Hindawi Publishing Corporation
ISRN Rehabilitation
Volume 2013, Article ID 928956, 11 pages
http://dx.doi.org/10.1155/2013/928956

Clinical Study

Rehabilitation of Back Extensor Muscles' Inhibition in Patients with Long-Term Mechanical Low-Back Pain

Chidozie Emmanuel Mbada,[1] Olusola Ayanniyi,[2] Samuel Olusegun Ogunlade,[3] Elkanah Ayodele Orimolade,[4] Ajibola Babatunde Oladiran,[4] and Abiola Oladele Ogundele[5]

[1] *Department of Medical Rehabilitation, College of Health Sciences, Obafemi Awolowo University, Ile-Ife, Nigeria*
[2] *Department of Physiotherapy, College of Medicine, University of Ibadan, Ibadan, Nigeria*
[3] *Department of Orthopaedic and Trauma, College of Medicine, University of Ibadan, Ibadan, Nigeria*
[4] *Department of Orthopaedic Surgery and Traumatology, Obafemi Awolowo University Teaching Hospitals Complex, Ile-Ife, Nigeria*
[5] *Department of Physiotherapy, Obafemi Awolowo University Teaching Hospitals Complex, Ile-Ife, Nigeria*

Correspondence should be addressed to Chidozie Emmanuel Mbada; doziembada@yahoo.com

Received 30 May 2013; Accepted 8 July 2013

Academic Editors: K. Hashimoto, J. D. Kingsley, J. J. Sosnoff, M. Syczewska, and M. Yu

This study investigated the effect of static or dynamic back extensors endurance exercise in combination with McKenzie Protocol (MP) in patients with Long-term Mechanical Low-Back Pain (LMLBP). This randomized controlled trial involved 84 patients, who were assigned into MP Group (MPG), MP plus Static Back Extensors Endurance (SBEE) Exercise Group (MPSBEEG), or MP plus Dynamic Back Extensors' Endurance (DBEE) Exercise Group (MPDBEEG). Twenty-five, 22, and 20 participants in MPG, MPSBEEG, and MPDBEEG, respectively, completed the thrice weekly eight-week study (drop-out rate = 20.2%) and outcomes were measured in terms of SBEE, DBEE, and Back Muscles Fatigue (BMF) at the 4th and 8th week, respectively. There were significant differences in groups mean change scores on SBEE (14.6 ± 8.44, 45.7 ± 17.0 and 17.1 ± 10.2 sec), DBEE (2.88 ± 1.88, 12.9 ± 11.1, and 10.7 ± 6.51 rep), and BMF (12.6 ± 2.16, 10.1 ± 2.08, and 10.8 ± 2.19) at week 4, and SBEE (29.6 ± 8.44, 60.7 ± 17.1, and 32.1 ± 10.2 sec), DBEE (8.36 ± 2.22, 18.1 ± 10.1, and 16.6 ± 6.24 reps), BMF (3.88 ± 1.67, 5.41 ± 2.32, and 4.35 ± 1.63) at week 8, respectively ($P < 0.05$). It was concluded that MP alone, or in combination with SBEE or DBEE, exercise was effective in the rehabilitation of back extensors' endurance and fatigability in patients with LMLBP. However, the addition of SBEE to MP led to significantly higher positive effects.

1. Introduction

Long-term mechanical low-back pain (LBP) results in inhibition and atrophy of the deep segmental muscles such as multifidus and overactivity of the longer superficial muscles of the trunk with resultant decreased dynamic activity and increased fatiguibility [1–4]. Long-term mechanical LBP is more difficult to treat [5–7] and treatment outcomes give variable results [8–10] and it consequently results in both physical and psychological deconditionings that trap the patient in a vicious circle characterized with decreased physical performance, exacerbated nociceptive sensations, depression, impaired social functioning, and work disability [11].

One of the more commonly used physical therapy approaches in the management of long-term mechanical LBP with documented effectiveness is the McKenzie Protocol (MP) [12–15]; However, there seems to be inconclusive evidence whether the MP addresses the accompanying back muscles inhibition in patients with long-term mechanical LBP. Some studies considered the McKenzie's extension exercises as passive and presumably opined that it may not counter the back muscles' inhibition and atrophy resulting from long-term LBP [16–18], however, a study by Fiebert and Keller [19] among apparently healthy individuals demonstrated that the McKenzie's extension exercises were not truly passive for lumbar back extensor muscles.

On the other hand, back endurance exercise is believed to enhance muscle reactivation and reconditioning [20–23]. There is emerging evidence to suggest that endurance training of the low-back extensors in patients with LBP can be effective in reducing pain, disability, and work loss, and improving fatigue threshold and physical performance [24–27]. Pain-related muscular inhibition of the back muscles characteristically leads to loss of muscle motor units, muscle atrophy, iatrogenic muscular inhibition, and decreased strength and endurance [20–22, 28, 29]. Unfortunately, assessment and training of endurance of the back extensor muscles compared with muscular strength have been reported to be less frequently carried out [30], though, endurance capabilities of these muscles may be as important or even more important than strength in the treatment and prevention of LBP [31]. Furthermore, there seems to be a dearth of studies involving dynamic endurance exercise of the back extensor muscles compared with a chronicle of studies that have investigated the effect of static muscular endurance exercise training in patients with acute [24], subacute [27], and long-term LBP [32], respectively. Meanwhile, dynamic endurance may be needed more than static endurance as most of the daily tasks involve dynamic movement [33, 34]. Therefore, the objective of this study was to investigate the effect of static or dynamic back extensors endurance exercise in combination with McKenzie Protocol on static and dynamic back extensor muscles' endurance and fatigability in patients with long-term mechanical LBP.

2. Materials and Methods

A single-blind randomized controlled trial involving 84 patients with LMLBP was conducted. Long-term LBP was defined as a history of LBP of not less than 3 months. Mechanical LBP refers to back pain of musculoskeletal origin that results from inflammation caused by irritation or trauma to the disk, the facet joints sufficient enough to stress, deform, or damage the ligaments, or the muscles of the back [35, 36] in which symptoms vary with physical activity [37]. The participants were patients attending the physiotherapy department, Obafemi Awolowo University (OAU) Teaching Hospitals Complex and the OAU Health Centre, Ile-Ife, Nigeria, respectively. Eligibility to participate in the study was carried out with the McKenzie Institute's Lumbar Spine Assessment Format (MILSAF). The MILSAF was used to recruit a homogenous sample of participants who demonstrated directional preference (DP) for extension.

Exclusion criteria for this study were as follows:

(1) red flags indicative of serious spinal pathology with signs and symptoms of nerve root compromise (with at least two of these signs: dermatomal sensory loss, myotomal muscle weakness, and reduced lower limb reflexes),

(2) any obvious spinal deformity or neurological disease,

(3) a reported history of cardiovascular diseases contraindicated to exercise; or individuals who were with elevated blood pressure (>140/90 mmHg),

(4) pregnancy or previous spinal surgery,

(5) previous experience of McKenzie method,

(6) directional preference for flexion, lateral or no directional preference based on the McKenzie assessment.

