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Original Research

Ultrasonography comparison of diaphragm thickness and excursion between athletes with and without lumbopelvic pain

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ABSTRACT

Objective: The aim of this study was to compare diaphragm thickness and excursion between athletes with and without lumbopelvic pain (LPP) by trans-costal and trans-hepatic rehabilitative ultrasound imaging (RUSI), respectively.
Design: A case-control study.
Setting: Amateur and semiprofessional athletes teams.
Participants: Forty matched-paired athletes with LPP (n = 20; LPP case group) and without LPP (n = 20; Healthy control group) were recruited.
Main outcome measures: Diaphragm thickness and excursion (cm) were assessed during relaxed respiratory activity (maximum inspiration–T^{ins}, expiration–T^{exp} and difference–$T^{ins\text{-}exp}$) by trans-costal and trans-hepatic rehabilitative ultrasound imaging (RUSI), respectively.
Results: Statistically significant differences ($P < .05$) with an effect size from moderate to large ($d = 0.63$–1.07) were shown for bilateral diaphragm thickness reductions at T^{ins} and thickness difference at T^{ins}-T^{exp} of the right hemi-diaphragm for athletes with LPP compared to healthy athletes.
Conclusions: Athletes who suffered from LPP presented a reduced diaphragm thickness compared to healthy matched-paired athletes. Therefore, these novel findings may suggest that diaphragm reeducation could be a main focus of intervention related to athletic performance, prevention and rehabilitation. Nevertheless, these findings should be considered with caution due to the possible influence of the RUSI measurement errors of the diaphragm activation during normal breathing.

1. Introduction

Lumbopelvic pain (LPP) may be considered as a common compliant in athletes (Fett, Trompeter, & Platen, 2017). Indeed, athletes who suffered from LPP have shown an altered spine stabilization function associated to the loss of trunk deep muscles anticipatory contraction (P. W. Hodges & Richardson, 1996; Panjabi, 2003; Swain, Bradshaw, Whyte, & Ekegren, 2017). Concretely, the term "core" has been widely used in order to refer to a belt-like tension to the trunk provided by the automatic activation of these deep muscles (Kibler, Press, & Sciascia, 2006). Thus, the "core" stability is essential to perform trunk and limb movements in a correct way, especially in athletes (Kibler et al., 2006).

Regarding the deep muscular stabilizers, the transversus abdominis and internal oblique, multifidus, diaphragm and pelvic floor muscles comprised the "core" that provides an adequate

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motor control and stability to the spine of athletes (Huxel Bliven & Anderson, 2013). Several valid and reliable tools were used to evaluate static and dynamic muscular conditions, such as electromyography (EMG), magnetic resonance imaging (MRI) and rehabilitative ultrasound imaging (RUSI), which may be considered as a conservative, non-invasive, non-expensive, valid and reliable tool for measuring the thickness at rest and during contraction of the deep trunk muscles (J. Hides et al., 2006; P. Hodges, Pengel, Herbert, & Gandevia, 2003; Potter, Cairns, & Stokes, 2012; Teyhen, 2007).

Thus, RUSI has been widely applied for the static and dynamic evaluation of the "core" deep trunk muscles in athletes and LPP, such as the abdominal wall muscles (Ferreira, Ferreira, & Hodges, 2004; Gala-Alarcón et al., 2018; Paris-Alemany et al., 2018; Paungmali, Joseph, Sitilertpisan, Pirunsan, & Uthaikhup, 2017; Romero-Morales et al., 2018; Sitilertpisan et al., 2011; Teyhen et al., 2007; Whittaker, Warner, & Stokes, 2013), multifidus (J. A. Hides & Stanton, 2014; J. A. Hides, Stanton, McMahon, Sims, & Richardson, 2008; J. A. Hides, Stanton, Mendis, Franettovich Smith, & Sexton, 2014; Mahdavie, Rezasoltani, & Simorgh, 2017; Stokes, Hides, Elliott, Kiesel, & Hodges, 2007; Wachi et al., 2017) and pelvic floor muscles (J. A. Hides et al., 2008; Painter, Ogle, & Teyhen, 2007; Thompson, O'Sullivan, Briffa, Neumann, & Court, 2005; Whittaker, Thompson, Teyhen, & Hodges, 2007). Nevertheless, there is a lack of research regarding the diaphragm morphology and muscular activity in athletes who suffer from LPP (Brown et al., 2013; Harper et al., 2013; Terada, Kosik, McCann, & Gribble, 2016; Testa et al., 2011).

