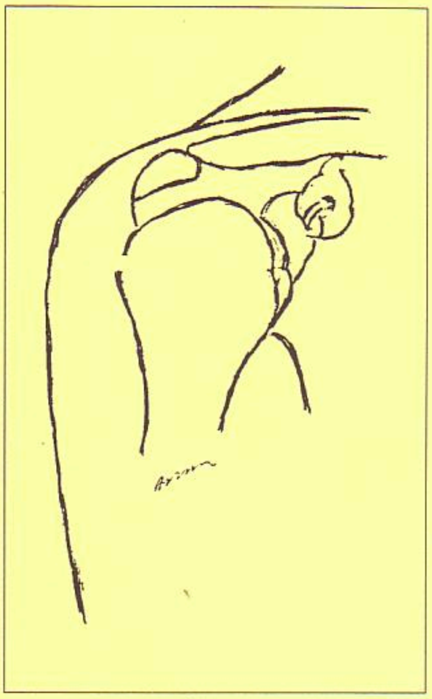
Hand Position	Points
Behind head, elbow forward	2
Behind head, elbow back	2
Top of head, elbow forward	2
Top of head, elbow back	2
Full elevation from top of head	2

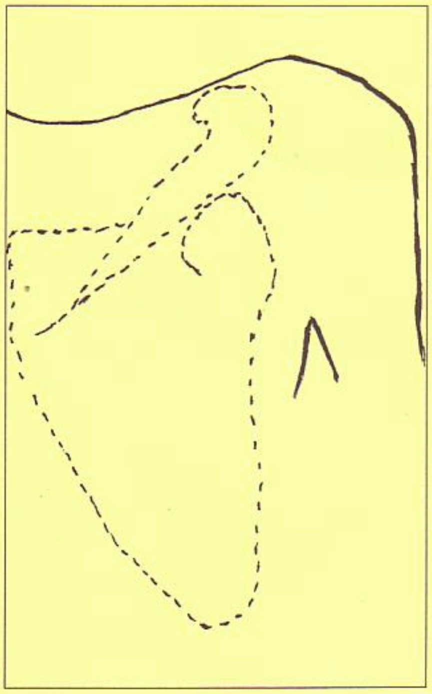
5) Internal Rotation Max. = 10

Dorsum Hand Position	Points
Lateral thigh	0
Buttock	2
Lumbosacral junction	4
Waist (L3 vert)	6
T12 vert	8
Interscapular (T7 vert)	10

6) Overall Scoring for Individual Parameters

	Max.	Right	Left
Pain	15		
Activities of daily living	20		
Range of motion	40		
Power	25		
Total	100		





f. Letter of invitation

Letter of Invitation:
Version 1 dated 20-04-2005.

Dated: 20-04-2005

Mr. ………

Adress..
……………….
……………….

Sub: Invitation to attend review clinic.

Dear Mr/ Ms/ Mrs/Ms…

We would like to invite you to attend a review clinic aimed at following up results after shoulder stabilization surgery.

You have been requested to participate, as you are underwent shoulder stabilization surgery.

Please find enclosed an information sheet related to the study.

Your routine clinical care would not be affected by participation in the study.

Review of such nature help us in maintaining a high standard of care and get valuable feedback to further improve the quality of service provided. Publishing of the results of such studies is an important means of advancement of knowledge.

Your co-operation would be much appreciated. Please find a return envelope enclosed to indicate the most suitable time for you to come for the study.

Thanking you,

Yours truly,

Puneet Monga

Clinical Research Fellow, (Orthopaedics)
Wrightington Wigan and Leigh NHS Trust.

Contact Tel:
01942244000 bleep 6260
07817847512 (Mobile)

g. Patient information sheet

Wrightington, Wigan and Leigh NHS
NHS Trust

PATIENT INFORMATION SHEET Version No 2 and Date 14-08-2005

TITLE OF STUDY: Capsulo-labral reconstruction

NAME OF RESEARCHERS: P Monga, S Topping, RK Swamy, AO Browne.

You are being invited to take part in a research study. Before you decide to participate 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 us if you wish. Ask us 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?
To assess the long term outcome after shoulder stabilization surgery

Why have I been chosen?
You have been chosen because you had undergone shoulder stabilization surgery.

