Original research

Trunk muscle activation of core stabilization exercises in subjects with and without chronic low back pain

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The authors declare no conflict of interest regarding the publication of this article.

ABSTRACT

BACKGROUND: Weakness and atrophy in trunk muscles have been associated with chronic low back pain (CLBP).

OBJECTIVE: This study aimed to identify isometric exercises resulting the highest trunk muscle activity for individuals with and without CLBP.

METHODS: Fourteen males with CLBP and 15 healthy age-matched healthy subjects were recruited for this study. Muscle activity during maximal voluntary isometric contraction (MVIC) was measured for a comparative reference with surface electromyography (sEMG) from six trunk muscles. Thereafter maximum EMG amplitude values were measured during eleven trunk stability exercises. The maximal EMG activity in each exercise relative to the MVICs was analyzed using generalizing estimating equations (GEE) models with the unstructured correlation structure.

RESULTS: The GEE models showed statistically significant differences in muscle activity between exercises within both groups ($p<0.001$), with no significant differences between groups ($p>0.05$). The highest muscle activity was achieved with the hip flexion machine for multifidus, side pull with a resistance band for lumbar extensors, side and single-arm cable pull exercises for thoracic extensors, rotary plank and the hip flexion machine for abdominal.

CONCLUSION: This study found five isometric trunk exercises that exhibited highest muscle activity depending on muscle tested, with no significant difference between individuals with and without CLBP.

Keywords: Electromyography, Force measurement, Isometric strength, Resistance exercise, Gym machine.

1. Introduction

The prevalence of chronic low back pain (CLBP) at working age is 20 % in both genders and increases linearly from the third decade of life up to age 60 [1] causing more disability than other musculoskeletal conditions [2]. Approximately 80% of patients have nonspecific low back pain (LBP), i.e., current diagnostic equipment yields no specific diagnosis [3]. CLBP has been shown to be associated with muscle atrophy locally in the deep multifidi on segment of pain, which gradually affects both the fast and slow switch fibers of all the muscles in the entire low back area [4]. The muscles undergo fibrotic transformation and often fat infiltration, and thus muscle size does not necessarily diminish [5]. This decreases back function, although it is not known whether these structural changes in back muscles cause, or are merely the result of CLBP [4]. Therefore, exercises may be an important rehabilitative approach. However, there is no consensus on, which type of exercise is best. Progressive resistance exercise has been shown to promote anti-inflammatory metabolism and the release of growth factors, and to reverse the muscle atrophy process [6]. The target of many exercise studies has been to strengthen only the back extensor muscles [7], however, muscle atrophy has also shown to involve the lumbar flexor muscles [8]. While moderate-certainty evidence exists that exercise is an effective treatment for CLBP, the effect on pain and disability have been found to be small [9]. Moreover, previous studies have shown only low strength gains [10]. These contrast with the results found for the upper spine, as progressive isometric strength training has been shown to double strength and clinically significantly reduce pain and disability also in the long term [11].

The aim of the present study was to find exercise methods that have potential to be more efficient in improving trunk muscle strength compared to exercises commonly used in physiotherapy. Most of the studies evaluating core muscle activity during exercises have been conducted with healthy participants. Thus, the second purpose was to evaluate if the same exercises are appropriate for both groups, patients with CLBP and healthy subjects.

2. Materials and methods

The present study is a cross-sectional case-control study that was conducted in accordance with the principles of the Declaration of Helsinki.

2.1. Participants

Patients diagnosed with CLBP in primary or occupational health care facilities, and who had failed to improve following conservative treatments, were referred to the spine clinic of the tertiary district hospital for further investigations. Treatments usually consisted of advice to be physically active in ordinary life, ergonomic and postural counseling, home exercises, manual therapy and other non-medical physiotherapy treatments for CLBP. A sample of fifteen voluntary male patients with CLBP was recruited from the Department of Physical and Rehabilitation Medicine. The same physiatrist performed a physical examination, and if a patient proved to be suitable for the study the patient was explained the study procedure and the possibility of joining the research. Participants completed a questionnaire as a part of the screening process on their health, medication and possible incidence of LBP, and their height and body mass were measured. The inclusion criteria were at least 18 years old, male gender, a body mass index of less than 30, and local pain in the low back region longer than three months. The body mass index was set because a thick subcutaneous layer of fat acts as an insulator that weakens the recording of an electrical signal from the skin electrodes. The exclusion criteria were health conditions that could prevent them from performing the exercises safely and with sufficient intensity, such as infection, cardiorespriratory disease, high energy trauma or signs of specific low back pain like ankylosing spondylitis or disc prolapse.[12] Fifteen healthy male participants were selected as volunteered controls to match the patient population in age and anthropometry. None of them were engaged in strength training or competitive sports. They were employees of the Central Hospital and students at the University and informed about the study via an official e-mail of the institutions. Participants with a history of LBP, which could inhibit muscle activation, or any health condition that could prevent them from performing the measurements safely, were excluded. All participants were provided with information about the study protocol and possible risks and discomfort related to the tests.

2.2. Electromyography

Measurements were conducted in the Biomechanics Laboratory at the Central Hospital. To minimize skin impedance, the skin was shaved, treated with abrasive material, and cleaned with alcohol. Disposable pregelled Ag/AgCl surface electrodes with a pick-up area of approximately 1.0 cm^2 each (BlueSensor M, Ambu A/S, Ballerup, Denmark) were placed unilaterally over the trunk muscles as shown in Figure 1. The detection electrodes were positioned according to Seniam guidelines for surface EMG measurements [13] and cables fitted with preamplifiers were used to ensure good signal quality. The reference electrode was positioned beside each pair of detection electrodes, at approximately 10 cm distance from each, as specified by the manufacturer. A strip of tape was placed on top of each electrode with an overlap of 3 cm on each side to prevent the wires from disconnecting the electrodes during execution of the exercises. A wireless ME6000 EMG system (Mega Electronics Ltd, Kuopio, Finland) with 6 channels was used to record the sEMG signal. The raw sEMG signals, sampled at 1000 Hz were amplified and filtered with cutoff frequencies at 8 and 500 Hz. The preamplifier had a common mode rejection ratio of 110 dB.

