TITLE: Implementing the PREP2 algorithm to predict upper limb recovery potential after stroke in clinical practice: a qualitative study

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ABSTRACT

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Background

Predicting motor recovery after stroke is a key factor when planning and providing rehabilitation for individual patients. The PREP2 algorithm has been developed to help clinicians predict upper limb functional outcome. Translating evidence-based interventions into clinical practice can be challenging and slow. However, shortly after its ~~external~~ **local** validation, PREP2 was successfully implemented into clinical practice at the same site in New Zealand. In parallel to further model validation, useful lessons can be learned from this experience to aid future implementation.

Objective

To explore how PREP2 was implemented in clinical practice within the Auckland District Health Board (ADHB) in New Zealand.

Design

A case study design using semi-structured interviews.

Methods

Nineteen interviews were conducted with clinicians involved in stroke care at ADHB. To explore factors influencing implementation, interview content was coded and analysed using the Consolidated Framework for Implementation Research. Strategies identified by

the Expert Recommendations for Implementing Change (ERIC) project were used to describe how implementation was undertaken.

Results

Implementation of PREP2 was initiated and driven by therapists. Key factors driving implementation were the support given to staff from the implementation team; the knowledge, beliefs and self-efficacy of staff, and the perceived benefits of having PREP2 prediction information. Twenty-six ERIC strategies were identified relating to three areas: the implementation team, the clinical/academic partnerships and the training.

Limitations

Limitations included potential self-selection bias, reliance on clinicians' ability to recall events, and potential social desirability bias affecting interview content.

Conclusions

The PREP2 prediction tool was successfully implemented in clinical practice at ADHB. Barriers and facilitators to implementation success have been identified, and implementation strategies described. Lessons learned can aid future development and implementation of prediction models in clinical practice.

Introduction

Predicting recovery potential for individual patients after stroke is difficult but important for planning rehabilitation, setting realistic treatment goals and managing patient expectations. Competing priorities for rehabilitation mean time available for upper limb (UL) therapy is often very limited, with an average of four minutes spent on arm-related activity during treatment sessions.[1] This means UL therapy needs to be targeted and individualised to achieve the greatest gains in a short timeframe.

Current practice for making predictions for UL recovery after stroke is a 'wait-and-see' approach. Clinicians often find it difficult to accurately predict functional outcomes. Studies suggest therapists are accurate in approximately 50-60% of patients, which is little better than chance.[2, 3] Currently, no single clinical measure or neurological biomarker accurately predicts motor recovery or outcome for all patients. **There is also presently no consensus on the use of predictive models of stroke motor recovery, though it is generally agreed that any model will need to clearly demonstrate clinical feasibility and external validity before implementation in routine clinical practice.**[4, 5] One of the most important clinical predictors for UL recovery is severity of initial motor impairment.[6] However, around half of patients with severe initial impairment achieve good UL function within the first 3 months post-stroke.[7] This is because they have a functionally intact corticospinal tract that is not apparent on clinical assessment, but is detectable with transcranial magnetic stimulation (TMS). Incorrectly assuming poor UL recovery potential in patients with severe motor impairment early after stroke may affect patient goal setting and selection of rehabilitation strategies, leading to failure to realise actual recovery potential.

The Predict Recovery Potential (PREP2) algorithm[8] (Figure 1) sequentially combines clinical assessment and TMS testing in the first week following stroke to predict UL functional outcomes at 3 months post-stroke. A detailed description of the PREP2 algorithm is provided online.[9] In brief, the PREP2 algorithm starts with evaluating paretic UL strength by obtaining a shoulder abduction and finger extension (SAFE) score, using Medical Research Council (MRC) grading. If the SAFE score on day 3 post-stroke is 5 or more, patients are expected to have an Excellent or Good UL functional outcome within 3 months, depending on their age (< or ≥ 80 y). If a patient's day 3 SAFE score is less than 5, TMS is used to evaluate corticospinal tract function. If a motor-evoked potential is elicited (MEP+) in the extensor carpis radialis or first dorsal interosseous muscles of the paretic UL, the patient is expected to achieve a Good UL functional outcome. Patients without MEPs (MEP-) are expected to achieve a Limited or Poor UL functional outcome by 3 months, depending on their overall stroke severity measured with the National Institute of Health Stroke Scale (NIHSS).