Do I have to take part?
It is up to you to decide whether or not to take part. If you decide to take part you are still free to withdraw at any time. A decision not to take part will not affect the standard of care you receive in the long term.

What will happen to me if I take part?
You would be invited to attend a follow up clinic at a mutually convenient date and time. Over there, you would be asked few clinically relevant questions. Physical examination relevant to your shoulder would be performed. You would be asked to fill a questionnaire related to your shoulder function.

What do I have to do?
Your visit would be similar to a routine clinic appointment.

What are the possible disadvantages and risks of taking part?
There are no risks to you from the study. It only involves the inconvenience of a single visit to the hospital at a specific time.

What are the benefits of taking part?
You can be assured that by adding to the understanding towards shoulder stabilization procedures, you may potentially help in improved patient care and better understand of shoulder instability. This opens up avenues for better rehabilitation and improvement in surgical techniques 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 Stockport local Research Ethics Committee has reviewed this study.

Would the expenses for the visit be re-imbursed?
Travel and parking charges to and from the hospital would be reimbursed.

Your GP will be informed about your participation in this study. If you wish not, please inform us.

If you so desire, a summary of the research findings could be sent to you at the termination of the study.

Please feel free to call me for further information.

Puneet Monga
Tel: 07725312370

Postal Queries may be sent to:
Mr Puneet Monga
C/o R&D Department
Wrightington Wigan and Leigh NHS Trust.
Wrightington Hospital
Appley Bridge
Wigan WN6 9EP

Thank you for taking the time to read about the study, if you have any questions please do not hesitate to ask.

h. Log of problems during data capture / analysis

CONTROLS

Sub4

Circum1 has late start of data collection. [discard}

Sub5

Movement in trunk markers w.r.t. each other (consistent) three markers stationary. OK to use

Ab_scap 1 : late start of data collection [discard]

Sub 7.

Forward flexion 003 : sternum 4 marker 74%. Three markers ok. Use data

Forward flexion 4 files have abnormal movment in x place (discard)

Sub 8

Forward flex 001: one marker Rfarm_3 is 88.4% . three markers ok. Can use

All forward flex files : Rfarm_3 is less than 90% three markers ok, can use

Forward flex 5: R farm 3 is 81%; three markers ok. Can use

Sub9

Forward flex 5:farm 3 81.5% trace. Three markers ok. Can use.

Circ 2 marker jump circ 2 file not used in analyses. discard

Circum 4 outlier discarded on analysis. discard

Sub 2

discarded: trunk markers are a problem

CASES

Sub 5

Abduction scap unaffected 1 early finish of data recording. Discard.

Circum effected 4 c3d thorax moving as arm. File not used for graphs / analysis. Discard

Abduction_effected file 001 software cross talk. Discard.

Circum_effected 005 becomes a throw in c3d. software cross talk, discard

Sub 4

Abduction _effected 001; right humeral 3 marker 57.6% rest of the three OK (100%) [should be OK in c3d]

Abduction _effected 002; right humeral 3 marker 70.9% rest of the three OK [should be OK in c3d]

Abduction _effected 003; right humeral 3 marker 76% rest of the three OK [should be OK in c3d]

Abduction _effected 004; right humeral 3 marker 72.3% rest of the three OK [should be OK in c3d]

Abduction _effected 005; right humeral 3 marker 76% rest of the three OK [should be OK in c3d]

Abduction _effected 006; right humeral 3 marker 80% rest of the three OK [should be OK in c3d]

Sub 2

Abduc_scap_effected002: sternal marker fell off! Rest three 100% (should be okay)

Next 3 files Sternal 3 still on floor: rest of the three 100% (should be okay)

Forward flex effected 004 NO data at all; not used in analysis (obviously!)

Forward flex 005 non effected; early finish data collection. Discard.

Mj for flex _non effected 5 early stop of recording : file discarded.

Sub 1

Good data

Only Minor gapfills

Abd Scap effected 003 outlier; removed from analysis

Sub 3

Forward flex 004 left: data collection ended too soon. Not used in analysis. Discard.