For the EMG amplitude analysis, manually selected artifact-free raw EMG sections were used. The raw EMG data were rectified and smoothed to a 50-ms root mean square (RMS) algorithm. The highest RMS EMG amplitude was selected to represent the peak RMS EMG amplitude from the actual test set of 6 repetitions with 10 repetition maximum (RM) (described below).

The normalized muscle activity level (percentage of maximum amplitude) in each exercise was determined by relating the peak RMS EMG amplitude to the RMS EMG amplitude measured during the maximal voluntary isometric contraction (MVIC). MVIC of the trunk muscles was measured using inhouse-constructed frames for the strain-gauge dynamometers (Tedea-Huntleigh Ltd., Cardiff, UK). MVIC of the trunk extensors and flexors was measured with the subject standing in erect position with feet positioned 20 cm apart (Figure 2A). The support of the frame was located at the height of the anterior superior iliac spine. During the flexion strength measurements, the height of the sensor element was adjusted in the middle of the sternum. The subject turned round for the extension strength measurement and the sensor element was maintained at the same level. MVIC of the trunk rotators was measured with the subject in sitting position with the hip and knee angles at 90^0 and the pelvis stabilized by a belt (Figure 2B). In addition, subject supported his lower extremities against a pad between his knees. The pads supporting the shoulders were adjusted individually for each subject. The vertical axis of the spine was aligned linearly with that of the measuring sensor.

The maximal voluntary isometric strength tests were practiced in each direction until the subject was able to perform the exercise correctly. In all tests, two maximal isometric efforts for 5 seconds were performed in each direction with two minutes rest between efforts. If the second performance exceeded the first one by ≥ 10 %, a third attempt was performed. The isometric strength results were registered with Force measurement software (Protacon Ltd, Jyväskylä, Finland). The peak EMG amplitude value of the highest performance was used to calculate the normalized muscle activity levels.

2. 3. Exercise tests

To determine the 10-repetition maximum (RM) load for the dynamic exercises, sets of 10 repetitions were performed with 3-5 minutes of rest between sets and the load was increased for each successive set until the subject was unable to perform 10 consecutive repetitions in a set. Ten RM was calculated based on the final set. The load of 10 RM, which is recommended for strength training, equals approximately 75% of MVIC [14].

All other measurements were executed in the same session, scheduled one week after the RM test session. For each exercise, the subject first performed one warm-up set of 10 repetitions using 50% of the pre-determined 10 RM load. In the second set, which was the actual test set, the participant performed 6 repetitions with the 10 RM load. The same procedure was implemented in both directions for the unidirectional movements. Pace of performance was standardized using a metronome. One movement was standardized to two seconds to indicate when the subject should be at the limit of each range of motion, and thus the duration of each repetition was four seconds. Subjectively perceived average LBP during previous week was assessed by a visual analogue scale (VAS, 0 - 100) at the baseline with the questionnaire and during exercise test after the completion of each exercise [15].

2.4. Exercise description

The order of execution of the evaluated isometric low back exercises were (Figure 3): upper trunk rotation with broomstick, four-point kneeling with leg lift, plank with leg lift, rotary plank, back bridge with alternating leg lift, band side pull (Theraband®), Russian twist, single-arm cable push, single-arm cable pull and Y exercise (Frapp®), and hip flexion (Matrix® rotatory hip machine). Appendix 1 describes how the exercises were performed.

2.5. Statistical analyses

The sample size was evaluated using simulation-based sample size. The calculations are based on a 10 % difference within the groups between EMG activity in each exercise relative to MVIC. Target sample size of 30 participants (15 per group) was required for a two-sided significance level of 0.05 (85% power). Data are presented as the means with standard deviations (SD). The normality of variables was evaluated graphically and by using the Shapiro-Wilk test. Between groups comparisons in isometric strength tests and extra loads used in 10 RM resistance exercises were made by using student's t-test. The normalized maximal EMG activity values between the different exercises in both groups was analyzed using generalizing estimating equations (GEE) models with the unstructured correlation structure. A bootstrap-type method was used (10 000 replications) to estimate the standard error. Bonferroni adjustments were performed to correct significance levels for the multiple test. Stata 17.0 (StataCorp LP, College Station, TX, USA) was used for the statistical analyses.

3. Results

The clinical and demographic data are presented in Table 1. There were no significant differences in the demographic data observed between the patients and healthy subjects ($p>0.05$). Patients had in average mild to moderate pain commonly with several years duration.

The results of the maximal isometric strength tests at baseline and the extra loads used in the Russian twist, cable, and hip flexion machine exercises are shown in Table 2. In healthy subjects, MVIC of the trunk muscles was 871 N in flexion, 982 N in extension and 105 Nm in rotation. MVIC strength was 10 - 30 % lower in patients with CLBP than in healthy subjects and the difference was also statistically significant in extension and rotation to the left. External exercise loads were lower in patients with CLBP compared to healthy subjects, and the difference was significant in Russian twist, Y cable and hip flexion machine exercises.

The maximal EMG activity in each exercise relative to maximal activity in the MVIC tests is presented in Table 3. The GEE models showed that there were statistically significant differences in muscle activity between exercises in both patients with CLBP ($p<0.001$) and healthy subjects ($p<0.001$).

In the lumbar multifidus, the hip flexion machine exercise induced the highest EMG activity in both patients and healthy subjects: 70 % in patients and 53 % in healthy subjects (Figure 4). The band side pull also induced high lumbar multifidus activity in healthy subjects but not patients: 61 % vs. less than 50 %. In the lumbar erector spinae, the highest activity was observed with the band side pull with resistance band in both patients and healthy subjects: 55 % in patients and 43 % in healthy subjects. In the thoracic erector spinae, the highest

EMG activity of 70 % or over in both groups was observed with the band side pull, and single-arm cable pull.

