Manuscript Title: Does Change in Isolated Lumbar Extensor Muscle Function Correlate with Good Clinical Outcome? A Secondary Analysis of Data on Change in Isolated Lumbar Extension Strength, Pain and Disability in Chronic Low Back Pain

Running head: Changes in Strength, Pain, and Disability

Authors: James Steele[a], James Fisher[a], Craig Perrin[a], Rebecca Conway[a], Stewart Bruce-Low[a], Dave Smith[b],

[a]School of Sport, Health and Social Science, Southampton Solent University, Southampton, UK

[b]Department of Exercise and Sport Science, Manchester Metropolitan University, Manchester, UK

Corresponding author:

James Steele (james.steele@solent.ac.uk)

School of Sport, Health and Social Science

Southampton Solent University,

East Park Terrace,

Southampton

Hampshire,

SO14 0YN

Telephone: +442382 016465

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Abstract

*Purpose: S*econdary analysis of data from studies utilising isolated lumbar extension exercise interventions for correlations among changes in isolated lumbar extension strength, and pain and disability.

Materials and Methods: Studies reporting isolated lumbar extension strength changes were examined for inclusion criteria including: 1) participants with chronic low back pain, 2) intervention $\geq$ 4 weeks including isolated lumbar extension exercise, 3) outcome measures including isolated lumbar extension strength, pain (Visual Analogue Scale), and disability (Oswestry Disability Index). Six studies encompassing 281 participants were included. Correlations among change in isolated lumbar extension strength, pain, and disability. Participants were grouped as 'met' or 'not met' based on minimal clinically important changes and between groups comparisons conducted.

Results: Isolated lumbar extension strength and Visual Analogue Scale pooled analysis showed significant weak to moderate correlations (r = -0.391 to -0.539, all $p < 0.001$). Isolated lumbar extension strength and Oswestry Disability Index pooled analysis showed significant weak correlations (r = -0.349 to -0.470, all $p < 0.001$). For pain and disability, isolated lumbar extension strength changes were greater for those 'met' compared with those 'not met' ($p <$ 0.001 to 0.008).

Conclusions: Improvements in isolated lumbar extension strength may be related to positive and meaningful clinical outcomes. As many other performance outcomes and clinical outcomes are not related, isolated lumbar extension strength change may be a mechanism of action affecting symptom improvement.

Key words: Rehabilitation; Exercise; Mechanism of Action

Introduction

Chronic low back pain is one of the most prevalent medical conditions in today's societies representing a total economic cost amounting to billions worldwide [1]. Exercise is a common prescription for chronic low back pain though previous Cochrane reviews have generally reported small effect sizes [2,3]. However, these have typically considered 'exercise' as a single class of treatment and have not adequately described, defined and categorised the 'exercise' studies they have examined. Consideration of 'exercise' as single treatment category potentially explains the generally inauspicious wide-sweeping conclusions drawn. A more recent systematic review has instead looked to examine broadly the impact of different exercise types, reporting that resistance training and stabilisation/motor control type training approaches may offer the greatest benefits for pain and disability [4].

Both of these exercise approaches are aimed at improving different functional deficits thought to present, and potentially play a role in, chronic low back pain. Motor control training approaches are aimed at improving the ability of the neuromuscular system to control specific movement quality and/or create stability, whereas resistance training approaches are aimed at improving general components of neuromuscular function such as strength and endurance. Indeed, theories regarding the mechanisms of action often offered to explain the benefits of exercise can be roughly grouped as being mechanical, such as those described above, neural (e.g. desensitisation), or cognitive and/or operant conditioning based [5]. Motor control and resistance training based approaches produce positive clinical outcomes in chronic low back pain [4], though it has been questioned whether changes in function from them are responsible or even related to changes in pain and/or disability [6-8]. Mannion et al. [8] recently reported that changes in abdominal muscle function after a motor control based exercise intervention were not significantly correlated with changes in disability (r = 0.08 to 0.16). Further, a

systematic review examining the relationships between changes in trunk mobility, strength, and endurance did not support that improvements in these aspects of functional performance were related to improvements in pain and/or disability [7]. Thus, neural/cognitive theories of mechanism of action for exercise are now more prominent.

These findings might be expected as prior reviews report a lack of evidence for consistent associations between decrease in functional performance (i.e. deconditioning) and development or presence of chronic low back pain [9,10]. However, these reviews lacked consideration of the specific component that was deconditioned [11]. A more recent review re-appraised the evidence regarding the specific role of deconditioning of the lumbar extensor muscles (i.e. thoracic and lumbar erector spinae, including the iliocostalis lumborum and longissimus thoracis, the multifidus, and also the quadratus lumborum when contracted bilaterally [11]). There appears to be consistent evidence that deconditioning of these muscles (reduced lumbar extension strength/endurance, atrophy, and excessive fatigability) is associated with chronic low back pain, and this deconditioning may be involved in the multifactorial symptoms and dysfunctions present in chronic low back pain [11]. Further, this relationship may find its origins in our evolutionary past [12].

Because of this specific deconditioning, the conclusion that changes in function are not related to changes in pain and/or disability has been contested as potentially premature [13]. In their review, Steiger et al. [7] focused primarily upon measures of trunk function, which incorporates both hip and lumbar extension/flexion. In light of the specific relationship between lumbar extensor deconditioning and chronic low back pain [11], it should be noted that measures of trunk extension are poor indicators of isolated lumbar extension function [14]. As such, a lack

of relationship between change in measures of 'trunk' function and pain/disability are not necessarily indicative of a similar relationship with measures of 'lumbar' function.

