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Evaluation of hip muscles using torque- and power-velocity relationships in chronic low back pain subjects

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Abstract

The aim of the present study was to evaluate hip muscles in chronic low back pain (CLBP) patients, thanks to the torque- and power-velocity relationships and to determine whether a possible imbalance can be related to the trunk muscles. Twelve CLBP patients and fifteen healthy subjects (Control Group, CG) participated to the study. CLBP and CG performed isokinetic trunk and hip flexions and extensions at several velocities. Mechanical parameters, such as theoretical maximal isometric torque (T_0) and maximal power (P_{max}) were extrapolated from torque- and power-velocity relationships. T_0 and P_{max} were significantly higher in CG than CLBP ($p < 0.05$), whatever the considered movement, showing a muscle weakness in CLBP. A significant difference was obtained between the two lower limbs for CLBP when considering P_{max} during hip extension. Although no relationship was clearly observed between hip weakness and trunk weakness for CLBP, results obtained for CLBP could be attributed to a deconditioning syndrome and to muscle inhibition typically observed in these subjects. This study showed the importance to take hip muscle rehabilitation into account in CLBP support.

Keywords: hip ; trunk ; low back pain, isokinetic ; torque- and power-velocity relationships

1 Introduction

Chronic low back pain (CLBP) is characterized by a strength imbalance between trunk flexor and extensor muscles (Ripamonti et al. (1); Poireau et al. (2); Mayer et al. (3)). This imbalance is responsible for significant functional impairment (Poireau et al. (4); Genty et al. (5); Vanvalcenaher et al. (6); Nachemson and Lindh, (7)) which should be treated with a complex rehabilitation program (Poireau et al. (8)). Trunk rehabilitation is essential for CLBP subjects (Ripamonti et al. (1); Mayer et al. (3)). Nevertheless, other muscles should be considered. In a previous study, Scholtes et al. (9) observed relationships between lower limb and pelvis movement in CLBP. Indeed, people with low back pain who play rotation-related sports are able to move their lumbopelvic region with a greater extent and earlier during lower limb movements than people without low back pain. Recently, focusing our attention on the leg extensor muscles, we observed higher torque (19.2%) and power (19.8%) productions in healthy subjects compared with CLBP patients (Lemaire et al. (10)). Even if no relationship

was revealed between the weakness of the leg extensor muscles and the trunk imbalance in CLBP patients, it can't be denied that these two statements are probably linked, and can be explained by a CLBP inactivity, a fear relative to daily activity movements, and finally to the CLBP deconditioning syndrome.

These previous studies suggest that lower limb and pelvis muscles must be considered in the management of CLBP rehabilitation. Some previous studies focused on lower limbs in CLBP (Lemaire et al. (10); Yahia et al. (11); Scholtes et al. (9)). However, to the authors' knowledge, no study focused on hip muscles assessments, which are anatomically directly linked to the trunk muscles. Indeed, several hip flexor and extensor muscles have their proximal insertions on the trunk (Vitte et al. (12)). Deconditioning syndrome that occurs on trunk muscles and its consequences on muscle properties (Poiraudeau et al. (13)) would also have an impact on hip muscles. This impact could probably also be linked to low back pain, since these muscles have an important postural and dynamic role especially at the lumbar spine (Marieb (14)).

The aim of the present study was then *i)* to evaluate hip flexor and extensor muscles torque production capacity using torque- and power-velocity relationships in both CLBP and healthy subjects, and *ii)* to determine whether a possible imbalance between the two sides in CLBP hip muscle strength can be related to the trunk muscles.

2 Methods

2.1. Subjects

Twenty-seven subjects signed an informed consent to participate in this study. A control group (CG) was composed of fifteen healthy males with no prior history of low back pain. Healthy subjects were recruited in the rehabilitation centre or from a call for volunteers, and should respect the anthropometric characteristics (40.5 ± 5.0 years, 1.8 ± 0.6 m, 72.4 ± 8.7 kg) of the low back pain patients to allow group's comparison. To also avoid any bias in the study, subjects of control group were not involved in any physical training.