In the oblique abdominal muscles, elbow blank rotation and the band side pull were the only exercise in which muscle activity was over 50 % of MVIC in both patients and healthy subjects (Figure 5). However, in the exercise with the hip flexion machine and in the Russian twist, over 50 % activity was recorded in healthy subjects. In the rectus abdominis muscle, elbow blank rotation was only exercise inducing over 50 % activity in both groups. Healthy subjects approached the 50 % level in the hip flexion machine exercise but showed considerably lower muscle activity in all the other exercises. The lowest muscle activity levels, which were below 30 % in all the muscle groups measured, were found for the broomstick. No significant differences were found in percentage of maximal EMG activity between the male patients and healthy subjects in any of the exercises.

All participants were able to complete both maximal isometric strength tests as well as all exercises that were evaluated. None of the healthy subjects experienced LBP when performing the exercises. Five patients reported no or only minor pain (VAS $\leq$ 10) and nine patients moderate or severe pain (VAS $\geq$ 30). All exercise were experienced causing pain by at least one patient. Five patients reported pain during the elbow plank with leg lift exercise, four during the rotary plank and back bridge with leg lift, three during the cable push and pull. The remaining five exercises, i.e., broomstick twist, kneeling leg lift, Russian twist, cable Y-exercise and hip flexion machine, were reported as painful by only one patient. One patient reported pain in all the exercises except the band side pull. No long-term worsening of pain or other negative effects caused by MVIC tests or performed exercises was reported.

4. Discussion

This study examined trunk muscle activity during core stability exercises in patients with CLBP and asymptomatic individuals. The major finding was a large variation in maximal trunk muscle activity between core stability exercises within both CLBP patients and healthy subject groups. Another important finding was that there were no significant differences in maximal muscle activity between the CLBP patients and healthy subjects at any muscle in any of the exercise. A novel discovery was that in both the patients with CLBP and healthy subjects the lumbar multifidi were better activated by hip flexion with the multi-hip machine than by any other exercises used. In the patients, over 50 % activation in the lumbar multidifus was induced also by the band side pull in relation to MVIC, suggesting that it is also an effective exercise.

Patient and healthy subject groups were analyzed separately, in order to see which exercise works best in each group, and not to compare the groups. The intention was to evaluate isometric muscle activation of specific exercises, and therefore the assessment of MVIC measurements was chosen for comparison to closely resemble the actual exercises being evaluated. In healthy subject, MVIC of the trunk muscles was at the same level as reported previously [16-18].

The current recommendation is that the minimum threshold for effective muscle strength and hypertrophy is about 30% of the one RM [19]. However, the relationship between muscle force and the amount of electrical activity produced is not linear, but slightly curvilinear. Several factors such as the structure and biomechanics of joints and muscles vary across individuals and within the body part of the same person. About 10 % greater relative electrical activity is often needed to produce the same percentage force [20].

The functionally deep multifidi are the primary stabilizing muscles of the spine [21]. Commonly used home exercises treating CLBP, such as the plank with leg lift, rotary plank and back bridge with leg lift, activated the mulfidus only a little. In addition, the load is not increased with these exercises. Progression with these exercises is limited to increase repetitions and thus become more endurance than strength training. In both the multi-hip machine and elastic band exercises the load can be progressively increased, which is an important factor that should be considered while planning rehabilitation program.

Trunk muscles are increasingly activated when more stabilization is needed [18]. In the lumbar erector muscle, the band side pull produced the highest muscle activity; in the patient group over 50% MVIC, and in the healthy group 43% MVIC. For the thoracic erector spinae, the band side pull and single-arm cable pull exercises were the best exercises, inducing about 70 % of MVIC. A progressive increase in load can be easily accomplished in both exercises, and both can be done also at home with a resistance band if gym training is not possible.

In the external and internal oblique, 50 % of MVIC was only achieved in both groups with the rotary plank and band side pull exercises. However, this activation level was well exceeded by the healthy group in the hip flexion with multi-hip machine exercise. In the rectus abdominis, over 50 % of MVIC was only reached with the rotary plank exercise.

Differences in average maximal muscle activation between the patient and healthy groups were mostly minor. In the patient group, some of these may be related to pain inhibition or unconscious fear of pain, preventing the exercise from being performed with full effort. However, some of the results favored the patient group. Colado et al. [22] reported low maximum EMG values for the static supine-bridge exercise in healthy volunteers without back pain. In the present study, the back bridge with alternating leg lift similarly showed low muscle activity, indicating that it may not be effective in preventing or reversing trunk muscle atrophy in patients with CLBP. Nevertheless, these exercises are commonly used in back rehabilitation without advancing more demanding exercises. These exercises are also clearly inferior for sports training aimed at strength gain.

In rehabilitation of lumbar muscles, progression from localized stabilizing exercises in the supine and prone positions to localized stabilizing exercises in a stance posture and hence to global stabilizing exercises has been recommended [22,23]. However, this type of exercise program has not been found to be particularly effective. It differs considerably from straight forward stabilizing isometric strength training, which has proven to be highly effective treatment for pain in upper spine rehabilitation [14]. The increase in muscle strength was also associated with improvement of mobility and disability. In many studies the exercise load has been too low to improve back muscle strength [24]. To achieve good results in rehabilitation, the stabilizing exercises must be done with sufficient load and volume [14]. Oliva-Lozano et al. [25] compared maximal EMG activity in various paraspinal muscles across seven different exercises and found that the dead lift produced the highest muscle activity. One problem with comparing exercise studies is that the terms used may be misleading. Aasa et al. [26] compared low-load motor control exercises with high-load lifting exercise., but the load used in the dead-lift exercises was subjectively determined by physiotherapists and not based on strength tests. In their study the results showed non-significant improvement in lifting capacity in both groups. Thus, both groups were in fact performing low-load motor control exercises. The deadlift exercise was excluded from the present study as high axial compression load of the spine has been associated with increased injury risk [27,28]. Moreover, this risk is not preventable by excluding high-risk patients by radiological imaging [29]. In CLBP patients, high-load isokinetic back training has been found to be more effective in treating pain intensity and the strength of the back muscles than low-load trunk stabilization training [30]. However, isokinetic devices are expensive and require professional staff to operate them and control performance individually for each patient. Based on this, these exercises were excluded from the present study. Effective low-cost high-intensity exercises that are commonly used in upper spine rehabilitation are thus needed in treating CLBP.

