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Original Article

Implementing grip strength assessment in hip fracture patients: a feasibility project

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Abstract

Objectives: Risk stratification scores are used in hip fracture surgery, but none incorporate objective tests for low muscle strength. Grip strength testing is simple and cheap but not routinely assessed for patients with hip fracture. This project aimed to assess the feasibility of implementing grip strength testing into admission assessment of patients with hip fracture. **Methods**: A scalable protocol and a corresponding training programme of instructional presentations and practical assessments were designed and delivered by and for physiotherapy staff. Grip strength values were collected pre-surgery on patients with hip fracture at a single centre whilst supine in bed. Implementation of the process was evaluated using narrative, quantitative and cost measures. **Results**: 53 hip fracture patients with a mean age 80.6 (SD 10.4), of which 36 (67.9%) were female, were included. Testing was offered to 42/52 (81%) patients. Cognitive impairment prevented 14/42 (33%) of patients from completing testing; one patient declined testing. Of the 27 patients who completed testing, 14/27 (52%) had low grip strength as defined by EWGSOP2 criteria. The projected cost of testing for one year was £2.68-£2.82 per patient. Fidelity to the protocol was high using multiple criteria. **Conclusions**: Grip strength assessment is acceptable to physiotherapy staff and can be rapidly and cost-effectively implemented into hip fracture admission assessment.

Keywords: Feasibility, Grip strength, Hip fracture, Implementation, Sarcopenia

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Introduction

Hip fracture is the most common serious injury in older people and is the most common cause of death following an accident[1]. In 2018, there were 66,140 hip fractures in the UK[1]. This figure is expected to reach 100,000 cases annually by the year 2025[2]. The management of hip fracture carries a huge economic as well as individual burden, costing UK health and social services over £1 billion per year[3]. Hip fracture was associated with a 30-day postoperative mortality rate of 6.1% in England, Wales and Northern Ireland during 2018[1]. Current preoperative assessment in hip fracture involves multiple risk prediction tools, such as the Nottingham Hip Fracture Score (NHFS) and the Rockwood Clinical Frailty Scale (CFS).

Although the NHFS has been demonstrated to reliably predict post-operative mobility and mortality[4,5], there remains room for improving upon existing risk scores, as evidenced in a 2020 validation of the NHFS which demonstrated poor predictive ability for a wide range of important outcomes, including post-operative complications[6]. No current risk score used in hip fracture surgery provides a direct assessment of muscle function or strength, which are key predictors of poorer outcomes in older people. Sarcopenia is a condition of progressive, generalised loss of muscle mass and strength with advancing age. It can be quantified by; low muscle strength (reduced grip strength)[7], low muscle mass/quality as determined by Appendicular Skeletal Muscle Mass (ASMM) measured through energy X-ray absorptiometry (DEXA) or Bio-electrical Impedance Analysis (BIA)[8], and low functional ability (e.g. reduced gait speed)[9]. Sarcopenia manifests clinically in reduced functional mobility as a result of low muscle strength, affecting as many as 1 in 4 hospital inpatients[9,10]. Sarcopenia is a major determinant of recovery following hip fracture, and is associated with lower rates of walking recovery[11] and independence of bladder and bowel function[7]. Patients living with sarcopenia have greater risk of postoperative mortality, morbidity and increased length of stay following hip fracture surgery[12]. Accumulating evidence also demonstrates that sarcopenia is a predictor of mortality and morbidity following hip fracture surgery[7,12,13]. Adjuncts to the NHFS, such as objective measures of sarcopenia (grip strength), may therefore enhance risk prediction in patients with hip fracture, who commonly live with frailty and sarcopenia, and may highlight patients who require modifications to standard care to improve their outcomes.

Sarcopenia diagnosis requires an assessment of muscle strength[9]. Overall muscle strength can be objectively and cost-effectively assessed in older people on admission to hospital using handgrip strength[14]. Grip strength is an objective and non-invasive assessment which correlates with muscle strength across other body compartments[9,15], and has been shown to be predictor of poor functional recovery, mortality and increased length of stay following hip fracture surgery[7,12]. Grip strength testing has previously been demonstrated as a simple, cheap and effective screening tool for sarcopenia in the routine hospital admission assessment of older people[14]. However, few studies have focused on grip strength testing in the acute phase of hip fracture[7,11,16] and only one study has evaluated the 2019 European Working Group on Sarcopenia in Older People 2 (EWGSOP2) criteria for low grip strength[7].

No studies have evaluated the feasibility of implementing grip strength, which may provide a simple and effective adjunct to BIA, in hip fracture patients[8]. Therefore, this project primarily aimed to assess the feasibility of implementing grip strength testing into the routine admission assessment of patients with hip fracture, with a view to producing a standardised protocol and scalable cost model for implementation in other orthopaedic departments. The secondary aim was to pilot collection of grip strength data alongside hip fracture outcomes, which in future may be employed as an adjunctive measure to enhance risk prediction.