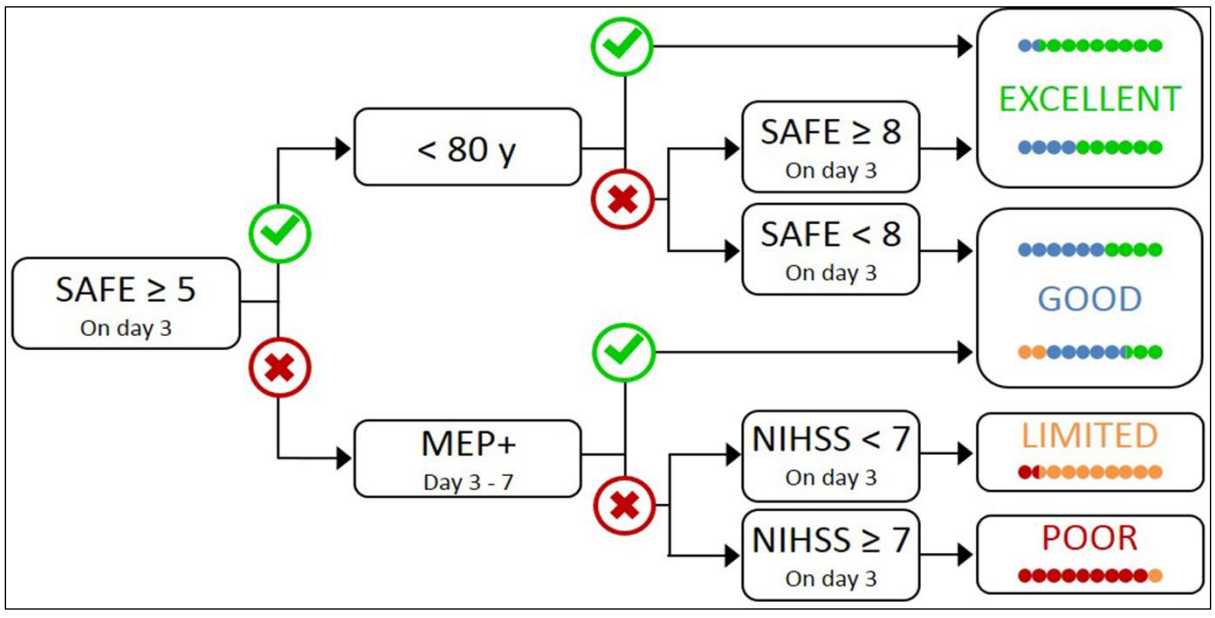

Figure 1: The PREP2 Algorithm[8]

The PREP2 prediction categories are:[8]

- *Excellent:* Expected to be able to use the hand and arm in usual daily activities.
- *Good:* Expected to be able to use the hand and arm in usual daily activities but likely to be affected by weakness, slowness and clumsiness.
- *Limited:* Expected to have limited use of the hand and arm but may have some gross grasp function and be able to use in some bilateral activities.
- *Poor:* Expected to have limited return of movement without functional use of the hand and arm.

PREP was developed[10] (n=50), then refined to PREP2 (n=157+original 50)[8] in Auckland, New Zealand. PREP2 was refined by removing the need for MRI, improving the clinical utility of the algorithm and highlighting the importance of considering the dynamic interplay between the intervention and implementation early in development.

PREP2 makes correct predictions for 75% of patients. The **majority of** positive and negative predictive values for **different** PREP2 **categories were over 80%.** ~~**ranged between 83% and 99%.**~~ **However, there is still scope for further improvement in the predictive accuracy of the algorithm, especially within the Good category.** ~~**However, it**~~ **Additionally, the PREP2 algorithm** has not **yet** been externally validated at a different site or in a different healthcare system. PREP2 **refinement and** validation work is **therefore** on-going and needs evaluating prior to **promoting** widespread implementation of PREP2.

In parallel to further validation it is important to explore clinical utility, as developing an unusable model is of little value. The MRC guidance for stratified medicine recognizes that "the ability of the stratified medicine approach to change clinical practice and positively impact on human health depends not only on the methodological rigour … but also on effective engagement and communication with the wider stakeholders involved."[11]. A major challenge in healthcare is translating research advances into changes in healthcare delivery. Typically there is a 17-year lag between scientific evidence reporting and clinical implementation[12], which delays access to potential benefits for patients and clinicians. Unusually, the PREP2 algorithm was implemented into routine clinical care at the Auckland District Health Board (ADHB) within 18 months of ~~external~~ validation at this site. The Prognosis Research Strategy (PROGRESS) group have highlighted the need for more research into understanding what impedes, and what accelerates, appropriate translation of evidence to use of prognostic models.[13]. We aim to use implementation frameworks to capitalise on this unique opportunity to explore clinically driven, 'natural' implementation of a new prediction tool, to describe the process and learn lessons for future implementation.

Purpose

To explore how PREP2 was implemented into clinical practice within ADHB in New Zealand.

Objectives

1. To explore factors influencing implementation of PREP2, as perceived by staff.
2. To identify the implementation and training strategies used to implement PREP2 into clinical practice.