Indeed, B-mode RUSI has shown to be valid and reliable in order to evaluate trans-costal and trans-hepatic diaphragm morphology and activity during breathing (Goligher et al., 2015; Harper et al., 2013; Testa et al., 2011). Recently, prior MRI studies showed a thinner diaphragm with reduced respiratory excursion and worse muscle cooperation in subjects with LPP (Vostatek, Novák, Rychnovský, & Rychnovská, 2013). Greater fatigability (Janssens et al., 2013), smaller excursion and higher position of the diaphragm were reported in patients with LPP (Kolář et al., 2012). Nevertheless, RUSI technique has shown to use a portable and cheaper tool than MRI with a rising use in the physical therapy field (Fernández Carnero et al., 2019; Fernández-Carnero, Calvo-Lobo, Garrido-Marín, & Arias-Buría, 2018). Considering specifically the physical therapy in sport, the deep muscular stabilizers of the spine of athletes with LPP may present an impaired "core" motor control and stability (Huxel Bliven & Anderson, 2013). Despite prior RUSI studies in athletic populations with LPP have shown morphological and contractile alterations in muscles of the abdominal wall (Ferreira et al., 2004; Gala-Alarcón et al., 2018; Paris-Alemany et al., 2018; Paungmali et al., 2017; Romero-Morales et al., 2018; Sitilertpisan et al., 2011; Teyhen et al., 2007; Whittaker et al., 2013), lumbar region (J. A. Hides & Stanton, 2014; J. A. Hides et al., 2008, 2014; Mahdavie et al., 2017; Stokes et al., 2007; Wachi et al., 2017) and pelvic floor (J. A. Hides et al., 2008; Painter et al., 2007; Thompson et al., 2005; Whittaker et al., 2007), there is a lack of research addressing the diaphragm thickness and excursion during normal breathing by RUSI in athletes with LPP with respect to healthy matched-paired controls (Brown et al., 2013; Harper et al., 2013; Terada et al., 2016; Testa et al., 2011).

In addition, the effects of diaphragm training on lumbar stabilizer muscles have shown an improvement of the segmental stability in patients with LPP (Finta, Nagy, & Bender, 2018), and the pelvic floor and diaphragm have been proposed as synergists muscles with transversus abdominis, being responsible for increasing and maintaining the intraabdominal pressure during postural tasks (P. W. Hodges, Butler, McKenzie, & Gandevia, 1997). The main role of diaphragm in trunk stabilization has been investigated for more than 50 years, although the exact mechanisms still remain poorly understood (Kolar et al., 2010). Patients with LPP appeared to show an abnormal position as well as a steeper slope of the diaphragm muscle, which may be considered as a contributing cause of this condition (Kolář et al., 2012). Indeed, this deep muscular stabilizer function of the diaphragm may play a main role in the spine of athletes with LPP (Huxel Bliven & Anderson, 2013). We hypothesized that athletes who suffered from LPP may show reduced diaphragm thickness and excursion due to the key role of the diaphragm muscle as a deep muscular stabilizer of the "core" in the athletic population and the diaphragm thickness was related to neuromuscular alterations in the lumbo-pelvic region being mainly considered a postural stabilizer more than a respiratory muscle according to force–length relationship modifications (Celli, 1989; Hruska, 1997; Huxel Bliven & Anderson, 2013; Terada et al., 2016). Therefore, the aim of this study was to compare diaphragm thickness and excursion between athletes with and without LPP by trans-costal and trans-hepatic RUSI, respectively.

2. Methods

2.1. Study design

A case-control study was carried out according to the STrengthening the Reporting of OBservational studies in Epidemiology (STROBE) criteria and checklist (Vandenbroucke et al., 2014). Indeed, the diaphragm thickness and excursion were compared between athletes with and without LPP by means of trans-costal and trans-hepatic RUSI. Previously, this research was approved by the Ethic Committee of the Universidade da Coruña and all subjects provided their written consent inform form. The Helsinki declaration and all human experimentation rules were considered (World Medical Association Declaration of Helsinki, 2014).