Forward flex right 001 forearm 2 and 3 both 57% and 67% trajectory. No effect

Fwd flex right 002 to 005 forearm 2 and 3 are in adequate in all files. No effect

F flex right 2 early stop data collection; deleted from analysis (6 original recordings though!)

Forward flex 5 ; large gap fill; unsatisfactory; omitted at analysis. Data collection ended too soon.

POST OP sub 3

F flex EFF 1,4,5 files not usable in c3d

F Flex uneff file 3 late start of datacollection Discard.

i. Patient questionnaire

Wrightington, Wigan and Leigh NHS
NHS Trust

Assessment sheet

Full title of Study: Three-dimensional analysis of shoulder instability

Personal Details

Name

Date of birth District number
Sex Tel No:
Address:

GP name:
GP address:

Dominant hand: Right / Left

BEFORE THE OPERATION:

What was your main reason for having the operation done?
Pain / Instability / Recurrent dislocation / Other…………………………….....

What was your occupation before the operation? ……………………………………

Did your shoulder prevent you from fully performing your occupational work before the operation? Yes / No

Were you involved in sports before the operation? Yes /No

If yes, what was your level of involvement (recreational / amateur / professional?)

Did your shoulder prevent you from fully participating in sports before the operation? Yes / No.

Did you have any dislocation of the shoulder before the operation? Yes /No

If yes, how many times?…………
If yes, what was the approximate interval between the first dislocation and the surgery? …………. Months………years.

AROUND THE TIME OF THE OPERATION:

How long were you off work following the operation? ………………….

How long did it take for you to return to sports, if at all, after the operation? ……….

AFTER THE OPERATION:

Has your shoulder dislocated following surgery? Yes / No.

If yes, how many times? …………..

Did your Occupation change after the operation? Yes / No

If yes, what did it have to change to?
On the other hand, were you able to return to your desired occupation due to the success of the operation: yes /no / not applicable.

Has your shoulder prevented you from fully performing your occupational work after the operation?

Have you been involved in sports after the operation? Yes /No

If yes, what level of involvement: (recreational / amateur / professional?)

Has your shoulder prevented you from fully participating in sports after the operation?   Yes / No.

Was the main problem for which you had the operation done (pain / instability /dislocation etc..) sorted after the operation?
Yes / No

How would you rate your overall satisfaction following the procedure?

Extremely satisfied / satisfied / satisfied with reservations / dissatisfied

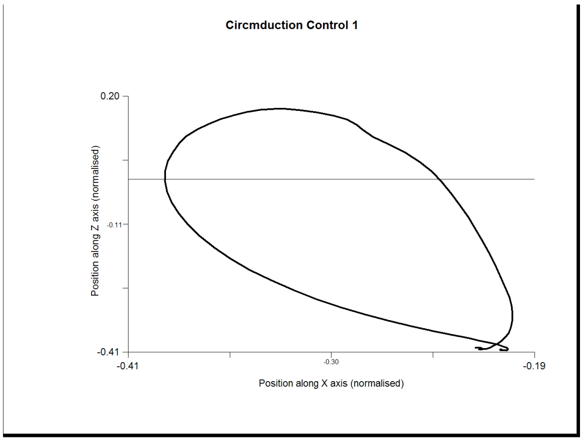
Any further comments, which you would wish to make….