Methods

Study Design

A case study approach was used with data collected via semi-structured interviews. The theoretical frameworks underpinning the study design were the Normalization Process Theory and Consolidated Framework for Implementation Research (CFIR). Normalization Process Theory can be used to understand the dynamic processes involved in enabling new interventions to become embedded in routine practice[14]. The CFIR provides a menu of constructs that have been associated with effective implementation[15] and includes the domains: inner setting (e.g. stroke service settings); characteristics of the individuals (e.g. clinicians); intervention characteristics (e.g. PREP2); and outer setting (e.g. patient and external factors). In addition, the refined compilation of implementation strategies from the Expert Recommendations for Implementing Change (ERIC) project[16] was used to describe implementation strategies.

The Standards for Reporting Qualitative Research: A Synthesis of Recommendations[17] was used.

Setting

ADHB, New Zealand.

Participant Selection

Clinicians involved in stroke care at ADHB were invited to participate and were provided with participant information sheets via clinical leaders in allied health, nursing and medical services. Interested clinicians contacted the research team by email or phone. After providing written informed consent, participants were interviewed outside of their working hours. They each received a $50 voucher as a koha (gift) to acknowledge their participation.

Data Collection

The Normalization Process Theory and the CFIR were used in the development of the interview guide for the study (Appendix 1), based on previous literature.[18, 19] The interview guide was reviewed and piloted by clinical therapists.

The interviews were conducted by the lead author (LC). Participants were not known to the interviewer. Participants were aware that the interviewer was not part of the PREP2 research team or implementation team and wanted an honest perspective to learn lessons for implementation, and that criticisms were welcomed. Interviews were digitally recorded and transcribed verbatim to enable in-depth analysis.

Researcher Characteristics and Reflexivity

The researchers held a pragmatist worldview, basing the inquiry on the assumption that collecting diverse types of data provides a more complete understanding of a research problem. The interviewer is a clinician-scientist, both an experienced researcher and Physical Therapist in stroke rehabilitation. Hence, she was aware of a number of potential issues which may influence how PREP2 is implemented. To reduce any associated bias, two further researchers were involved in the analysis and interpretation of the data. These two researchers have clinical backgrounds in Medicine (BC) and Physical Therapy (SA) and are experienced in health research.

Data Analysis

Interview transcripts were imported into NVivo 12 for analysis. The CFIR was used to code data, with additional free codes developed where needed. To establish a shared understanding and interpretation of the coding framework, all three researchers started by coding the same two transcripts. The coded transcripts were compared and any variance in interpretation of data and application of codes was discussed to arrive at a mutual decision. Subsequently the remaining transcripts were coded separately by two researchers independently. Excerpts used were identified by participant number only.

Member checking

Key themes identified during data analysis were synthesized and depicted as four infographics, one for each CFIR domain (see Supplementary file). The infographics and table summarising implementation strategies used (Table 1) were sent to participants for feedback.

Results

Nineteen interviews were conducted across the hyperacute, acute, rehabilitation and community stroke services in May 2019.

Participants were Physical Therapists (PTs) (n=8); Occupational Therapists (OTs) (n=4), Nurses (n=2), Medical Doctors (n=2), Rehabilitation Assistants (n=2) and a Speech and Language Therapist (n=1). Their experience within neurology varied from less than one to over 20 years' experience.

Data collection ended upon achieving data saturation, which was agreed through ongoing analysis by three researchers.

Factors Influencing Implementation of PREP2

Factors are presented according to their CFIR domains, together with supporting quotes. Table 2 summarises these results.

Inner Setting

Culture

All participants agreed that PREP2 is now embedded in routine clinical care, advancing from research to practice. Implementation was phased: starting with patients with a SAFE score of 5 or more and delivering Excellent and Good predictions, and later adding TMS testing and NIHSS score for patients with a SAFE score of less than 5 and delivering all 4 predictions. PREP2 has become integrated within standard orientation for new staff.

P04: "it's just another thing to do and it's become the norm"

Readiness for Implementation

At an organisational level, there was approval and buy-in from management staff. Leadership engagement was recognized as an important source of support, but implementation was led by the Physical Therapy team.

P02: "obviously getting clearance from a management perspective… we were really well supported"

P10: "it's sort of run by a [PT] really and they understand it … do it themselves, really lead it and then liaise with the medical team"

Implementation evolved over time, with OTs involved at a later stage. There was recognition that this could have been earlier.

P17: "the inclusion of occupational therapy in the PREP2 project was never really a thing, maybe it's because it was developed by a [PT] and … it started off there but I feel like OT probably missed the boat a little bit"

Structural Characteristics

The timing of PREP2 assessments over the first week post-stroke meant the involvement of different wards (acute and rehabilitation) and different staff to obtain and deliver PREP2 predictions. These logistical factors meant sufficient staffing was required across services to enable completion of tests.