Chronic Low Back Pain (CLBP) group was composed of twelve subjects (42.4 ± 7.4 years, 1.7 ± 4.5 m, 91.8 ± 29.6 kg) involved in a five weeks multidisciplinary rehabilitation program. This program was proposed by The Centre de l'Arche (Le Mans, France), following the Lombaction's protocol from Angers (France) hospital. All the CLBP patients were recruited by the head clinician in charge of CLBP program of the rehabilitation center following the low back pain definition proposed by the French Society of Rheumatology (*i.e.*, back pain for at least 3 months) (Bernard and Dusquenoy (15)). For the present study, inclusion criteria for the CLBG patients were presence of chronic pain defined as a daily or almost daily pain for at least six months and a lumbar or lumbosacral pain before the start of the treatment. Selected patients had reported lower back pain for at least five years and had not been free of pain for a year. None of the subjects had any hip or lower limb injury or surgery, and no other associated

pathology (*e.g.*, multiple sclerosis, Guillain-Barre, muscular dystrophy, pelvic inflammatory disease). They were able to exert a maximal effort on isokinetic device. The rehabilitation program proposed at the Centre de l'Arche does not take into account current daily pain as an exclusion criterion. For the present study, exclusion criterion was a history of spine surgery. Testing was carried out in accordance with the ethical standards laid down in the 1964 Helsinki Declaration. Since the two groups presented a significant difference in weight values, results were normalized relatively to the subjects' body weight in order to allow comparison between groups.

2.2. Protocol

The protocol of the present study was carried out during three different sessions on three following different days. Both groups performed the same protocol. Trunk flexions and extensions were tested on day 1 and 2 respectively, as recommended by Ripamonti et al. (16). Assessment of hip flexions and extensions was performed on the third day. Each measurement was done within a week following the admission of the CLBP patients in the CLBP program. To limit errors due to faulty equipment and inherent wrong measurement, all the measurements were realized by the same highly qualified investigator.

2.2.2. Trunk flexion and extension measurements

Trunk flexions and extensions were both conducted on a Biodex[®] isokinetic dynamometer (Model 900-240, Biodex Corporation, Shirley, NY, USA). Subjects were seated on a chair, with the dynamometer aligned bilaterally with the anterior superior iliac crests at the mid-axillary line of the trunk. The upper body was then strapped to the back of the chair equipped with three fixable pads at the head, the dorsal region and the bottom of the back. Legs were also strapped and positioned on the footrest with a maximal knee angle of 15 degrees to minimize leg involvement in trunk movements (Smith et al. (17)). Subjects were asked to hold the trunk strap with their hands, without contracting the upper limbs. Upper limb muscles activity was not controlled by any device but one experimenter made sure that subjects did not use their upper limbs as an extra help to produce force. If any arm movement was observed, the trial was not recorded and was repeated after a rest period of at least 4 minutes. Once the subject position was properly established, mechanical stops were positioned to allow a range of motion of 60 degrees (from 90 to 30 degrees relatively to the horizontal axis). This amplitude was selected to prevent subjects working in non-conventional zones. This amplitude was recorded by the

computerized monitor after the Biodex lever arm had been placed in front of the 90 and 30 degrees graduations around the rotation axis.

Trunk extensors and flexors were assessed on two different days. On the first day, flexor muscles were evaluated, whereas the extensor muscles were assessed at the same time on the following day. After a period of standardized warm-up (10 minutes warm-up on a cycle ergometer (50 watts at 50 to 60 rpm) each subject performed submaximal trunk flexions and extensions before the testing session. During the test, subjects performed five contractions (Baltzopoulos and Brodie, (18)) at 120, 105 and 90 deg.s⁻¹ and three at 75, 60 and 45 deg.s⁻¹. Only the concentric part of the movement was considered. At a given preset velocity, subjects were asked to perform the concentric contraction as rapidly and forcefully as possible, and to return to their initial position without any effort during the eccentric phase (isokinetic velocity was then fixed at 300 deg.s⁻¹). A one-second break was set between two consecutive contractions to avoid any possible influence of the eccentric part of the movement. A 4 minutes rest period was observed between two preset-velocity trials. Verbal encouragements were given to the participants during all trials.