Methods

Planning and design

This project describes the process of implementing handgrip strength testing into the routine admission assessment of patients with hip fracture in a single National Health Service (NHS) centre in the UK. Training and implementation were guided by the Normalisation Process Theory (NPT)[17] which is a theoretical framework used successfully in recent grip strength research to identify enablers of, and barriers to, implementation[14]. The NPT was selected because it specifically focusses on the integration of new procedures into standard practice by exploring the attitudes and motivations of staff and patients, with recent evidence supporting its use in hospital settings[18]. The principles of the NPT are *coherence, cognitive participation, collective action and reflexive monitoring*; a summary of these principles and their respective components of the project are shown in Supplementary Table 1. Findings are reported according to the 'Standards for Reporting Implementation Studies' (StaRI)[19] and assessed using standardised outcomes for implementation studies[20]. The project was conducted in four stages outlined below.

Stage 1. Development of a protocol and training programme

A protocol was drafted by the project team based on a recent study which implemented grip strength testing into hospital admission assessment of older people[14]. An orthogeriatrician and physiotherapist from the orthopaedic ward were selected to work collaboratively with the project team in refining the protocol through an iterative process of separate face-to-face interviews. These staff were selected on the basis of their extensive clinical experience and previous engagement with departmental research. This process ensured that the protocol was suited to the specific

capabilities of patients with hip fracture, whilst promoting NPT principles. Specifically, the interviews engaged staff in understanding the project to support *coherence* and facilitated the recruitment of a senior physiotherapist as a highly motivated local champion.

A grip strength testing protocol was drafted by the project team and refined during two separate semi-structured interviews by a consultant geriatrician and Band 6 physiotherapist. The timeline of the project is shown in Supplementary Figure 1. During these interviews staff demonstrated *coherence* through understanding the rationale behind grip strength testing. This was evidenced when the Band 6 physiotherapist suggested that testing could satisfy the need for an objective measure of frailty rather than depending on unreliable and subjective clinical examinations. Both staff actively suggested potential enablers of and barriers to implementation which demonstrated *cognitive participation*. The early engagement of a Band 6 physiotherapist facilitated their role as a highly motivated local champion, who provided managerial support for other staff and nominated a Band 3 physiotherapist assistant as ward lead.

Stage 2. Delivery of the training programme

The training programme comprised two sessions delivered by a project team member (WJD) and two cascade training sessions delivered by the local champion. Training sessions were held at pre-scheduled break times on the hospital site to cause minimal disruption to clinical practice. Sessions included an instructional presentation, a practical demonstration and assessment with the grip strength device. Staff were trained using the Jamar hydraulic hand dynamometer (J.A. Preston Corporation, United States of America), which was chosen as it is widely used in sarcopenia research and is considered a gold standard tool for its established reliability[21]. The first training session was delivered individually to a senior physiotherapist. A ward lead was identified during the first session; this role involved taking personal responsibility for data collection and entry into patient notes. Four physiotherapy staff were trained in the second session, which concluded with a group discussion which encouraged staff to *cognitively participate* in identifying barriers to implementation and fostered a sense of shared responsibility to ensure *collective action*. Staff were provided with training leaflets and a form to collect information on staff grade and experience, and narrative feedback on the training sessions. During training sessions, all staff underwent practical assessment in grip strength testing. Both cascade training sessions were delivered to one physiotherapist assistant.

Stage 3. Data collection

We planned to assess grip strength testing in all hip fracture patients attending Northumbria Specialist Emergency Care Hospital from March 2020 onwards. Patients were excluded if they were physically unable to complete grip strength testing or had severe cognitive impairment which prevented them from completing testing. As this project concerned the implementation of an already widely used measure into local clinical practice, research ethics approval was not required or sought. Data were handled in accordance with Caldicott principles[22]. Grip strength values were recorded on the Grip Strength Measurement Form; this document was used for recording results and was kept in patient records. Values from the Grip Strength Measurement Form were entered onto a local database and subsequently uploaded to the National Hip Fracture Database (NHFD) by specialist nurses. Risk prediction scores were all calculated preoperatively; NHFS, Abbreviated Mental Test Score (AMTS) and CFS were calculated by the medical team during admission assessment, and American Society of Anesthesiologists (ASA) grade was scored in the immediate preoperative period by the attending anesthetic team. Formal feedback was given individually by the local champion as a representative for the team during weekly feedback meetings throughout the data collection period. The purpose of these meetings was to give opportunity for the local champion to report on the personal experience of staff and to give insight into patient attitudes, guided by the NPT principle of *reflexive monitoring*. Narrative data from these meetings were recorded on paper and subsequently analysed against standardised outcomes for implementation studies[20]. When meetings were unable to be conducted face-to-face on the ward, phone calls or email were used.

