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Grip and Muscle Strength Dynamometry in Acute Burn Injury: Evaluation of an Updated Assessment Protocol

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Abstract

External stabilization is reported to improve reliability of hand held dynamometry, yet this has not been tested in burns. We aimed to assess the reliability of dynamometry using an external system of stabilization in people with moderate burn injury and explore construct validity of strength assessment using dynamometry.

Participants were assessed on muscle and grip strength three times on each side. Assessment occurred three times per week for up to four weeks. Within session reliability was assessed using intraclass correlations calculated for within session data grouped prior to surgery, immediately after surgery and in the sub-acute phase of injury. Minimum detectable differences were also calculated. In the same timeframe categories, construct validity was explored using regression analysis incorporating burn severity and demographic characteristics.

Thirty-eight participants with total burn surface area 5 – 40% were recruited. Reliability was determined to be clinically applicable for the assessment method (intraclass correlation coefficient >0.75) at all phases after injury. Muscle strength was associated with sex and burn location during injury and wound healing. Burn size in the immediate period after surgery and age in the sub-acute phase of injury were also associated with muscle strength assessment results.

Hand held dynamometry is a reliable assessment tool for evaluating within session muscle strength in the acute and sub-acute phase of injury in burns up to 40% total burn surface area. External stabilization may assist to eliminate reliability issues related to patient and assessor strength.

Key Words

Burns; Muscle Strength; Hand Strength; Rehabilitation; Patient Outcome Assessment

INTRODUCTION

Decreased muscle strength is a significant impairment which burn injured patients are faced with after their injury [1]. For this reason muscle strength is regularly targeted in rehabilitation programs. The prescription of therapeutic exercise requires an accurate and consistent mode of assessment to monitor both the necessity and effectiveness of a chosen treatment. Hand held dynamometry (HHD) has been shown to assess muscle strength reliably when compared to isokinetic dynamometry [2], the reference standard in muscle strength testing. The advantages of HHD include lower cost, increased time efficiency, greater portability and ease of use compared to isokinetic dynamometry [3]. Our group has previously demonstrated HHD, including muscle strength and grip strength dynamometry, to be reliable and valid in the assessment of muscle strength in patients with acute, minor burn wounds [4] and patients with a recently healed upper limb burn injury [5], though there is currently no data available for people with more severe burn injuries.

Although deemed appropriate to use in a burn injured population, we have identified aspects of the assessment process which warrant further development. Other authors have demonstrated the strength of the clinician performing the assessment can affect the reliability of results, particularly when compared between different assessors [6-8]. A solution proposed utilizes external stabilization to enhance reliability of testing procedures. By implementing an external system of stabilization, it is possible to reduce variability that exists in relation to the physical strength of the assessor. Minimizing the strength differential between tester and assessor in this way has been shown to improve reliability in other populations [9, 10].

In burns, the use of HHD has not been tested in patients with moderate or major burn injury. Nor has the use of external stabilization been evaluated. To be able to demonstrate reliability and validity in this population would allow for wider application of the tool in a burns clinical environment. This study aimed to assess the reliability of HHD using an external system of stabilization in people with moderate burn injury. We also aimed to explore construct validity of strength assessment using HHD with external stabilization by exploring the effects of age, sex, total burn surface area (TBSA), location of burn, type of surgery, time post burn and pain intensity on strength assessment.

METHODOLOGY

Participants

Subjects were recruited from the State Adult Burns Unit at Royal Perth Hospital & Fiona Stanley Hospital between August 2014 and April 2017. Inclusion criteria were as follows:

- TBSA 5% to 40%,
- Consent obtained and able to begin assessment within 72 hours of the burn injury, and
- Aged 18 years or older.

Exclusion criteria were:

- Length of admission <72 hours,
- Electrical injury,
- Palmar hand burns,
- Concomitant trauma preventing participation in an exercise program,
- Musculoskeletal or neurological conditions or injuries preventing participation in an exercise program, and
- Patients unable to comprehend English language.

Procedure

Only patients who were admitted as inpatients to the burns unit for treatment of their injury were approached for recruitment. Consent to participate was provided by all subjects. Ethical approval was granted by the Royal Perth Hospital HREC 14-008 & The University of Notre Dame Australia HREC 014138F.

Testing of muscle strength commenced within 72 hours of the burn injury. Testing was undertaken up to three times per week for a period of up to four weeks. After surgery, testing was ceased for 48 to 72 hours as per our standard surgical and rehabilitation practices. At the commencement of each session, a short, active warm up consisting of upper limb and/or lower limb ergometry and stretches was completed by patients. At the commencement of the testing procedures, a score out of 10 representing a baseline level of pain intensity was collected from each patient (0=no pain, 10=worst pain imaginable). The muscle strength testing procedure described by Gittings et al. [4] was adjusted and utilized. The specific changes made to the original protocol included exclusion of the assessment of hamstrings, whilst adding assessment of shoulder press and leg press combined muscle strength, as these movements were more applicable to our standard, clinical exercise regimen. External traction belt stabilization was introduced for all muscle groups in the updated testing procedures. The testing order was standardized with three alternate trials of left and right sides of elbow flexion, elbow extension, shoulder abduction, shoulder press, grip strength, isolated knee extension and leg press.