Permuted block randomization was used to assign participants to one of three treatment groups. Viz- the McKenzie Protocol Group (MPG) ($n = 29$), MP plus Static Back Endurance Exercise Group (MPSBEEG) ($n = 27$), and MP plus Dynamic Back Endurance Exercise Group (MPDBEEG) ($n = 28$). Sixty seven (32 males (47.8%) and 35 females (52.2%)) participants completed the 8-week study. Twenty five participants completed the study in MPG, 22 in MPSBEEG, and 20 in MPDBEEG. A total drop-out rate of 20.2% was observed in the study. Each group received treatment thrice weekly for eight weeks and outcomes were assessed at the end of 4th and 8th weeks of study. Ethics and Research Committee of the Obafemi Awolowo University Teaching Hospitals Complex (Reg no.: ERC/2010/01/02) and the joint University of Ibadan/University College Hospital Institutional Review Committee (Ref no.: UI/UC/10/0194), respectively, gave approval for the study.

2.1. Instruments. A height meter (Seca 240—made in UK) calibrated from 0 to 200 cm was used to measure the height of each participant to the nearest 0.1 cm. A weighing scale (Hana weighing Scale—made in China) calibrated from 0 to 120 kg was used to measure the body weight of participants in kilograms to the nearest 1.0 kg. A metronome (Wittner Metronome system Maelzel, Made in Germany) was used to set the tempo for dynamic back endurance muscles endurance. A Quartz stop watch (Quartz USA) was used to determine the endurance time or the isometric holding time in seconds (i.e., from the onset of the BSME to volitional fatigue). A plinth that could be inclined at angles 30°, 45°, and 60° was used for the purpose of conducting the BSME and RAUT and the McKenzie Protocol, static and dynamic back endurance exercise, respectively. Two nonelastic straps were used to ensure stability during the BSME and RAUT tests, respectively. A towel was positioned beneath the ankle straps to reduce the strain on the distal aspect of the tendo calcaneus (Achilles tendon) and thereby ensure comfort of the participants during the tests. The Borg scale of perceived exertion [38] was used to assess level of fatigue to both BSME and RAUT, respectively. The scale was translated into the Yoruba language. The translation was done at the Department of Linguistics and African Languages of Obafemi Awolowo University, Ile Ife. Pearson product moment correlation coefficient (r) of 0.84 was obtained for the criterion validity of the back translation of the Yoruba version.

2.2. Physical Performance Test. Physical performance assessment for both static and dynamic back extensors endurance was conducted prior the commencement of treatment intervention and at the 4th and 8th weeks of treatment, respectively. Physical performance tests used in this study included the modified Biering-Sørensen test of Static Muscular Endurance (BSME) and Repetitive Arch-Up Test (RAUT) for dynamic endurance, respectively. Prior to the endurance tests, the participants were instructed in detail on the study procedures. The test was preceded by a low-intensity warm-up phase of five minutes that comprised stretches and strolling at a self-determined pace around the research venue.

Figure 1: The modified Biering-Sorensen test of static muscular endurance position.

Figure 2: Horizontal phase of the Repetitive Arch-Up Test.

Figure 3: Downward phase of the Repetitive Arch-Up Test.

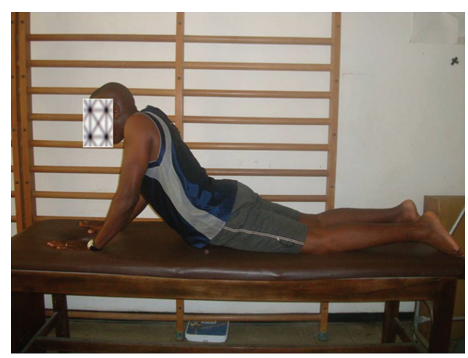

Figure 4: McKenzie's extension exercise posture in lying.

The modified BSME and RAUT were performed in random order among the participants with a 15-minute interval provided between both tests. The tests ended with a cool-down phase, comprising the same low-intensity stretches and strolling around the research venue for about five minutes.

2.2.1. Assessment of Static Back Extensors' Endurance. The BSME was used to assess the static back endurance. During the test the participant laid on the plinth in the prone position with the upper edge of the iliac crests aligned with the edge of the plinth with their hands held by their sides. The lower body was fixed to the plinth by two nonelastic straps located around the pelvis and ankles. Horizontality in the test position was ensured by asking the participant to maintain contact between his/her back and a hanging weighted ball. Once a loss of contact for more than 10 seconds was noticed, the participant was encouraged once to immediately maintain contact again. Once the participant could not immediately correct or hold the position or claimed to be fatigued the test was terminated [20, 39] (Figure 1).

2.2.2. Assessment of Dynamic Back Extensors' Endurance. Repetitive Arch-Up Test (RAUT) was used to assess the static back endurance. During the test, the participant lay in a prone position on the plinth with the arms positioned along the sides. The iliac crest was positioned at the edge of the plinth. The lower body was fixed to the plinth by two non-elastic straps located around the pelvis and ankles. With the arms held along the sides touching the body, the subject was asked to flex the upper trunk downward to 45° as indicated by a board. The participant then raised the upper trunk upwards to the horizontal position followed by returning back downward to 45 degrees to complete a cycle. The repetition rate was one repetition per two to three seconds. The movement was repeated as many times as possible at a constant pace synchronous to a metronome count. Once the movement becomes jerky or nonsynchronous, or did not reach the horizontal level, the subject was encouraged once to immediately correct the motion again. The test was terminated once the participant could not go on with the tempo of the motion or reported fatigue or exhaustion [39] (Figures 2 and 3).

2.3. Treatment. The participants were instructed in details on the procedures of study at inclusion. Treatment for the different groups was in three phases comprising warmup, main exercise, and cooldown, respectively. The warm-up phase involved a low-intensity activities comprising stretches and strolling at self-determined pace around the research venue for aduration of five minutes. Treatment also ended with a cool-down phase comprising of the same low-intensity exercise as the warm-up for about five minutes.

The McKenzie Protocol (MP) involved a course of specific lumbosacral repeated movements in extension that cause the symptoms to centralize, decrease, or abolish. The determination of the direction preference for extension was followed by the main MP activities including "Extension lying prone," "Extension In Prone" and "Extension in standing" (Figures 4 and 5). The MP also included a set of back care education

Figure 5: McKenzie's extension exercise posture in standing.

Figure 6: Exercise position 1: prone position with arms by the sides of the body, and head and trunk lifted off the plinth from neutral to extension for static and Dynamic Back Extensors' Endurance exercise.

Figure 7: Exercise position 2: prone position with hands interlocked at occiput so shoulders are abducted to 90° and elbows flexed, and head and trunk lifted off the plinth from neutral to extension for static and dynamic back extensors endurance exercise.

Figure 8: Exercise position 3: prone position with both arms elevated forwards, and head and trunk lifted off the plinth from neutral to extension for static and dynamic back extensors endurance exercise.

instructions which comprised a 9-item instructional guide on standing, sitting, lifting, and other activities of daily living for home exercise for all the participants.

2.3.1. Static Back Extensors Endurance Exercise. In addition to completing the MP (i.e., back extension exercises plus the back care education), static back extensors endurance exercise included five different exercises of increasing level of difficulty where the positions of the upper and lower limbs were altered. The participants began the exercise training programme with the first exercise position but progressed to the next exercises at their own pace when they could hold a given position for 10 seconds. On reaching the fifth progression, they continued with the fifth progression until the end of the exercise programme.