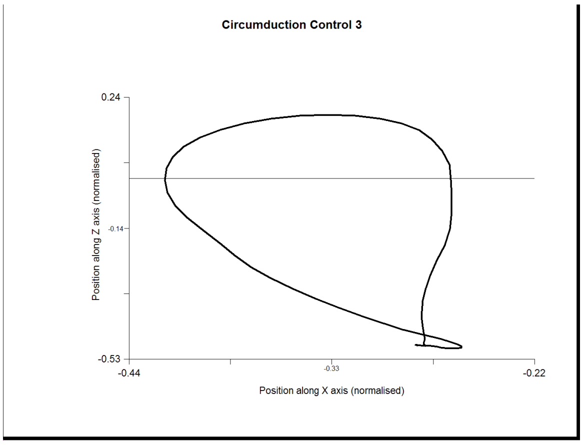
---

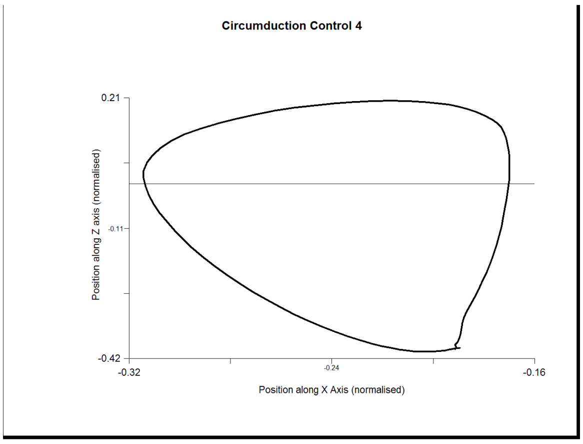
j. Circumduction graphs

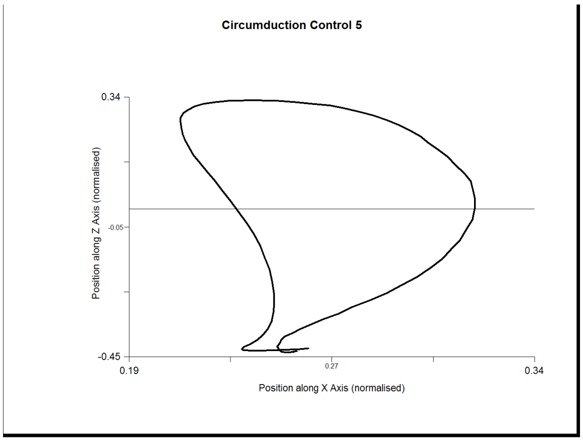
Circumduction Graphs (Controls)

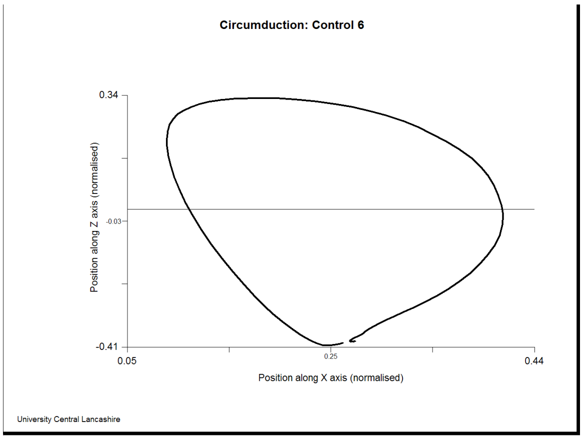
Elbow position in XZ plane with respect to Trunk coordinates.