Many studies have utilised exercise interventions that, though improving elements of trunk function, are ineffective in improving lumbar extensor function. Numerous exercises are purported to specifically condition this musculature including: bench and roman chair trunk extensions, use of free weights (e.g. deadlifts, squats, good mornings), floor and stability ball exercise (e.g. trunk extensions, bridging, 4-point kneeling), and resistance machines including those with and without restraints for isolated lumbar extension exercise [15]. Many of these lack evidence for efficacy in conditioning the lumbar extensors, however, isolated lumbar extension appears to be the exception [16]. Indeed, a review of studies using isolated lumbar extension resistance training in patients with chronic low back pain suggests it is effective in improving isolated lumbar extension strength and meaningfully reducing pain and disability [17].

However, irrespective of the outcome measure for function, most studies have not reported correlations between functional and clinical changes [7]. In addition, fewer studies have examined this association for specific lumbar extensor function (e.g. isolated lumbar extension strength) whilst utilising isolated lumbar extension resistance training as an intervention. Of studies reporting this, some suggest there may be a relationship between improvements in this outcome and clinical changes. Nelson et al. [18] reported change in isolated lumbar extension strength and change in pain were significantly but weakly correlated (r = -0.318) in 677 participants with chronic low back pain who underwent a 9 week isolated lumbar extension resistance training intervention. Steele et al. [19] reported significant weak to moderate correlations for change in pain (r = -0.464 to -0.651) and change in disability (r = -0.453 to -

0.522) in 24 participants with chronic low back pain undergoing 12 weeks of isolated lumbar extension resistance training. In contrast, however, Rittweger et al. [20] reported no significant correlations for change in isolated lumbar extension strength and change in pain in 50 participants with chronic low back pain after a 12 week isolated lumbar extension resistance training intervention.

Despite lack of research reporting relationships between changes in isolated lumbar extension strength and changes in pain and/or disability, recent review suggests numerous studies have measured this outcome in participants with chronic low back pain [17]. As such, a body of data exists that could be examined retrospectively for correlations between these variables. Therefore, the purpose of the present study was to conduct a secondary analysis of data from studies utilising isolated lumbar extension resistance training interventions for correlations between changes in isolated lumbar extension strength, pain, and disability. This included pooling of data from the present group's studies in addition to acquisition of raw data from studies identified in a recent literature review [17].

Materials and Methods

Study Selection

Data from 4 studies conducted by the authors were included [19,21-23]. In addition, 23 studies identified in a prior review [17] were examined with respect to the following inclusion criteria: participants suffered from chronic low back pain (symptoms lasting >12 weeks), an intervention including isolated lumbar extension resistance training and lasting for ≥4 weeks was performed, and outcomes reported included isolated lumbar extension torque, pain using Visual Analogue Scale, and/or disability using the Oswestry Disability Index. Inclusion criteria were chosen to facilitate pooling with the 4 studies from the authors (i.e. studies needed to have

utilised similar outcome measures). Of those examined, 10 studies met the inclusion criteria and corresponding authors of these studies were contacted to request release of data for synthesis. Of these studies, raw data were available from only 2. Data not included were due to lack of response from corresponding authors or the data no longer being available. Thus, 6 studies including 281 participants were pooled for analysis [19-24]. Two of the included studies also included the Roland Morris Disability Questionnaire [24] and a Patient Disability Index [20] as outcome measures. Analysis was therefore conducted separately for these outcomes (see below). Data was obtained with the understanding that prior ethical approval for the studies included permitted such distribution of data as long as it remained anonymous.

Data Synthesis and Analysis

Study characteristics including participant demographics (average reported age, sex, duration of chronic low back pain, pain, and disability) in addition to the isolated lumbar extension intervention used (duration, repetition number, load, set volume, and frequency) were extracted. Dependent upon data reporting, isolated lumbar extension torque was considered as peak from multiple angle testing throughout the range of motion, average of all angles tested, and as 'strength index' calculated as the area under the curve for all angles tested. Where necessary, raw torque data was converted from ft·lbs to N·m, and pain measured using Visual Analogue Scale was converted to a value from 0 to 100 mm if applicable (i.e. if a 0 to 10 scale was used) for synthesis. Changes across the intervention period ('post-test' minus 'pre-test') for isolated lumbar extension torque variables, Visual Analogue Scale, Oswestry Disability Index, Roland Morris Disability Questionnaire, and Patient Disability Index were calculated for all participants' data available including both intervention and control groups. Data for individual studies, in addition to pooled data, were examined for assumptions of normality of distribution using a Shapiro-Wilk test. Data sets meeting assumptions of normality of

distribution were examined for correlations among change in isolated lumbar extension peak/average/strength index torque, Visual Analogue Scale, Oswestry Disability Index, Roland Morris Disability Questionnaire, and Patient Disability Index using a Pearson's correlation, and data sets violating assumptions of normality of distribution using a Spearman's correlation. Correlations were examined within individual studies in addition to in a pooled analysis. Correlation coefficients were interpreted as weak (r = 0.30 to 0.50), moderate (r = 0.50 to 0.70) or strong (r > 0.70). For Visual Analogue Scale, Oswestry Disability Index, and Roland Morris Disability Questionnaire minimal clinically important change values as suggested by Ostelo et al. [25] were also used to group participants as either having 'met' or 'not met' minimal clinically important changes (change of 15mm for Visual Analogue Scale, 10pts for Oswestry Disability Index, and 5pts for Roland Morris Disability Questionnaire). Between groups comparisons for pooled data were performed using Mann Whitney U tests, as data violated assumptions of normality, for change in isolated lumbar extension peak/average/strength index torque. Statistical analyses were performed using SPSS (version 22; IBM, Portsmouth, Hampshire, UK) and $p \leq 0.05$ accepted as the limit for statistical significance.