It is important to note that treatment of CLBP may require more than just high intensity activation exercises for trunk muscles, which was on the focus in the present study. Although some of the exercises commonly used in CLBP rehabilitation produced very modest muscle activation in this study, it does not mean that they are of no value. Some exercises may be useful for recognizing muscle activation and improving postural control and coordination, and may also be suitable for the initial stages of rehabilitation when patients are not able to perform more advanced exercises. The cause of CLBP has shown to be multifactorial, and thus various treatment approaches may need to be incorporated [31].

There were differences in exercise performance between patients, as some exercises were better tolerated by some patients than others. Calatayud et al. [32] found that the lateral plank exercise frequently caused LBP. The present study showed that the traditional mat exercises commonly issued for home practice induced pain as often as gym exercises. Moreover, no single exercise suited all or was painful for all patients with LBP irrespective of whether it was a low or high load exercise. Thus, pain is not a reason to stick to low intensity exercises, as has been found previously in patients with chronic pain in upper spine [33].

The trunk stabilizing Y exercise with a cross cable pulley was developed from the previously separate push and pull isometric trunk exercises with pulley [34]. Exercise load is gradually increased in progressive resistance exercises, but with one arm cable push and pull exercises will cause balance problems due to traction force from only one direction. In Y-exercise force from front and back balance each other as the same load is used in both pulleys. Thus, the aim was to resolve the problem that, to avoid loss of balance because the force comes from one direction only, a simultaneous pull and push from opposite directions would enable a well-balanced position and thus allow a greater load. However, the results showed that the exercise load in the Y-exercise was lower for both groups than in the one-arm exercises, because the exercise is technically more difficult to perform and more practice is needed to master it. The strength of the upper limb also is a limiting factor with all these exercises in contrast to the hip machine exercise.

The hip machine exercise is commonly thought to be a leg-specific exercise. In the present study it was found to be the best exercise for lumbar multifidus muscle activation, and it activates also oblique abdominal muscles effectively. Moreover, it was well tolerated exercise modality in patients with CLPB, which is in line with our clinical experience. This is probably due to the fact that there is no direct axial loading of the spine, despite the high loading of the lumbar muscles.

There are some limitations of the study. Muscle strength has been shown to depend on age and gender, which may have a significant effect on research results [35]. Thus, only men at the working age were included in the study to avoid excessive heterogeneity of the study population. This may impair the generalizability of research to women, because men have shown to be in average 30 % stronger compared to women and thus execution and response to high intensity exercising may differ.

The results were in line with previous studies showing large differences in muscle activity between exercises and different muscles [24]. As stated before, direct comparison of studies is problematic owing to the use of different measurement equipment, placement of electrodes and maximal strength tests. In addition to differences in study protocols and exercise performance, discrepancies between results may also be explained by demographic factors and the size of the study population. There are also always some physiological and methodological concerns relating to clinical appropriateness when interpreting EMG results. First, due the wide intra-individual variation in EMG amplitude, even with normalized values, the direct comparison of participants is not justified. Second, in human volitional performances it is often uncertain whether a subject truly generates maximal force and pain affects performance in patients with CLBP. As a result patients usually start training at a lower level than healthy participants as shown in the present study. On the other hand, this may increase the strength gain potential due to the effect of the exercise.

All surface EMG measurements are subject to contamination from adjacent muscles depending on their activation and size. Especially so the multifidi that are covered by the erector spinae. In the present study electrode placement was performed according to Arokoski et al. [36], who suggested that surface electromyography (sEMG) may be used in the assessment of multifidus muscle function. Body movement also affects the results, as electrodes move with the skin, which is stretched above the muscle. However, the present study involved only isometric exercises.

Systematic reviews show some effect of various exercise types used in CLBP on pain and disability with no major difference between types of exercise [37]. Often low-load home-based exercises are instructed by therapists instead of more intensive gym exercises, which would enable progressive loading in rehabilitation. This study supports the notion that there are huge differences in trunk muscle activity depending on exercise modalities that are used to improve trunk muscle function and restore muscle structure after established atrophy in CLBP. Larger sample size with randomization and long-term follow-up would allow to identify most effective exercise protocols for rehabilitation and sports. Since they require considerable researcher resources and are expensive, it is important that the methods to be studied are chosen from those previously found smaller studies in order to ensure the most potential exercise programs.

5. Conclusion

The hip flexion machine, side pull with resistance band, single arm cable pull, and elbow plank rotation exercises produced highest maximal muscle activity in trunk muscles, and may be recommended for strengthening the trunk muscles. Activation was muscle group-specific as no single exercise activated all the trunk muscles. The study suggests that there is no reason to stick only to low-load home exercises, as they activate the muscles less and were not better tolerated than high load exercises by patients with CLBP. The results obtained in this study can be utilized in developing more versatile trunk exercise programs for rehabilitation and training.

Acknowledgments

The authors thank the participants for their contribution and PT Samppa Tolvanen for performing measurements and the data collection.

Author contribution

JY, TP, AH and JM were involved in protocol development and gaining ethical approval. JM and JY had overall responsibility for the conducting of the study and for monitoring progress. Statistical analysis was undertaken by HK in collaboration with JY and JM. JY wrote the draft of the manuscript, and all the authors contributed to critically revising it and approved the final version of the manuscript.