<u>Outcome Measurement</u>

Muscle Strength Dynamometry

Peak muscle strength in kilograms of force was recorded for each trial using a hand held Lafayette Muscle Meter no. 01165 (SI Instruments, SA, Australia). This device is a portable, hand held dynamometer capable of quantifying muscle strength up to a recommended limit of 136 kg. Each participant received a demonstration of the testing procedure and standard instructions to push against the dynamometer as hard as possible for the duration of the test. Encouragement to do so was provided during the active testing process. Three isometric muscle tests of five seconds each were performed on left and right sides for each muscle group. A traction belt (Pelican Manufacturing P/L, Australia), equivalent to an automobile seat belt strap with adjustable buckles was set up over the dynamometer, to a fixed anchor point. The belt length was adjusted to provide resistance in a position suitable to facilitate an isometric contraction from the participant as seen in Figure 1a-e. In the case of elbow extension stabilization was provided against the arm rest of the chair and for leg press, stabilization was provided against an immoveable footplate. The positioning of each test is described in Table 1 and pictured in Figure 1. Where the location of the burn wound was not tolerated by the patient and prevented the planned placement of the dynamometer, a gel pad was used to improve comfort or the dynamometer was moved to a comparable position within 5cm of the standard placement. Separate analyses were undertaken for left and right side for each muscle group.

Grip Strength Dynamometry

Grip strength was assessed in kilograms using a Jamar handheld dynamometer (Surgical Synergies, SI Instruments, SA, Australia). Instruction and demonstration of the test was provided at the initial testing session. Each test lasted for ~three seconds and encouragement to squeeze the dynamometer as hard as possible was provided during the test. Subjects performed three tests alternating between left and right hands. Positioning for this test is outlined in Table 1 & Figure 1. No additional stabilization was required for GSD as there is no interaction between the physical capacities of tester and participant. The assessor did provide support of the dynamometer to facilitate consistent elbow positioning of patients.

Data Analysis

Descriptive statistics were used to describe demographic and clinical characteristics of participants. The distribution of the muscle strength variables was assessed to determine appropriate analytical methods. Results are presented as appropriate based on distribution of data. All analyses were completed using STATA v14.0 (StataCorp, Chicago, IL).

Reliability

Within session reliability was assessed by calculation of ICCs for each muscle group, on each side, using multilevel mixed-effects linear regression, initially with no covariates. A learning effect was identified on comparison of estimated mean strength between the first and subsequent assessment trials for lower limb muscle groups. Therefore, the decision was made to calculate ICCs for all muscle groups, excluding the first trial, from each assessment session. ICC's were also calculated following adjustment for the effect of pain intensity as reported by the subject at the commencement of muscle strength assessment. Clinically applicable reliability was accepted where ICCs >0.75. Excellent reliability was indicated by an ICC >0.9 [11]. We chose to assess within session reliability longitudinally defined in the time frame categories of: prior to surgery (initial); immediately after surgery; and, at three weeks after the burn injury (sub-acute), to assess the use of muscle strength assessment across the timeline of acute wound healing after a burn injury. The assessment immediately after surgery included only the sub-set of participants who required surgical intervention. In the sub-acute phase, data for all participants were included in analyses.

Minimal Detectable Difference

Based on trials two and three on the first assessment day, minimal detectable difference (MDD) was calculated for each muscle group for the initial testing session using the following distribution based formula [12]:

$$\text{MDD (95\%)} = t \times SD_{baseline} \times \sqrt{(2(1\text{-rho\_testretest}))}$$

Where the t was the t-distribution value for the sample size and $SD_{baseline}$ was represented by the standard deviation for the second muscle test trial. Minimum detectable differences were also calculated, based on trials two and three, for the immediately post-operative and sub-acute phases of injury using the same formula.

V*alidity*

Linear mixed-effects regression was utilized to assess the associations of clinical variables and muscle strength assessments for each muscle group. This was undertaken using trials two and three at initial, post-surgery and sub-acute time points. Random effects components for participants were accounted for in the analyses. The clinical variables assessed were TBSA, pain, assessment session number, type of surgery required, age, sex and burn location. Type of surgery was categorized as no surgery, ReCell® only and split skin grafting (SSG). These categories were used as a quasi-measure of burn depth in analysis due to ambiguities in recordings of burn depth. In practice in Western Australia, a SSG is used to acutely reconstruct burns of greater depth when compared to the use of ReCell® only. Age, TBSA, surgery type and burn location were included in regression analysis as categorical variables. Age and TBSA were categorized to aggregate the small effect size per unit of measure, presenting a more clinically meaningful result compared to when continuous variables were modelled. Age was dichotomized into ≤30 years or >30 years, whilst TBSA was categorized as 5-10%, 11-20%, 21-30% and 31-40% TBSA. Burn location for arm, hand and legs were categorized as left, right, bilateral or none. As one subject was reported to have received conservative management, the "no surgery" reference group category was not appropriate to include in the multivariable analyses.. All variables were initially assessed using univariate analysis. Variables which displayed associations with muscle strength, accepted as $\alpha=0.1$, were entered into multivariable analysis. Variables were removed in a manual, backward step-wise manner to determine the final model. For explanatory variables in the final model, the level of statistical significance was accepted at $\alpha=0.05$.