2.3.2. Dynamic Back Extensors Endurance Exercise. In addition to completing the MP, dynamic back extensors endurance exercise included five different exercises. The dynamic back endurance exercise was an exact replica of the static back extensors endurance exercise protocol in terms of exercise positions, progressions, and duration. However, instead of static posturing of the trunk in the prone lying position and holding the positions of the upper and lower limbs suspended in the air during all the five exercise progressions for the 10 seconds, the participant was asked to move the trunk and the suspended limbs 10 times (Figures 6, 7, 8, 9, and 10).

The details of the treatment procedure for MPG, MPSBEEG, and MPDBEEG have been published elsewhere by the authors [40].

2.4. Data Analysis. Data were analyzed using descriptive and inferential statistics of one-way analysis of variance (ANOVA) and multiple comparisons post hoc tests at $P = 0.05$. The data analyses were carried out using SPSS 13.0 version software (SPSS Inc., Chicago, IL, USA).

3. Results

The mean age, height, weight, BMI, and pain intensity of all the participants were 51.8 ± 7.35 years, 1.66 ± 0.04 m, 76.2 ± 11.2 kg, 27.2 ± 4.43 kg/m^2, and 6.55 ± 1.75, respectively. Across group comparison of participants' baseline anthropometric and clinical parameters is presented in Table 1. The result indicates that the participants' baseline measures across the MPG, MPSBEEG, and MPDBEEG were comparable ($P > 0.05$). Repeated measures ANOVA and post hoc multiple

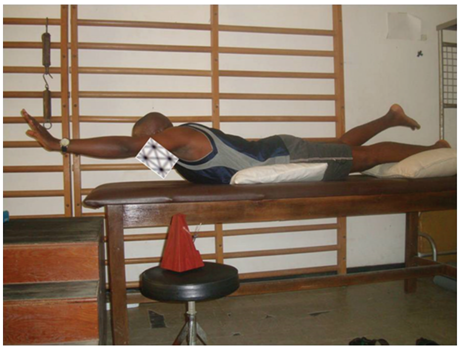

Figure 9: Exercise position 4: prone position and head, trunk and contralateral arm and leg lifted off the plinth from neutral to extension for static and dynamic back extensors endurance exercise.

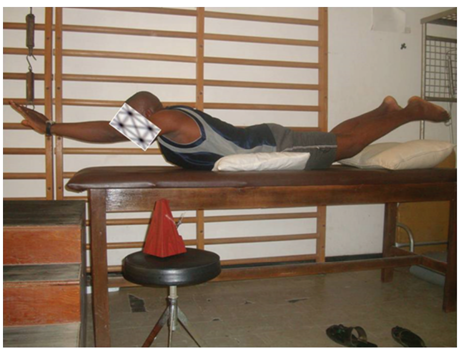

Figure 10: Exercise position 5: prone position with both arms elevated forwards and both legs (with knees extended) lifted off the plinth from neutral to extension for static and dynamic back extensors endurance exercise.

comparisons of the participants' clinical variables across the 3 time points of the study are presented in Table 2.

Results among the different groups showed that there were significant differences ($P < 0.05$) in the participants' outcome parameters across the 3 timepoints of the study.

One-way ANOVA and least Significant difference post hoc multiple comparison of the participants' treatment outcomes (mean change) at weeks four and eight of the study are presented in Table 3. From the result, there were significant differences in groups' mean change scores on static endurance (14.6 ± 8.44, 45.7 ± 17.0, and 17.1 ± 10.2 sec), dynamic endurance (2.88 ± 1.88, 12.9 ± 11.1, and 10.7 ± 6.51 rep), and muscle fatigue (12.6 ± 2.16, 10.1 ± 2.08, and 10.8 ± 2.19) at week 4, and static endurance (29.6 ± 8.44, 60.7 ± 17.1, and 32.1 ± 10.2 sec), dynamic endurance (8.36 ± 2.22, 18.1 ± 10.1, and 16.6 ± 6.24 resp.), muscle fatigue (3.88 ± 1.67, 5.41 ± 2.32, and 4.35 ± 1.63) at week 8, respectively. Least significant difference (LSD) post hoc analysis was used to elucidate where the differences within between groups lie.

4. Discussion

This study investigated the effect of static or dynamic back extensors endurance exercise in combination with McKenzie Protocol on back extensor muscles' endurance and fatiguability in patients with long-term mechanical LBP. From the result of this study, no significant difference in physical characteristics and baseline outcome parameters of the participants in the different treatment groups was observed. Baseline characteristics are believed to be predictors of response to treatment in clinical trials for LBP [41–43]. Comparability in baseline measure in clinical trials is reported to reduce the chances of cofounders other than the intervention in predicting outcomes. In this study, the groups were comparable in their general characteristics and baseline clinical parameters. Therefore, it is implied that the results obtained at different point in the course of the study could have been large due to the effects of the various treatment regimens.

Within-group comparison across the 3 timepoints (weeks 0–4, 4–8, and 0–8) of the study revealed that the MP had significant effects on muscle fatigue and static and dynamic endurance, respectively. Studies on the effect of the MP on muscle fatigability and endurance (static or dynamic) seem to be not available in the literature. However, this present study found that patients that were treated with the MP only had significant reduction in back muscles' fatigability level and increased static and dynamic back extensor muscles' endurance, respectively. It is opined that the effect of MP on muscle fatigue and endurance might be due to the relationship between pain and each of muscle fatigue and endurance. MP has been reported from previous studies to significantly ameliorate pain in patients with long-term LBP [12, 14, 44, 45]. It is believed that chronic pain and fatigue often occur together in majority of individuals with musculoskeletal pain and that muscle pain and fatigue are not independent conditions and may share a common pathway that is disrupted in chronic muscle pain conditions [46]. Similarly, pain in itself has been reported to precipitate decreased muscle endurance resulting from increased muscle metabolite from prolonged muscle tension and spasm [47], muscle deconditioning [48] and inhibition of the paraspinal muscles [48]. It is adduced that the MP may not have a direct effect on muscle fatigue and endurance but a consequence of its effect on pain. However, this speculation is open to empirical investigation.

Within-group comparison across the 3 timepoints (weeks 0–4, 4–8, and 0–8) of the study revealed that the MP plus Static Back Endurance Exercise (MPSBEE) had significant effects on muscle fatigue and static and dynamic endurance, respectively. There seems to be a scarcity of similar studies to which the result obtained in this study can be compared directly. However, there are other reports that indicate that endurance training of the low-back extensors can be effective to elevate fatigue threshold and improve performance, thus reduce disability [24, 25, 27, 49], and decrease work loss [26, 50, 51]. Furthermore, endurance training is believed to cause mechanical loading of the muscles [52] which in turn leads to tissue adaptation [53].

The orientation and posture for the static back extensor endurance exercise in this study were extension in sagittal plane while in prone lying. It is believed that an increase in sagittal curvature and change in spinal shape may alter physiologic loading through the spine as a consequence of

Table 1: Comparison of participants' baseline anthropometric and clinical parameters.