2.2.1 Hip flexion and extension measurements

Hip flexions and extensions were conducted using a calibrated Biodex System 4 dynamometer (Biodex Medical Systems, Inc., Shirley, NY). The motor axis was aligned with the major trochanter of the femur. Subjects were lying on their back on the dynamometer with an angle of 15 degrees at the hip joints to prevent lordosis. Subjects were fastened with belts at the chest, pelvis and thigh to minimize the contribution of the body parts that were not supposed to be involved in the movement. Subjects had to keep their hands crossed on the chest. The thigh of the tested hip was attached to the level arm of the Biodex (Fig. 1). The tested hip was attached to the lever arm of the dynamometer. If any compensation with the back was observed, the trial was not recorded and was repeated after a rest period of at least 4 minutes. The range of motion during hip flexions and extensions evaluation was fixed at 75 degrees, with a starting position corresponding to the leg extended at an angle of 15 degrees relatively to the hip joint (0 degree corresponding to a complete hip extension). The final position of the leg was defined for an angle of 90 degrees at the hip joint.

After a standardized warm up (*i.e.*, the same as the one done before the trunk assessment), subjects were asked to perform three submaximal trials at each preset velocity (*i.e.*, 180, 150, 90, 60 and 45 deg.s⁻¹) during a familiarization session preceding the criterion test. During the testing session, subjects performed four maximal contractions at the five preset velocities.

Velocity order was randomized to avoid any fatigue or velocity effect. Hip side evaluation (*i.e.*, left or right) was also randomized. At each velocity, subjects were asked to perform maximal concentric flexions and extensions as rapidly and forcefully as possible. A 1-s break was set between two consecutive contractions to avoid any possible influence of the stretch-shortening cycle.



Figure 1: Initial subject's positions during hip flexion (left picture) and extension (right picture) contractions.

2.3. Mechanical parameters determination

To avoid any underestimation of torque (Parker et al. (19); Kellis et al. (20); Delitto (21)) and to ensure data reliability, inertia of the lower limb and of the isokinetic lever arm was measured ahead of testing. This calibration was conducted with the participant lying on the back with a hip angle of 70 degrees (90 degrees corresponding to a complete hip extension), straight leg for hip measurements. Inertia of the trunk was also calculated with the subject seated in the starting position for the trunk flexions. In both conditions, subjects were asked to be completely relaxed. Gravitational errors of the tested body segment and dynamometer input arm were estimated by measuring the dynamometer moment in these specific positions. Data were then recorded and automatically stored on a PC (sampling at 100 Hz) via an electronic interface card (Biodex Medical Systems Inc. X2151, Shirley, NY, USA).

2.4. Torque- and power-velocity relationships

For each preset velocity, and whatever the considered movement and limb, peak torque (T_{peak}) was identified as the highest value attained during the period of constant velocity, which was determined from the raw data. Instantaneous peak power (P_{peak}) was then calculated as the product of T_{peak} and the corresponding preset velocity.

Linear torque-velocity relationships were then determined using T_{peak} measured at each preset velocity, for both lower limbs and trunk evaluations. Therefore, T_{peak} was expressed as $T_{\text{peak}} = aV + b$, where V was the preset velocity and a and b the linear regression coefficients. From

those relationships, the theoretical maximal isometric torque (T_0) was extrapolated as the intercept with the torque axis (null velocity) and hence equal to the coefficient b . The maximal velocity was also extrapolated from this relationship and corresponds to the intercept with the velocity axis (null torque). This parameter is not detailed in this article as we consider more interesting to focus our attention on torque and power only. Power-velocity relationships were defined from second order polynomial relationships, and were determined using P_{peak} values measured at each preset velocity. The maximal power (P_{max}), corresponding to the apex of the power-velocity relationship, was extrapolated from the second order polynomial equation and were expressed as: $P_{\text{peak}} = cV^2 + dV + e$, where c , d and e were the second order polynomial regression coefficients. Throughout this paper, the indices “f” and “e” are used to identify flexion and extension results, respectively.

2.2.5. Statistical analysis

Data are presented as their mean \pm Standard Deviation). Skewness and Kurtosis analysis were used to verify the normality of the distribution and the homogeneity of variance in the data sets. Torque-velocity and power-velocity relationships were described by linear and polynomial regressions, respectively. Corresponding coefficients of correlation (r^2) and levels of significance (p) were also calculated. A factorial analysis of variance (ANOVA) was used to analyze results obtained for right (R) and left (L) hip side values during flexions and extensions, hip flexor/extensor ratio obtained for both sides, and trunk flexion and extension parameters for each group. A factorial ANOVA was also used to compare results obtained between CG and CLBP for each mechanical parameter. Finally, simple and multiple regressions were also used to identify relationships between hip and trunk mechanical parameters for each group. The significant level was set at $p < 0.05$.