P15: "You need people … both from acute and rehab… it's harder for the rehab people to be doing the TMS when the patient is still in the acute setting"

Networks and Communication

Communication was recognized as important to enable tests to be completed on time and ensure consistent language regarding the delivery of prediction information. This had positive spill-over effects on general communication within the multi-disciplinary team.

P19: "When everyone uses the same terminology and gives the patient the same information, it's easy for them to process because they're not getting conflicting ideas"

P04: "with the aphasic patients and delivering upper limb predictions to them, it does involve a collaborative effort and getting the right people involved so having discussions with speech and language therapists"

Communication between staff was generally good within a service, although shift patterns of nursing staff were recognized as challenging. Communication was more difficult when patients moved across services, such as transferring to the rehabilitation ward or the community.

P04: "I'm on the hyperacute and acute stroke unit so once patients have been accepted to rehab they go up pretty quickly… I'm sure there's things been lost in translation when people move"

P03: "they'd come up to the wards sometimes we'll ask them … 'what have you been told about your recovery of your upper limb?' and they'll be like 'nothing'. You don't know whether they don't remember or whether they chose not to take it in"

Implementation climate

Generally, the organisation was supportive towards training and staff development, with the PREP2 implementation team delivering training that staff were encouraged to attend.

P03:" they do such good training and they do … keep us really well informed"

P14: "we don't really have to justify attending [training], …the autonomy is on you, the onus is on you to attend … you're encouraged to prioritise it"

There was recognition that there was no feedback loop to learn from patients, with no insight regarding prediction validity.

P05: "it's probably one of the gaps in our stroke service … we don't actually follow up stroke patients in clinic… there's no other mechanism that we really get any feedback"

Characteristics of the Individuals

Knowledge and Beliefs

Most staff held positive perceptions regarding PREP2 as a tool to predict UL functional outcome and could articulate detailed patient stories that seemed influential in shaping those beliefs.

P02: "… PREP … that's awesome, useful, meaningful, something that we can actually use on a daily basis, something that gives us information that we really want in the first few days or weeks after a patient's stroke, something that gives us a bit of direction, gives us confidence that we're … going down the right track with a patient, that we're … working towards things that are actually realistically achievable for them or things that are actually the best use of their energy and time"

P04: "this is relevant, this is evidence, this is a way to give people a realistic prediction of their upper limb recovery which is exactly what we've been searching for, for years."

Self-Efficacy

It was acknowledged that staff are trained to different levels depending on their needs. Most PTs and OTs are trained to complete the clinical assessments (SAFE score, NIHSS) and deliver Excellent and Good predictions, with fewer people trained to have expertise in TMS and deliver Limited and Poor predictions.

P05: *"the poor prediction or the good prediction if they've got MEPs, that's done by the TMS team and I don't think I personally would be at the point yet, with enough experience to up-skill to do that"*

Therapists had differing levels of understanding in the multiple aspects of PREP2, with variable confidence and recognition that building confidence took time.

P01: "so it was … kind of, these are great but I don't really understand how to use them… I struggled for a long time for the language that I used when I spoke to patients about translating that kind of prediction into rehab"

P02: "I'm extremely confident with using PREP…it's … gone through a spectrum of being not confident at all to use PREP even in clinical practice to being confident to use it myself to being confident to teach it to other people to be confident to support it in to implementation, confident to teach it as a service"

Other Personal Attributes

Passionate and knowledgeable therapists gave the wider team support and confidence and were key in maintaining momentum with implementation. This included an identified 'champion' as an advocate.

P15: "you need a really strong and passionate core team who are promoting it. Because I think we definitely did here, like one of the girls who was heavily involved in it … she does talk about it a lot but … she's so passionate about it and so no one can … forget about it or let it slip … because she's like a big driver for it"

P16: "*having a champion… somebody that they are able to contact in case they would like to ask questions"*

Therapists also appreciated the opportunity to be involved in 'ground-breaking practice' and to learn new skills that advance PT and OT professions, although this opportunity was also felt to be a bit daunting.

P17: *"it's completely brand new to all of us, like it's almost an entirely new scope for [PTs] here…which is really exciting"*

P04: *"but it is quite a bit of pressure… it is quite a step up in terms of what we are doing in clinical practice and you are delivering quite significant information to a patient and it does come with a bit of responsibility"*

Intervention Characteristics

Complexity

The PREP2 algorithm includes relatively 'simple' biomarkers but there are still complexities when implementing it in a clinical setting**.**

Understanding who, and how many staff, need to be trained for the different aspects of PREP2 to ensure sustainability was identified as an important and ongoing issue. This was challenging due to high staff turn-over caused by staff absence, rotation, leave or resignation.