2.2. Sample size calculation

A sample size calculation was performed by means of the difference between two independent groups using the G*Power 3.1.9.2 software (G*Power©, University of Dusseldorf. Germany) and considering the difference (maximum inspiration − expiration) thickness of the left diaphragm (cm) obtained by trans-costal RUSI of a pilot study ($n = 10$) with 2 groups (mean ± SD), 5 athletes with LPP (-0.008 ± 0.052 cm) and 5 healthy matched control athletes (0.052 ± 0.063 cm) (Faul, Erdfelder, Lang, & Buchner, 2007). The thickness of the left diaphragm was selected as the main outcome for the sample size calculation due to this measure has been associated to neuromuscular dysfunction in the lumbopelvic region and this muscle may be more a postural stabilizer than a respiratory muscle secondary to the altered force–length relationship (Celli, 1989; Hruska, 1997; Terada et al., 2016). Indeed, 2-tailed hypothesis, effect size of 1.03, α error probability of 0.05, power (1-β error probability) of 0.80 and an allocation ratio (N2/N1) of 1 were used for calculating the sample size. Therefore, a total sample size of 32 athletes, divided into 16 participants with LPP and 16 healthy matched controls, was determined. Regarding the possible 20% loss to follow-up, 40 athletes were considered as the total sample size.

2.3. Participants

A consecutive convenience sampling method was used to recruit the 40 athletes, which were divided into case group ($n = 20$ athletes with LPP) and control group ($n = 20$ matched paired control athletes without LPP) from April 2018 to July 2018. The inclusion criteria were semiprofessional or amateur athletes (at least a training schedule during 2 h and 1 day per week as well as playing 1 match per week) with moderate (level II) or vigorous (level III) physical activity (>600 METs/min/week) according to the International Physical Activity Questionnaire (IPAQ) and between 18 and 55 years of age (Hagstromer, Oja, & Sjostrom, 2006). For the control group, healthy matched paired athletes without LPP at least during the previous year were included. The control group were matched for demographic data as well as physical activity, sport category, respiratory distress scores, dominant side, handed throw side, foot jump side and smoker habit) (Romero-Morales et al., 2018). For the case group, athletes with bilateral non-specific LPP were included if they presented persisting pain for more than 6 weeks with a distribution between the iliac crest and the popliteal fossa as well as a positive active straight leg raise test (Whittaker et al., 2013). Despite Whittaker et al. included patients with unilateral non-specific LPP, we selected athletes with bilateral non-specific LPP. Thus, the subjects of the case group had to present bilateral symptoms and positive tests.

Exclusion criteria for both groups comprised the presence of lumbopelvic congenital or musculoskeletal disorders (at least the previous year), rheumatisms or neuromuscular alterations (different from non-specific LPP for the case group), body mass index (BMI) higher than 31 kg/m^2, prior diagnoses of respiratory or neurological conditions, surgeries and lower limb conditions (i.e. fractures, sprains, or chronic ankle instability) (Terada et al., 2016), skin alterations, inability in order to follow the instructions during the research course, or pregnancy (Whittaker et al., 2013). In addition, rest and daily exercise or fitness activities reductions for more than 4 weeks, as well as the presence of hyperventilation syndrome evaluated by means of the Nijmegen questionnaire (a score of $\geq$24 points) were also considered as exclusion criteria (Paris-Alemany et al., 2018; Van Dixhoorn & Duivenvoorden, 1985; Whittaker et al., 2013).

2.4. Descriptive data and questionnaires

Descriptive data such as sex, age (years), height (cm), weight (kg), BMI (kg/cm^2 according to the Quetelet's index) (Garrow, 1986), sport category (basketball, fitness, soccer or volleyball), dominant side (right or left), handed throw side (right or left), foot jump side (right or left) and smoke habit (yes or no) were collected (Romero-Morales et al., 2018). Various tools such as the International Physical Activity Questionnaire (IPAQ) (Hagstromer et al., 2006), the Nijmegen questionnaire (Van Dixhoorn & Duivenvoorden, 1985) and the Roland-Morris Disability Questionnaire (RMDQ) (Kovacs et al., 2002) were self-reported by the athletes.