Variable	MPG ($n = 25$) $\overline{x} \pm$ SD	MPSBEEG ($n = 22$) $\overline{x} \pm$ SD	MPDBEEG ($n = 20$) $\overline{x} \pm SD$	F ratio	P value
Age (yr)	50.6 ± 7.57	51.2 ± 7.50	53.8 ± 6.83	1.106	0.339
Height (m)	1.67 ± 0.04	1.66 ± 0.04	1.68 ± 0.04	2.185	0.331
Weight (Kg)	76.3 ± 9.95	75.2 ± 13.2	77.2 ± 10.8	0.156	0.856
BMI (Kg/m^2)	27.5 ± 4.20	27.3 ± 5.25	26.9 ± 3.89	0.093	0.912
VAS	6.56 ± 1.83	6.50 ± 1.71	6.60 ± 1.79	0.017	0.983
SE	36.7 ± 11.8	37.3 ± 13.4	39.2 ± 18.6	0.162	0.851
DE	11.7 ± 2.63	11.3 ± 2.10	11.3 ± 4.27	0.129	0.879
SRPE	13.5 ± 2.12	12.5 ± 2.01	12.2 ± 1.73	2.870	0.064
DRPE	14.1 ± 2.55	14.1 ± 2.16	13.4 ± 1.05	0.986	0.380

Alpha level was set at $P < 0.05$.
Key:
MPG: McKenzie Protocol Group.
MPSBEEG: McKenzie Protocol plus Static Back Endurance Exercise Group.
MPDBEEG: McKenzie Protocol plus Dynamic Back Endurance Exercise Group.
$\overline{x}$: Mean.
SD: Standard deviation.
VAS: Visual Analogue Scale.
SE: Static Endurance.
DE: Dynamic Endurance.
SRPE: Rate of perceived exertion to Biering-Sørensen test of Static Muscular Endurance.
DRPE: Rate of perceived exertion to Repetitive Arch-Up Test.

Table 2: Repeated measures ANOVA and post hoc multiple comparisons of the clinical variables across the 3 timepoints of the study.

Outcome	Baseline $\overline{x} \pm$ SD	4th week $\overline{x} \pm$ SD	8th week $\overline{x} \pm$ SD	F ratio	P value
MPG ($n = 25$)					
SE	36.7 ± 11.8^a	51.4 ± 10.2^b	66.4 ± 10.2^c	47.402	0.001
DE	11.2 ± 2.63^a	14.6 ± 2.52^b	20.0 ± 2.92^c	62.126	0.001
SRPE	13.4 ± 2.12^a	12.6 ± 2.16^a	9.06 ± 2.16^b	22.419	0.025
DRPE	14.1 ± 2.55^a	13.7 ± 2.11^a	10.7 ± 2.11^b	16.767	0.001
MPSBEEG ($n = 22$)					
SE	37.3 ± 13.4^a	83.1 ± 10.9^b	98.1 ± 10.1^c	159.362	0.001
DE	11.3 ± 2.10^a	24.2 ± 10.0^b	29.4 ± 8.93^c	13.981	0.001
SRPE	12.5 ± 2.02^a	10.5 ± 2.08^b	7.05 ± 2.08^c	38.069	0.001
DRPE	14.2 ± 2.16^a	12.7 ± 1.91^b	9.68 ± 1.91^c	29.448	0.001
MPDBEEG ($n = 20$)					
SE	39.2 ± 18.6^a	56.2 ± 18.5^b	75.2 ± 18.5^c	15.011	0.001
DE	11.3 ± 4.27^a	22.0 ± 8.45^b	27.9 ± 8.27^c	26.890	0.001
SRPE	12.2 ± 1.73^a	10.8 ± 2.19^b	7.80 ± 2.19^c	23.652	0.001
DRPE	13.4 ± 1.05^a	9.35 ± 1.35^b	6.35 ± 1.35^c	158.731	0.001

Alpha level was set at $P < 0.05$.
Superscripts ($^{a,\,b,\,c}$).
For a particular variable, mean values with different superscript are significantly ($P < 0.05$) different. Mean values with same superscripts are not significantly ($P > 0.05$) different. The pair of cell means that is significant has different superscripts.
Key:
$\overline{x}$: Mean.
SD: standard deviation.
VAS: Visual Analogue Scale.
SE: Static Endurance.
DE: Dynamic Endurance.
SRPE: rate of perceived exertion to Biering-Sørensen test of Static Muscular Endurance.
DRPE: rate of perceived exertion to Repetitive Arch-Up Test.

Table 3: One-way ANOVA and least significant difference post hoc multiple comparison of the participants' treatment outcomes (mean change) at weeks four and eight of the study.

Outcome	MPG (n = 25) $\overline{x} \pm$ SD	MPSBEEG (n = 22) $\overline{x} \pm$ SD	MPDBEEG (n = 20) $\overline{x} \pm$ SD	F ratio	P value
Week four					
SE	14.6 ± 8.44^{a}	45.7 ± 17.0^{b}	17.1 ± 10.2^{a}	43.703	0.001
DE	2.88 ± 1.88^{a}	12.9 ± 11.1^{b}	10.7 ± 6.51^{b}	12.088	0.001
SRPE	12.6 ± 2.16^{a}	10.1 ± 2.08^{b}	10.8 ± 2.19^{b}	3.916	0.025
DRPE	13.7 ± 2.11^{a}	12.7 ± 1.91^{a}	9.35 ± 1.35^{b}	60.250	0.001
Week eight					
SE	29.6 ± 8.44^{a}	60.7 ± 17.1^{b}	32.1 ± 10.2^{a}	41.620	0.001
DE	8.36 ± 2.22^{a}	18.1 ± 10.1^{b}	16.6 ± 6.24^{b}	13.981	0.001
SRPE	3.88 ± 1.67^{a}	5.41 ± 2.32^{b}	4.35 ± 1.63^{b}	5.616	0.012
DRPE	3.40 ± 1.00^{a}	4.55 ± 1.30^{a}	7.05 ± 1.05^{b}	60.210	0.001

Alpha level was set at $P < 0.05$.
Superscripts (^{a,b,c}).
For a particular variable, mean values with different superscript are significantly ($P < 0.05$) different. Mean values with same superscripts are not significantly ($P > 0.05$) different. The pair of cell means that is significant has different superscripts.
Key:
$\overline{x}$: Mean.
SD: standard deviation.
SE: Static Endurance.
DE: Dynamic Endurance.
SRPE: rate of perceived exertion to Biering-Sørensen Test of Static Muscular Endurance.
DRPE: rate of perceived exertion to Repetitive Arch-Up Test.

a shift in trunk mass [54]. Also, it is adduced that the increased mechanical loading resulting from the change in spinal posture during a static hold or posturing in prone-extension may put a stress on the musculature of the back extensors. The previously stated assertion is corroborated by studies that indicated that changes in spinal posture may lead to alterations in length-tension relationships and function of paraspinal musculature [55], moment arm lengths, and force vector orientations [56]. In addition, increased mechanical loading may have a reactivating effect on the paraspinal musculature [57–59] and this may account for one of the ways static back endurance exercise achieves it therapeutic effect. Conversely, mechanical loading that exceeds the fatigue threshold of the back muscles is deleterious [60–63]. However, change in muscles properties in response to static contraction is proposed to be dependent on the relationship between motor unit activity and conduction velocity of the muscle fiber membrane [64, 65]. Nonetheless, it is difficult to compare the result of this study directly with other previous findings without caution; this is because of the variability that exists in mode, load, frequency, and volume of exercise training. Also, some of the previous studies did not clearly delineate resistance training of the lumbar extensor as either strength or endurance, static or dynamic.