Conflict of interest

No potential conflict of interest was reported by the authors.

Data availability statement

The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.

Ethical approval

The research plan was approved by the Research Ethics Committee of the Central Finland Health Care District (Diary number 11U/2014).

Funding

The author reports no funding.

Informed consent

The purpose of the study and its course were explained to the participants orally and in writing. All participants signed written informed consent prior to study initiation.

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TABLE 1. Demographic and clinical data of male patients with CLBP and matched healthy subjects. The values are given as mean and standard deviation.

	Patients (n = 14)	Healthy subjects (n = 15)
Age (y)	35.6 (11.6)	32.3 (10.9)
Weight (kg)	86.2 (19.9)	79.7 (9.3)
Height (cm)	178.1 (8.6)	179.5 (6.2)
BMI (kg/m2)	26.9 (4.4)	24.7 (2.6)
Duration of CLBP (months)	59.5 (70.2)	
VAS pain (0 to 100 scale)	44.2 (20.2)	

Abbreviations: BMI, body mass index; CLBP, chronic low back pain; VAS, visual analog scale.

Table 2. Results of maximal isometric strength tests at baseline and loads used in 10 RM resistance exercises based on repetition tests in male patients with CLBP and healthy subjects.

	CLBP (n = 14)	Healthy (n = 15)	%-difference	P-value
Isometric strength tests				
Flexion (N)	795 (310)	871 (128)	10 %	0.424
Extension (N)	775 (220)	982 (111)	27 %	0.007
Rotation right (Nm)	89 (84)	100 (3)	12 %	0.373
Rotation left (Nm)	84 (28)	109 (2)	30 %	0.019
External load exercises				
Russian twist (kg)	11 (5)	15 (4)	36 %	0.039
Single-arm cable push (kg)*	33 (7)	39 (9)	18 %	0.069
Single-arm cable pull (kg)*	41 (9)	44 (10)	7 %	0.409
Y cable exercise (kg)* †	28 (6)	35 (12)	25 %	0.045
Hip flexion machine (kg)*	80 (0)	94 (0)	18 %	<0.001

Abbreviations: CLBP, chronic low back pain; N, Newton; Newton meter

Values are presented as mean ± SD.

Abbreviations: CLBP, chronic low back pain; kg, kilogram; N, Newton; Nm, Newton meter; RM, repetition maximum

Statistically significant at 0.05 alpha level.

*The real load is 50 % of the nominal load presented in the table due to movable round pulley.

† The same load was used in both pulleys

Table 3. Peak activity of surface electromyography relative to maximum voluntary isometric contraction of six core muscles during isometric core exercises. Results are expressed as % of MVIC (SD).

	Lumbar multifidus	Lumbar erector spinae	Thoracic erector spinae	External oblique abdominis	Internal oblique abdominis	Rectus abdominis
Broomstick rotation						
Patients	13.0 (10.7)	19.5 (12.6)	25.7 (12.3)	18.2 (13.6)	17.3 (12.6)	17.9 (25.9)
Healthy	14.2 (10.5)	19.6 (24.6)	19.2 (22.4)	22.3 (16.6)	20.1 (16.5)	7.7 (6.5)
Kneeling with leg lift						
Patients	45.4 (20.0)	40.7 (22.2)	22.9 (11.2)	26.7 (13.1)	22.5 (12.5)	14.3 (13.9)
Healthy	47.0 (24.4)	28.1 (18.7)	18.6 (8.8)	19.0 (9.0)	15.6 (5.6)	7.2 (5.1)
Plank with leg lift						
Patients	40.0 (29.5)	16.4 (10.2)	21.9 (11.4)	42.6 (23.2)	44.4 (24.7)	33.5 (18.4)
Healthy	20.8 (10.6)	10.3 (6.1)	24.4 (19.0)	39.0 (23.3)	35.8 (14.6)	24.3 (9.8)
Rotary plank						
Patients	30.4 (25.6)	31.9 (25.2)	57.4 (27.1)	70.9 (27.6)	69.6 (31.3)	58.2 (29.0)
Healthy	38.7 (30.3)	33.8 (20.2)	49.7 (23.3)	62.4 (22.7)	63.7 (20.6)	52.1 (27.5)
Back bridge with leg lift						
Patients	35.4 (27.0)	47.4 (25.0)	29.0 (19.9)	22.9 (16.4)	19.6 (8.7)	11.9 (7.8)
Healthy	35.5 (17.7)	37.2 (19.4)	24.6 (27.4)	18.3 (7.4)	21.4 (13.1)	7.0 (4.8)
Band side pull						
Patients	60.9 (22.8)	54.7 (25.0)	73.2 (21.2)	53.4 (26.9)	50.3 (34.2)	14.9 (9.9)
Healthy	40.8 (18.3)	43.3 (14.5)	76.9 (19.8)	59.7 (22.4)	54.5 (23.8)	13.9 (11.3)
Russian twist						
Patients	18.1 (14.1)	31.4 (25.1)	37.0 (14.9)	34.2 (17.9)	32.3 (18.5)	16.4 (8.4)
Healthy	22.2 (19.5)	20.8 (12.0)	46.6 (18.2)	51.3 (29.7)	59.1 (26.7)	22.2 (22.8)
Cable push						
Patients	25.3 (25.6)	17.5 (10.1)	42.6 (21.5)	33.9 (21.6)	36.2 (30.1)	18.5 (15.1)
Healthy	22.8 (17.4)	14.4 (8.7)	43.4 (25.3)	33.8 (16.7)	41.6 (23.4)	13.9 (11.4)
Cable pull						
Patients	24.2 (20.6)	37.0 (23.2)	69.1 (21.3)	33.6 (27.9)	24.7 (19.2)	10.9 (6.6)
Healthy	30.7 (15.3)	35.0 (13.2)	73.4 (27.8)	36.0 (18.9)	28.2 (14.8)	11.7 (8.4)
Y cable exercise						
Patients	22.4 (23.5)	25.5 (12.5)	50.4 (18.3)	19.2 (12.0)	32.8 (28.9)	14.1 (8.7)
Healthy	34.1 (24.7)	29.4 (20.7)	49.0 (30.0)	28.4 (14.0)	54.2 (24.2)	11.6 (7.1)
Hip flexion machine						
Patients	70.4 (20.1)	40.1 (18.4)	29.4 (14.4)	47.0 (26.2)	47.6 (28.3)	39.4 (27.0)
Healthy	53.5 (24.9)	30.9 (22.2)	37.3 (19.8)	57.7 (27.1)	65.8 (24.6)	47.9 (31.3)