Results

Study Characteristics

Data from 281 participants were available from 6 studies. The range of participants mean ages was reported as ~40 to 46 years. Sex ratio of participants was on average ~2:1 (male:female). The range of participants mean reported duration of chronic low back pain symptoms was ~11 to 15 years, baseline mean pain was ~41 to 46 mm, and baseline mean disability ~14 to 39 pts. The isolated lumbar extension interventions were all of 12 weeks in duration, using repetition numbers ranging from 8 to 20, loads ranging 20% to 80% of maximal voluntary contraction, all for a single set of repetitions, and were performed 1x to 2x/week.

Correlations between change in isolated lumbar extension torque, pain, and disability

For isolated lumbar extension average torque (see table 1) and Visual Analogue Scale significant moderate correlations were found for 3 of 3 studies (r = -0.526 to -0.560; p = 0.016 to <0.001) with pooled data showing a significant moderate correlation (r = -0.539; p < 0.001) and for Oswestry Disability Index significant moderate correlations were found for 2 of 4 studies (r = -0.503 to -0.510; p = 0.033 to <0.001) with pooled data showing a significant weak correlation (r = -0.444; p < 0.001). For isolated lumbar extension peak torque (see table 2) and Visual Analogue Scale significant weak correlations were found for 4 of 4 studies (r = -0.298 to -0.483; p = 0.050 to 0.011) with pooled data showing a significant weak correlation (r = -0.391; p < 0.001) and for Oswestry Disability Index significant weak to moderate correlations were found for 3 of 4 studies (r = -0.235 to -0.522; p = 0.047 to <0.001) with pooled data showing a significant weak correlation (r = -0.349; p < 0.001). For isolated lumbar extension strength index torque (see table 3) and Visual Analogue Scale significant weak to moderate correlations were found for 4 of 4 studies (r = -0.285 to -0.624; p = 0.045 to <0.001) with pooled data showing a significant weak correlation (r = -0.415; p < 0.001) and for ODI significant weak to moderate correlations were found for 2 of 3 studies (r = -0.405 to -0.564; p = 0.015 to <0.001) with pooled data showing a significant weak correlation (r = -0.470; p < 0.001). Figures 1 and 2 show scatter graphs for pooled correlations.

Tables 1, 2, and 3, and figures 1 and 2 should be placed about here

For isolated lumbar extension average torque and Roland Morris Disability Questionnaire in the one study reporting this outcome [24] a significant correlation below the threshold for interpretation as weak was found (r = -0.274, p = 0.017). For isolated lumbar extension strength

index torque and Patient Disability Index in the one study reporting this outcome [20] a significant correlation below the threshold for interpretation as weak was found (r = -0.296, p = 0.037).

Between group comparisons by minimal clinically important change

For Visual Analogue Scale, Mann Whitney U tests revealed significant differences between 'met' compared with 'not met' for change in isolated lumbar extension average torque ('met' n = 41, 'not met' n = 73; U = 857.0, p < 0.001), isolated lumbar extension peak torque ('met' n = 41, 'not met' n = 73; U = 1047.5, p = 0.008), and isolated lumbar extension strength index ('met' n = 83, 'not met' n = 81; U = 2259.5, p < 0.001). Box and whisker plots for each group are shown in figure 3. Those who 'met' Visual Analogue Scale minimal clinically important changes had a significantly greater change in all isolated lumbar extension outcomes.

For Oswestry Disability Index, Mann Whitney U tests revealed significant differences between 'met' compared with 'not met' for change in isolated lumbar extension average torque ('met' n = 72, 'not met' n = 117; U = 2151.5, p < 0.001), isolated lumbar extension peak torque ('met' n = 56, 'not met' n = 58; U = 1059.0, p = 0.001), and isolated lumbar extension strength index ('met' n = 56, 'not met' n = 58; U = 815.0, p < 0.001). Box and whisker plots for each group are shown in figure 4. Those who 'met' Oswestry Disability Index minimal clinically important changes had a significantly greater change in all isolated lumbar extension outcomes.

Figures 3 and 4 should be placed about here

For Roland Morris Disability Questionnaire, Mann Whitney U tests did not reveal a significant difference between 'met' (median±interquartile range for change = 41.0±51.0Nm), compared

with ‘not met’ (median±interquartile range for change = 22.7±58.75Nm), for change in isolated lumbar extension average torque (‘met’ $n = 19$, ‘not met’ $n = 56$; $U = 410.5$, $p = 0.139$).

Discussion

Recent systematic review has concluded there is no relationship between change in most function or performance outcomes and improvements in clinical outcomes after exercise [7]. However, data reported herein suggests change in isolated lumbar extension strength may be associated with positive clinical outcome. Indeed, results of this secondary analysis show most, but not all, studies included showed significant relationships between increased isolated lumbar extension strength and both reduced Visual Analogue Scale and Oswestry Disability Index. When data was pooled from studies all correlations for Visual Analogue Scale and Oswestry Disability Index were found to be significant. Further, those who achieve minimal clinically important changes for both Visual Analogue Scale and Oswestry Disability Index also achieve significantly greater changes in isolated lumbar extension strength. Two studies also reported Roland Morris Disability Questionnaire and Patient Disability Index as outcomes both of which also showed significant correlations between isolated lumbar extension strength changes and positive clinical outcomes, however, those meeting Roland Morris Disability Questionnaire minimal clinically important changes did not have significantly greater changes in isolated lumbar extension strength than those that did not. Considering the relatively consistent correlations found between change in isolated lumbar extension strength and positive clinical outcome it is interesting to consider why this may be the case when this is not the case for other function and performance measures.