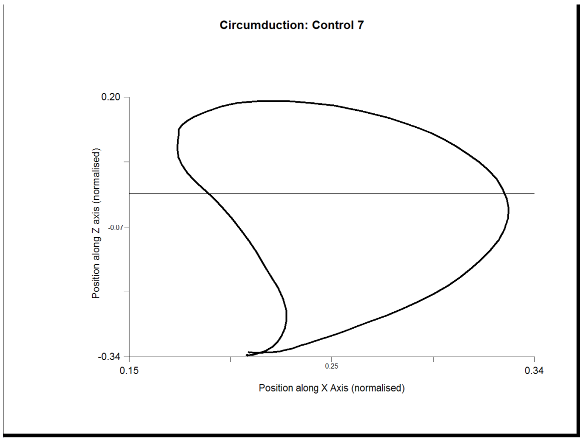


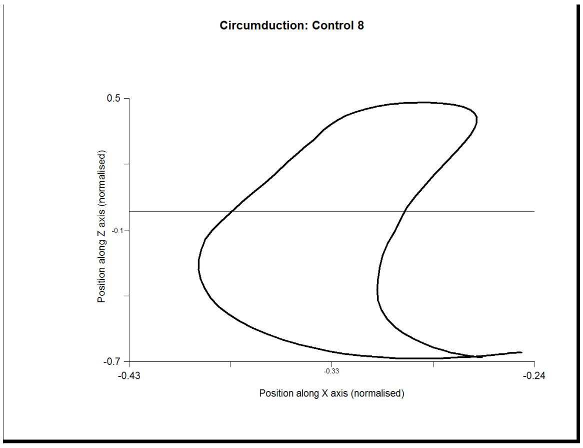


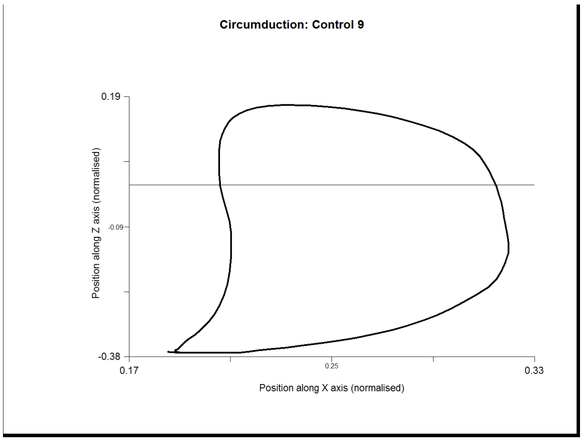


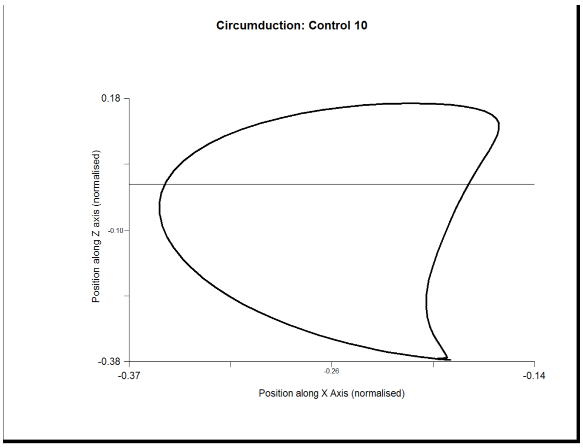

Circumduction Control 5
0.34
-0.05
-0.45
Position along Z Axis (normalised)
0.19
0.27
0.34
Position along X Axis (normalised)


Circumduction: Control 6
0.34
-0.03
-0.41
Position along Z axis (normalised)
0.05
0.25
0.44
Position along X axis (normalised)
University Central Lancashire


Circumduction: Control 7
0.20
-0.07
-0.34
Position along Z axis (normalised)
0.15
0.25
0.34
Position along X Axis (normalised)

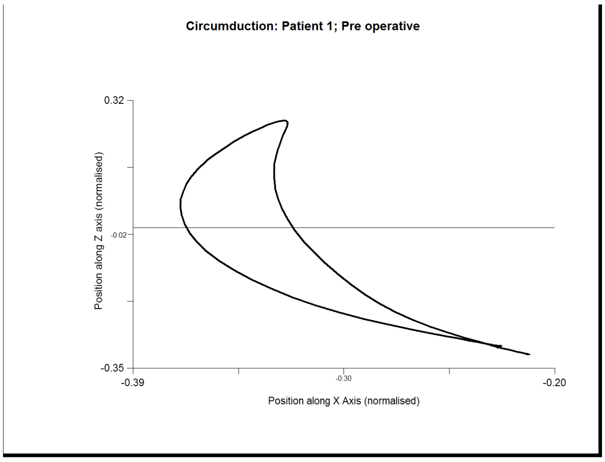




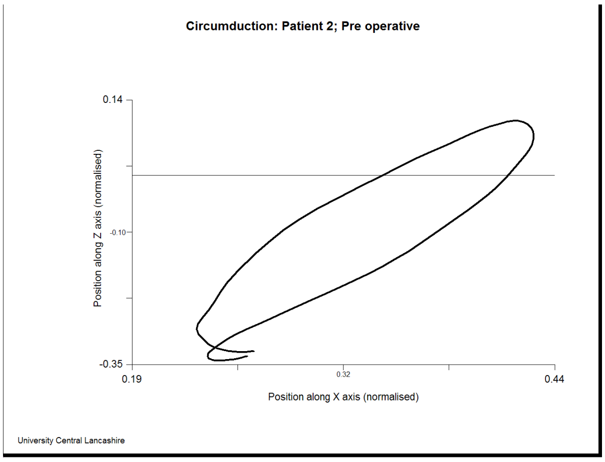


Circumduction Graphs (Patients-Pre operative)