Abbreviations:%MVIC, percentage of maximal voluntary contraction

Figure 1. Placement of the surface EMG electrodes: Rectus abdominis 3 cm lateral and just above from the umbilicus; external oblique halfway between the anterior-superior iliac spine and lower border of the sternum parallel with the muscle fibers running obliquely; internal oblique parallel to the inguinal ligament over the retroaponeurotic; thoracic and lumbar erector spinae at T9 and L3 level 5 cm and 4 cm laterally from the midline, respectively; multifidus 2 cm laterally at L5 level. The inter-electrode distance of the detecting electrodes was 20 mm.

Figure 2. Measurement of maximal voluntary isometric contraction of the trunk muscles. Subjects were tested standing in erect position on nonslip material with feet positioned 20 cm apart (A). The support was located at the height of the anterior superior iliac spine during the flexion strength measurement and the sensor element in the middle of the sternum. During the extension strength measurement, when the subject turned round, the hip support and sensor element was maintained at the same level on the thoracic spine in the middle of the scapulae (A). Rotation torques were measured in the sitting position (B). The subject was seated on the height-adjustable dynamometer with the hip and knee angles at 90^0 and the pelvis stabilized by a belt. In addition, subject supported his lower extremities against a pad between his knees. The pads supporting the shoulders were adjusted individually for each subject. The vertical axis of the spine was aligned linearly with that of the measuring sensor. The placement of the strain-gauge dynamometer (SGD) are shown in both isometric strength test devices (arrow).

Figure 3. Isometric stabilizing core exercises compared in the study.

Figure 4. The graph depicts in percentage of maximal electromyographic (EMG) activity of the back muscles during the performance of each isometric core exercise in relation to highest

activity obtained during maximal voluntary isometric contraction (MVIC) tests. Bonferroni corrected 95% confidence intervals are presented with whiskers.

Figure 5. The graph depicts in percentage of maximal electromyographic (EMG) activity of the abdominal muscles during the performance of each isometric core exercise in relation to highest activity obtained during maximal voluntary isometric contraction (MVIC) tests. Bonferroni corrected 95% confidence intervals are presented with whiskers.

Figure 1.

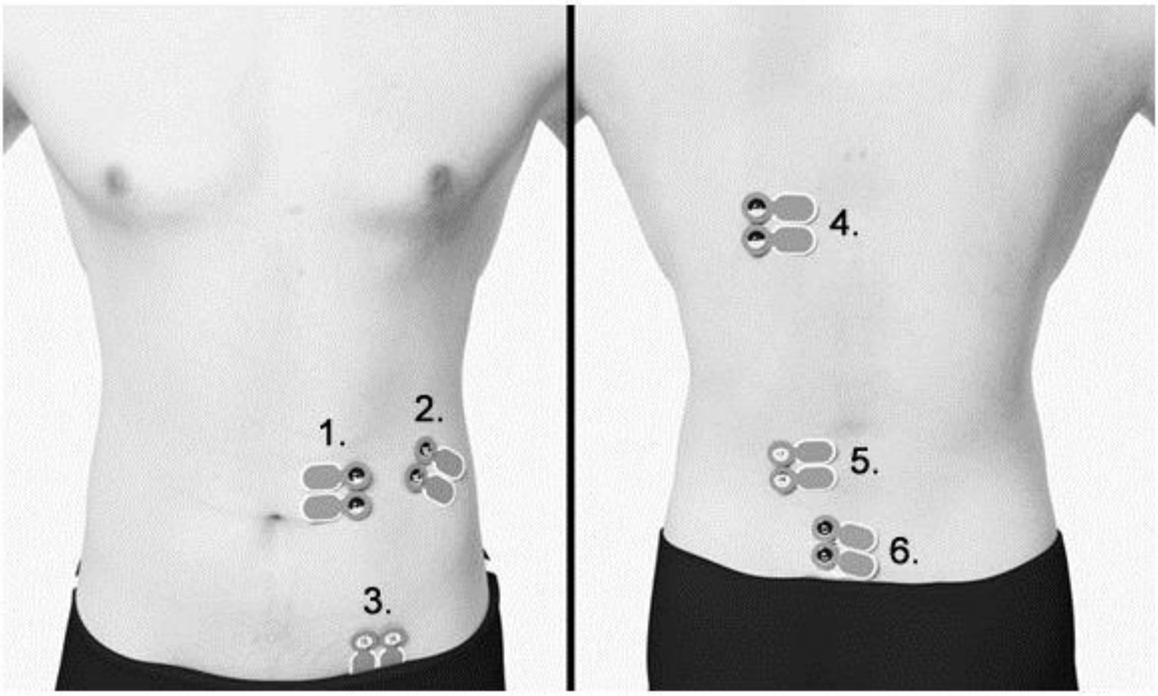


Figure 2.