As noted, theories regarding mechanisms of action for exercise in chronic low back pain can be broadly grouped as mechanical, neural, and cognitive [5]. Lack of relationship between

changes in many function and performance outcomes with changes in clinical outcomes has been interpreted to argue against mechanical theories and instead support neural/cognitive theories [7]. Indeed, the biopsychosocial model incorporating these components has been adopted to explain the complex relationships between nociception, pain, and suffering [26]. However, despite the lack of relationships between most function and performance outcomes and clinical outcomes [7], isolated lumbar extension function stands out. This may be related to the specific role deconditioning of the lumbar extensor musculature might play in initiation and development of chronic low back pain [11,12]. As such, when interventions effective for conditioning this musculature are used (i.e. isolated lumbar extension resistance training), they may address a key causative mechanism. However, evidence suggests that deconditioning of the lumbar extensors in and of itself is not responsible for the initiation of pain causing mechanisms but may lead to mechanisms responsible for injury (i.e. poor motor control and movement performance [11]). Indeed, improvements seen with isolated lumbar extension resistance training, and relationships between change in isolated lumbar extension strength and pain and disability, may be due to the positive impact it has upon these mechanisms.

Isolated lumbar extension strength is associated with lifting capacity [27,28] which improves after isolated lumbar extension resistance training interventions in persons with chronic low back pain [29]. Fisher et al. [30] even found in recreationally trained males performing an isolated lumbar extension resistance training intervention increased deadlift one repetition maximum. isolated lumbar extension strength is also associated with lumbar kinematic pattern variability during gait in chronic low back pain participants [31]. This also improves after an isolated lumbar extension resistance training intervention [32] and other work shows that change in isolated lumbar extension strength predicts improvements in walking endurance in obese older persons with chronic low back pain [33]. Thus, the relationship between improved

isolated lumbar extension strength and clinical outcomes as a result of isolated lumbar extension resistance training may be due to improved motor control and movement performance.

However, changes falling under the neural/cognitive theories of mechanisms of action may also be involved in the relationships between changes in isolated lumbar extension strength and clinical outcomes. High baseline fear-avoidance beliefs and disability are predictive of poor outcomes after isolated lumbar extension resistance training interventions in persons with chronic low back pain [34], although such interventions may also improve psychosocial outcomes [35]. It is possible changes in isolated lumbar extension function are a 'surrogate' indicator of improvements in psychosocial outcomes and these are responsible for clinical improvements. Indeed, measures of physical performance may in fact measure pain-related behaviour [36]. However, initial deconditioning of the lumbar extensors identified through isolated lumbar extension strength tests in chronic low back pain participants is also corroborated with other physiological measures (atrophy and fatigability identified through electromyography [11]). Further, if isolated lumbar extension strength changes were acting as a surrogate for improvements in psychosocial factors affecting clinical outcomes, then we would expect to see similar relationships between other function and performance measures and clinical outcomes. Though this does not rule out neural/cognitive mechanisms of action for isolated lumbar extension, it does suggest that there may also be some influence of mechanical mechanisms of action through improved isolated lumbar extension strength.

It is worth noting there was some heterogeneity in the isolated lumbar extension resistance training interventions employed in the studies included. Studies from the authors' group [19,21-23] in addition to Rittweger et al. [20] all used a similar manipulation of resistance

training variables, notably characterised by participants training to momentary failure and thus maximal effort [11,12]. Though, Rittweger et al. [20] in their original paper reported no significant correlations between change in isolated lumbar extension strength and change in VAS. However, they examined correlations within groups (an isolated lumbar extension resistance training group and a vibration training group) and not for pooled data as we have here. Helmhout et al. [24] contrastingly had participants train with low loads not to failure, and thus a relatively lower effort. This was the only study included in the current analysis not showing a significant relationship between changes in isolated lumbar extension strength and clinical outcome. A further study from this group using a similarly low load, low effort isolated lumbar extension resistance training intervention reported improvements in disability, but no change in multifidus cross sectional area [6]. Evidently, clinical improvement can occur after any exercise or treatment independently of change in function/performance, and this might be a result of neural/cognitive mechanisms [7]. However, these studies [6,24] employed isolated lumbar extension resistance training interventions lacking in efficacy with respect conditioning the lumbar extensors [16]. Contrastingly, studies from the present authors group [19,21-23] and Rittweger et al. [20] employed higher effort isolated lumbar extension resistance training interventions better evidenced to produce improvements in muscular condition, including strength [37], hypertrophy [38], and aerobic capacity [39]. As such, the significant relationships in these studies might suggest that, although any exercise can produce improvement, exercise addressing the mechanical mechanism of muscular conditioning may optimise outcomes. Indeed, low volume, low frequency, yet high effort isolated lumbar extension resistance training consistently produces significant improvements in pain and disability that meet minimal clinical important changes [17].