Within-group comparison across the 3 timepoints (weeks 0–4, 4–8, and 0–8) of the study revealed that MP plus Dynamic Back Endurance Exercise (MPDBEE) had significant effects on muscle fatigue and static and dynamic endurance, respectively. Over the past decades, different types of dynamic exercises have been employed in the management of patients with LBP with varying reported successes [66–69]. Johannsen et al. [70] found that dynamic endurance training improved isokinetic back muscle strength and endurance, while Arokoski et al. [71] reported that they are effective in activating the paraspinal muscles. The basis for dynamic exercises in low-back rehabilitation in most of the previous studies was due to the fact that, in reality, some daily tasks involve dynamic movement and may require dynamic endurance more than static endurance [33, 72, 73]. During dynamic tasks, it has been shown that the force generation and muscle recruitment activities associated with twisting change significantly as a function of the trunk posture [74] and the activity of the trunk muscles can be used to speculate the stress on the lumbar intervertebral joints [57–59, 75]. Consequently, the dynamic tasks could possibly lead to LBP [76]. Therefore, the concept of dynamic training for the trunk muscles to act in a synchronous manner to maintain stability [72] is supported by reported link between mechanical instability of the lumbar spine and LBP disorders [77] and the association of LBP with muscle dysfunction [78]. However, to the knowledge of the researchers, there seems to be an apparent dearth of studies that have examined the effects of combining the MP and dynamic endurance training of the back extensors.

The efficacy of each of the MP, MPSBEE, and MPDBEE as observed in this study could be as a result of the fact that each of the regimen-contained active exercise was carried out in extension positions. Some studies submitted that exercises and postures in extension improve and resolve symptoms in patients with specific and nonspecific LBP [79–82]. Active exercise is described as functional exercise performed by the patient or client. Previous studies have shown that active exercise, irrespective of the type, is more effective in the management of patients with long-term LBP than passive therapy [83–85]. Active exercises in their different forms in long-term LBP are aimed at restoring back function by improving movement, strength, endurance, and general fitness [86]. The MP utilizes a system of patient self-generated force to mobilize or manipulate the spine through a series of active repeated movements or static positioning and it is based on the patient's pain response to certain movements and postures during assessment [35]. Similarly, endurance exercises are active exercises that require static posturing or repeated movements in order to initiate overload stimuli on the musculature.

Mbada et al. [40] summarized that pain is the major impairment of long-term LBP and it results in deconditioning of the musculoskeletal system leading to loss of motion, stiffness, cartilage degeneration, fear-avoidance behaviour, iatrogenic muscular inhibition, and muscle atrophy [28, 29]. Like a vicious cycle, the deconditioning syndrome may also precipitate and perpetuate pain which consequents in recurrent or acute-on-chronic LBP. Pain leads to muscle guarding or splinting of all movements in the affected region, splinting or disuse leads to muscular atrophy, which in turn results in weakness [28]. The weakness, therefore, may be secondary to inhibition caused by the noxious stimuli caused by pain [28]. The movement component of treatment regimens as used in this study may have resulted in reconditioning of the patients by making them expand the limits to their physical functioning, retard muscle atrophy, enhance their pain control ability, and improve the psychosocial factors affected by LBP. This is in order to counteract the effect of long-term LBP which precipitates inhibition of movements and thus results in physical inactivity and consequent neurological and physiological changes of the paraspinal musculature resulting in back muscles' inhibition, selective loss of Type 2 muscle fibers, weakness, and shortening [85, 87–89].

Apart from the observed significant effects of each of the treatment regimens on back static and dynamic back extensors endurance and muscular fatiguability in this study, comparatively, MP plus Static Back Endurance Exercise (MPSBEE) led to higher significant improvement on static and dynamic endurance and reduction in muscle fatiguability at weeks four and eight, respectively. From the post-hoc results across the 3 time points of the study, it was observed that the different treatment regimens had significant effect at week four on static and dynamic endurance except on muscular fatiguability of the MP group that was only significant at the week eight. Previous studies indicated that static training programme was effective for increasing isometric (static) endurance of the trunk extensor muscles in healthy [25, 90] and patient populations [27, 91–93], respectively. Another study among healthy male adults found that static training can increase both isometric and dynamic endurance while dynamic training can increase dynamic endurance only [76]. The treatment methodology for the participants in this group involved both movement and mechanical loading components. The treatment regimen may have possible stimulating and reactivating effect on the inhibited muscles of the back extensors caused by long-term LBP. This is because skeletal muscle tissues adapt to higher level of stimulus. An overload stimulus is believed to improve neural control, muscle contractile protein size, and muscular hypertrophy [28]. Addition of load to movement is reported to enhance predominantly fast motor unit recruitment [94]. The physiological principle on which static endurance training depends is the overload principle. This principle states simply that the strength, endurance, and hypertrophy of a muscle will increase only when the muscle performs for a given period of time at its maximum strength and endurance capacity, that is, against workloads that are above those normally encountered [76].

5. Conclusion

From the finding of this study, it was concluded that the McKenzie protocol alone, or in combination with static or dynamic back extensor muscles endurance exercise, was effective in the rehabilitation of back extensor muscles endurance and fatiguability in patients with long-term LBP. However, the addition of static endurance exercise to the McKenzie protocol led to significantly higher positive effect.

References

[1] T. Sihvonen, J. Partanen, O. Hanninen, and S. Soimakallio, "Electric behavior of low back muscles during lumbar pelvic rhythm in low back pain patients and healthy controls," *Archives of Physical Medicine and Rehabilitation*, vol. 72, no. 13, pp. 1080–1087, 1991.

[2] J. E. Cassisi, M. E. Robinson, P. O'Conner, and M. MacMillan, "Trunk strength and lumbar paraspinal muscle activity during isometric exercise in chronic low-back pain patients and controls," *Spine*, vol. 18, no. 2, pp. 245–251, 1993.

[3] T. Sihvonen, M. Huttunen, M. Makkonen, and O. Airaksinen, "Functional changes in back muscle activity correlate with pain intensity and prediction of low back pain during pregnancy," *Archives of Physical Medicine and Rehabilitation*, vol. 79, no. 10, pp. 1210–1212, 1998.

[4] C. Richardson, G. Jull, P. Hodges, and J. Hides, *Therapeutic Exercise for Spinal Segmental Stabilization in Low Back Pain*, Churchill Livingstone, London, UK, 1999.

[5] J. T. Cottingham and J. Maitland, "A three-paradigm treatment model using soft tissue mobilization and guided movement-awareness techniques for a patient with chronic low back pain: a case study," *Journal of Orthopaedic and Sports Physical Therapy*, vol. 26, no. 3, pp. 155–167, 1997.

[6] J. Hildebrandt, M. Pfingsten, P. Saur, and J. Jansen, "Prediction of success from a multidisciplinary treatment programme for chronic low-back pain," *Spine*, vol. 22, no. 1, pp. 990–1001, 1997.

[7] H. Frost, S. E. Lamb, and C. H. Shackleton, "A functional restoration programme for chronic low back pain," *Physiotherapy*, vol. 86, no. 6, pp. 285–293, 2000.