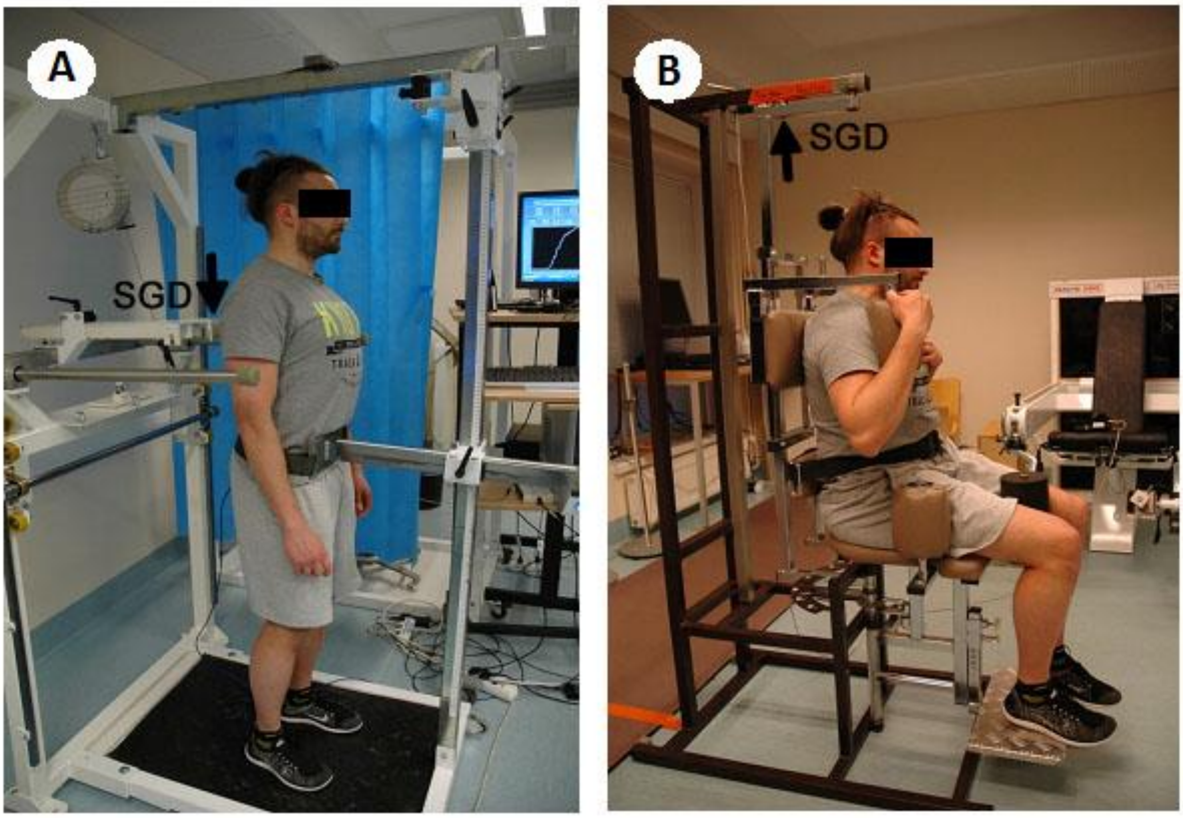


Figure 3.