It is worth noting there was variability in individual relationships between change in isolated lumbar extension strength and change in pain and disability (Figures 1 and 2). Nelson et al. [18] reported specific sub-grouping did not affect group outcomes despite all participants receiving the same isolated lumbar extension resistance training intervention. Although, considering the heterogeneity of chronic low back pain, some degree of variability in the responsiveness of individuals to different treatments might be expected. Nelson et al. [18] also asked participants to rate pain changes on a 5-item scale ('worse', 'no change', 'slight decrease', 'decreased', 'substantially decreased'), reporting 64% rated a substantial decrease, 14% rated a decrease, 6% rated a slight decrease, 12% rated no change, and 3% rated a worsening of symptoms. Though improvements in isolated lumbar extension strength may be generally related to clinical improvements, there may be instances where the presence of certain symptoms and dysfunctions might impact that relationship. Models attempting to explain, predict and integrate the multifactorial nature of chronic low back pain have emerged within the literature [40]. Indeed, due to the multifactorial nature of chronic low back pain, sub-grouping (i.e. splitting of larger heterogeneous low back pain populations into smaller homogenous groups) may be valuable in directing effective treatment. Indeed, recent work has highlighted that there is evidence of *true* inter-individual variations in responsiveness (i.e. independent of test-retest variation in outcome measures) to isolated lumbar extension resistance training in persons with chronic low back pain [41]. Thus, further studies should consider prognostic factors that might help practitioners discern *a priori* whether a person is likely to be either a good or bad responder to ILEX resistance training in terms of clinical outcome.

Conclusion

The results presented here suggest improvements in isolated lumbar extension strength may be related to positive and meaningful clinical outcomes. However, this may be contingent on application of a higher effort isolated lumbar extension resistance training intervention. Considering the absence of relationships between many other function or performance changes and clinical outcomes, conditioning of the lumbar extensor musculature may be a mechanism of action affecting symptom improvement. The precise nature of this relationship and how this mechanism of action specifically works is still unclear. However, these results suggest specific conditioning of the lumbar extensor musculature could be considered an important outcome to focus upon in clinical practice in persons suffering from chronic low back pain.

Declaration of Interest

The authors declare no conflicts of interest.

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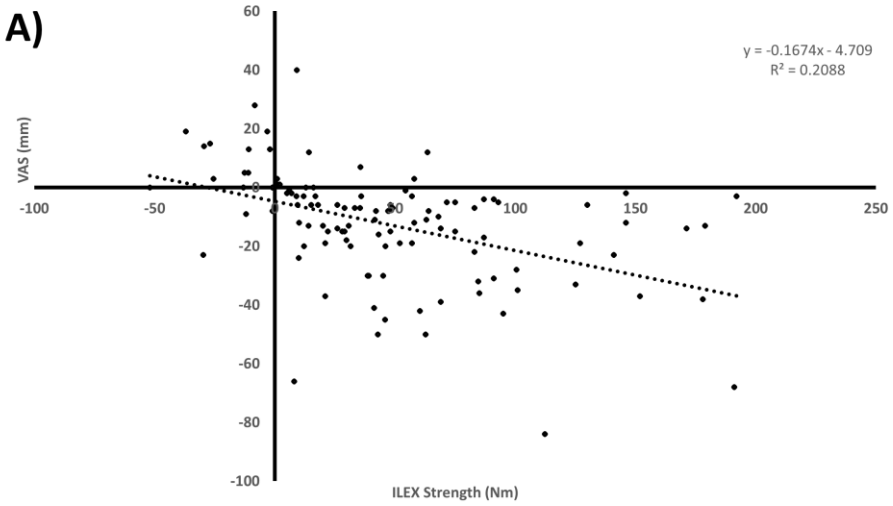
Figure Titles

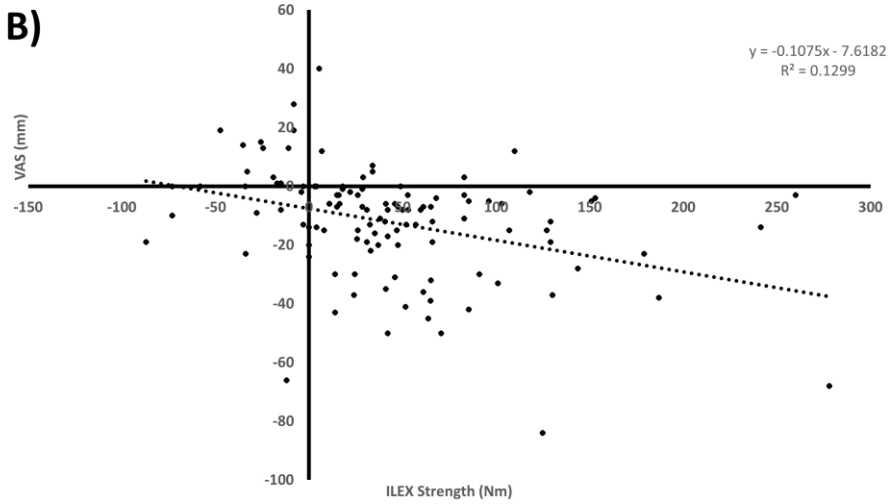
Figure 1. Scatter graph of pooled data for correlations between change in Visual Analogue Scale and A) change in isolated lumbar extension average torque, B) change in isolated lumbar extension peak torque, and C) change in isolated lumbar extension strength index. ILEX = isolated lumbar extension; VAS = Visual Analogue Scale