3 Results

3.1. Trunk measurements

Considering all subjects, the torque- and power-velocity relationships exhibited a significant linear shape ($r = 0.63-1$; $p < 0.05$) and a second-order function ($r = 0.86-1$; $p < 0.05$) whatever the considered movement (*i.e.*, flexion and extension), respectively. The torque and power-relationships obtained from mean values for both CG and CLBP groups and for each velocity are presented in Fig. 2 and 3, respectively.

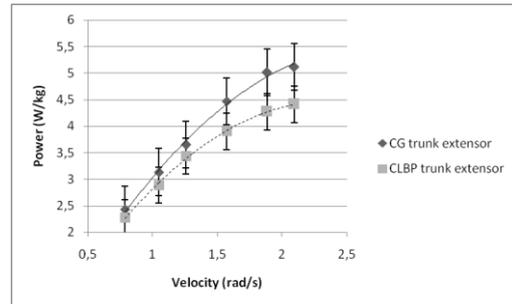
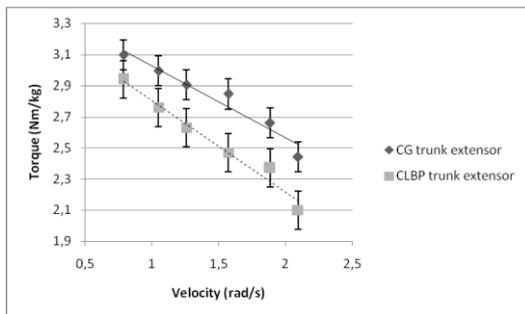
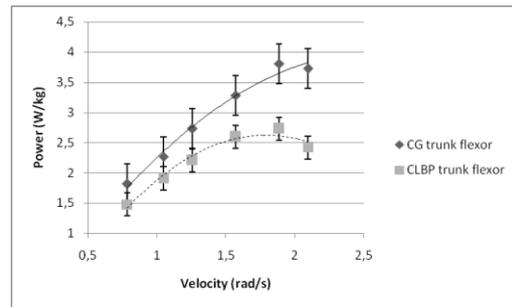
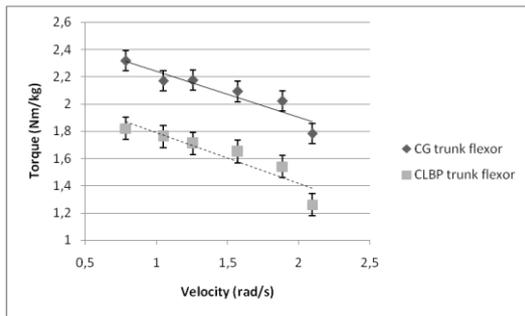


Figure 2: Torque-velocity relationships obtained for control group (CG) and low back pain group (CLBP) for trunk flexion and extension movements.

Figure 3: Power-velocity relationships obtained for control group (CG) and low back pain group (CLBP) for trunk flexion and extension movements.

Values obtained for T_0 in CG during flexion (2.7 ± 0.5 Nm/kg) and extension (3.6 ± 0.6 Nm/kg) were significantly higher ($p < 0.05$) than those obtained in CLBP (2.0 ± 0.6 Nm/kg and 3.0 ± 1.1 Nm/kg for flexion and extension, respectively). In the same way, P_{max} obtained in CG was significantly higher ($p < 0.05$) during both flexion (4.8 ± 1.5 W/kg) and extension (7.1 ± 2.5 W/kg) than P_{max} obtained in CLBP (3.0 ± 1.1 W/kg during flexion and 4.7 ± 1.9 W/kg during extension). Thus, whatever the considered group, $T_{0,e}$ and $P_{max,e}$ were significantly higher than those measured during trunk flexion ($p < 0.05$).

Finally, Flexor/Extensor ratio showed no statistical difference between the two groups (0.77 ± 0.22 vs. 0.70 ± 0.16 for CG and CLBP, respectively), whatever the considered velocity.

