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1 **Original research**

2

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

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26 **ABSTRACT**

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

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

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

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

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

46

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

49

50 **1. Introduction**

51 The prevalence of chronic low back pain (CLBP) at working age is 20 % in both genders and
52 increases linearly from the third decade of life up to age 60 [1] causing more disability than
53 other musculoskeletal conditions [2]. Approximately 80% of patients have nonspecific low
54 back pain (LBP), i.e., current diagnostic equipment yields no specific diagnosis [3]. CLBP
55 has been shown to be associated with muscle atrophy locally in the deep multifidi on segment
56 of pain, which gradually affects both the fast and slow switch fibers of all the muscles in the
57 entire low back area [4]. The muscles undergo fibrotic transformation and often fat
58 infiltration, and thus muscle size does not necessarily diminish [5]. This decreases back
59 function, although it is not known whether these structural changes in back muscles cause, or
60 are merely the result of CLBP [4]. Therefore, exercises may be an important rehabilitative
61 approach. However, there is no consensus on, which type of exercise is best. Progressive
62 resistance exercise has been shown to promote anti-inflammatory metabolism and the release
63 of growth factors, and to reverse the muscle atrophy process [6]. The target of many exercise
64 studies has been to strengthen only the back extensor muscles [7], however, muscle atrophy
65 has also shown to involve the lumbar flexor muscles [8]. While moderate-certainty evidence
66 exists that exercise is an effective treatment for CLBP, the effect on pain and disability have
67 been found to be small [9]. Moreover, previous studies have shown only low strength gains
68 [10]. These contrast with the results found for the upper spine, as progressive isometric
69 strength training has been shown to double strength and clinically significantly reduce pain
70 and disability also in the long term [11].

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

77 **2. Materials and methods**

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

80 2.1. Participants

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

103 the measurements safely, were excluded. All participants were provided with information
104 about the study protocol and possible risks and discomfort related to the tests.

105 2.2. Electromyography

106 Measurements were conducted in the Biomechanics Laboratory at the Central Hospital. To
107 minimize skin impedance, the skin was shaved, treated with abrasive material, and cleaned
108 with alcohol. Disposable pregelled Ag/AgCl surface electrodes with a pick-up area of
109 approximately 1.0 cm² each (BlueSensor M, Ambu A/S, Ballerup, Denmark) were placed
110 unilaterally over the trunk muscles as shown in Figure 1. The detection electrodes were
111 positioned according to Seniam guidelines for surface EMG measurements [13] and cables
112 fitted with preamplifiers were used to ensure good signal quality. The reference electrode was
113 positioned beside each pair of detection electrodes, at approximately 10 cm distance from
114 each, as specified by the manufacturer. A strip of tape was placed on top of each electrode
115 with an overlap of 3 cm on each side to prevent the wires from disconnecting the electrodes
116 during execution of the exercises. A wireless ME6000 EMG system (Mega Electronics Ltd,
117 Kuopio, Finland) with 6 channels was used to record the sEMG signal. The raw sEMG
118 signals, sampled at 1000 Hz were amplified and filtered with cutoff frequencies at 8 and 500
119 Hz. The preamplifier had a common mode rejection ratio of 110 dB.

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

125 The normalized muscle activity level (percentage of maximum amplitude) in each exercise
126 was determined by relating the peak RMS EMG amplitude to the RMS EMG amplitude
127 measured during the maximal voluntary isometric contraction (MVIC). MVIC of the trunk

128 muscles was measured using inhouse-constructed frames for the strain-gauge dynamometers
129 (Tedea-Huntleigh Ltd., Cardiff, UK). MVIC of the trunk extensors and flexors was measured
130 with the subject standing in erect position with feet positioned 20 cm apart (Figure 2A). The
131 support of the frame was located at the height of the anterior superior iliac spine. During the
132 flexion strength measurements, the height of the sensor element was adjusted in the middle of
133 the sternum. The subject turned round for the extension strength measurement and the sensor
134 element was maintained at the same level. MVIC of the trunk rotators was measured with the
135 subject in sitting position with the hip and knee angles at 90⁰ and the pelvis stabilized by a
136 belt (Figure 2B). In addition, subject supported his lower extremities against a pad between
137 his knees. The pads supporting the shoulders were adjusted individually for each subject. The
138 vertical axis of the spine was aligned linearly with that of the measuring sensor.