Stage 4. Data analysis

Results were analysed against standardised outcomes for implementation studies, which comprised 'acceptability', 'adoption', 'coverage', 'fidelity' and 'implementation cost'[20]. Each outcome was assessed separately using a mixture of narrative, quantitative and cost analysis methods which are outlined in Table 1. Acceptability was assessed through staff and patient perceptions on the complexity of testing, the ease of integration into standard practice and the degree of disruption caused by testing; both staff and patient feedback was sought during weekly feedback meetings with the local champion as direct communication with other physiotherapy staff and patients was not possible. Adoption was considered as the intention to measure grip strength by the physiotherapy team. Coverage assessed the proportion of patients who ultimately completed testing. Fidelity was assessed against a checklist of narrative and quantitative outcomes shown in Supplementary Table 2. Weekly feedback meetings were initially conducted face to face or remotely.

Cost analysis

Two simple cost models were considered using a combination of fixed and variable costs. Cost model 1 reflected the total costs of implementing grip strength for this project, which included a bursary that covered the costs

Outcome	Assessment method
Acceptability	Staff: • Assessed through comments in interviews, group discussion and feedback forms Patient: • Assessed through narrative feedback via staff interviews. • Assessed as the number of patients willing to attempt testing as a proportion of those approached by the physiotherapy team
Adoption	• Assessed as the number of patients who attempted testing as a proportion of all patients with hip fracture
Coverage	• Assessed as the number patients who completed testing as a proportion of all eligible patients
Fidelity	• Assessed through narrative feedback from the local champion and assessed using grip strength data against the Fidelity checklist (see Supplementary Table 2)
Implementation costs	• Assessed using two cost models which considered the cost of implementation in this project and the cost of implementation over a year

Table 1. Project outcomes and methods. Standardised outcomes for implementation research were selected based on their ability to provide a comprehensive assessment of the feasibility of implementing grip strength into routine practice.

of training provision but did not include the cost of employing staff to attend the training session, as these sessions were organised during pre-scheduled break times throughout the standard working day. Fixed costs included the purchase and annual recalibration of two dynamometers: one dynamometer was used for testing and the other dynamometer was kept as a replacement. Cost model 2 was designed to be scalable to other wards and hospital sites. Therefore, it considered the total costs of implementing grip strength over a year-long period with training delivered by standard ward staff found across all orthopaedic departments. For example, the second model considered costs for training sessions to be delivered by Band 5-7 nurses and attended by Band 1-7 nurses; these staff grades were selected based on the grade of staff in similar studies[14]. Variable costs for the second model were scaled up for 700 patients as this is a representative number of annual admissions for a high volume centre. The cost of employment was calculated based on estimated salaries from a representative sample of NHS job vacancies[23].

Statistical analysis

Quantitative data were collected exported directly from the NHFD and analysed using IBM SPSS Statistics v25 (IBM, New York, USA) to generate descriptive statistics at baseline and assess quantitative outcomes. The 2019 EWGSOP2 cut-off values of <27 kg for men and <16 kg for women were used to identify patients with low grip strength[9] and data were reported separately for both sexes. For stratification by cognitive function, an AMTS of ≥8 was deemed normal, 5-7 was deemed moderate cognitive impairment and 2-4 was marked cognitive impairment[24]. Narrative data were gathered from 5 interview sessions and from responses to an 8-question feedback form. Narrative content was compared against the five outcomes for implementation studies outlined in Table 1[20], with a judgement made by the project team member conducting the feedback sessions as to whether the outcomes were met.

To assess the significance of the difference in pre-operative characteristics between both male and female patients and between those who could and could not complete grip strength testing, an independent sample *t*-test was performed on parametric variables (age), a Mann-Whitney U test was performed on non-parametric data (NHFS, AMTS) and a Pearson's Chi-squared test was performed on categorical variables (ASA grade, CFS, pre-fracture residential status and mobility status). A two-sided p value of <0.05 was taken as significant.

Results

Development of the protocol and training programme

Common themes arising in both sessions are outlined below along with respective amendments made to the protocol.

Cognitive impairment

Both staff expressed concerns that some patients may not understand commands due to cognitive impairment, which is present in 50% of patients with hip fracture before or during hospitalisation[25]. Staff also noted that patients with mild or moderate cognitive impairment may still be able to complete testing. Consequently, the protocol advocated that all patients were to attempt testing regardless of previous cognitive assessment results, but severe cognitive impairment was recognised as an exclusion criterion. See Supplementary Table 3 for a list of quotes supporting each NPT principle.

Concurrent upper limb injury

Staff noted that there are various upper limb pathologies which may prevent testing; for example, concurrent upper

	Fixed costs	Variable cost per patient	Cost model 1	Cost model 2
Fixed costs				
Project team member bursary	£1500.00	-	£1500.00	-
Cost to deliver training (per session)	£5.99-£10.70	-	-	£5.99-£10.70
Cost of time to attend training (per staff member)	£4.33-£10.70	-	-	£4.33-£10.70
Cost of two dynamometers	£523.66	-	£523.66	£523.66
Cost of annual recalibration of two dynamometers	£148.80	-	£148.80	£148.80
Variable costs				
Cost of time to conduct test	-	£0.96	£40.32	£672.00
Cost of time to enter data onto NHFD	-	£0.64	£26.88	£448.72
Cost to deliver refresher training	-	£0.01-£0.02	-	£5.99-£10.70
Cost of time to attend refresher training (per staff member)	-	£0.01-£0.02	-	£4.33-£10.70
Total costs	**£754.37-£2172.46**	**£1.62-£1.64**	**£2239.66**	**£1875.09-£1975.08**