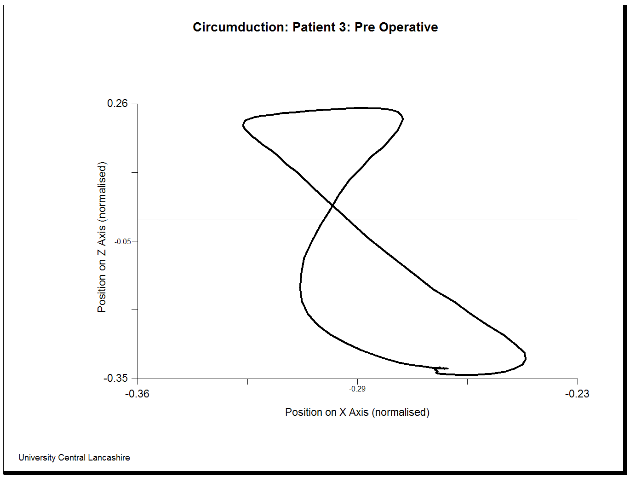
Elbow position in XZ plane with respect to Trunk coordinates.



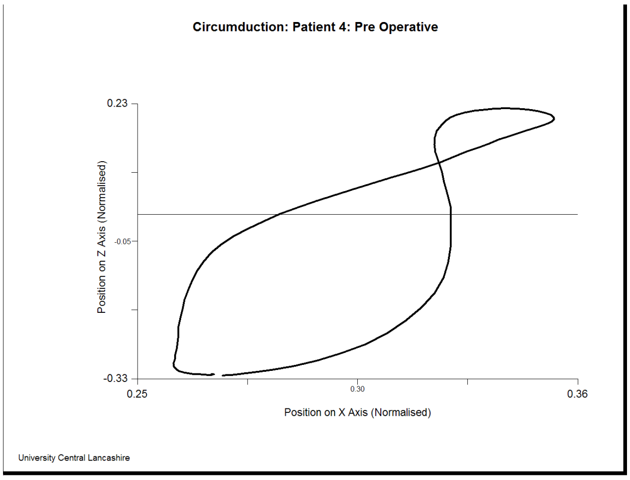
Circumduction: Patient 1; Pre operative
0.32
-0.02
-0.35
-0.39
-0.30
-0.20
Position along Z axis (normalised)
Position along X Axis (normalised)

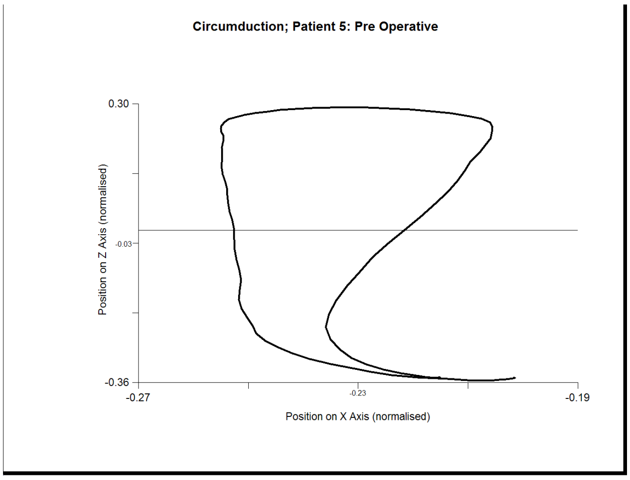


Circumduction: Patient 2; Pre operative
0.14
-0.10
-0.35
0.19
0.32
0.44
Position along Z axis (normalised)
Position along X axis (normalised)
University Central Lancashire