3.2 Hip measurements

Values obtained for right and left sides for T_0 and P_{max} during hip flexions and extensions for both groups are presented in Table 1.

Table 1: Mechanical parameters extrapolated from torque- and power-velocity relationships: maximal torque (T_0) and power (P_{max}) for trunk and right (R) and left (L) hip flexions (Flex) and extensions (Ext) in chronic low back pain patients (CLBP) and control group (CG). Values are Mean (SD).

	Hip					
	CG		CLBP			
	Flex	Ext	Flex R	Ext R	Flex L	Ext L
T_0 (Nm.kg ⁻¹)	1.6 (0.4)	2.6 (0.6)	0.9 (0.3)‡	1.4 (0.5)‡	0.9 (0.3)‡	1.3 (0.4)‡
P_{max} (W.kg ⁻¹)	4.5 (1.4)	9.1 (6.5)	2.0 (1.8)‡	2.7 (1.7)‡	1.6 (1.1)‡	1.8* (0.8)‡

* $p < 0.05$, significantly different in a paired group

‡: $p < 0.05$, significant difference between the two groups within the considered movement

The torque- and power-velocity relationships obtained, for both CG and CLBP, are presented in Fig. 4 and 5, respectively. Considering all subjects, the torque-velocity relationships exhibited a significant linear shape whatever the considered movement (flexion: $r = 0.8 - 1$; $p < 0.05$; extension: $r = 0.78 - 1$; $p < 0.05$). The power-velocity relationships were then significantly described by a second-order function during both trunk flexion and extension ($r = 0.95 - 1$; $p < 0.05$ and $r = 0.94 - 1$; $p < 0.05$, respectively).

T_{peak} obtained for each preset velocity (*i.e.*, 45, 60, 90, 150 and 180 $\text{deg}\cdot\text{s}^{-1}$) for CG was significantly higher ($p < 0.001$) than that measured for CLBP for both flexion and extension movements. Consequently, T_0 obtained for CG was significantly higher ($p < 0.05$) than the one measured for CLBP (difference obtained between groups during flexion: 24% for right side and 29% for left side; difference obtained between groups during extension: 42% for right side and 45% for left side). This significant difference was also obtained for P_{max} with higher values obtained for CG compared to CLBP (difference obtained between groups during flexion: 43% for right side and 62% for left side; difference obtained between groups during extension: 82% for dominant side and 74% for left side). Considering all subjects, results obtained for both hip flexion and extension showed no difference between right and left sides except for P_{max} in CLBP during extension.

Hip muscle ratios showed statistical difference between CG and CLBP for right (0.6 ± 0.2 vs. 0.8 ± 0.2 , respectively; $p < 0.05$) and left sides (0.6 ± 0.2 vs. 0.7 ± 0.1 , respectively; $p < 0.05$).

Finally, no relationships between lower limb and trunk strength or power were observed whatever the considered group.

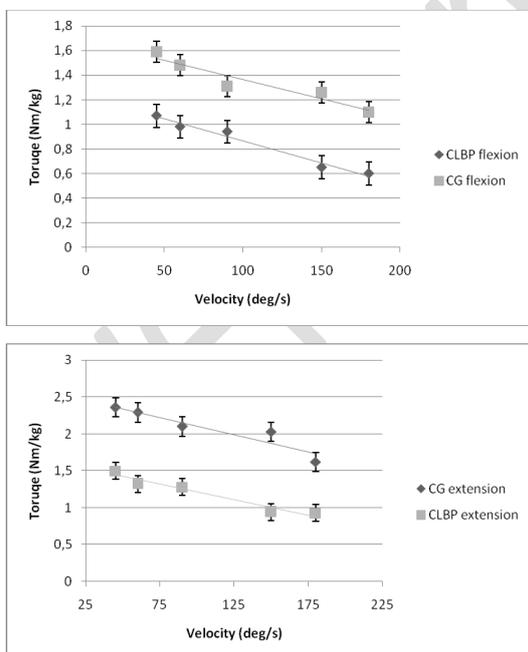


Figure 4: Torque-velocity relationships obtained for control group (CG) and low back pain group (CLBP) during hip flexion and extension movements for the right side.