Table 2. Total fixed and variables costs per patient of implementing grip strength into routine practice. The total costs of implementation are shown as Cost model 1 and the total costs of implementation for 1 year with training delivered by ward staff is shown as Cost model 2. NHFD: National Hip Fracture Database.

limb injury occurs in 4.1% of hip fractures[26]. A field was added to the Grip Strength Measurement Form to record if pain, stiffness or weakness prevented patients from completing testing on either hand.

Limited mobility

Patients have restricted mobility in the pre-operative period of hip fracture and staff observed that many can only achieve a sitting angle of 30-40° in bed. Previous research has shown that grip strength values are still reliable when taken in the supine position providing that elbow flexion is maintained at 90°[27], despite deviating from the seated position advocated by the American Society of Hand Therapists (ASHT)[28]. The final protocol, which was amended accordingly to allow for testing at 30-40° in bed with 90° elbow flexion, is shown in Supplementary Figure 2.

Stage 2. Delivery of training programme

Four training sessions were delivered to a total of six staff; five staff were trained directly by a project team member, including two Band 3 physiotherapist assistants and three Band 5-6 physiotherapists. The local champion delivered two cascade training sessions to an individual Band 2 physiotherapist assistant who worked on weekends; a second training session was required for this member of staff due to difficulties in understanding the protocol as a result of a language barrier.

The first session was delivered individually to the local champion. The practical assessment was performed on patients with hip fracture from the ward, who were positioned in bed at 30-40° with elbow flexion of 90°. Two values were taken from both hands with a minute break in between measurements as per the project protocol[14]. Results were recorded to the nearest kilogram (kg) and the device was disinfected after use. The second training session was delivered to four physiotherapy staff. Staff used each other as mock patients for the practical assessment and recorded values on the Grip Strength Measurement Form. In the following group discussion, staff members reached the consensus that measurements should be taken between 08.00-09.00 am on the day of surgery to ensure that grip strength would be tested preoperatively. This process fostered a sense of shared responsibility, promoting the NPT principle of *collective action*. A feedback survey was distributed at the end of this session and was completed by all attending staff. Two cascade training sessions were subsequently delivered on the ward by the local champion to a Band 2 physiotherapist assistant who worked on weekends. All training sessions lasted for 30 minutes and all staff were assessed as competent in grip strength testing through observation by a project team member or the local champion.

Stage 3. Data collection

The first period of data collection ran from 02 March 2020 until 23 March 2020. Outside of these formal sessions, staff

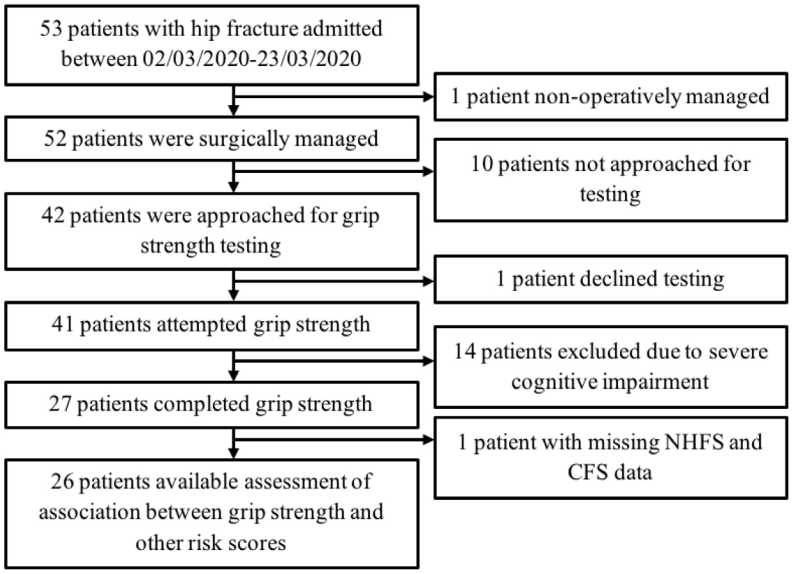

Figure 1. Patient inclusion flowchart, n=53.

sought extra opportunities to give feedback through phone calls and email, thus demonstrating their active engagement in the *reflexive monitoring* process. All data were recorded in patient notes by the ward lead and uploaded to the NHFD by a specialist nurse in the way that had been planned. A second data collection period was recommenced on 17 August 2020 and is in-progress.