[8] Clinical Standards Advisory Group CSAG, *Report on Back Pain*, HMSO, London, UK, 1994.

[9] J. Rainville, J. Sobel, C. Hartigan, G. Monlux, and J. Bean, "Decreasing disability in chronic back pain through aggressive spine rehabilitation," *Journal of Rehabilitation Research and Development*, vol. 34, no. 4, pp. 383–393, 1997.

[10] D. M. Carpenter and B. W. Nelson, "Low back strengthening for the prevention and treatment of low back pain," *Medicine and Science in Sports and Exercise*, vol. 31, no. 1, pp. 18–24, 1999.

[11] C. Demoulin, M. Vanderthommen, C. Duysens, and J.-M. Crielaard, "Spinal muscle evaluation using the Sorensen test: a critical appraisal of the literature," *Joint Bone Spine*, vol. 73, no. 1, pp. 43–50, 2006.

[12] D. C. Cherkin, R. A. Deyo, M. Battié, J. Street, and W. Barlow, "A comparison of physical therapy, chiropractic manipulation, and provision of an educational booklet for the treatment of patients with low back pain," *The New England Journal of Medicine*, vol. 339, no. 15, pp. 1021–1029, 1998.

[13] R. McKenzie and S. May, *The Lumbar Spine. Mechanical Diagnosis & Therapy*, vol. 1, Spinal Publications, Waikanae, New Zealand, 2nd edition, 2003.

[14] L. A. Carneiro Machado, M. V. S. De Souza, P. H. Ferreira, and M. L. Ferreira, "The McKenzie method for low back pain: a systematic review of the literature with a meta-analysis approach," *Spine*, vol. 31, no. 9, pp. E254–E262, 2006.

[15] O. Ayanniyi, O. T. Lasisi, B. O. A. Adegoke, and M. O. Oni-Orisan, "Management of low back pain: attitudes and treatment preferences of physiotherapists in Nigeria," *African Journal of Biomedical Research*, vol. 101, pp. 41–49, 2007.

[16] R. Donelson, G. Silva, and K. Murphy, "Centralization phenomenon. It usefulness in evaluating and treating referred pain," *Spine*, vol. 15, no. 3, pp. 211–213, 1990.

[17] M. R. Bookhout, "Biomechanical assessment of low back pain," *Journal of Back Back Musculoskeletal Rehabilitation*, vol. 1, pp. 33–45, 1991.

[18] M. R. Underwood, "Patients' beliefs as to the cause of their low back pain," *Journal of Back and Musculoskeletal Rehabilitation*, vol. 9, no. 1, pp. 65–67, 1997.

[19] I. Fiebert and C. D. Keller, "Are "passive" extension exercises really passive?" *Journal of Orthopaedic and Sports Physical Therapy*, vol. 19, no. 2, pp. 111–116, 1994.

[20] F. Biering-Sorensen, "Physical measurements as risk indicators for low-back trouble over a one-year period," *Spine*, vol. 9, no. 2, pp. 106–119, 1984.

[21] S. V. Risch, N. K. Norvell, M. L. Pollock et al., "Lumbar strengthening in chronic low back pain patients: physiologic and psychological benefits," *Spine*, vol. 18, no. 2, pp. 232–238, 1993.

[22] S. Luoto, M. Heliövaara, H. Hurri, and H. Alaranta, "Static back endurance and the risk of low-back pain," *Clinical Biomechanics*, vol. 10, no. 6, pp. 323–324, 1995.

[23] J. Mayer, V. Mooney, and S. Dagenais, "Evidence-informed management of chronic low back pain with lumbar extensor strengthening exercises," *Spine Journal*, vol. 8, no. 1, pp. 96–113, 2008.

[24] P. Plum and J. F. Rehfeld, "Muscular training for acute and chronic back pain," *The Lancet*, vol. 1, no. 8426, pp. 453–454, 1985.

[25] M. T. Moffroid, L. D. Haugh, A. J. Haig, S. M. Henry, and M. H. Pope, "Endurance training of trunk extensor muscles," *Physical Therapy*, vol. 73, no. 1, pp. 10–17, 1993.

[26] S. M. LeFort and T. E. Hannah, "Return to work following an aquafitness and muscle strengthening program for the low back injured," *Archives of Physical Medicine and Rehabilitation*, vol. 75, no. 11, pp. 1247–1255, 1994.

[27] B. Chok, R. Lee, J. Latimer, and S. B. Tan, "Endurance training of the trunk extensor muscles in people with subacute low back pain," *Physical Therapy*, vol. 79, no. 11, pp. 1032–1042, 1999.

[28] B. Holmes, S. Leggett, V. Mooney, J. Nichols, S. Negri, and A. Hoeyberghs, "Comparison of female geriatric lumbar-extension strength: asymptotic versus chronic low back pain patients and their response to active rehabilitation," *Journal of Spinal Disorders*, vol. 9, no. 1, pp. 17–22, 1996.

[29] B. W. Nelson, D. M. Carpenter, T. E. Dreisinger, M. Mitchell, C. E. Kelly, and J. A. Wegner, "Can spinal surgery be prevented by aggressive strengthening exercises? A prospective study of cervical and lumbar patients," *Archives of Physical Medicine and Rehabilitation*, vol. 80, no. 1, pp. 20–25, 1999.

[30] M. L. Pollock, S. H. Leggett, J. E. Graves, A. Jones, M. Fulton, and J. Cirulli, "Effect of resistance training on lumbar extension strength," *American Journal of Sports Medicine*, vol. 17, no. 5, pp. 624–629, 1989.

[31] B. E. Udermann, J. M. Mayer, J. E. Graves, and S. R. Murray, "Quantitative assessment of lumbar paraspinal muscle endurance," *Journal of Athletic Training*, vol. 38, no. 3, pp. 259–262, 2003.

[32] D. A. Thompson, *Sensitivity of paraspinal EMG spectral analysis to training. Two preliminary studies [Doctoral thesis]*, Queens University, Kingston, Canada, 1992.

[33] J. P. Leigh and R. M. Sheetz, "Prevalence of back pain among fulltime United States workers," *British Journal of Industrial Medicine*, vol. 46, no. 9, pp. 651–657, 1989.

[34] C. N. Burnett, T. M. Glenn, C. Kisner, and L. A. Colby, "Principles of aerobic exercise," in *Therapeutic Exercise: Foundations and Techniques*, pp. 111–142, Jaypee Brothers, New Delhi, India, 3rd edition, 1996.

[35] R. A. McKenzie, *The Lumbar Spine: Mechanical Diagnosis and Therapy Spinal Publication*, Spinal Publication, Waikanae, New Zealand, 1981.

[36] V. Mora, "Chronic mechanical back pain strategies for intervention when conservative treatment fails," *Journal of the American Academy of Physician Assistants*, vol. 17, no. 7, pp. 12–16, 2004.

[37] G. Waddell, "Low back pain: a twentieth century health care enigma," *Spine*, vol. 21, no. 24, pp. 2820–2825, 1996.

[38] G. A. V. Borg, "Psychophysical bases of perceived exertion," *Medicine and Science in Sports and Exercise*, vol. 14, no. 5, pp. 377–381, 1982.