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

146 2. 3. Exercise tests

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

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

162 2.4. Exercise description

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

168 2.5. Statistical analyses

169 The sample size was evaluated using simulation-based sample size. The calculations are
170 based on a 10 % difference within the groups between EMG activity in each exercise relative
171 to MVIC. Target sample size of 30 participants (15 per group) was required for a two-sided
172 significance level of 0.05 (85% power). Data are presented as the means with standard
173 deviations (SD). The normality of variables was evaluated graphically and by using the
174 Shapiro-Wilk test. Between groups comparisons in isometric strength tests and extra loads
175 used in 10 RM resistance exercises were made by using student's t-test. The normalized
176 maximal EMG activity values between the different exercises in both groups was analyzed
177 using generalizing estimating equations (GEE) models with the unstructured correlation

178 structure. A bootstrap-type method was used (10 000 replications) to estimate the standard
179 error. Bonferroni adjustments were performed to correct significance levels for the multiple
180 test. Stata 17.0 (StataCorp LP, College Station, TX, USA) was used for the statistical
181 analyses.

182 **3. Results**

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

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

192 External exercise loads were lower in patients with CLBP compared to healthy subjects, and
193 the difference was significant in Russian twist, Y cable and hip flexion machine exercises.

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

198 In the lumbar multifidus, the hip flexion machine exercise induced the highest EMG activity
199 in both patients and healthy subjects: 70 % in patients and 53 % in healthy subjects (Figure
200 4). The band side pull also induced high lumbar multifidus activity in healthy subjects but not
201 patients: 61 % vs. less than 50 %. In the lumbar erector spinae, the highest activity was
202 observed with the band side pull with resistance band in both patients and healthy subjects:
203 55 % in patients and 43 % in healthy subjects. In the thoracic erector spinae, the highest

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

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

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

226

227

228 **4. Discussion**

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

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

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

251 The functionally deep multifidi are the primary stabilizing muscles of the spine [21].
252 Commonly used home exercises treating CLBP, such as the plank with leg lift, rotary plank
253 and back bridge with leg lift, activated the multifidus only a little. In addition, the load is not
254 increased with these exercises. Progression with these exercises is limited to increase
255 repetitions and thus become more endurance than strength training. In both the multi-hip

256 machine and elastic band exercises the load can be progressively increased, which is an
257 important factor that should be considered while planning rehabilitation program.

258 Trunk muscles are increasingly activated when more stabilization is needed [18]. In the
259 lumbar erector muscle, the band side pull produced the highest muscle activity; in the patient
260 group over 50% MVIC, and in the healthy group 43% MVIC. For the thoracic erector spinae,
261 the band side pull and single-arm cable pull exercises were the best exercises, inducing about
262 70 % of MVIC. A progressive increase in load can be easily accomplished in both exercises,
263 and both can be done also at home with a resistance band if gym training is not possible.

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

268 Differences in average maximal muscle activation between the patient and healthy groups
269 were mostly minor. In the patient group, some of these may be related to pain inhibition or
270 unconscious fear of pain, preventing the exercise from being performed with full effort.

271 However, some of the results favored the patient group. Colado et al. [22] reported low
272 maximum EMG values for the static supine-bridge exercise in healthy volunteers without
273 back pain. In the present study, the back bridge with alternating leg lift similarly showed low
274 muscle activity, indicating that it may not be effective in preventing or reversing trunk
275 muscle atrophy in patients with CLBP. Nevertheless, these exercises are commonly used in
276 back rehabilitation without advancing more demanding exercises. These exercises are also
277 clearly inferior for sports training aimed at strength gain.

278 In rehabilitation of lumbar muscles, progression from localized stabilizing exercises in the
279 supine and prone positions to localized stabilizing exercises in a stance posture and hence to
280 global stabilizing exercises has been recommended [22,23]. However, this type of exercise
281 program has not been found to be particularly effective. It differs considerably from straight
282 forward stabilizing isometric strength training, which has proven to be highly effective