Acceptability of intervention

Staff

Staff reported in post-training surveys that "training was very informative, clear and hands on" (Physiotherapist 2), the Jamar dynamometer was "easy to use" and they received "good advice on how to integrate into service" (Physiotherapist assistant 1, ward lead). Surveys showed that all staff felt that testing would integrate into their standard routine and was very easy to perform, and none felt that they needed extra training. The specialist nurses conducting data entry nurse reported that entering grip strength values added 2 minutes extra to the standard 5 minutes of data entry for each patient, which was an acceptable modification of their standard routine and is costed in the Cost Model 2. Staff reported that "most patients coped fine with grip strength testing" and that "they found the process simple to complete" (Physiotherapist assistant 1, ward lead). 97.6% (41/42) of eligible patients who were approached for testing were willing to engage.

Adoption

81% (42/52) of patients were identified as possible candidates for testing preoperatively between 08.00-09.00am on the day of surgery. Testing was not offered for 19% (10/52) of patients and only 30% (3/10) of these patients had a reason recorded in their notes; a common theme for being missed was that patients were taken to theatre earlier than expected and therefore could not be tested preoperatively. Testing and documentation on the grip strength form reportedly took an average of 6 minutes per patient.

Coverage

Severe cognitive impairment prevented 14 patients from completing testing despite attempting testing; one further participant declined testing, and thus 64.3% (27/42) patients offered testing completed testing successfully. 22.2% (6/27) of the patients who successfully completed testing had some degree of cognitive impairment (AMTS <8) and 7.4% (2/27) had marked cognitive impairment (AMTS 2-4). The only patient who declined grip strength testing also declined other assessments, such as AMTS, due to inebriation at the time of testing. Figure 1 shows the patient inclusion flowchart.

Fidelity

The local champion reported that patients were consistently positioned at 30-40° but an elbow flexion

angle of 90° was not always achieved due to restricted patient mobility. For 92.6% (25/27) of patients, two values for both hands were recorded and the only patients with unilateral data had upper limb pathology. The local champion reported that the Dynamometer was consistently disinfected with an alcohol wipe following each use.

Implementation cost

Cost model 1 considered the total cost of implementation for this project, which was £2239.66. The mean average cost of testing provision per patient for Cost model 1 was £53.33. A full breakdown of cost analysis is shown in Table 2. Cost model 2 calculated the total costs of implementation for one-year with training delivered by ward staff, which were £1875.09-£1975.08. This model was calculated on 700 patients attempting testing over a year, which is a representative number of cases in a high volume hip fracture admission centre. Nurse banding was selected based on staff grade in recent grip strength implementation research[14]. The mean cost of testing provision per patient for the second cost model was £2.68-£2.82.

Pilot analysis of first grip strength cohort

Due to the COVID-19 pandemic, data collection was terminated earlier than expected on 23 March 2020. All non-emergency clinical and research activity was closed down at this time to reduce the risk of viral transmission. Over the three-week data collection period, 53 patients were admitted with hip fracture with mean age 80.6 years (SD 10.4). 36 (67.9%) were female. Mean NHFS was 5.0 (SD 1.9), mean AMTS was 6.1 (SD 4.0) and mean CFS was 4.1 (SD 1.5). 16 (30.2%) patients were admitted from a place of residential care and 27 (50.9%) patients had some indoor mobility but never went outside without assistance before their fracture. See Table 3 for descriptive statistics at baseline. Of the 27 patients who completed grip strength testing, 20 female patients had mean grip strength 16.8 kg (SD 5.5) and 7 male patients had mean grip strength 21.7 kg (SD 4.2). 13 patients (12 female, 1 male) had normal grip strength and 14 patients (8 female, 6 male) had low grip strength, as defined by the 2019 EWGSOP2 cut-off values of <27 kg for men and <16 kg for women[9]. Table 4 shows the preoperative characteristics of patients who attempted grip strength testing.

Variable	
Age, mean (SD) (years)	80.6 (10.4)
Female sex (%)	36 (67.9%)
ASA grade	
1 (%)	1 (1.8)
2	16 (30.2)
3	26 (49.1)
4	10 (18.9)
NHFS	
Median (IQR)	5.5 (4-6)
AMTS	
Median (IQR)	8 (1.5-10)
CFS	
1-4 (%)	30 (61.2)
5-6	17 (34.7)
7-8	2 (4.1)
Residential status	
Own home/sheltered housing	37 (69.8)
Residential care	16 (30.2)
Pre-fracture mobility status	
Freely mobile without aids	10 (18.9)
Mobile outdoors with one aid	12 (22.6)
Mobile outdoors with two aids or frame	3 (5.7)
No functional mobility	1 (1.9)
Some indoor mobility but never goes outside without help	27 (50.9)
Grip strength testing results	
Testing not attempted (%)	10 (19.2)
Declined grip strength testing	1 (1.9)
Patients attempted grip strength testing	41 (78.8)
Patients could not complete testing	14 (27.0)
Patients eligible for testing	38 (73.1)
Patients completed grip strength testing	27 (71.1)

Table 3. Descriptive statistics for all patients with hip fracture, n=53. NHFS: Nottingham Hip Fracture Score. AMTS: Abbreviated Mental Test Score. ASA: American Society of Anaesthesiologists. CFS: Clinical Frailty Score.