P15: "just making sure that you have a really good mix of people across the wards …people trained in different things… so you could have a core team that can do the whole thing but I think it's really important to have lots of people who can help and do aspects of it"

The time cost of PREP2 was challenging, both in terms of undertaking the training required and completing the assessments. Interestingly, the cost of the TMS machine was not identified as a significant factor, possibly because the site already had access to one.

P04: "I did all of my self-directed learning in my own time… I wasn't able to do any of that within my clinical hours"

P08: "doing the assessments did take away from the early rehab … I found it frustrating because I'd rather have been doing the treatment"

Evidence strength and quality

Having underpinning evidence for PREP2 increased staff confidence in using its predictions and in general beliefs that the predictions were accurate, and when wrong they were "not wrong by much" (P17). Practical experience of using PREP2 was also influential.

P10: "actually seeing the studies and seeing actual data on the predictive accuracy of it … that's quite useful"

Relative advantage

Overall clinicians found PREP2 predictions were useful for guiding and focusing UL rehabilitation, although a few reported it had little influence on their treatment choices.

P04: "it just gave me hope and confidence to keep pushing and keep advocating and knowing that this person does have the potential"

P19: "they get the same amount of therapy it's just the focus of the therapy, so someone that has a good or an excellent, we're really focussing on re-learning how to use that hand and doing everything with that hand trying to get the good one out of the way to really focus. Whereas if someone's got the poor, you're focussing pretty much the same amount of therapy time but on compensation rather than promoting use, and so it just means that

you're getting better quality – well not better quality because the quality is the same but you're getting what the patient needs sooner rather than trying to mix both"

P14: *"the good [prediction] doesn't have that much effect on my practice … because I do my normal upper limb therapy"*

Staff felt there was a benefit of reducing uncertainty for the patient around prognosis and giving better information to the patients. It enabled patients to deal with bad news of a poor outcome sooner, and careful consideration and support are given when delivering a poor prediction.

P05: "it's hard when people ask you questions and you're always saying 'I don't know, we'll have to see how you go' so it's nice to have something that you can kind of reference… I think it helps with that acceptance earlier on so for example if you get the poor prediction, in a way it's nicer, like they can start to … accept that"

P19: "it gives them the ability to sort of deal with it and try and move on, like we've got psychology [a clinical psychologist] involved with a lot of patients so they can talk about the change to the future."

There were additional benefits in terms of better monitoring of patients, identifying deterioration sooner.

P04: "it … builds on our confidence in terms of noticing change, and especially with the SAFE score because it is a really good way to monitor for those evolving infarcts"

Some difficulties were posed when a prediction wasn't borne out in practice as quickly as expected.

P01: "it's harder when people take longer to achieve their predictions because it's hard to stay positive for that person when they're not seeing the outcomes that they are hoping for."

Outer Setting

Patient needs and resources

There was recognition that patients (and their families) differ in terms of whether they want a prediction or not.

P05: "they've only had a couple who haven't wanted to know, like most people want to know."

It was also recognized that prediction information could affect a patient's mood and/or motivation, either positively or negatively, and that having support available was helpful.

P12: "they may or may not be able to take it well, but … they just need time and help, some support trying to go through the process and eventually people will accept it."

P08: "it can motivate a lot of people in that uncertain or worried time"

Implementation strategies

Implementation strategies evolved and were developed through trial and error rather than being theoretically-driven. Initially it was thought that the main barrier to implementation would be the use of TMS and so a “TMS team” was formed. The group worked as a collective and had no nominated leader. Over time, this group self-identified as the “Implementation team” and their focus evolved to ensure training for all aspects of PREP2, with a recognition that sustainability was key, and that wider staff involvement was needed. Later, a ‘PREP2 lead therapist’ role was created which ring-fenced time for implementation of PREP2. The therapy team and academic team had a close relationship, with some staff having joint roles.

Table 1 details the ERIC implementation strategies used, together with lessons learned for future implementation efforts.

Discussion

The example of PREP2 implementation at ADHB demonstrates a practice change that was initiated and driven by therapists. This study used the CFIR for analysis as a determinant framework to link CFIR constructs to the success of the PREP2 implementation. The CFIR domains identified as influential were the inner setting, the characteristics of the staff and aspects of the intervention itself. Specifically, the support given to staff from the implementation team; the knowledge, beliefs and self-efficacy of staff; and the perceived benefits of having PREP2 prediction information, supported the implementation. This has parallels with what others have found. For example, a review regarding implementation in occupational therapy found the inner setting to be the most commonly identified determinant,[20] and knowledge and beliefs of therapists have previously been shown to be influential.[18, 21, 22] What is yet to be understood, is how modifiable these factors are, if at all, and which implementation strategies are best placed to align to them.