[39] H. Alaranta, "Strength and endurance testing," in *The Clinical Application of Outcomes Assessment*, S. G. Yeomans, Ed., pp. 158–162, Appleton & Lange, Stamford, Calif, USA, 2000.

[40] C. E. Mbada, O. Ayanniyi, and S. O. Ogunlade, "Effect of static and dynamic back extensor muscles endurance exercise on pain intensity, activity limitation and participation restriction in patients with Long-Term Mechanical Low-Back Pain," *Rehabilitacja Medyczna*, vol. 15, no. 3, pp. 11–20, 2011.

[41] J. D. Childs, J. M. Fritz, T. W. Flynn et al., "A clinical prediction rule to identify patients with low back pain most likely to benefit from spinal manipulation: a validation study," *Annals of Internal Medicine*, vol. 141, no. 12, pp. 1032–1042, 2004.

[42] E. M. Hagen, E. Svensen, and H. R. Eriksen, "Predictors and modifiers of treatment effect influencing sick leave in subacute low back pain patients," *Spine*, vol. 30, no. 24, pp. 2717–2723, 2005.

[43] M. R. Underwood, V. Morton, and A. Farrin, "Do baseline characteristics predict response to treatment for low back pain? Secondary analysis of the UK BEAM dataset [ISRCTN32683578]," *Rheumatology*, vol. 46, no. 8, pp. 1297–1302, 2007.

[44] R. Stankovic and O. Johnell, "Conservative treatment of acute low-back pain. A prospective randomized trial: McKenzie

method of treatment versus patient education in "mini back school"," *Spine*, vol. 15, no. 2, pp. 120–123, 1990.

[45] T. Reddeck, "An evaluation of the McKenzie regimen-validity of the disc model," in *Proceedings of the 10th Biennial Conference of Manipulative Physiotherapists Association of Australia*, Melbourne, Autralia, November 1997.

[46] University of Iowa UoI, "Biological Link Between Pain and Fatigue Discovered," 2008, http://www.sciencedaily.com/.

[47] R. B. Armstrong, "Mechanism of exercise-induced delayed onset muscular soreness: a brief review," *Medicine and Science in Sports and Exercise*, vol. 16, no. 6, pp. 529–538, 1984.

[48] S. H. Roy and L. I. E. Oddsson, "Classification of paraspinal muscle impairments by surface electromyography," *Physical Therapy*, vol. 78, no. 8, pp. 838–851, 1998.

[49] C. Manniche, L. Bentzen, G. Hesselsoe, I. Christensen, and E. Lundberg, "Clinical trial for intensive muscle training for chronic low back pain," *The Lancet*, vol. 2, no. 8626-8627, pp. 1473–1476, 1988.

[50] I. Lindström, C. Ohlund, C. Eek, L. Wallin, L.-E. Peterson, and A. Nachemson, "Mobility, strength, and fitness after a graded activity program for patients with subacute low back pain: a randomized prospective clinical study with a behavioral therapy approach," *Spine*, vol. 17, no. 6, pp. 641–652, 1992.

[51] B. Gundewall, M. Liljeqvist, and T. Hansson, "Primary prevention of back symptoms and absence from work: a prospective randomized study among hospital employees," *Spine*, vol. 18, no. 5, pp. 587–594, 1993.

[52] M. T. Moffroid, "Endurance of trunk muscles in persons with chronic low back pain: assessment, performance, training," *Journal of Rehabilitation Research and Development*, vol. 34, no. 4, pp. 440–447, 1997.

[53] M. Kjær, "Role of extracellular matrix in adaptation of tendon and skeletal muscle to mechanical loading," *Physiological Reviews*, vol. 84, no. 2, pp. 649–698, 2004.

[54] D. J. Pearsall and J. G. Reid, "Line of gravity relative to upright vertebral posture," *Clinical Biomechanics*, vol. 7, no. 2, pp. 80–86, 1992.

[55] P. B. O'Sullivan, K. M. Grahamslaw, M. Kendell, S. C. Lapenskie, N. E. Möller, and K. V. Richards, "The effect of different standing and sitting postures on trunk muscle activity in a pain-free population," *Spine*, vol. 27, no. 11, pp. 1238–1244, 2002.

[56] S. M. McGill, R. L. Hughson, and K. Parks, "Changes in lumbar lordosis modify the role of the extensor muscles," *Clinical Biomechanics*, vol. 15, no. 10, pp. 777–780, 2000.

[57] T. M. Cook, S. Mann, and G. E. Lovested, "Dynamic comparison of the two-hand stoop and assisted one-hand lift methods," *Journal of Safety Research*, vol. 21, no. 2, pp. 53–59, 1990.

[58] S. M. McGill, "Electromyographic activity of the abdominal and low back musculature during the generation of isometric and dynamic axial trunk torque: implications for lumbar mechanics," *Journal of Orthopaedic Research*, vol. 9, no. 1, pp. 91–103, 1991.

[59] R. S. Delitto and S. J. Rose, "An electromyographic analysis of two techniques for squat lifting and lowering," *Physical Therapy*, vol. 72, no. 6, pp. 438–448, 1992.

[60] J. L. Kelsey, P. B. Githens, and T. O'Conner, "Acute prolapsed lumbar intervertebral disc. An epidemiologic study with special reference to driving automobiles and cigarette smoking," *Spine*, vol. 9, no. 6, pp. 608–613, 1984.

[61] M. A. Adams and W. C. Hutton, "The effect of posture on the role of the apophysial joints in resisting intervertebral compressive forces," *Journal of Bone and Joint Surgery. British*, vol. 62, no. 3, pp. 358–362, 1980.

[62] M. A. Adams, D. W. McMillan, T. P. Green, and P. Dolan, "Sustained loading generates stress concentrations in lumbar intervertebral discs," *Spine*, vol. 21, no. 4, pp. 434–438, 1996.

[63] M. Kankaanpää, S. Taimela, C. L. Webber Jr., O. Airaksinen, and O. Hänninen, "Lumbar paraspinal muscle fatigability in repetitive isoinertial loading: EMG spectral indices, Borg scale and endurance time," *European Journal of Applied Physiology and Occupational Physiology*, vol. 76, no. 3, pp. 236–242, 1997.

[64] C. Krogh-Lund and K. Jorgensen, "Modification of myo-electric power spectrum in fatigue from 15% maximal voluntary contraction of human elbow flexor muscles, to limit of endurance: reflection of conduction velocity variation and/or centrally mediated mechanisms?" *European Journal of Applied Physiology and Occupational Physiology*, vol. 64, no. 4, pp. 359–370, 1992.

[65] A. G. Crenshaw, S. Karlsson, B. Gerdle, and J. Friden, "Differential responses in intramuscular pressure and EMG fatigue indicators during low- vs. high-level isometric contractions to fatigue," *Acta Physiologica Scandinavica*, vol. 160, no. 4, pp. 353–361, 1997.

[66] C. Manniche, E. Lundberg, I. Christensen, L. Bentzen, and G. Hesselsøe, "Intensive dynamic back exercises for chronic low back pain: a clinical trial," *Pain*, vol. 47, no. 1, pp. 53–63, 1991.

[67] H. W. Lee, "Progressive muscle synergy and synchronization in movement patterns: an approach to the treatment of dynamic lumbar instability," *Journal of Manual and Manipulative Therapy*, vol. 2, pp. 133–142, 1994.