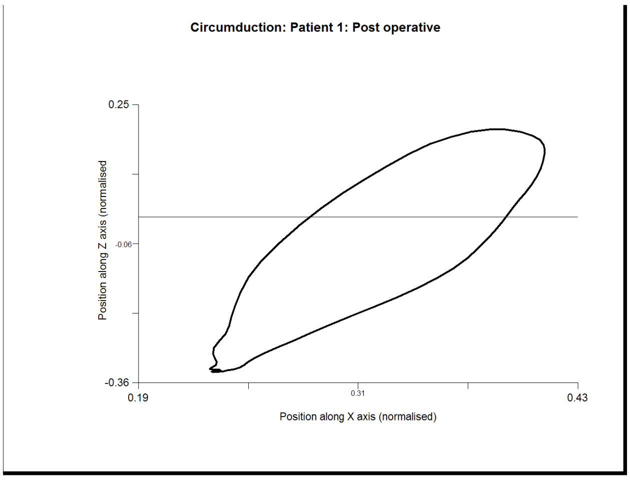
Circumduction: Patient 3: Pre Operative
0.26
-0.05
-0.35
-0.36
-0.29
-0.23
Position on Z Axis (normalised)
Position on X Axis (normalised)
University Central Lancashire

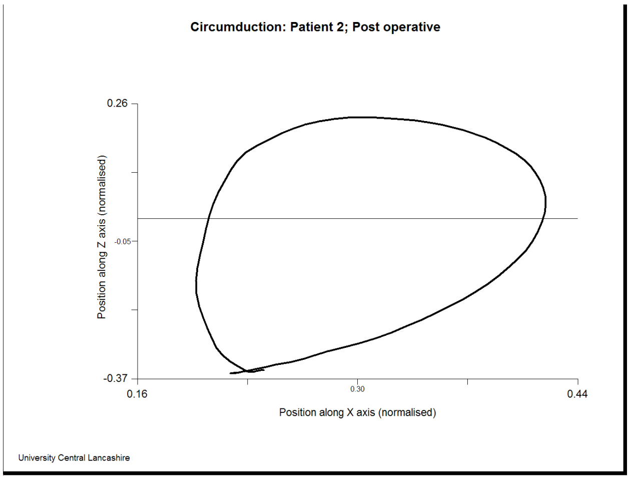




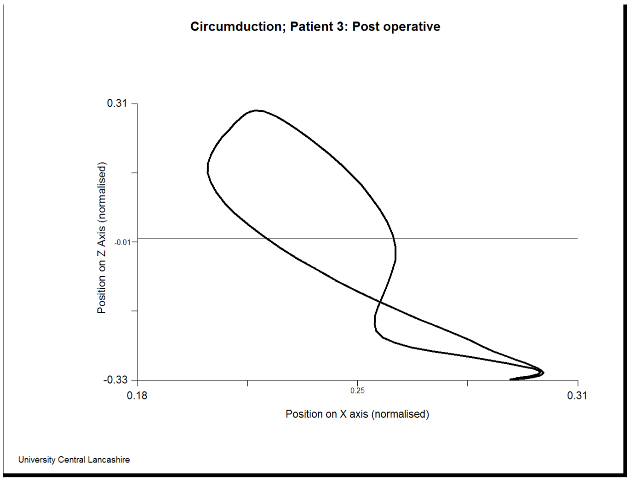
Circumduction Graphs (Patients- Post operative)

Elbow position in XZ plane with respect to Trunk coordinates.