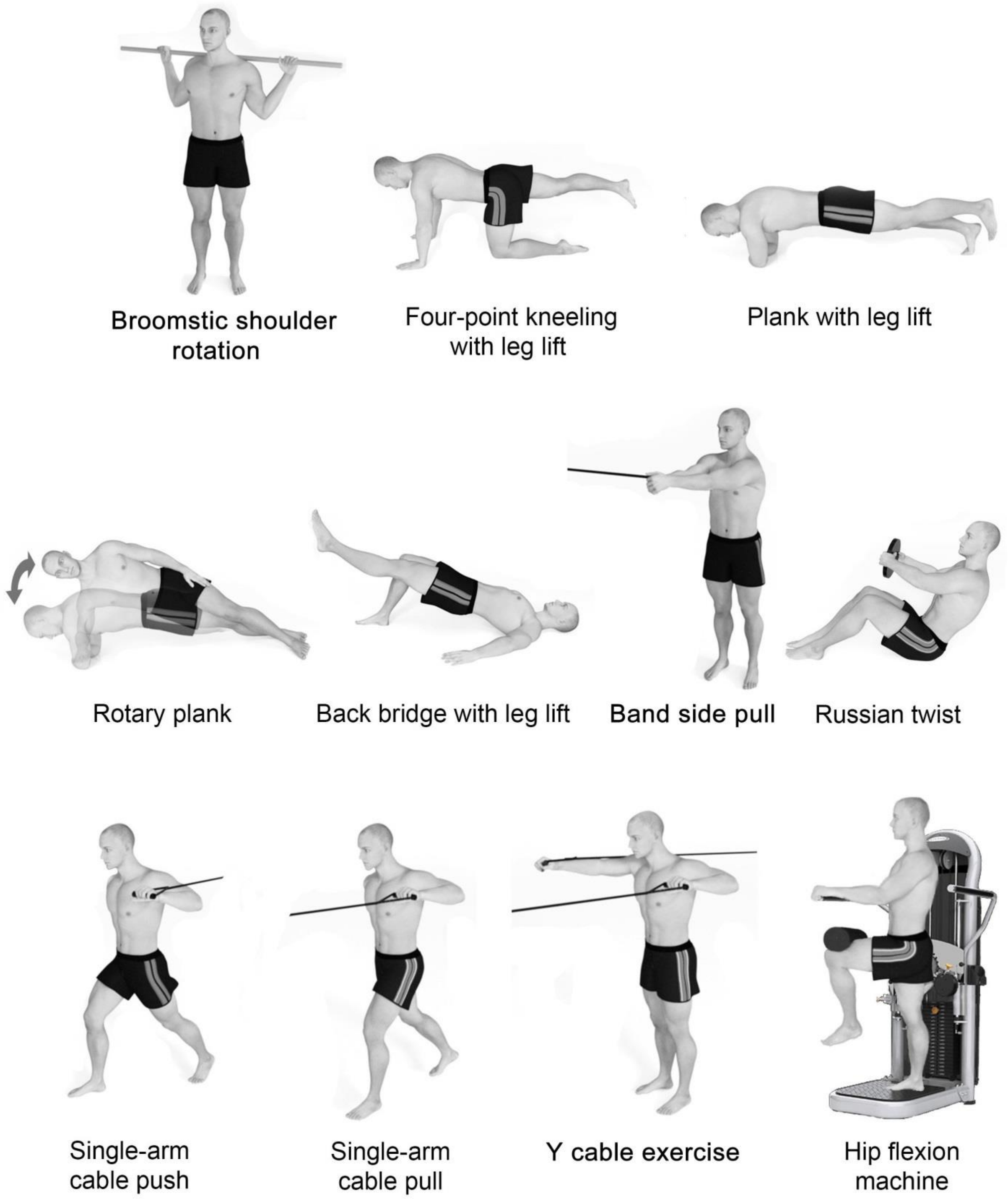
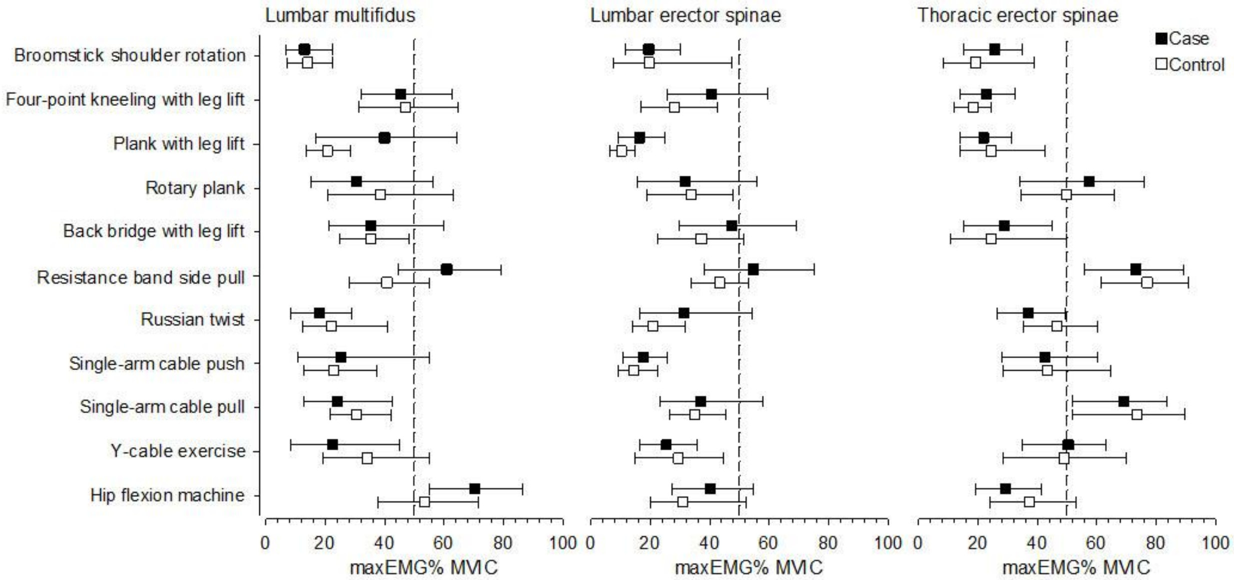

Broomstic shoulder rotation
Four-point kneeling with leg lift
Plank with leg lift
Rotary plank
Back bridge with leg lift
Band side pull
Russian twist
Single-arm cable push
Single-arm cable pull
Y cable exercise
Hip flexion machine

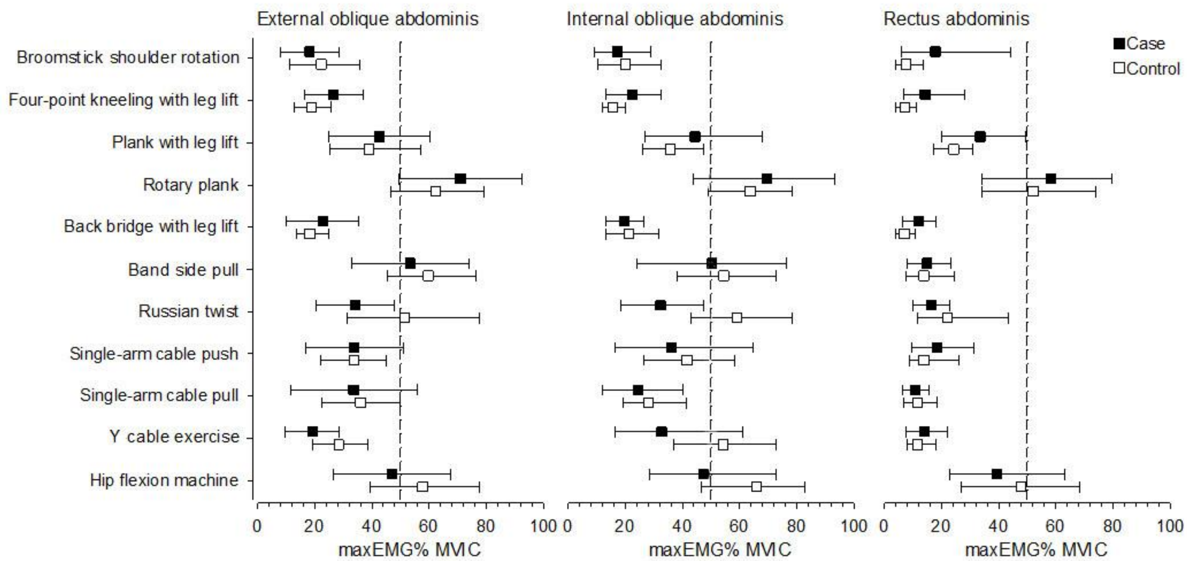
Figure 4.



Patients p<0.001

Healthy p<0.001

Figure 5.



Patients p<0.001

Healthy p<0.001