Discussion

In this project we demonstrate a feasible, scalable, cost effective and reproducible model for implementation of grip strength assessment in patients with hip fracture in a high-volume surgical centre. We share a standardised protocol which, in our pilot cohort, was well received by staff. A large proportion of eligible patients attempted grip strength testing, identifying many with low muscle strength who may be at higher risk of adverse postoperative outcomes[12]. Patients with low grip strength were older (mean age 78.1 vs 74.5), had a higher degree of cognitive impairment (mean AMTS 7.8 vs 9.4) and were more often admitted from residential care (14.3% vs 0%) than patients with normal grip strength. These findings support those of the only other study to evaluate the 2019 EWGSOP2 values for low grip strength in the acute hip fracture setting; however, the prevalence of low grip strength in our project was higher (52% vs 35%)[7].

	Able to complete grip strength testing		Unable to complete grip strength testing	
	Men	Women	Men	Women
n	7	20	4	10
Age, mean (SD)	74.1 (8.2)	77.2 (10.7)	83.8 (10.6)	89.0 (5.4)[b]
Grip strength, mean (SD) (kg)	21.7 (4.2)	16.8 (5.5)	-	-
Proportion with low grip strength*	6 (85.7)	8 (40)	-	-
ASA grade (%)				
1	0	0	1 (25)	0
2	3 (42.9)	10 (50)	0	1 (10)
3	3 (42.9)	8 (40)	2 (50)	7 (70)
4	1 (14.3)	2 (10)	1 (25)	2 (20)
NHFS				
Median (IQR)	5 (3-6)	4 (3-5)	7.5 (7-8)[a]	6 (5-7)[bc]
AMTS				
Median (IQR)	9 (7-10)	10 (8-10)	2 (0.3-5.3)[a]	0 (0-1.5)[b]
CFS				
1-4 (%)	6 (86)	14 (82)	1 (25)	1 (14)[b]
5-6	1 (14)	3 (18)	2 (50)	5 (71)[b]
7-8	0	0	1 (25)	1 (14)[b]
Pre-fracture mobility status (%)				
Freely mobile without aids	3 (42.9)	6 (30)	0	0[b]
Mobile outdoors with one aid	2 (28.6)	5 (25)	0	0[b]
Mobile outdoors with two aids or frame	0	2 (10)	0	0[b]
No functional mobility	0	0	0	1 (10)[b]
Some indoor mobility but never goes outside without help	2 (28.6)	7 (35)	4 (100)	9 (90)[b]
Pre-fracture residential status (%)				
Own home/sheltered housing	7 (100)	18 (90)	2 (50)[a]	1 (10)[b]
Residential care	0	2 (10)	2 (50)[a]	9 (90)[b]

[a]Significance level <0.05 when compared to men able to complete grip strength testing. [b]Significance level <0.05 when compared to women able to complete grip strength testing. [c]Significance level <0.05 when compared to men unable to complete grip strength testing.

Table 4. Preoperative characteristics of patients who attempted testing, n=41. NHFS: Nottingham Hip Fracture Score. AMTS: Abbreviated Mental Test Score. ASA: American Society of Anaesthesiologists. CFS: Clinical Frailty Score. *2019 EWGSOP2 criteria - <27 kg for men, <16 kg for women.

There are differences in both the cohort characteristics and testing procedures which may account for this. Firstly, both cohorts have similar average age (80.6 vs 80.3 years) but our project has a higher relative proportion of male patients (32.1 vs 23.0%). As male patients were disproportionately represented in the low grip strength cohorts of both studies, the discrepancy in sex ratios may have contributed towards our increased prevalence of low grip strength. Men in the general population have greater isometric strength than women; they also have greater bone size and strength than women. Thus, fewer men fracture their neck of femur than women, and when this does happen, it suggests a degree of muscle weakness disproportionately lower than would be needed to precipitate a fall and fracture in women. This may explain why men with low grip strength were over-represented in our data, but this requires further study.

Secondly, elbow flexion at 90° was not always achieved in this project due to the restricted mobility of patients whilst in the supine position; this angle is required to exert maximal pressure on the dynamometer in the supine position[27]. Though other similar studies have conducted testing in the supine position[7,11,16], they did not provide

an assessment of fidelity to the protocol regarding patient positioning. Therefore, it remains unclear whether patient positioning contributed towards the increased prevalence of low grip strength.

In this project, grip strength testing was attempted on all patients regardless of cognitive function. Of the limited studies evaluating grip strength in the acute phase of hip fracture, one listed severe cognitive impairment in their exclusion criteria but did not specify how this was defined[7] and another did not explain whether the exclusion of patients who did not undergo testing was related to cognitive impairment[11]. In our project, 22.2% (6/27) of patients who completed testing had some degree of cognitive impairment (AMTS <8), thus allowing clinically valuable information to be collected from patients who may otherwise have been excluded. We also identify that there may be a third cohort who may warrant further analyses, those patient "unable to complete grip strength testing". This information may facilitate more refined risk stratification within a group of patients who are already at high risk of adverse outcomes following hip fracture surgery[25]. Furthermore, the ability of patients with cognitive impairment to complete testing is a testament to its simplicity and was a major factor contributing towards the success of implementation. Using multi-frequency BIA to assess body composition may potentially be useful as an alternative or adjunct assessment of sarcopenia for patients with physical or cognitive disability who are unable to perform grip strength testing[8], but this requires further study, as muscle mass does not directly reflect muscle strength, and is a weaker predictor of adverse outcomes than strength in general older cohorts.