RESULTS

Thirty-eight patients, with a TBSA range of 6-40%, were recruited in the allocated timeframe to participate in this study. Patients took part in 318 strength assessment sessions made up of 953 individual muscle group assessments. Patients attended assessment sessions until the end of four weeks. Their demographic and descriptive details are outlined in Table 2. Missing assessment data can be attributed to participants who ceased attending assessment sessions because of complete wound healing or disengagement with the burns service. Analysis was completed to compare these sub-groups of participants at the sub-acute time point, there was no difference between those who ceased attending session and those who continued assessment. Surgical limitations meant that, on occasion, some muscle groups could not be assessed safely in the assessment session immediately after surgery. The original patients recruited to this project did not have access to leg press in the sub-acute phase due to a lack of specific equipment at the time and explains the available leg press data in the sub-acute analyses.

Unadjusted ICCs are presented, as adjustment for pain intensity did not affect the overall outcomes. Clinically applicable within session reliability was observed for all muscle groups across each time point after burn injury. In the sub-acute phase data, we assessed the effect of excluding patients who required a second surgery during that period of recovery. In doing so, we determined that only five patients required a second surgery. Exclusion of these participants resulted in nil or minimal changes to the ICCs, whilst maintaining clinically applicable to excellent within session reliability. Minimal detectable differences are also reported in Table 3 for initial, post-operative and sub-acute phase testing.

<u>VALIDITY</u>

In multivariate models, sex, burn location, surgery type and TBSA were associated with muscle strength across all assessed time points. Males demonstrated greater muscle strength. Age was negatively associated with strength in the sub-acute period of recovery only. Arm burns were associated with reduced strength around the elbow joint. The presence of a hand burn was associated with significantly lower shoulder press and grip strength. Leg burns were associated with a reduction of strength in knee extension only after surgery. Burn size as assessed by TBSA was only associated with a decrease in muscle strength after surgery. Results of multivariate analysis are presented in Table 4.

DISCUSSION

This study was undertaken to update a muscle strength testing protocol our group has previously published [4]. Updates to the protocol included new muscle group assessment for shoulder press and leg press, as well as utilizing external stabilization during testing. The patient group was extended to include patients with moderate to major burn injury (ie. 5 – 40% TBSA). Thus, we have demonstrated that our updated HHD testing protocol improves on the previous standard method [4] and extends the applicable TBSA range from 0 – 40% TBSA, providing a reliable tool for evaluating within session muscle strength in this patient group. Clinically acceptable reliability was demonstrated for all assessed periods of injury acuity. Intraclass correlations prior to and immediately after surgery exceeded 0.75. In the sub-acute phase of injury, reliability was improved and ICC's for all muscle groups exceeded 0.85. Hand held dynamometry has historically demonstrated issues with reliability related to assessor sex and strength [6, 8]. The use of external stabilization has been shown to ameliorate biases related to this problem and improve testing reliability [10, 13-16]. In this study and in practice we confirmed the use of external stabilization to be useful in reducing the assessor-patient strength disparity throughout our clinical testing procedures. We would continue to recommend a rehearsal test in clinical practice, as a learning effect after the first of three trials was noted to occur.

The sensitivity of MSD can be interpreted from the calculated MDD's for this group. The MDD's in this group are greater during the initial testing period when compared to our previous work which assessed MDD's on the first testing session [4]. Larger MDD's indicate greater variability and suggest that comparison between muscle strength measures, particularly at different time points of the healing continuum, should be made carefully as changes in the assessed muscle strength may be attributed to changes in a number of performance factors other than an appreciable change in strength. We believe the variability present in this group could be related to the greater range of burn severity included in the current study, but may also be attributed to effects of other physical and psychological effects of a burn injury which were not assessed such as anxiety, fatigue and malaise. In the sub-acute phases of injury of recovery, the MDDs are noted to be less, indicating a reduction in variability of host response during the assessment process. Therefore, an observed change during the sub-acute phase of burn injury is more likely to demonstrate a true change in muscle strength. These values allow us, as clinicians, to be able to estimate clinically important changes in muscle strength throughout the rehabilitation journey of patients. The sensitivity of this measurement process however did not appear to be sufficient to determine an effect of surgery and age on muscle strength. In agreement with our results, in an uninjured population with a similar age range to our sample, Lopes et al. [17] determined there was no effect of age on hand grip strength. Conversely, other literature assessing appendicular muscle strength have determined increasing age to be a factor considered influential in decreasing muscle strength in the general population [18-20]. For lower limb muscles test results in the sub-acute time period, our assessment method identified or confirmed an association with age when dichotomized as greater than, or less than 30 years.

The age range of our sample was 18 – 50 years and while no association was evident when assessed as a continuous variable, validity was indicated when broader age categories were compared.