The ERIC implementation strategies were used to retrospectively describe the implementation undertaken by ADHB staff. We observed the use of 26 of the 73 ERIC implementation strategies, which is a similar number to that detailed in other studies.[23, 24] The ERIC strategies used comprised three areas: the implementation team, the clinical/academic partnerships and the training. Based upon the factors identified to influence implementation of PREP2, and the implementation strategies observed, we have provided guidance to aid future implementation efforts of prediction models. This offers lessons learned based on practical experience, detailed using a systematic approach. There

505 are published approaches to identifying determinants and matching strategies to address
506 them.[25-27] It has also been argued that implementation strategies should be considered *a*
507 *priori*,[28] with prospective planning to optimise the likelihood of implementation success, and
508 take account of complexity across different domains. [29] This remains uncommon in clinical
509 practice and was not the case here. The implementation evolved over time, and
510 undoubtedly took a 'convoluted' journey, although ultimately implementation happened
511 and has been sustained. The individuals driving implementation were key: even if they made
512 mistakes and faced setbacks, they persevered and resolved issues. It is unknown whether
513 the implementation could have happened more quickly if fewer detours had occurred due
514 to implementation strategies having been identified prospectively. Methods such as the
515 CFIR-ERIC matching tool, which aims to address which ERIC implementation strategies
516 would best address specific CFIR-based contextual barriers, could be useful.[30] **Although**
517 **PREP2 is not yet ready for widespread implementation, ~~O~~o**ur approach identified
518 retrospectively what worked well at ADHB and provided lessons learned to support future
519 implementation efforts of prediction models in research and ultimately in clinical practice. It
520 is a challenge to develop models that are both robust and clinically useable. Guidance such
521 as that offered by the PROBAST tool[31], provides a structured way to assess the risk of bias of
522 studies on prediction models, and to assess their applicability for the targeted context and
523 population. However, using this tool would have resulted in PREP2 being considered as
524 having high concern of applicability due to the nature of measures used (namely the TMS
525 component). Our in-depth study of implementation found that TMS was successfully used
526 with patients within one week post-stroke, highlighting the need to acknowledge all the
527 factors that influence implementation, not just the aspects of the intervention itself.
528

Using both the CFIR constructs and ERIC categories provided a useful method for ensuring a comprehensive inquiry of the implementation process and factors influencing it. Consistent use of frameworks and theories should help contribute to knowledge about what works, where, and why. There were some challenges with overlaps between domains of the CFIR and the implementation strategies, with this inter-connectedness noted previously and felt to be a necessity.[23]

Limitations

Participants in this study were invited volunteers, thus introducing a self-selection bias where staff with stronger opinions may be overrepresented. More rigorous and resource-intensive methods of reporting implementation strategies have been reported, such as one study[32] in which implementation meetings in six sites over a five-month period were observed, recorded and transcribed. However, this was not feasible when investigating clinically-driven implementation retrospectively. The data collected in this study relied on the healthcare professionals' ability to recall events from a few weeks to years prior to the interviews which may affect data accuracy. Further, as the data is self-report in nature there is the risk of a social desirability bias. However, prior to, and during the interviews it was highlighted to participants that the interviewer was independent to the PREP2 team, the data collected would be anonymised and that it would not be possible for them to be identified, in the hope that they would be as candid as possible.

Conclusions

Despite the well-established challenges and time lags associated with the implementation of evidence-based interventions into clinical practice, the PREP2 intervention was successfully implemented. The CFIR was used to explore the factors influencing this implementation success, and we identified which implementation strategies were used. Key individuals were influential in driving forward implementation and characteristics of the clinical setting, together with the perceived advantage of the PREP2, contributed to implementation success. Future teams hoping to validate and implement prediction tools in clinical practice could build on the lessons learned and prospectively consider how these fit to their local context.

Author Contributions and Acknowledgments

Concept/idea/research design: L. Connell, MC Smith, C Stinear

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Fund procurement: L Connell, C Stinear

Providing participants: C Stinear

Consultation (including review of manuscript before submitting): MC Smith, C Stinear

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Ethical approval

This study was approved by the relevant university research ethics boards (UCLan STEMH 1000 & 00078 AHREC).

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Disclosures

The authors each completed the ICJME Form for Disclosure of Potential Conflicts of Interest. Conflict of Interest: none declared.

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Table 1: Implementation strategies used and lessons for future implementation efforts.