Grip strength has previously been evaluated in the acute phase of hip fracture[7,11,16], but none of these studies have provided a detailed report of their training programme. Such information is vitally important for building a reproducible framework for implementing grip strength testing on a wider scale. A study which implemented grip strength testing into admission assessment of older patients has provided such information, but their protocol does not accommodate for the physical requirements of patients with hip fracture[29]. Our project is the first to provide a full report of the training programme for testing grip strength in pre-operative phase of hip fracture.

Another important factor in scaling up grip strength testing is cost. One study demonstrated that training 155 hospital nursing staff to measure grip strength was cheap; however, the paper did not give a full breakdown of costs as it reported costs for all five wards together[14]. A detailed report on financial costs is important when implementing a new assessment into standard care in an economically strained national healthcare system. This project provides details on the cost of implementation for one ward, with training and testing provided by nursing staff commonly found across orthopaedic departments, creating a model that can be scaled up at other hospital sites.

Grip strength testing was rapidly and cost-effectively integrated into the assessment of patients with hip fracture on an orthopaedic ward. A protocol was designed with input from experienced clinical staff and the NPT effectively guided the training and implementation process. A team of physiotherapy staff were trained over a relatively short number of sessions and played an active role in the monitoring process. The support of a highly motivated local champion was essential in ensuring a high coverage rate across the project period. Grip strength testing identified a high proportion of patients with hip fracture with low muscle strength who may be at high risk of poor postoperative outcomes. These patients were older, had a higher degree of cognitive impairment and had significantly higher CFS and NHFS in comparison to patients with normal grip strength. This association suggests that low grip strength may correlate with higher CFS and NHFS and by definition may work in combination with NHFS as an independent predictor of adverse outcomes; however, more data is needed to verify this relationship.

Our project was designed as a feasibility project and therefore has limitations inherent in the design and objectives. Generalisability is limited as testing was implemented on only one ward at a single hospital where multiple staff had previous experience of research. This may be more challenging to translate to other wards or hospitals with different staff, culture, resources and patient care pathways. Additionally, due to the early termination of data collection period, the sample size was too small to run adequate analyses to determine whether grip strength is an independent predictor of adverse outcomes following hip fracture surgery. Lastly, in the cohort of patients who completed grip strength testing, male patients were overrepresented in the 'low grip strength' and 'could not complete testing' categories. This may create a false positive correlation between grip strength and NHFS as male sex scores one point more than being female on the NHFS.

Future research should initially focus on scaling up grip strength testing using this model across other orthopaedic departments. This will determine whether our project protocol generalisable and applicable on a wider scale, while providing further insight into the barriers and enablers of grip strength implementation on a wider scale. Once grip strength testing has been scaled up across other departments, large volumes of prospective outcome data can be gathered and correlated with grip strength to assess the predictive performance of grip strength against other risk scores used in hip fracture. Typically, a sample of several hundred participants would be needed for such a study, depending on the rate of adverse events and the number of predictive factors studied.

This project may inform the design of an integrated predictive score which combines grip strength with other variables. If completed at admission, this type of novel scoring system may identify patients in high risk cohorts.

The benefits of this may include the ability to target perioperative interventions such as planning more intensive or longer rehabilitation to higher risk patients, as well as informing prognostic conversations with patients/relatives and providing additional information to adjust for case mix when benchmarking service performance.

Author Contributions

SL, NS, KI, MRR, AC, AAS, MDW and AKS designed the project and formulated the implementation strategy. KI, TAS and WJD developed the protocol. WJD, SL, AC and NS implemented the protocol. WJD, NS and SL designed and delivered training. NS and SL collected data. WJD, MDW and AKS wrote the manuscript. All authors reviewed, edited and approved the final manuscript.

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Supplementary Material

NPT principle	Project element	Method
Coherence	Understand the relevance of measuring grip strength in older patients with hip fracture	Semi-structured interviews Presentation
	Understand how to measure grip strength using the Jamar dynamometer	Practical demonstration
	Understand how to record grip strength measurements in patient notes	Practical demonstration
Cognitive participation	Demonstrate competence in grip strength testing	Practical demonstration
	Discuss potential barriers to and enablers of implementation	Individual and group discussions
Collective action	Reach group consensus on plan for implementing grip strength testing	Group discussion
Reflexive monitoring	Report feedback on staff and patient experience of grip strength testing	Weekly feedback sessions

Supplementary Table 1. NPT principles, project elements and methods[17].