Construct validity can be confirmed for muscle strength assessment using HHD as the tool is able to detect the effect of sex and burn location over time, as well as an effect of TBSA, surgery type and age in the post-operative and sub-acute phases. Other aspects of validity such as criterion related, discriminatory and predictive validity of HHD in burns remain unknown. On initial assessment, MSD was able to distinguish a difference in muscle strength between males and females, whilst leg press on the right side approached a statistically significant sex difference in strength. Location of burn was associated with a change in muscle strength for left biceps, triceps and shoulder press, as well as grip strength bilaterally. Immediately after surgery, injury factors, specifically TBSA and surgery type showed associations with the assessment of muscle strength using HHD, whilst sex and burn location continued to be associated. We would postulate that the effect of leg burn location on knee extension muscle strength immediately after surgery may be attributable to the addition of a donor site on the thigh. In the sub-acute phase of recovery, surgery type, age $\leq$ 30 and sex remain associated with muscle strength in this group. In all cases of a sex difference, males were seen to have greater muscle strength than females, consistent with the general population [19-22]. Whilst location of burn was not influential on the reliability of the testing method, it is a unique challenge to muscle strength testing in this population. We have shown that the burn location can influence the magnitude of muscle strength and this may reflect a limitation of the testing technique, particularly if wound location is in the immediate vicinity of a testing site. Therefore, caution should be taken when making repeated, comparison measures in this situation.

The assessment procedure was able to show that requiring SSG, or greater burn depth, was associated with reduced muscle strength for elbow flexion, shoulder press, knee extension and leg press when compared to ReCell® only in both the immediate post-operative and sub-acute periods. The absence of association in the pre-operative period may suggest that the depth of a burn injury is not influential on muscle strength initially, but becomes a factor to consider in patient management and the provision of rehabilitation, based on the assessment of muscle strength using this method, after surgery has occurred. Using type of surgery as a quasi-measure of burn depth, or volume of tissue damage, was implemented due to ambiguities in the recording of burn depth. This may be interpreted as surgery type being the influential factor on muscle strength, however the two variables are not mutually exclusive. We would conclude that the analyses suggest that the HHD and the strength assessment procedures described herein are able to determine differences between the severities of burn injuries, as the HHD was also able to do so between different sizes of burn injury.

An effect of TBSA on muscle strength was only seen immediately after surgery where muscle strength decreased in more severe burns. Generally, more severe burn injuries will require longer and more invasive surgical procedures. The addition of a large donor site wound and the relative increase of TBSA from this, may contribute to the effect on muscle strength that we have seen immediately after surgery. So too may patient fatigue and anxiety of movement in the first assessment and exercise session after surgery. No effect of TBSA was seen during the initial or sub-acute assessments. At initial assessment, the large MDD and apparent lack of sensitivity may contribute to the lack of evidence of an effect of TBSA on muscle strength. In the sub-acute period, the low MDD's would suggest that burn injured patients are more stable and their physical assessments less influenced by the factors observed prior to and after surgical intervention. Thus, a change in muscle strength, as measured by our method, is more likely to be an accurate reflection of the underlying and true change in the sub-acute period. Analysis using TBSA may be limited by using a single value for TBSA which is recorded at the time of injury and maintained as an unchanged data point throughout the wound healing process. It may be more accurate to, in future, consider ongoing re-evaluation of unhealed TBSA and anatomical location to enhance the understanding of unhealed wounds on muscle strength and functional outcomes.

Location of the burn injury was associated with poorer muscle strength in a number of muscle groups. For interpretation of these results, it must be noted that the majority of participants presented with bilateral arm and/or leg injuries. For example, only one out of thirty patients with leg burns presented with a left sided injury, whilst 27 had a bilateral leg burn injuries and of 31 patients with arm burns, 20 were bilateral injuries. The association of burn location with muscle strength we observed and purport to primarily be influenced by the positioning for testing. The dynamometer may require to be positioned on the skin in close proximity to, or over, a wound particularly during elbow and knee testing, which could influence performance of the test. Hand burns were associated with decreased shoulder press and grip strength, which is not surprising as both require the dynamometer to interface with the hand. A burn in this location can lead to physical positioning difficulties and discomfort, affecting the testing process. Over time, as wound healing occurs, the location of burn should have less of an effect on testing and force generation. This is evident in the loss of association with muscle strength in the sub-acute recovery period.

Pain intensity at rest prior to testing did not affect the reliability of results at any of the time points analyzed. Nor was it associated with the magnitude of muscle strength. We did not ask the patient about their pain during the testing process and the results from that from of assessment might return different results to the ones seen here. Self-reported pain intensity is best conceptualized as the individual's assessment of threat to bodily tissue (Moseley 2007). This is likely to include factors such the person's appraisal of the state of peripheral tissue health and beliefs about the current robustness and capacity of the body. Pain however, should not be considered an exclusion for participation in strength assessment and exercise programs. Our facility's clinical practice is to provide a prescription of adequate pain relief regularly throughout the day as a priority to allow full participation in rehabilitation which begins from the day of hospital admission. We believe that having a quick and simple measure of a person's perceived maximal capacity at any particular time point is imperative for the safe prescription and monitoring of strength training across the whole rehabilitative journey and the results reported here support the reliability of this form of testing in both the acute and sub-acute phases of rehabilitation.

Conclusion

Muscle and grip strength dynamometry are reliable clinical assessment tools for evaluating within session muscle strength in burns. This tool can be used in burns up to 40% TBSA, during the first 4 weeks of recovery from a burn injury. Provision of a practice test for patients prior to official recording should occur in clinical application. Additionally, we encourage a system of external stabilization to be implemented during testing to eliminate reliability issues related to patient and assessor strength.

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TABLES

Table 1: Updated positioning for hand held dynamometry assessment.