283 treatment for pain in upper spine rehabilitation [14]. The increase in muscle strength was also
284 associated with improvement of mobility and disability. In many studies the exercise load has
285 been too low to improve back muscle strength [24]. To achieve good results in rehabilitation,
286 the stabilizing exercises must be done with sufficient load and volume [14]. Oliva-Lozano et
287 al. [25] compared maximal EMG activity in various paraspinal muscles across seven different
288 exercises and found that the dead lift produced the highest muscle activity. One problem with
289 comparing exercise studies is that the terms used may be misleading. Aasa et al. [26]
290 compared low-load motor control exercises with high-load lifting exercise-, but the load used
291 in the dead-lift exercises was subjectively determined by physiotherapists and not based on
292 strength tests. In their study the results showed non-significant improvement in lifting
293 capacity in both groups. Thus, both groups were in fact performing low-load motor control
294 exercises. The deadlift exercise was excluded from the present study as high axial
295 compression load of the spine has been associated with increased injury risk [27,28].
296 Moreover, this risk is not preventable by excluding high-risk patients by radiological imaging
297 [29]. In CLBP patients, high-load isokinetic back training has been found to be more effective
298 in treating pain intensity and the strength of the back muscles than low-load trunk
299 stabilization training [30]. However, isokinetic devices are expensive and require professional
300 staff to operate them and control performance individually for each patient. Based on this,
301 these exercises were excluded from the present study. Effective low-cost high-intensity
302 exercises that are commonly used in upper spine rehabilitation are thus needed in treating
303 CLBP.

304 It is important to note that treatment of CLBP may require more than just high intensity
305 activation exercises for trunk muscles, which was on the focus in the present study. Although
306 some of the exercises commonly used in CLBP rehabilitation produced very modest muscle
307 activation in this study, it does not mean that they are of no value. Some exercises may be
308 useful for recognizing muscle activation and improving postural control and coordination,

309 and may also be suitable for the initial stages of rehabilitation when patients are not able to
310 perform more advanced exercises. The cause of CLBP has shown to be multifactorial, and
311 thus various treatment approaches may need to be incorporated [31].

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

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

331 The hip machine exercise is commonly thought to be a leg-specific exercise. In the present
332 study it was found to be the best exercise for lumbar multifidus muscle activation, and it
333 activates also oblique abdominal muscles effectively. Moreover, it was well tolerated
334 exercise modality in patients with CLPB, which is in line with our clinical experience. This is

335 probably due to the fact that there is no direct axial loading of the spine, despite the high
336 loading of the lumbar muscles.

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

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

356 All surface EMG measurements are subject to contamination from adjacent muscles
357 depending on their activation and size. Especially so the multifidi that are covered by the
358 erector spinae. In the present study electrode placement was performed according to
359 Arokoski et al. [36], who suggested that surface electromyography (sEMG) may be used in
360 the assessment of multifidus muscle function. Body movement also affects the results, as

361 electrodes move with the skin, which is stretched above the muscle. However, the present
362 study involved only isometric exercises.

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

374

375 **5. Conclusion**

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

384

385

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388 performing measurements and the data collection.

389 **Author contribution**

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

395 **Conflict of interest**

396 No potential conflict of interest was reported by the authors.

397 **Data availability statement**

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

400 **Ethical approval**

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

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405 **Informed consent**

406 The purpose of the study and its course were explained to the participants orally and in
407 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/m ²)	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

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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

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563 Table 3. Peak activity of surface electromyography relative to maximum voluntary isometric
 564 contraction of six core muscles during isometric core exercises. Results are expressed as % of MVIC
 565 (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)

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

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

594

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

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

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

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602 Figure 5. The graph depicts in percentage of maximal electromyographic (EMG) activity of
603 the abdominal muscles during the performance of each isometric core exercise in relation to
604 highest activity obtained during maximal voluntary isometric contraction (MVIC) tests.