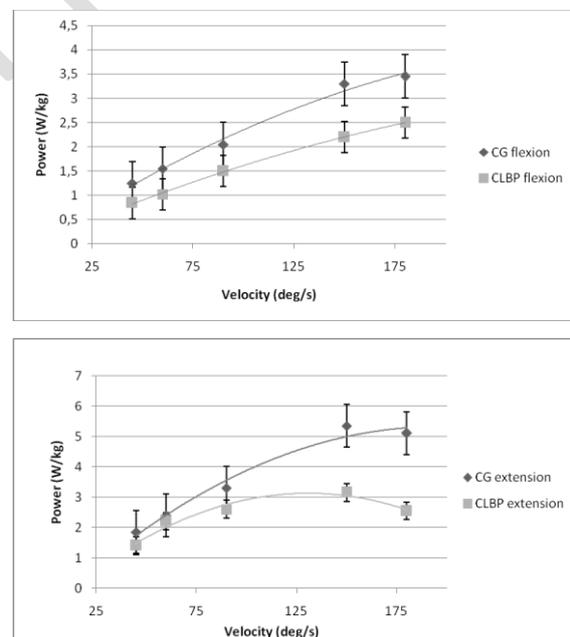


Figure 5: Power-velocity relationships obtained for control group (CG) and low back pain group (CLBP) during hip flexion and extension movement for right side. Results obtained for left side are identical.

4. Discussion

The purpose of the present study was to analyze hip muscle strength of CLBP patients, assuming that hip strength and/or power of CLBP should be lower than those measured in a healthy control group, presenting the same anthropometrical characteristics. It was also hypothesized that this muscle weakness would be linked to trunk strength muscle deficit in CLBP. Comparison between groups (*i.e.*, CG and CLBP) was based on mechanical parameters extrapolated from torque-and power-velocity relationships established during isokinetic hip and trunk flexions and extensions. Results showed that relationships obtained from trunk and hip muscles were in accordance with those previously obtained in several studies focusing on trunk (Ripamonti et al. (16)) or lower limbs (Yamauchi et al. (22); Thorstensson et al. (23); Perrine et Edgerton (24)). Our study showed that low back pain has no influence on torque- and power-velocity relationships for hip muscles.

Regarding trunk movements, results obtained in the present study were in accordance with those reported in previous studies comparing healthy subjects and CLBP. Indeed, strength and power produced by healthy subjects were significantly higher than those obtained from CLBP patients (Yahia et al. (11); Yahia et al. (25); Roques et al. (26); Thorstensson and Arvidson (27)). These significant differences were also observed from torque- and power-velocity relationships analysis. Results showed that *i*) extrapolated T_{0e} was significantly higher than T_{0f} , whatever the considered group, and that *ii*) T_0 and P_{max} obtained for CG were significantly higher than those determined for the CLBP ($p < 0.05$) during both trunk flexion and extension movements with a greater impairment for trunk extensors relatively to trunk flexors. These expected results are in accordance with previous studies (Ripamonti et al. (1); Crossman et al. (28); Elfving et al. (29)), and are explained by the CLBP deconditioning, defined by a loss of function of the trunk muscles (Mayer et al. (3)) with specific deficits of lumbo-pelvic extensors and decreased resistance to fatigue (Vanvelcenaher et al. (6)). Lumbar syndrome probably caused the further loss of lumbar muscle strength and may explain the imbalance of trunk musculature and the inability for CLBP to develop power. Finally, these expected results raise the question of the impact of the low back pain on the entire body, and particularly, on muscles of the lower limbs also connected to the trunk.

In the present study, torque and power measurements of CLBP showed significant lower values than those obtained in CG. This is probably a consequence of the deconditioning syndrome conventionally referred in CLBP (Poiraudeau et al. (13), Poiraudeau et al. (8)) for trunk muscles (Mayer et al. (3); Poiraudeau et al. (13)). Since trunk muscles are obviously not the only ones affected by this deconditioning (Netter, (35)), decline of daily activity in CLBP increased the wasting syndrome that can be found in trunk and in lower limbs (Lemaire et al. (10)), and probably cause the decrease in strength and power at these levels (Ripamonti et al. (1); Lemaire et al. (10); Poiraudeau et al. (13)). In the same way, hip muscle weakness found in this study for CLBP can also be explained by muscle atrophy, which is supported by the lower values obtained for T_0 in CLBP. Thus, physical changes in the back muscle composition (Poiraudeau et al. (2); Revel (36)) such as fatty involutions or muscle fiber atrophy (Bibré et al. (37)), or the alteration of muscle contractile properties found in CLBP for trunk muscles (Mayer et al. (3); Linton et al. (38)) could be extended to hip muscle and explain results obtained for T_0 and P_{max} during hip evaluation.