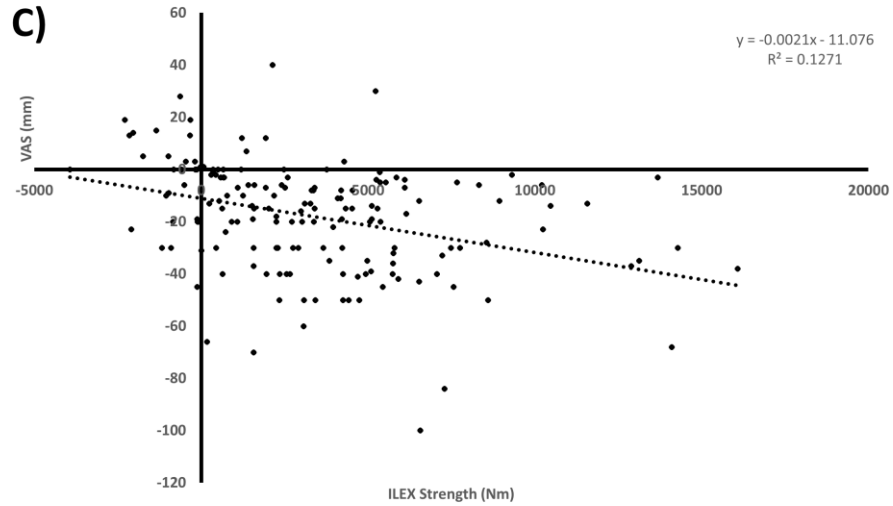
Figure 2. Scatter graph of pooled data for correlations between change in Oswestry Disability Index and A) change in isolated lumbar extension average torque, B) change in isolated lumbar extension peak torque, and C) change in isolated lumbar extension strength index. ILEX = isolated lumbar extension; ODI = Oswestry Disability Index

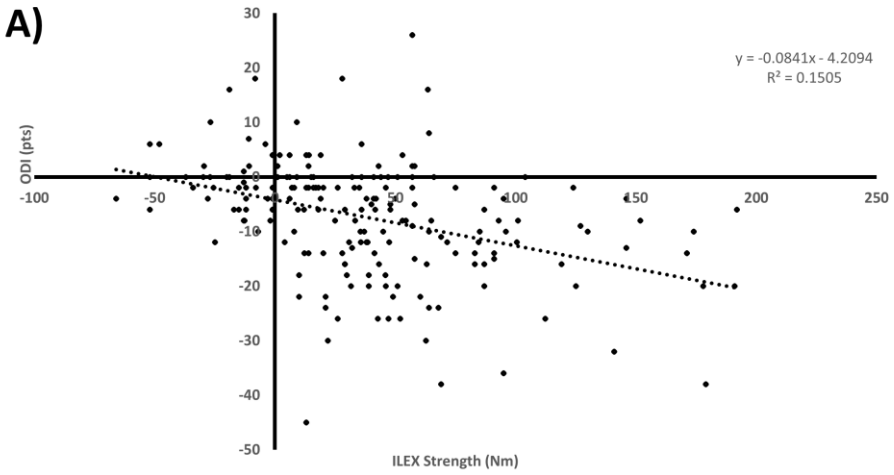
Figure 3. Box and whisker plot for A) change in isolated lumbar extension average torque, B) change in isolated lumbar extension peak torque, and C) change in isolated lumbar extension strength index for 'met' and 'not met' for Visual Analogue Scale minimal clinically important changes. ILEX = isolated lumbar extension; VAS = Visual Analogue Scale

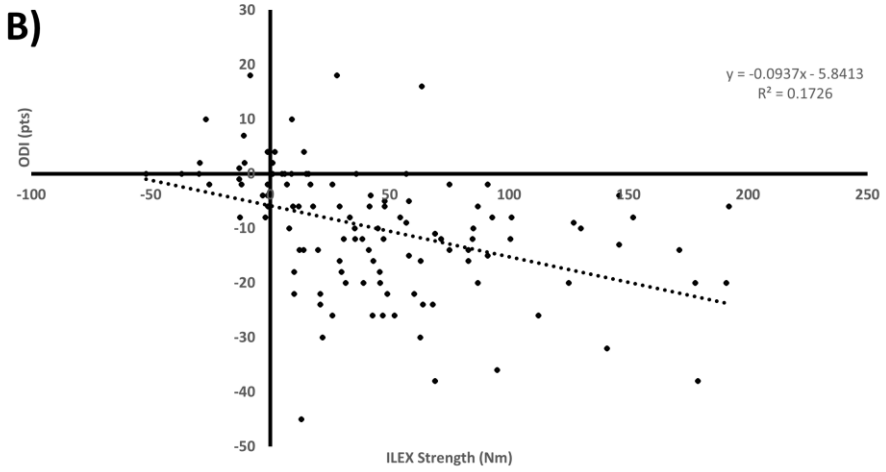
Figure 4. Box and whisker plot for A) change in isolated lumbar extension average torque, B) change in isolated lumbar extension peak torque, and C) change in isolated lumbar extension strength index for 'met' and 'not met' for Oswestry Disability Index minimal clinically important changes. ILEX = isolated lumbar extension; ODI = Oswestry Disability Index

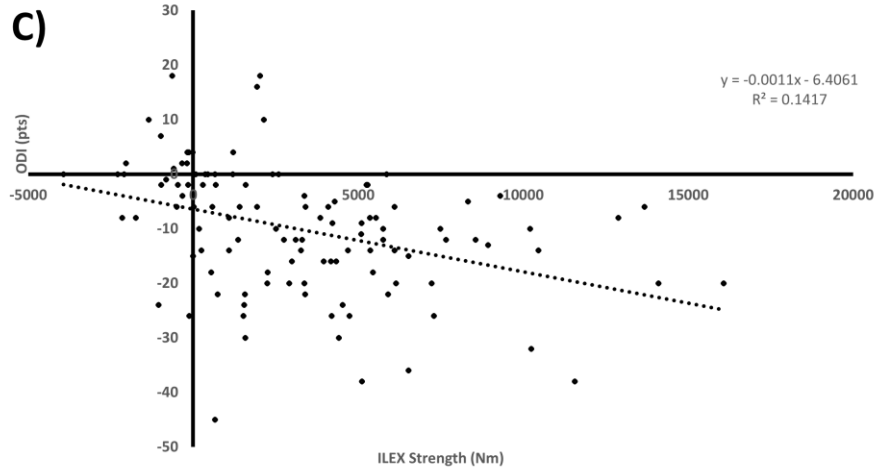

A)
y = -0.1674x - 4.709
R² = 0.2088
VAS (mm)
ILEX Strength (Nm)