605 Bonferroni corrected 95% confidence intervals are presented with whiskers.

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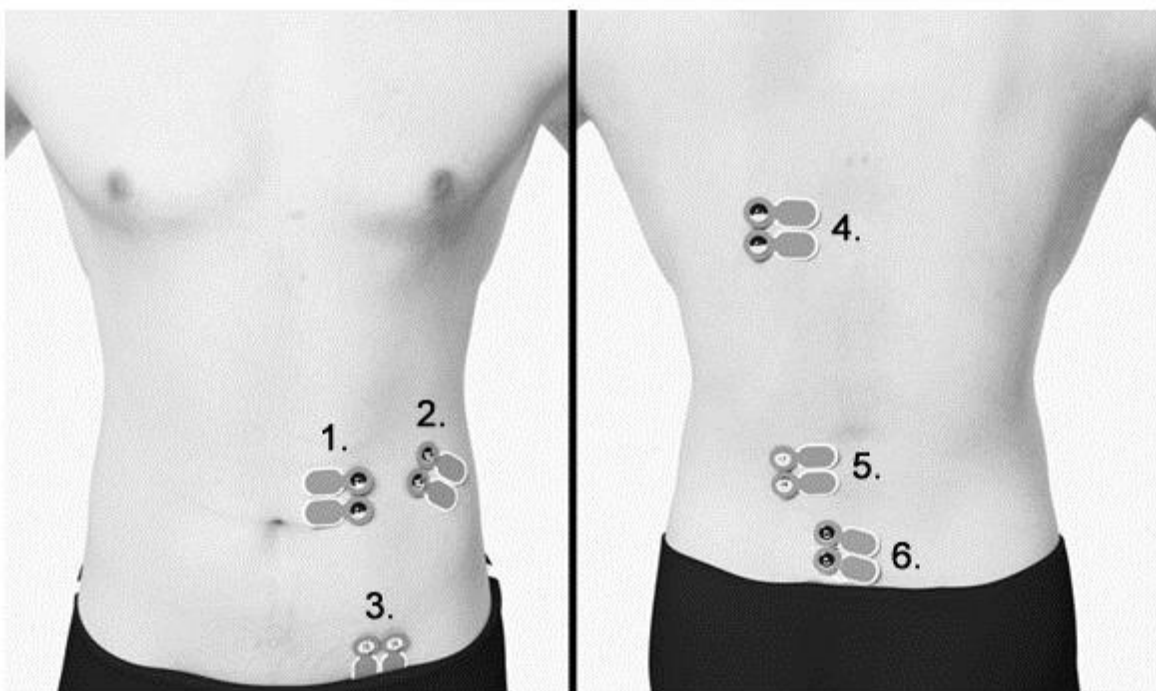
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613 Figure 1.



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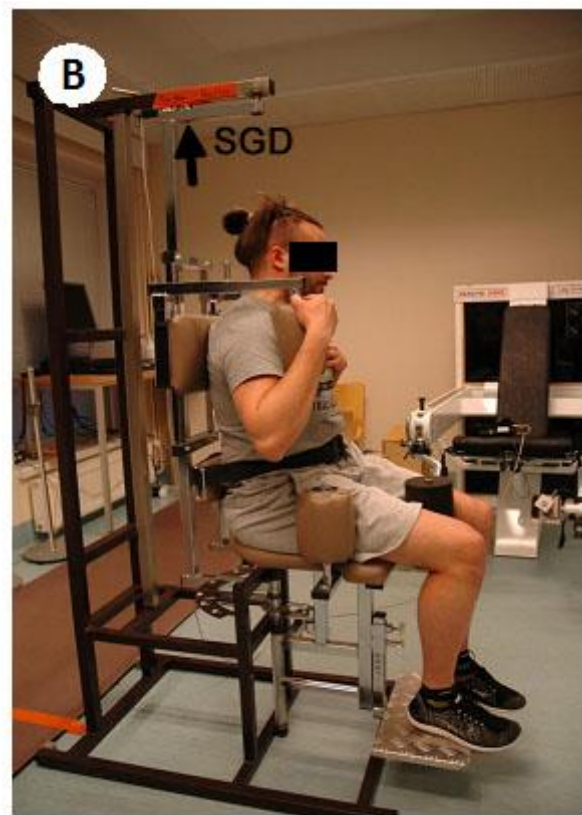
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622 Figure 2.



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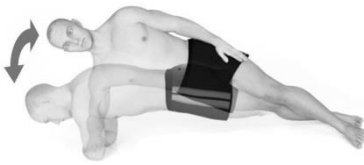
Broomstick shoulder rotation