First, the IPAQ was applied to determine the athletes' physical activity levels by means of the calculation of the metabolic equivalents of tasks per minute per week (METs/min/week) and their categorization into moderate (<1500 METs/min/week) or vigorous ($\geq$1500 METs/min/week) physical activity. This tool has shown appropriate psychometric properties (Craig et al., 2003).

Second, the Nijmegen questionnaire was used in order to establish the respiratory distress scores due to their relationship with the diaphragm muscle tissue during RUSI assessments in subjects with and without LPP (Whittaker et al., 2013). Indeed, this tool may be considered as a self-reported questionnaire in order to determine the hyperventilation degree or respiratory distress (van Dixhoorn & Duivenvoorden, 1985; Whittaker, 2008; Whittaker et al., 2013).

Finally, the Spanish version of the RMDQ was reported in order to measure the disability related to LPP. This reliable and valid tool comprised 24 items which measured daily life activities limitations secondary to LPP varied from 0 (no-disability) to 24 (maximum-disability) (Kovacs et al., 2002).

2.5. Diaphragm thickness and excursion

All RUSI and ImageJ software measurements were carried out by a specialized and expert physical therapist with more than 4 years of musculoskeletal ultrasound imaging experience who was blinded to case (athletes with LPP) or control (athletes without LPP) group allocation due to participants were assigned a code during all measurements and the operator was blinded to participants' allocation for both groups. A high quality tool of ultrasonography (Ecube i7; Alpinion Medical System; Seoul, Korea) was used to perform all ultrasound images. A linear probe (Broadband Linear type L3_12T, field of view of 38.4 mm, 128 elements) with a frequency range from 8 to 12.0 MHz and a footprint of 45 mm was utilized to perform trans-costal measurements at rest and supine decubitus position by B-mode ultrasound image (pre-fixed preset of 3 cm depth, 12 MHz frequency, 64 points gain, 64 points dynamic range and 1 focus located at 2 cm depth) (Harper et al., 2013). A convex probe (Broadband Convex type C1-6T, field of view of 60°, 128 elements) with a frequency range from 1.0 to 6.0 MHz and a footprint of 71.6 $\times$ 16.8 mm was utilized to perform trans-hepatic measurements at rest and supine decubitus position by B-mode ultrasound image (pre-fixed preset of 23 cm depth, 4 MHz frequency, 52 points gain and 74 points dynamic range and 1 focus located at 15 cm depth) (Testa et al., 2011). Then, static grayscale images of these RUSI measurements were stored in Digital Imaging and Communications in Medicine (DICOM) format, transferred to a computer and calibrated in centimeters (cm). The version 2.0 of the ImageJ software (U.S. - National Institutes of Health; Bethesda, Maryland, USA) was used to measure offline diaphragm thicknesses and excursion (Schneider, Rasband, & Eliceiri, 2012). Diaphragm thickness and excursion (cm) were assessed during relaxed respiratory activity (maximum inspiration, maximum expiration and difference) by trans-costal and trans-hepatic RUSI, respectively (Goligher et al., 2015; Harper et al., 2013; Testa et al., 2011).

Bilateral trans-costal ultrasound images were obtained by the linear probe placed perpendicularly to the lowest intercostal space (following the mid-axillary line from the caudal edge of the 11th rib to the cranial edge of the 12th rib), which allowed an adequate visualization of the diaphragm muscle without lung encroachment during the tidal breathing. The diaphragm was bilaterally located deep to the intercostal muscles layer and ribs. A total of 3 images were captured in each hemi-diaphragm at the maximum relaxed expiration (T^{exp}; Fig. 1A) and a total of 3 images were captured in each hemi-diaphragm at the maximum relaxed inspiration (T^{ins}; Fig. 1B). Bilateral diaphragm muscle thicknesses were measured by locating electronic calipers inside of the two hyperechoic perimuscular connective tissue lines which outlined the diaphragm muscle at the center of the intercostal space. The mean of 3 repeated measurements was calculated for each hemi-diaphragm in order to determine the thickness at maximum relaxed inspiration (T^{ins}) and maximum relaxed expiration (T^{exp}), as well as their differences (T^{ins}-T^{exp}). An excellent inter-rater reliability with a high intraclass correlation coefficient (ICC) was reported for T^{ins} (ICC = 0.97; 95% CI = 0.91–0.99) and T^{exp} (ICC = 0.98; 95% CI = 0.94–0.99) measurements by a prior reliability analysis carried out by Harper et al. (Harper et al., 2013).