B)
y = -0.1075x - 7.6182
R² = 0.1299
VAS (mm)
ILEX Strength (Nm)

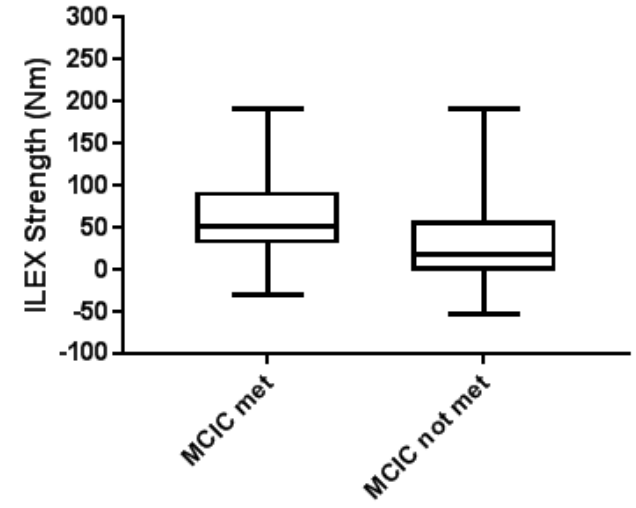

C)
y = -0.0021x - 11.076
R² = 0.1271
VAS (mm)
ILEX Strength (Nm)


A)
y = -0.0841x - 4.2094
R² = 0.1505
ODI (pts)
ILEX Strength (Nm)

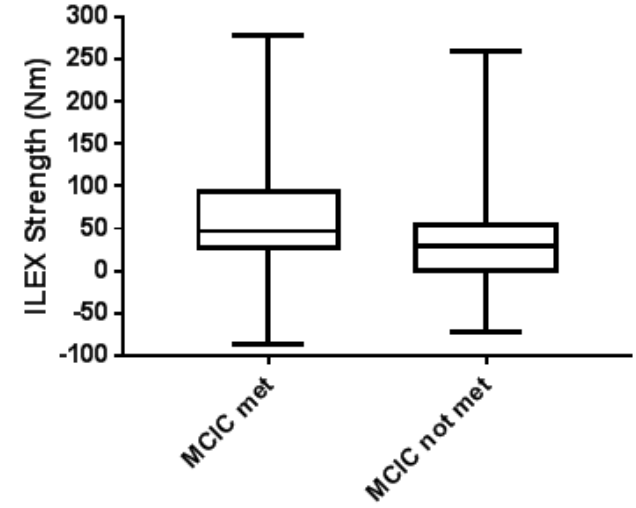

B)
y = -0.0937x - 5.8413
R² = 0.1726
ODI (pts)
ILEX Strength (Nm)


C)
y = -0.0011x - 6.4061
R² = 0.1417
ODI (pts)
ILEX Strength (Nm)

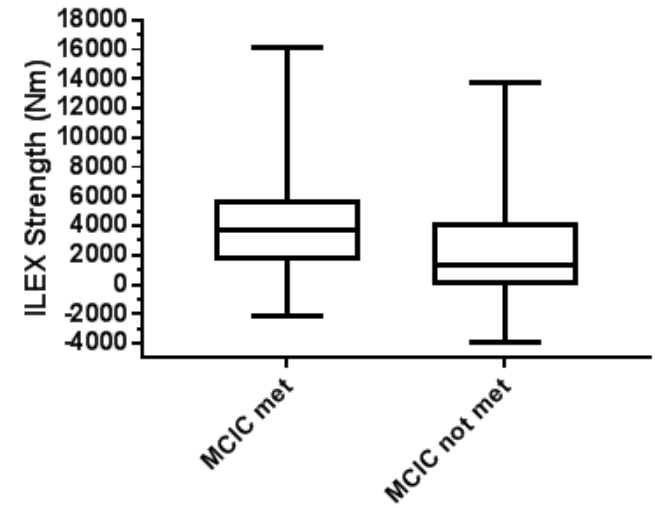
A)


ILEX Strength (Nm)
300
250
200
150
100
50
0
-50
-100
MCIC met
MCIC not met

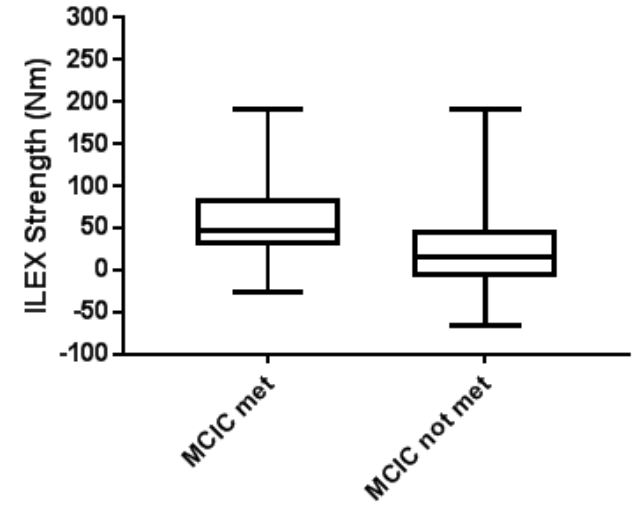
B)