[68] D. S. Elia, R. W. Bohannon, D. Cameron, and R. C. Albro, "Dynamic pelvic stabilization during hip flexion: a comparison study," *Journal of Orthopaedic and Sports Physical Therapy*, vol. 24, no. 1, pp. 30–36, 1996.

[69] H. Bentsen, F. Lindgärde, and R. Manthorpe, "The effect of dynamic strength back exercise and/or a home training program in 57-year-old women with chronic law back pain. Results of a prospective randomized study with a 3-year follow-up period," *Spine*, vol. 22, no. 13, pp. 1494–1500, 1997.

[70] F. Johannsen, L. Remvig, P. Kryger et al., "Exercises for chronic low back pain: a clinical trial," *Journal of Orthopaedic and Sports Physical Therapy*, vol. 22, no. 2, pp. 52–59, 1995.

[71] J. P. A. Arokoski, M. Kankaanpää, T. Valta et al., "Back and hip extensor muscle function during therapeutic exercises," *Archives of Physical Medicine and Rehabilitation*, vol. 80, no. 7, pp. 842–850, 1999.

[72] S. M. McGill, A. Childs, and C. Liebenson, "Endurance times for low back stabilization exercises: clinical targets for testing and training from a normal database," *Archives of Physical Medicine and Rehabilitation*, vol. 80, no. 8, pp. 941–944, 1999.

[73] E. Zinzen, D. Caboor, M. Verlinden et al., "Will the use of different prevalence rates influence the development of a primary prevention programme for low-back problems?" *Ergonomics*, vol. 43, no. 10, pp. 1789–1803, 2000.

[74] W. S. Marras, K. G. Davis, and K. P. Granata, "Trunk muscle activities during asymmetric twisting motions," *Journal of Electromyography and Kinesiology*, vol. 8, no. 4, pp. 247–256, 1998.

[75] R. E. Seroussi and M. H. Pope, "The relationship between trunk muscle electromyography and lifting moments in the sagittal and frontal planes," *Journal of Biomechanics*, vol. 20, no. 2, pp. 135–146, 1987.

[76] C. Pinupong, *Effects of isometric and dynamic endurance training on fatigability of back extensor muscle in male [Ph.D. thesis]*,

2005, submitted in a partial fulfilment of the requirements for the degree of master of science physiotherapy of the faculty of graduate studies Mahidol university.

[77] J. Cholewicki and S. M. McGill, "Mechanical stability of the in vivo lumbar spine: implications for injury and chronic low back pain," *Clinical Biomechanics*, vol. 11, no. 1, pp. 1–15, 1996.

[78] P. B. O'Sullivan, L. Twomey, and C. T. Allison, "Dysfunction of the neuro-muscular system in the presence of low back pain-implications for physical therapy management," *Journal of Manual and Manipulative Therapy*, vol. 5, no. 1, pp. 20–26, 1997.

[79] D. J. Ponte, G. J. Jensen, and B. E. Kent, "A preliminary report on the use of the McKenzie protocol versus Williams protocol in the treatment of low back pain," *Journal of Orthopaedic and Sports Physical Therapy*, vol. 6, no. 2, pp. 130–139, 1984.

[80] J. R. Kopp, A. H. Alexander, and R. H. Turocy, "The use of lumbar extension in the evaluation and treatment of patients with acute herniated nucleus pulposus. A preliminary report," *Clinical Orthopaedics and Related Research*, vol. 202, pp. 211–218, 1986.

[81] A. H. Alexander, A. M. Jones, and D. H. Rosenbaum Jr., "Nonoperative management of herniated nucleus pulposus: patient selection by the extension sign: long-term follow-up," *Orthopaedic Review*, vol. 21, no. 2, pp. 181–188, 1992.

[82] G. Nwuga and V. C. B. Nwuga, "Relative therapeutic efficacy of the Williams and McKenzie protocols in back pain management," *Physiotherapy Practice*, vol. 1, no. 2, pp. 99–105, 1985.

[83] H. Frost, J. A. Klaber Moffett, J. S. Moser, and J. C. T. Fairbank, "Randomised controlled trial for evaluation of fitness programme for patients with chronic low back pain," *British Medical Journal*, vol. 310, no. 6973, pp. 151–154, 1995.

[84] M. Kankaanpää, S. Taimela, O. Airaksinen, and O. Hänninen, "The efficacy of active rehabilitation in chronic low back pain: effect on pain intensity, self-experienced disability, and lumbar fatigability," *Spine*, vol. 24, no. 10, pp. 1034–1042, 1999.

[85] J. Rainville, C. A. Jouve, C. Hartigan, E. Martinez, and M. Hipona, "Comparison of short- and long-term outcomes for aggressive spine rehabilitation delivered two versus three times per week," *Spine Journal*, vol. 2, no. 6, pp. 402–407, 2002.

[86] J. Rainville, C. Hartigan, E. Martinez, J. Limke, C. Jouve, and M. Finno, "Exercise as a treatment for chronic low back pain," *Spine Journal*, vol. 4, no. 1, pp. 106–115, 2004.

[87] D. K. Ahern, D. J. Hannon, A. J. Goreczny, M. J. Follick, and J. R. Parziale, "Correlation of chronic low-back pain behavior and muscle function examination of the flexion-relaxation response," *Spine*, vol. 15, no. 2, pp. 92–95, 1990.

[88] J. Rainville, D. K. Ahern, and L. Phalen, "Altering beliefs about pain and impairment in a functionally oriented treatment program for chronic low back pain," *Clinical Journal of Pain*, vol. 9, no. 3, pp. 196–201, 1993.

[89] A. Rissanen, H. Kalimo, H. Alaranta, and R. G. Hazard, "Effect of intensive training on the isokinetic strength and structure of lumbar muscles in patients with chronic low back pain," *Spine*, vol. 20, no. 3, pp. 333–340, 1995.

[90] B. O. A. Adegoke and F. O. Babatunde, "Effect of an exercise protocol on the endurance of trunk extensor muscles—a randomized control trial," *Hong Kong Physiotherapy Journal*, vol. 25, pp. 2–9, 2007.

[91] A. F. Mannion, S. Taimela, M. Müntener, and J. Dvorak, "Active therapy for chronic low back pain part 1. Effects on back muscle activation, fatigability, and strength," *Spine*, vol. 26, no. 8, pp. 897–908, 2001.

[92] T. Petersen, P. Kryger, C. Ekdahl, S. Olsen, and S. Jacobsen, "The effect of McKenzie therapy as compared with that of intensive strengthening training for the treatment of patients with subacute or chronic low back pain: a randomized controlled trial," *Spine*, vol. 27, no. 16, pp. 1702–1708, 2002.

[93] B. E. Udermann, J. M. Mayer, R. G. Donelson, J. E. Graves, and S. R. Murray, "Combining lumbar extension training with McKenzie therapy: effects on pain; disability; and psychosocial functioning in chronic low back pain patients," *Gundersen Lutheran Medical Journal*, vol. 32, pp. 7–12, 2004.

[94] W. D. McArdle, F. I. Katch, and V. L. Katch, *Exercise Physiology*, Williams & Wilkins, Baltimore, Md, USA, 4th edition, 1996.