Four-point kneeling with leg lift



Plank with leg lift



Rotary plank



Back bridge with leg lift



Band side pull



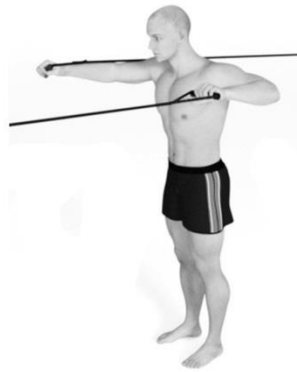
Russian twist



Single-arm cable push



Single-arm cable pull



Y cable exercise



Hip flexion machine

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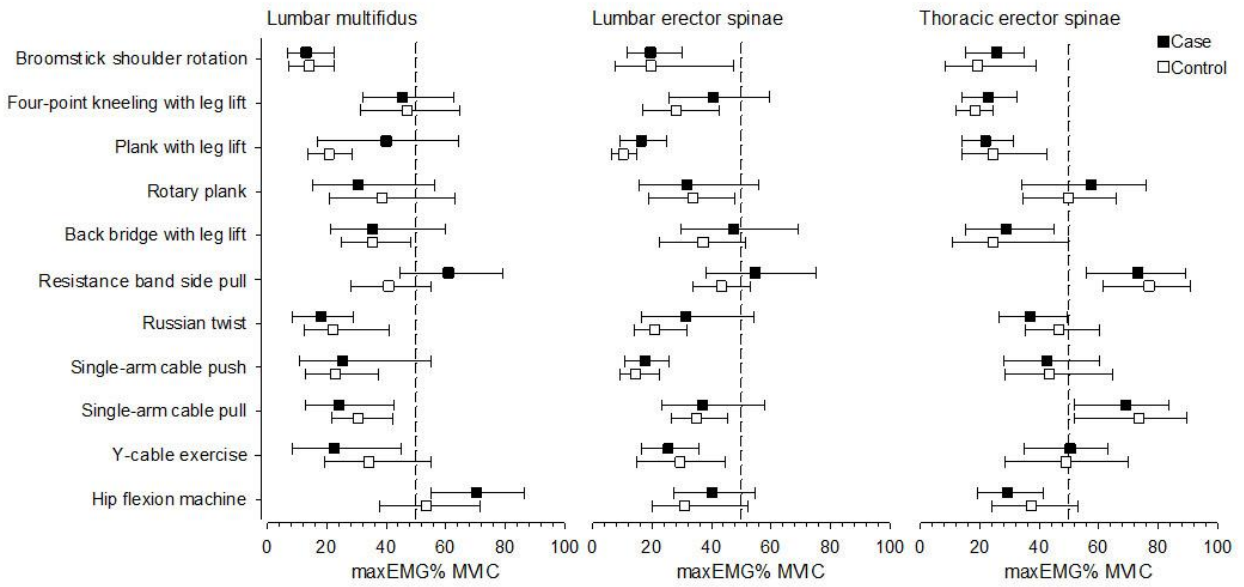
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640 Figure 4.



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642 Patients $p < 0.001$

643 Healthy $p < 0.001$

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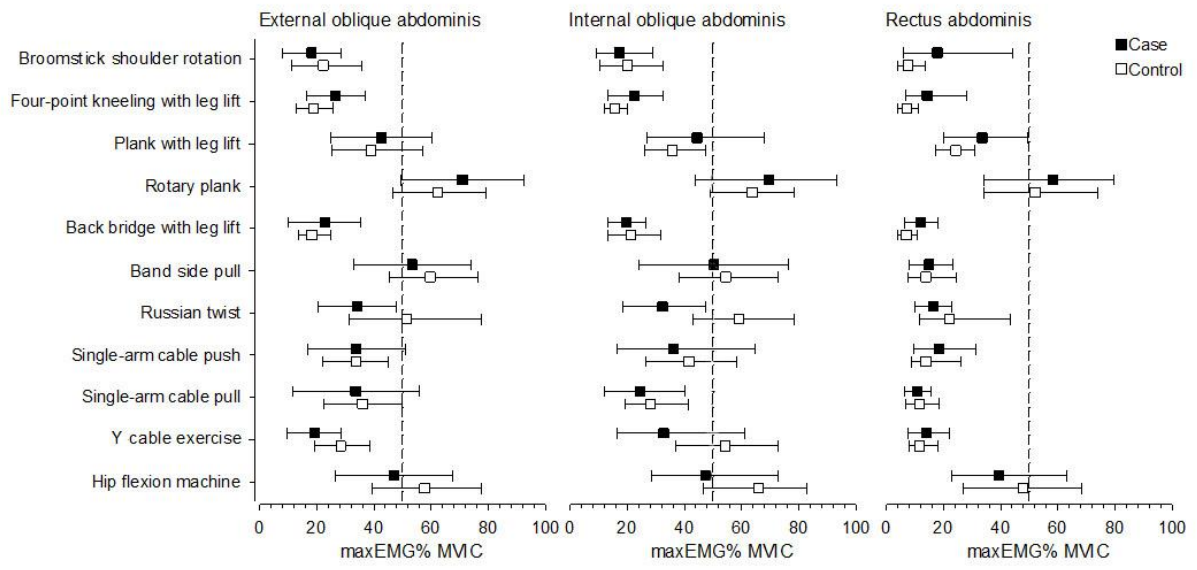
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661 Figure 5.



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663 Patients $p < 0.001$

664 Healthy $p < 0.001$

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