Since, to the authors' knowledge, hip muscles have never been studied in CLBP patients, it should be noted that results obtained for healthy subjects in both hip flexion and extension, were in accordance with those obtained in previous studies (Costa et al. (30); Julia et al. (32); Dugailly (33); Arokoski et al. (34)), supporting the protocol used in the present study, and its possible application to CLBP patients. Moreover, results obtained for CG showed no difference between right and left sides, whatever the considered mechanical parameter, in agreement with a previous study (Costa et al. (30)), whereas a statistical difference between right and left sides was detected for P_{max} during hip extension measurement in CLBP. The higher values obtained for the right extensor hip muscles probably induce muscular compensation and/or imbalance during daily activities such as walking, and generate abnormal movement and pain. Muscular compensation can also be due to calcaneal spurs and tarsal retinaculum syndrome or gonarthrosis. This can also be deduced from the hip muscle ratios. Indeed, ratios obtained for CLBP are significantly higher (around 0.8) than those obtained for CG (around 0.6, in agreement with previous study (Arokoski et al. (34))). This ratio value indicates, as for trunk muscles, a larger deficit of extensor muscles, sustaining the fact that CLBP are not able to mobilize their entire extensor muscular chain in the same way as healthy subjects. Scholtes et al. (9) showed that healthy subjects were able to demonstrate a greater maximal lumbopelvic motion modification after instructions than CLBP. This could also be linked to kinesiophobia (Linton et al. (38)) which may be responsible for inhibitions and for a decrease in strength and power that can contribute to immerse patients in the spiral of deconditioning (Poireau et al. (2)). It seems important to offer a rehabilitation program including strength and power for hip muscles because strength and power muscle weakness highlight in the present study remain constant after the rehabilitation. Strength training proposed during the multidisciplinary program could, for example, include some hip strength session, to bring some changes in the force reinforcement. This can be done using isokinetic dynamometer, to take care on the subject abilities and security. Another way can be by including bath therapy, since working on water allows relaxation and easier work.

Finally, no relationship was observed between trunk and hip muscles imbalance. This can be due to the subject's position imposed by the isokinetic device during the hip flexion and extension assessments. Indeed, subjects were asked to perform these movements lied on the back. This was probably one limitation of the present study, since these positions are far from these muscles physiological functioning conditions. Moreover, it would be more interesting to investigate the possible link between trunk and hip impairment during everyday life activities, such as walking or lifting tasks. This can be done by studying muscular activity and/or using video analysis to determine whether a segmental and/or muscular strategy can help to differentiate CLBP subjects from healthy ones. This should also allow investigating whether there is an effective physiological modification at hip muscle level, as it is clearly observed in trunk muscles. Nevertheless, results of the present study support the point that a specific attention should be brought on hip muscles during low back pain rehabilitation, as it was previously observed that rehabilitation program based on the complete body muscular program and training improved the well-being of CLBP patients (Poireau et al., 2001; Poireau et al., 2004). Another potential limitation of the current study is that we do not take into account low back pain history. It should be interesting to determine if there is a relationship between

the length of back pain and reduction in strength. Further studies are necessary to study the impact of pain history on reduction in strength.

4 Conclusion

The present study revealed a hip flexor and extensor muscles weakness for CLBP in addition to the classical trunk imbalance. Despite no relationship was observed between trunk and hip muscular imbalance, the present study enlightened new perspectives in the CLBP support. It should be interesting to evaluate hip muscles systematically at the beginning of the rehabilitation so as to propose the most suitable program for patients. It should also be interesting to introduce specific torque and power exercises for these muscles so as to limit trunk muscular compensations induced by muscle weakness at hip level that could occur in low back pain.

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