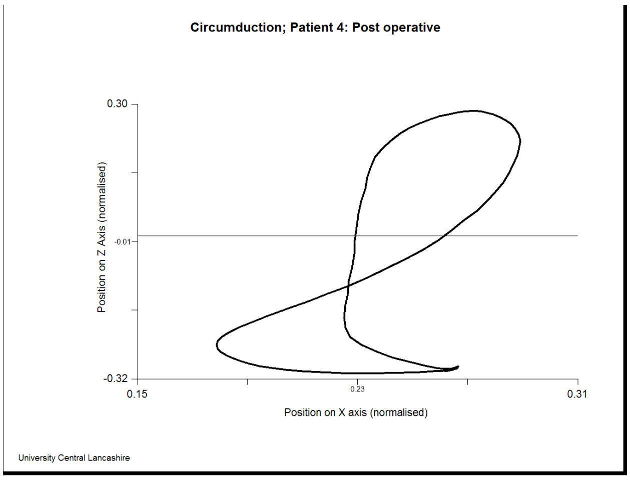




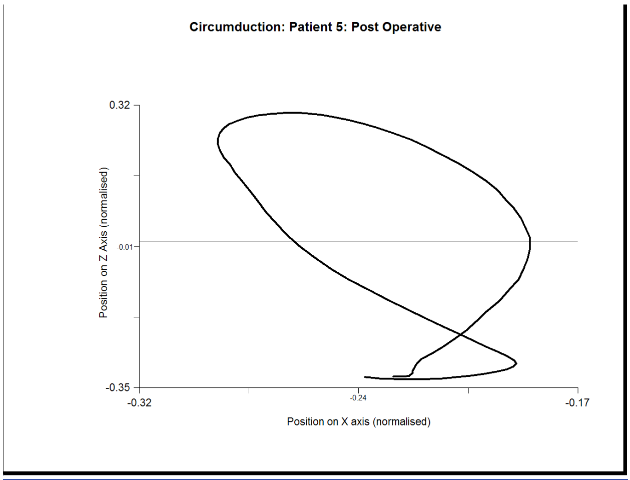
Circumduction: Patient 2; Post operative
0.26
-0.05
-0.37
0.16
0.30
0.44
Position along Z axis (normalised)
Position along X axis (normalised)
University Central Lancashire



Circumduction; Patient 3: Post operative
0.31
-0.01
-0.33
0.18
0.25
0.31
Position on Z Axis (normalised)
Position on X axis (normalised)
University Central Lancashire



Circumduction; Patient 4: Post operative
0.30
-0.01
-0.32
0.15
0.23
0.31
Position on Z Axis (normalised)
Position on X axis (normalised)
University Central Lancashire


Circumduction: Patient 5: Post Operative
0.32
-0.01
-0.35
Position on Z Axis (normalised)
-0.32
-0.24
-0.17
Position on X axis (normalised)

k. Individual Clinical scores and their subcomponents

Oxford Instability Score; Pre-op

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Total
Pt 1	4	2	5	1	5	3	2	4	5	4	1	5	**41**
Pt 2	3	3	4	2	4	4	3	5	4	4	5	5	**46**
Pt 3	2	3	2	2	3	4	4	5	5	5	2	2	**39**
Pt 4	1	1	1	2	3	3	2	2	4	3	1	5	**28**
Pt 5	2	2	4	3	3	3	1	3	4	2	3	5	**35**

Oxford Instability Score; Post op

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Total
Pt 1	1	2	2	3	4	4	3	4	3	3	2	5	**36**
Pt 2	1	3	3	1	2	2	2	2	4	3	2	5	**28**
Pt 3	1	2	2	3	3	2	2	3	4	4	3	4	**33**
Pt 4	1	1	1	1	1	1	1	1	1	1	1	1	**12**
Pt 5	1	1	2	1	3	1	1	1	3	1	2	1	**18**

Constant Score; Pre op

	Pain	ADL		ROM				Power	Total
		Activity Level	Positioning	Fwd Elev	Lat Elev	ER	IR		
Pt 1	15	2	10	8	8	10	8	19	**80**
Pt 2	15	4	8	8	8	6	10	0	**59**
Pt 3	15	4	10	10	10	10	10	10	**79**
Pt 4	15	2	10	10	10	10	10	25	**92**
Pt 5	15	4	10	10	10	10	8	25	**92**

Constant Score; Post operative.

	Pain	ADL		ROM				Power	Total
		Activity Level	Positioning	Fwd Elev	Lat Elev	ER	IR		
Pt 1	15	0	10	8	8	8	8	10	**67**
Pt 2	15	4	8	8	6	8	10	18	**77**
Pt 3	10	4	10	10	10	10	10	25	**89**
Pt 4	15	6	10	10	10	10	10	25	**96**
Pt 5	10	6	10	10	10	10	8	25	**89**

ADL: Activity of Daily Living

ROM: Range of Movement

ER: External Rotation

IR: Internal Rotation