	Relevant ERIC strategies	What worked well at Auckland District Health Board	Lessons for future implementation efforts
IMPLEMENTATION TEAM			
Development of the PREP2 implementation group	• Assess for readiness and identify barriers and facilitators • Identify and prepare champions • Obtain formal commitments • Organise clinician implementation team meetings • Develop and organize quality monitoring systems • Provide clinical supervision • Remind clinicians • Provide local technical assistance	PREP2 'leaders', who were key in championing and promoting PREP2, emerged and evolved informally over time. Eventually a formal role was allocated for a 'PREP2 lead therapist'. Implementation was led by the Physical Therapists. Occupational Therapists were keen to be involved and were involved later in the implementation process. Members of the PREP2 implementation group were often present on the ward. They trained staff, and were useful as a resource for specific cases and queries.	✓ Nominate and support formal PREP2 Champions to lead implementation. Allocate these as formal roles (if possible). ✓ Include a variety of Health Care Professionals (most importantly Physical Therapists and Occupational Therapists) in the implementation team. ✓ From the outset plan for sustainability in terms of training enough staff for the different parts of the PREP2 pathway. ✓ Ensure that members of the implementation team are often present within the clinical setting. ✓ Use a phased approach to implementation, e.g. train clinicians in use of the SAFE score first and delivering Excellent and Good predictions, before moving onto training in the use of the TMS and NIHSS and delivering Limited and Poor predictions.

Implementation activities	• Facilitation • Promote adaptability • Capture & share local knowledge • Tailor strategies • Conduct cyclical small tests of change • Audit and provide feedback	The support from management was beneficial. Clinicians worked with the implementation team to get feedback on their practice and continually drive improvement. Audit and feedback of PREP2 practice were undertaken.	✓ Obtain management staff approval and encourage their support and promotion of PREP2. ✓ Work with the wider Multi-Disciplinary Team to explore how PREP2 can be tailored to different patient needs, e.g. discuss communication strategies with speech language therapists ✓ Encourage working relations between clinicians and the implementation team that promote honest discussions about practice and strive for continual improvement. ✓ Undertake audits of practice; identify changes needed; action these changes, and then re-audit.
CLINICAL ACADEMIC PARTNERSHIPS			
Developing strong clinical/academic relations	• Create a learning collaborative • Build a coalition • Develop academic partnerships • Work with educational institutions	There were close links between the PREP2 research team, the implementation team and the clinicians. This was partly achieved by split clinical-academic roles. Clinicians found it helpful to be shown the evidence that underpins PREP2.	✓ Try to establish close links between clinicians and academics. Sites could explore the local academic resources available to them, or connect with the PREP2 team in Auckland via the PREP Training website.[33] ✓ Re-use existing resources to demonstrate the evidence underpinning PREP2, for example using the PREP2 websites.[33, 34]

TRAINING			
Delivery of training	• Conduct ongoing training • Make training dynamic • Use "train the trainer" strategies • Develop educational materials • Distribute educational materials	Overall, staff found training useful. Training formats included group workshops, one-to-one teaching and self-directed online learning.[33] A folder containing information about PREP2 was created as a useful resource for clinicians. Senior clinicians were trained to be able to support more junior staff in the delivery of PREP2.	✓ Tailor training methods and educational resources to your site (making use of existing resources).[33] ✓ Explore ways in which to build the confidence of senior clinicians in supporting junior colleagues in delivering PREP2, e.g. using a 'Train the Trainer' model. ✓ Make training specific and relevant to clinicians' roles. ✓ Incorporate PREP2 training into the induction and appraisal process. ✓ Try to enable protected time for training
Providing support to clinicians	• Provide ongoing consultation • Conduct educational meetings • Conduct educational outreach visits	The implementation team delivered formal and informal training, and one-to-one coaching was also available. They made themselves available for advice and queries from staff on the wards.	✓ Consider ways in which the implementation team support the clinical staff, including both formal and informal methods, with both group training and one-to-one sessions.

Table 2. Factors Influencing Implementation of PREP2

Consolidated Framework for Implementation Research (CFIR)	
Inner Setting	
Culture	PREP2 is embedded within the normal care for stroke survivors, with training for new staff part of standard orientation.
Readiness for Implementation	Leadership engagement recognized as important, but implementation was led by therapists.
Structural Characteristics	Different wards (acute/rehabilitation) and different staff are required for obtaining predictions, which has implications for logistics and staffing.
Networks and Communication	Communication is important to enable the tests to be completed on time, and to ensure consistent language when sharing PREP2 information with clinicians and patients (and their families). Communication between staff was generally good within a service, but more challenging with other services.
Implementation climate	Staff are generally supportive towards training and staff development. Lack of a systematic feedback loop meant there was no insight into the outcome of predictions.
Characteristics of Individuals	
Knowledge and Beliefs	Mostly positive perceptions regarding PREP2 as a tool for predicting upper limb functional outcome for individual patients.
Self-Efficacy	Recognition that people are trained on the parts of PREP2 that were relevant to them. Therapists had varied confidence levels in their abilities to perform the different aspects of PREP2 and took time to build confidence.
Other Personal Attributes	Passionate PREP2 champions and knowledgeable therapists gave the wider team support and confidence. Therapists appreciated the opportunity to be involved in 'ground-breaking practice' and to learn new skills that advance PT and OT professions.
Intervention Characteristics	
Complexity	PREP2 algorithm includes relatively 'simple' biomarkers but is still complex to implement in a clinical setting. Sustainability and staff turn-over need to be considered from the outset. Time needed for training and undertaking PREP2 assessments can be a challenge. Some difficulties posed when a prediction isn't borne out in an expected time-frame.