ILEX Strength (Nm)
300
250
200
150
100
50
0
-50
-100
MCIC met
MCIC not met

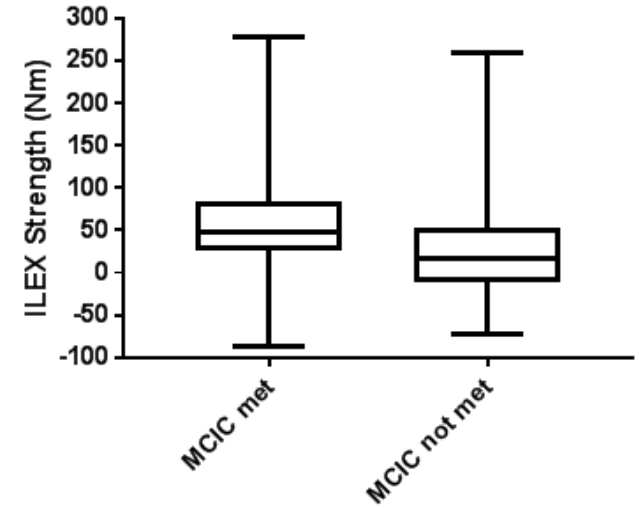
C)


ILEX Strength (Nm)
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
-2000
-4000
MCIC met
MCIC not met

A)


ILEX Strength (Nm)
300
250
200
150
100
50
0
-50
-100
MCIC met
MCIC not met

B)


ILEX Strength (Nm)
300
250
200
150
100
50
0
-50
-100
MCIC met
MCIC not met

C)

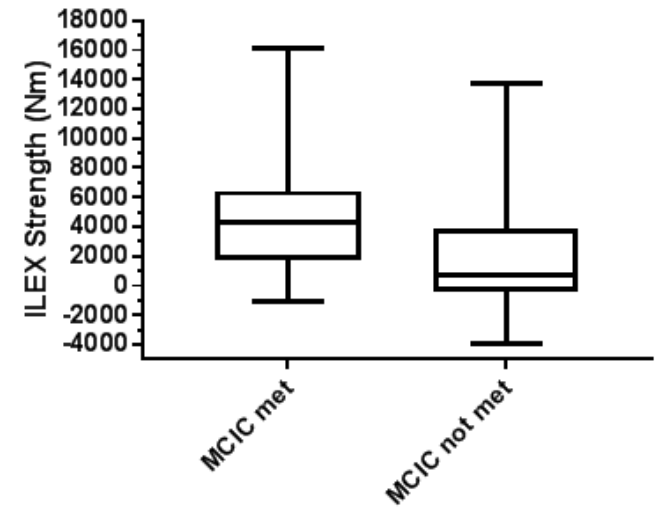

ILEX Strength (Nm)
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
-2000
-4000
MCIC met
MCIC not met

Table 1. Correlations between isolated lumbar extension average torque and Visual Analogue Scale/Oswestry Disability Index by study

Study	**Visual Analogue Scale**			**Oswestry Disability Index**		
	n	*r*	*p*	n	*r*	*p*
Helmhout et al., 2004	n/a	n/a	n/a	75	-0.120[b]	0.303
Bruce-Low et al., 2012	72	-0.526[b]	<0.001*	72	-0.510[b]	<0.001*
Steele et al., 2013	24	-0.544[a]	0.006*	24	-0.390[a]	0.059
Steele et al., 2017	18	-0.560[a]	0.016*	18	-0.503[a]	0.033*
Pooled data	114	-0.539[b]	<0.001*	189	-0.444[b]	<0.001*

*indicates significant correlation ($p < 0.05$); [a]indicates Pearson's correlation; [b]indicates Spearman's correlation

Table 2. Correlations between isolated lumbar extension peak torque and Visual Analogue Scale/Oswestry Disability Index by study

Study	**Visual Analogue Scale**			**Oswestry Disability Index**		
	n	*r*	*p*	n	*r*	*p*
Smith et al., 2011	42	-0.370[a]	0.016*	42	-0.522[a]	<0.001*
Bruce-Low et al., 2012	72	-0.298[b]	0.011*	72	-0.235[b]	0.047*
Steele et al., 2013	24	-0.483[a]	0.017*	24	-0.415[a]	0.044*
Steele et al., 2017	18	-0.468[a]	0.050*	18	-0.333[a]	0.177
Pooled data†	114	-0.391[b]	<0.001*	114	-0.349	<0.001*

*indicates significant correlation ($p < 0.05$); [a]indicates Pearson's correlation; [b]indicates Spearman's correlation; †Data from Smith et al. (2011) not available for pooled analysis

Table 3. Correlations between isolated lumbar extension strength index torque and Visual Analogue Scale/Oswestry Disability Index by study

Study	**Visual Analogue Scale**			**Oswestry Disability Index**		
	n	*r*	*p*	n	*r*	*p*
Rittweger et al., 2002	50	-0.285[b]	0.045*	n/a	n/a	n/a
Bruce-Low et al., 2012	72	-0.445[b]	<0.001*	72	-0.405[b]	<0.001*
Steele et al., 2013	24	-0.551[a]	0.005*	24	-0.363[a]	0.081
Steele et al., 2017	18	-0.624[a]	0.006*	18	-0.564[a]	0.015*
Pooled data	164	-0.415[b]	<0.001*	114	-0.470[b]	<0.001*

*indicates significant correlation ($p < 0.05$); [a]indicates Pearson's correlation; [b]indicates Spearman's correlation