Elbow Flexion

- **Posture:** Patient sitting, elbow flexed to 90 degrees, forearm in supination.
- **Position of dynamometer:** Distal radial-ulnar joint palmar side (~1 cm proximal to wrist).

Elbow Extension

- **Posture:** Patient sitting, elbow flexed to 90 degrees, forearm in pronation.
- **Position of dynamometer:** Distal radial-ulnar joint palmar side (~1 cm proximal to wrist).

Shoulder Abduction

- **Posture:** Patient sitting, shoulder abducted to 90 degrees, elbow flexed to 90 degrees.
- **Position of dynamometer:** Immediately proximal to lateral epicondyle of elbow.

Shoulder Press

- **Posture:** Patient sitting, shoulder abduction 90 degrees and full shoulder external rotation. Elbow flexion 90 degrees. Full Wrist extension.
- **Position of dynamometer:** Over thenar/ hypothenar eminence.

Knee Extension

- **Posture:** Patient sitting, knee in 90 degrees flexion.
- **Position of dynamometer:** Distal anterior tibia immediately proximal to talo-crural joint.

Leg Press

- **Posture:** Patient sitting, hip & knee flexion to achieve knee 90deg flexion.
- **Position of dynamometer:** Between sole of foot and foot plate.

Grip Strength

- **Posture:** Patient sitting. Shoulder in adduction, elbow flexion to 90 degrees, forearm & wrist in neutral position.
- **Position of dynamometer:** Patient holding grip strength dynamometer.

Table 2: Descriptive Statistics of Sample n=38

	N (%) or Median (IQR)
Sex male	33 (74%)
Age	30 (23 – 39) *
TBSA	14 (9 – 20) *
- 5-10% TBSA	13 (34%)
- 11-20% TBSA	17 (45%)
- 21-30% TBSA	5 (13%)
- 31-40% TBSA	3 (8%)
Surgery	37 (97%)
- No Surgery	1 (3%)
- ReCell ® Only	10 (26%)
- Split Skin Graft	27 (71%)
Arm Burn	28 (74%)
Hand Burn	25 (66%)
Leg Burn	30 (79%)
Foot Burn	8 (21%)

* data presented as Median (IQR)

Table 3: Intraclass Correlations (ICC) plus Minimal Detectable Difference (MDD) for all muscle groups at initial, after surgery & sub-acute time points. No adjustment for any covariates.

	Left				**Right**			
	N	**ICC**	**95% CI**	**MDD (kg)**	**N**	**ICC**	**95%CI**	**MDD (kg)**
Initial								
Elbow Flexion	36	0.912	(0.839, 0.954)	7.65	37	0.834	(0.711, 0.911)	9.82
Elbow Extension	37	0.918	(0.851, 0.956)	5.16	37	0.850	(0.737, 0.920)	6.32
Shoulder Abduction	37	0.926	(0.864, 0.961)	5.15	37	0.858	(0.749, 0.924)	6.59
Shoulder Press	37	0.878	(0.780, 0.935)	7.43	37	0.778	(0.623, 0.880)	8.22
Knee Extension	35	0.870	(0.767, 0.932)	11.0	34	0.837	(0.711, 0.915)	12.3
Leg Press	37	0.919	(0.852, 0.957)	19.6	36	0.853	(0.735, 0.924)	25.6
Grip	36	0.962	(0.928, 0.980)	8.37	36	0.963	(0.931, 0.980)	8.15
After Surgery								
Elbow Flexion	36	0.968	(0.939, 0.983)	5.33	37	0.928	(0.868, 0.962)	6.57
Elbow Extension	33	0.893	(0.802, 0.945)	5.51	33	0.905	(0.824, 0.952)	4.66
Shoulder Abduction	37	0.915	(0.845, 0.955)	4.62	37	0.871	(0.772, 0.931)	6.33
Shoulder Press	36	0.957	(0.920, 0.978)	4.53	36	0.856	(0.742, 0.924)	6.79
Knee Extension	33	0.885	(0.788, 0.941)	11.2	34	0.829	(0.694, 0.912)	14.9
Leg Press	32	0.912	(0.833, 0.955)	21.5	32	0.842	(0.714, 0.919)	23.7
Grip	35	0.966	(0.935, 0.982)	8.88	35	0.956	(0.916, 0.977)	10.3
Sub-Acute								
Elbow Flexion	30	0.930	(0.864, 0.966)	6.96	30	0.957	(0.915, 0.979)	5.08
Elbow Extension	30	0.884	(0.781, 0.942)	4.85	30	0.898	(0.806, 0.949)	4.81
Shoulder Abduction	30	0.906	(0.819, 0.953)	4.18	30	0.869	(0.754, 0.935)	4.57
Shoulder Press	30	0.910	(0.827, 0.955)	5.99	30	0.873	(0.762, 0.937)	6.37
Knee Extension	30	0.892	(0.795, 0.947)	11.5	30	0.884	(0.778, 0.943)	11.8
Leg Press	26	0.925	(0.847, 0.965)	15.8	26	0.928	(0.854, 0.966)	16.9
Grip	29	0.912	(0.828, 0.957)	7.98	29	0.970	(0.939, 0.985)	5.97