Right hemi-diaphragm trans-hepatic ultrasound images were obtained by anterior transverse scanning in order to determine diaphragm excursion. B-mode transverse scanning was carried out across the liver looking for the inferior vena cava on the right side and the gallbladder on the middle of the ultrasound screen. Then, ultrasound beam seemed to intercept the mid-posterior diaphragm portion, coinciding with the largest diaphragmatic motion during spontaneous breathing (Video 1). The convex probe was placed on the superior region of the abdomen at the right mid-clavicular line

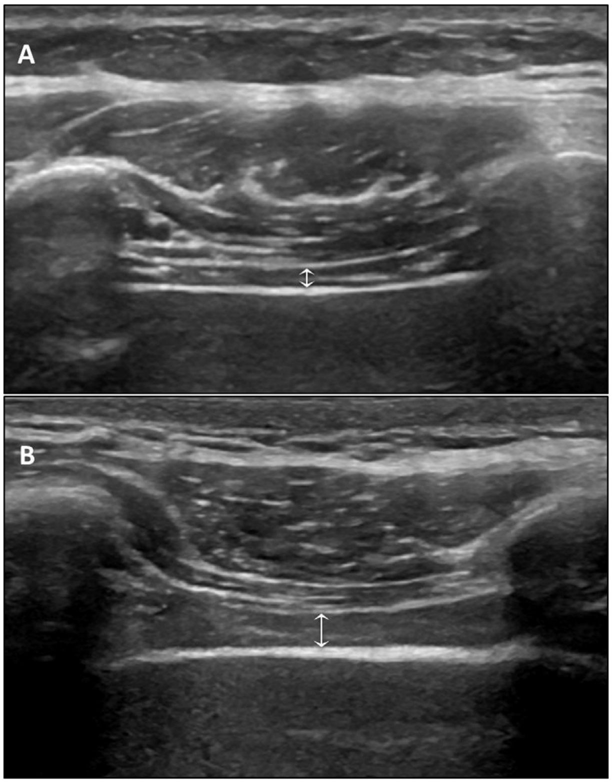

Fig. 1. Ultrasound imaging of the hemi-diaphragm by linear probe at the maximum relaxed expiration (T^{exp}; Fig. 1A) and maximum relaxed inspiration (T^{ins}; Fig. 1B).

immediately under the costal edge with firm pressure, steering in a cranial direction (with an inclination angle of 45°). The probe was firmly held in the described position during all phases of the relaxed respiratory cycle. Thus, the distance from the right hemi-diaphragm dome (the remotest diaphragmatic point) to the screen top along a cranio-caudal direction (coinciding with the mid-point of the convex probe) was captured by performing a total of 3 images at the maximum relaxed inspiration (T^{ins}; Fig. 2A) and a total of 3 images at the maximum relaxed expiration (T^{exp}; Fig. 2B). Right hemi-diaphragm muscle excursion was measured by locating electronic calipers between the center of the convex probe and the remotest point of the hiperechogenic curve line represented by the

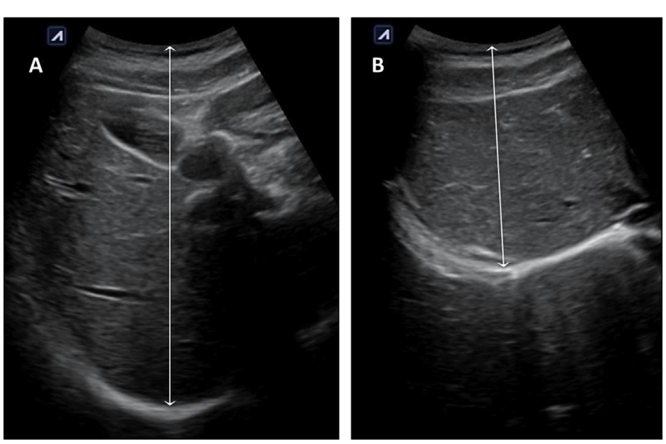

Fig. 2. Ultrasound imaging of the right hemi-diaphragm by convex probe at the maximum relaxed expiration (T^{exp}; Fig. 1A) and maximum relaxed inspiration (T^{ins}; Fig. 1B).