Protocol area	Fidelity assessment
1. Patients should be positioned at 30-40° and their elbows supported with 90° flexion.	Assessed qualitatively through daily observation by the local champion.
2. Two measurements should be taken for each hand and recorded in their notes.	Analysed quantitatively by the proportion of patients with two values for both hands recorded in their notes.
3. A valid reason should be recorded on the Grip Strength Measurement Form if testing was not attempted (e.g. patient taken to theatre early).	Assessed quantitatively by the proportion of patients who did not attempt testing who also had a valid reason recorded in their notes.
4. The dynamometer should be disinfected with an alcohol wipe after use.	Assessed qualitatively through daily observation by the local champion.

Supplementary Table 2. Fidelity checklist.

NPT principle	Staff feedback
Coherence	"*Good training session – machine easy to use and good advice on how to integrate into practice.*" – (Physiotherapist assistant 1, ward lead) "*We could potentially give patients with low grip strength nutritional or rehabilitative treatments.*" - (Physiotherapist 1, local champion). "*Testing could solve the issue of relying on our personal clinical examinations by giving us an objective test for frailty.*" – (Physiotherapist 2).
Cognitive participation	"*I feel that grip strength testing is easy and we received good information on how to integrate it with our standard duties. However, I think it might be difficult to test all patients before going to theatre.*" – (Physiotherapist 2). "*Some patients would have, for example, 8 for the first grip on right side and then 12 for the second grip on the right. I thought I was doing this wrong but [senior physiotherapist] was happy with this.*" – (Physiotherapist assistant 1, ward lead)
Collective action	"*I think we should test patients between 08.00-09.00 am so that they are tested before going to theatre.*" - (Physiotherapist 1, local champion). "*I think that [Band 3 physiotherapist assistant] should lead the project as they will embrace the responsibility.*"- (Physiotherapist 1, local champion).
Reflexive monitoring	"*The patients with dementia are different, some are able to follow instructions but there are some that I have been unable to do.*" – (Physiotherapist assistant 1, ward lead) "*Length of time depends on the patient, first I explain to patients and then it often takes around 5/6 minutes just for the grip strength by time you do the minute wait between each grip.*" – (Physiotherapist assistant 1, ward lead) "*Most of the patients do engage, finding the process fine and simple. I had a patient the other day who did just refuse to take part.*" – (Physiotherapist assistant 1, ward lead) "*I was surprised that some patients had low grip strength when they appeared visually robust.*" - (Physiotherapist assistant 1, ward lead)

Supplementary Table 3. Feedback quotes from orthopaedic physiotherapy staff. This table shows quotes from ward staff supporting each NPT (Normalisation Process Theory)[17] principle which were collected through interviews, group discussion and email.

		Study period (weeks)							
Stage of study	**Description**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8+**
1. Development of a protocol and training programme	Design a protocol and training programme	✓							
	Refine protocol during interviews		✓						
2. Delivery of a training programme	Deliver individual training session		✓						
	Deliver group training session			✓					
3. Data collection	Collect grip strength data				✓	✓	✓		
	Weekly observation and feedback				✓	✓	✓		
4. Data analysis	Quantitative, narrative and cost analysis							✓	✓

Supplementary Figure 1. Study timeline. Over the first three weeks, the study protocol was designed and refined, and training was delivered to physiotherapy staff. The data collection period ran for three weeks during which time weekly feedback meetings were held between ward staff and the project team.

1. *As most patients will not be able to sit out of bed, position them at 30-40° and ensure that their elbows are supported on the bed/ with pillows at 90°. (If patient is sitting out of bed, support elbows with pillow and follow protocol as standard).*
2. *Demonstrate how to use the Jamar handgrip dynamometer to the patient, then reset the red Peak-Hold Needle to 0kg.*
3. *Start with the patient's right hand.*
4. *Position their hand so that the thumb is round one side of the handle and the four fingers are around the other side – ensure that the handle is a comfortable size for the patient's hand (i.e. so they can squeeze it tightly).*
5. *Rest the base of the dynamometer on a pillow as the patient holds the dynamometer to support the weight.*
6. *Tell the patient that the handle won't move but the machine will show how strong their grip is.*
7. *Encourage the patient to squeeze as long and as tightly as they can - once the needle stops rising the patient can be told to stop squeezing.*
8. *Read grip strength in kilograms from the outside dial and record the result to the nearest 1kg on the Grip Strength Measurement Form.*
9. *Reset the red Peak-Hold Needle to 0kg.*
10. *Repeat measurement in the left hand.*
11. *Do one further measurement for each hand alternating sides, leaving at least 1 minute between measurements on the same hand.*
12. *Record the 2 measurements of each hand on the Grip Strength Measurement Form. Take the maximum values of all attempts.*
13. *Disinfect the dynamometer with an alcohol wipe between patients and place the dynamometer back in its case.*

Supplementary Figure 2. Standardised grip strength testing protocol produced during Stage 1 of this project that formed the basis of training during Stage 2. This protocol deviates from the standard protocol advocated by the ASHT in areas where it has been modified for use in hip fracture.