Table 4: Final multivariable linear mixed model of muscle strength assessment

INITIAL	LEFT		RIGHT	
	Variable	**Coeff. (95% CI) p-value**	**Variable**	**Coeff. (95% CI) p-value**
Elbow Flexion	Sex female	-10.5 (-18.0, -3.00) 0.006	Sex female	-7.30 (-14.2, -0.375) 0.039
	Arm Burn Left [a]	-13.1 (-21.8, -4.45) 0.003	Constant	26.5 (24.0, 29.1) <0.001
	Arm Burn Right [a]	1.43 (-6.19, 9.05) 0.712		
	Arm Burn Bilateral [a]	-6.92 (-13.8, -0.026) 0.049		
	Constant	31.1 (24.9, 37.1) <0.001		
Elbow Extension	Sex female	-8.86 (-13.8, -3.87) <0.001	Sex female	-7.49 (-12.1, -2.92) 0.001
	Arm Burn Left [a]	-8.58 (-14.3, -2.81) 0.004	Constant	18.6 (16.9, 20.2) <0.001
	Arm Burn Right [a]	0.827 (-4.23, 5.89) 0.749		
	Arm Burn Bilateral [a]	-2.85 (-7.40, 1.70) 0.219		
	Constant	20.2 (16.2, 24.3) <0.001		
Shoulder Abduction	Sex female	-9.12 (-14.3, -3.96) 0.001	Sex female	-8.03 (-12.7, -3.38) 0.001
	Constant	18.6 (16.7, 20.5) <0.001	Constant	19.0 (17.3, 20.7) <0.001
Shoulder Press	Sex female	-11.5 (-16.9, -6.12) <0.001	Sex female	-5.31 (-10.3, -0.303) 0.038
	Hand Burn Left [b]	-10.2 (-15.1, -5.31) <0.001	Constant	19.5 (17.6, 21.3) <0.001
	Hand Burn Right [b]	-7.28 (-12.1, -2.49) 0.003		
	Hand Burn Bilateral [b]	-8.05 (-12.8, -3.25) 0.001		
	Constant	24.9 (21.5, 28.3) <0.001		
Knee Extension	Sex female	-16.1 (-24.7, -7.40) <0.001	Sex female	-15.8 (-25.8, -5.86) 0.002
	Constant	32.0 (29.0, 34.9) <0.001	Constant	32.5 (29.1, 35.9) <0.001
Leg Press	Sex female	-22.0 (-42.0, -1.96) 0.031	No association	
	Constant	83.2 (75.8, 90.6) <0.001		
Grip	Sex female	-27.3 (-39.0, -15.5) <0.001	Sex female	-23.3 (-35.0, -11.6) <0.001

	Hand Burn Left [b]	-29.1 (-39.5, -18.8) <0.001	Hand Burn Left [b]	-16.6 (-26.9, -6.34) 0.002
	Hand Burn Right [b]	-17.0 (-26.3, -7.74) <0.001	Hand Burn Right [b]	-27.7 (-37.0, -18.5) <0.001
	Hand Burn Bilateral [b]	-22.9 (-32.2, -13.6) <0.001	Hand Burn Bilateral [b]	-20.1 (-29.4, -10.8) <0.001
	Constant	52.4 (45.6, 59.1) <0.001	Constant	53.8 (47.1, 60.6) <0.001
POST-OPERATIVE	**LEFT**		**RIGHT**	
Elbow Flexion	Arm Burn Left [a]	-13.4 (-23.9, -2.90) 0.012	Surgery SSG[f]	-8.91 (-14.7, -3.14) 0.002
	Arm Burn Right [a]	5.80 (-3.24, 14.8) 0.208	Constant	26.1 (21.1, 31.1) <0.001
	Arm Burn Bilateral [a]	-5.32 (-13.0, 2.34) 0.17323.0 (16.4,		
	Constant	29.6) <0.001		
Elbow Extension	Sex female	-6.18 (-11.8, -0.610) 0.030	Sex female	-7.23 (-11.6, -2.89) 0.001
	Constant	16.1 (14.1, 18.1) <0.001	TBSA 11-20 [d]	-0.749 (-2.41, 3.91) 0.642
			TBSA 21-30 [d]	1.98 (-3.25, 7.23) 0.458
			TBSA 31-40 [d]	-6.86 (-12.1, -1.62) 0.010
			Constant	17.6 (15.1, 20.1) <0.001
Shoulder Abduction	Sex female	-5.76 (-11.0, -0.470) 0.033	Sex female	-7.21 (-12.0, -2.34) 0.003
	Constant	15.8 (13.8, 17.8) <0.001	TBSA 11-20 [d]	-4.13 (-7.92, -0.348) 0.032
			TBSA 21-30 [d]	-5.53 (-10.9, -0.183) 0.043
			TBSA 31-40 [d]	-11.3 (-17.8, -4.90) 0.001
			Constant	21.1 (18.0, 24.2) <0.001
Shoulder Press	Sex female	-6.80 (-13.4, -0.164) 0.045	Sex female	-6.13 (-10.8, -1.43) 0.011
	Constant	16.8 (14.3, 19.3) <0.001	Surgery SSG[f]	-4.62 (-8.39, -0.853) 0.016
			Constant	21.5 (18.2, 24.9) <0.001
Knee Extension	Sex female	-10.2 (-19.7, -0.738) 0.035	Leg Burn Left [c]	-13.7 (-32.7, 5.28) 0.157
	Leg Burn Left [c]	-19.6 (-37.8, -1.46) 0.034	Leg Burn Right [c]	-7.87 (-22.1, 6.34) 0.277
	Leg Burn Right [c]	-2.22 (-15.8, 11.3) 0.748	Leg Burn Bilateral [c]	-12.3 (-19.7, -4.94) 0.001