Evidence Strength and Quality	Having evidence to support PREP2 helped clinicians believe in its accuracy and usefulness.
Relative Advantage	PREP2 predictions helped guide and focus UL rehabilitation. Receiving a prognosis is felt to help patients with acceptance. Unintended consequence of helping detect deterioration.
Outer Setting	
Patient Needs and Resources	Patients and their families varied in terms of whether they wanted to know their prediction. Knowing their prediction may impact on the patient's mood and motivation, either positively or negatively.

Appendix 1. Interview guide for study

INTRODUCTORY QUESTIONS	
– Can you describe your role in stroke rehabilitation? – For how long have you been working specifically in stroke rehabilitation? – Is this your first time being involved in research?	
PREP2	
– How did you hear about the PREP2? – Can you describe in your own words what the PREP2 is? (ask about both obtaining the information and using the predictions) – Can you describe in your own words how the PREP2 is incorporated in to your work?	
CHARACTERISTICS OF INDIVIDUAL	
– What is your opinion on the concept of predictive algorithms/ PREP2 for people with stroke? – Had you any concerns about getting the right information on prognosis? – Had you any concerns about giving out the prediction information? – Do you think that PREP2 will is helpful your clinical setting? – How confident are you in using PREP2? – How confident do you think your colleagues feel about using PREP2?	
COHERENCE	
Differentiation *(Is PREP2 perceived to be different from traditional ways of working?)*	Does using PREP2 mean you do anything different from what you used to do on a daily basis anyway? If yes, how is it different?
Communal Specification *(Does everybody understand PREP2?)*	Do you think the purpose of the PREP2 is clearly conveyed in the resources provided? Was the training sufficient?
Individual Specification *(Does everybody understand what they have to do when using PREP2?)*	Does using PREP2 fit into your role in inpatient rehabilitation? Do the patients understand what they have to do when undertaking the tests for the PREP2 (SAFE/ NIHSS/ TMS)? Do you think patients understand the predictions?
Internalisation *(Does everybody think it is worth the effort?)*	Do the people you work with like PREP2? Do you think patients think PREP2 is worth the effort?
COGNITIVE PARTICIPATION	
Initiation *(Are there key individuals that advocate for PREP2?)*	Was there enough direction in getting going at the start? Did your manager support you being involved in the implementation?
Enrolment	Are other colleagues now using PREP2 regularly?

(Have people "bought into" PREP2?)	
Legitimation *(Are the right people doing the right tasks?)*	Does anything get in the way of implementing PREP2?
Activation *(Is everybody ready to make an action plan?)*	What has helped in implementing PREP2? Has using PREP2 affected how your work is organised?
COLLECTIVE ACTION	
Interactional Workability *(Is the work involved in delivering PREP2 appropriately allocated?)*	Have there been any problems implementing PREP2?
Relational Integration *(Do staff trust each other's work and expertise in using the PREP2?)*	Are people confident that PREP2 can be implemented as it should be?
Skill Set Workability *(Can people perform the tasks that are being asked of them?)*	Do people have the right skills and knowledge needed to implement PREP2? (ask about both obtaining the information and using the predictions) Has there been any training provided?
Contextual Integration *(Is PREP2 adequately supported by the host organisation?)*	Is there sufficient support from your works setting for implementing PREP2? Is there anything in particular that supported the implementation of PREP2?
REFLEXIVE MONITORING	
Systematizing *(Is implementing PREP2 worthwhile?)*	How do you measure if PREP2 is worthwhile or not?
Communal Appraisal *(Are people finding implementing PREP2 a worthwhile venture?)*	Do people generally think it is worth continuing to use PREP2?
Individual Appraisal *(Do individuals evaluate the new practice as worthwhile?)*	Will you continue to use PREP2 in practice? What factors would influence this decision?
Reconfiguration *(Do people modify their practice in response to evaluations made?)*	Is PREP2 easy to implement? Do you do anything differently after having experience of using PREP2? Any lessons learned we can pass on to others?