	Leg Burn Bilateral [c]	-12.0 (-19.2, -4.69) 0.001	Surgery SSG[f]	-7.83 (-15.2, -0.469) 0.037
	Constant	35.7 (29.7, 41.8) <0.001	Constant	39.4 (31.1, 47.8) <0.001
Leg Press	No associations		Sex female	-24.7 (-44.3, -5.06) 0.014
			TBSA 11-20 [d]	-1.65 (-16.6, 13.3) 0.828
			TBSA 21-30 [d]	-14.5 (-36.9, 7.92) 0.205
			TBSA 31-40 [d]	-55.5 (-93.9, -17.1) 0.005
			Surgery SSG[f]	-20.6 (-37.0, -4.30) 0.013
			Constant	96.1 (81.0, 111.2) <0.001
Grip	Hand Burn Left [b]	-26.0 (-38.6, -13.5) <0.001	Hand Burn Left [b]	-11.5 (-22.8, -0.330) 0.044
	Hand Burn Right [b]	-4.49 (-15.5, 6.56) 0.426	Hand Burn Right [b]	-25.5 (-35.7, -15.2) <0.001
	Hand Burn Bilateral [b]	-18.9 (-30.8, -6.94) 0.002	Hand Burn Bilateral [b]	-21.0 (-31.7, -10.4) <0.001
	Constant	41.2 (34.0, 48.4) <0.001	Constant	44.5 (38.1, 51.0) <0.001
SUB-ACUTE	**LEFT**		**RIGHT**	
Elbow Flexion	Sex female	-12.7 (-19.6, -5.82) <0.001	Sex female	-11.3 (-17.6, -4.85) 0.001
	Surgery SSG[f]	-9.64 (-14.9, -4.30) <0.001	Surgery SSG[f]	-10.4 (-15.3, -5.48) <0.001
	Constant	33.1 (28.3, 37.9) <0.001	Constant	33.7 (29.3, 38.1) <0.001
Elbow Extension	Sex female	-8.40 (-12.4, -4.39) <0.001	Sex female	-8.14 (-12.4, -3.88) <0.001
	Constant	20.3 (18.6, 21.8) <0.001	Constant	20.0 (18.5, 21.6) <0.001
Shoulder Abduction	Sex female	-8.52 (-12.5, -4.51) <0.001	Sex female	-7.80 (-11.4, -4.16) <0.001
	Constant	18.5 (17.1, 20.0) <0.001	Constant	18.8 (17.5, 20.1) <0.001
Shoulder Press	Sex female	-10.0 (-16.1, -3.93) 0.001	Sex female	-7.82 (-12.8, -2.86) 0.002
	Surgery SSG[f]	-6.77 (-11.4, -2.15) 0.004	Age ≤ 30 [e]	-3.63 (-7.01, -0.253) 0.035
	Constant	25.3 (21.2, 29.5) <0.001	Constant	23.6 (21.1, 26.0) <0.001
Knee Extension	Surgery SSG[f]	-11.3 (-19.0, -3.59) 0.004	Age ≤ 30 [e]	-10.1 (-17.8, -2.33) 0.011
	Constant	38.4 (31.9, 45.0) <0.001	Constant	37.2 (31.6, 42.9) <0.001

Leg Press	Age ≤ 30 [e]	-16.9 (-30.3, -3.24) 0.015	Sex female	-35.4 (-57.0, -13.8) 0.001
	Constant	81.1 (71.4, 90.9) <0.001	Surgery SSG[f]	-29.8 (-44.9, -14.8) <0.001
			Constant	100.7 (87.6, 113.8) <0.001
Grip	Sex female	-15.5 (-24.5, -6.54) 0.001	No associations	
	Constant	40.2 (37.3, 43.1) <0.001		

[a] Reference group = no arm burn

[b] Reference group = no hand burn

[c] Reference group = no leg burn

[d] Reference group = TBSA 5-10%

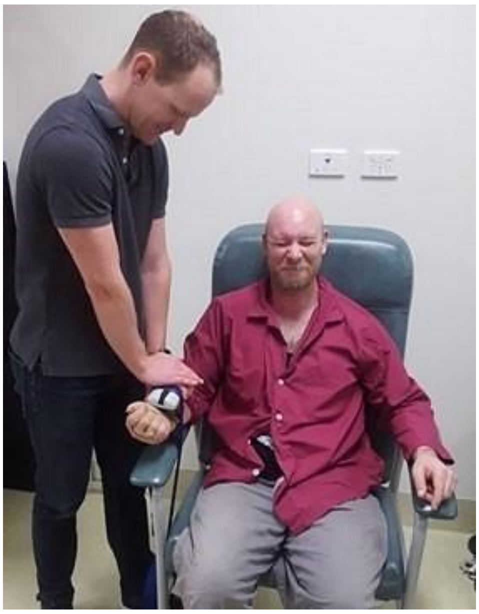
[e] Reference group = age >30 years

[f] Reference group = ReCell Only surgical intervention

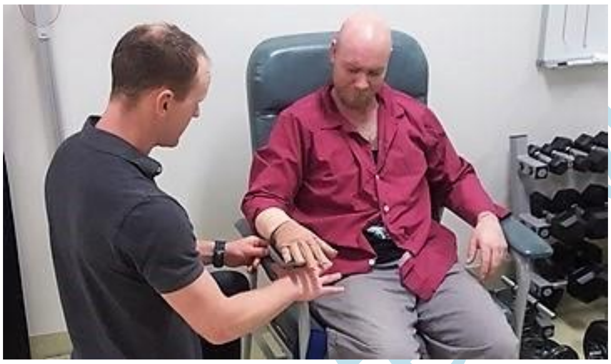
Figure Legends

Figure 1: Positioning for Hand Held Dynamometry, including description of external stabilisation for elbow flexion (a), elbow extension (b), shoulder abduction (c), shoulder press (d), knee extension (e), leg press (f) and grip (g). a) Traction belt over top of dynamometer, attached to anchor point below chair. b) Stabilisation provided by arm rest of chair. c) Traction belt over top of dynamometer, attached to anchor point below chair. d) Traction belt over top of dynamometer, attached to anchor point below chair. e) Traction belt over top of dynamometer, attached to anchor point on chair. f) Stabilisation from foot plate of leg press machine. g) Assessor supporting dynamometer to ensure consistent elbow position.

Figure 1



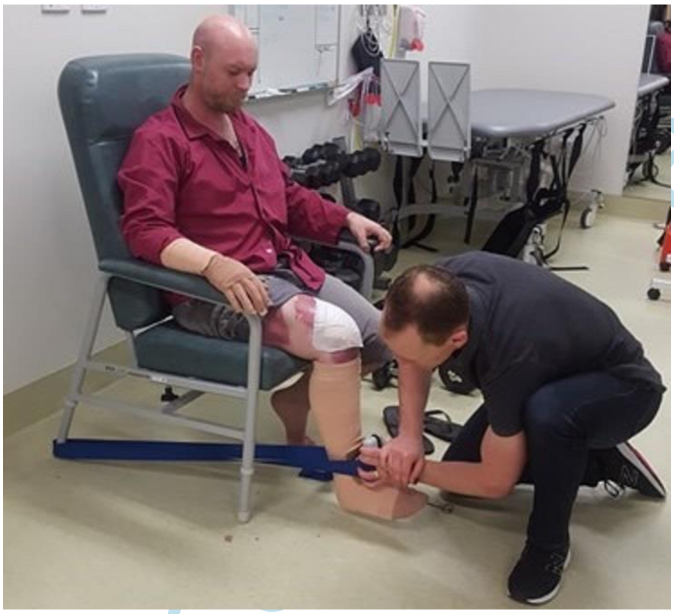
a)



b)

c)


d)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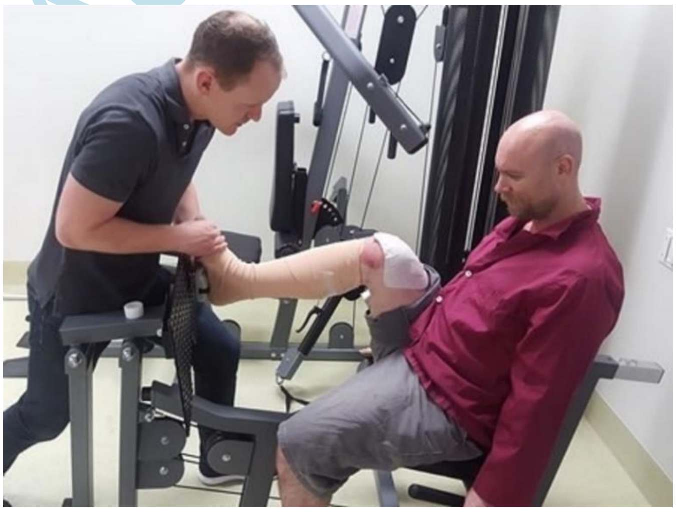
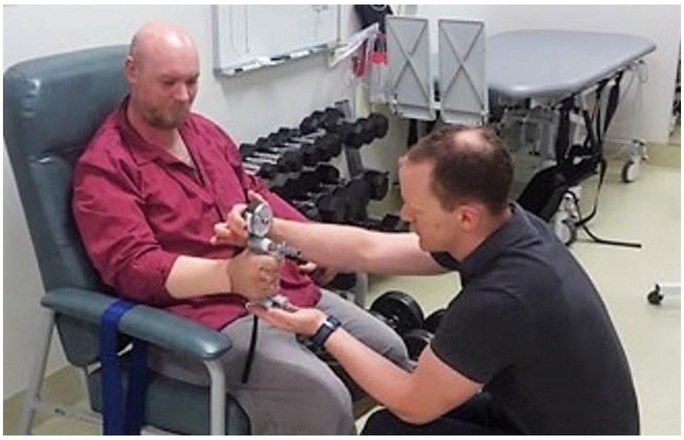

f)

 g)