diaphragm dome. The mean of 3 repeated measurements was calculated for the right hemi-diaphragm in order to determine the excursion at maximum relaxed inspiration (T^{ins}) and maximum relaxed expiration (T^{exp}), as well as their differences (T^{ins}-T^{exp}). According to a prior reliability analysis carried out by Testa et al., the intra-rater variability for the right hemi-diaphragmatic excursion measurements during resting breathing, carried out by an experienced investigator, was 1 mm (6%) (Testa et al., 2011). Thus, ultrasound quantitative assessment of diaphragmatic motion was reported as a reproducible method (lower limit values varied from 0.9 cm for women to 1 cm for men during relaxed breathing) according to prior research studies (Boussuges, Gole, & Blanc, 2009; Houston, Morris, Howie, Reid, & McMillan, 1992). In addition, a significant correlation ($r = 0.89$) was previously shown between the hemi-diaphragm motion maximum amplitude measured by ultrasound and spirometry according to Ayoub et al. (Ayoub et al., 1997).

Supplementary video related to this article can be found at https://doi.org/10.1016/j.ptsp.2019.03.015.

2.6. Statistical analyses

Statistical Package of Social sciences (SPSS 24.0v of IBM; Armonk—NY; IBM—Corp) was applied in order to carry out all statistical analyses using an α error of 0.05 and a statistically significant P-value lower than 0.05 with a confidence interval (CI) of 95%.

For quantitative data, the Shapiro-Wilk test (according to Lilliefors correction) was applied to evaluate normality distribution. Parametric data (adjusted to the normal curve according to the Shapiro-Wilk test with a P-value $\geq .05$) were described as mean ± standard deviation (SD) completed with range (minimum – maximum), and differences between LPP athletes and healthy athletes were analyzed by Student t-test for independent samples (according to Levene test for equality of variances). Non-parametric data (non-adjusted to the normal curve according to the Shapiro-Wilk test with a P-value $< .05$) were described as median ± interquartile range (IR) completed with range (minimum – maximum), and differences between LPP athletes and healthy athletes were analyzed by Mann-Whitney U test for independent samples.

For categorical data, frequencies (n) completed with percentages (%) were applied to describe these values as well as differences between LPP athletes and healthy athletes were analyzed by Chi-square test (χ^2) or Fisher exact test (dichotomous variables). The right and left hemi-diaphragm thickness differences were categorized as positive (+) and negative (−) values, compared by the Fisher exact test and represented by dispersion graphs in order to determine paradoxical breathing patterns and distributions. The effect size was determined by the Cohen's d and categorized as small (d from 0.20 to 0.49), medium (d from 0.50 to 0.79) or large ($d > 0.8$) effect sizes (Kelley & Preacher, 2012).

Furthermore, multivariate predictive analyses for bilateral hemi-diaphragm thickness (T^{ins}) and right hemi-diaphragm thickness difference (T^{ins}-T^{exp}) were performed by linear regression to predict these statistically significant differences between both LPP and healthy athletes according to the previous described analysis. Linear regression analyses were carried out by stepwise selection methods and R^2 coefficients was calculated to establish the quality adjustment. Descriptive data such as quantitative (age, sex, weight, height, BMI, IPAQ, RMDQ and Nijmegen scores) and categorical data (IPAQ category, sport category, dominant side, handed throw side, foot jump side and smoker habit) were included like independent variables. Right and left hemi-diaphragm thickness (T^{ins}) and right hemi-diaphragm thickness difference (T^{ins}-T^{exp}) were included as dependent variables.

According to the case-control study design, the intraclass correlation coefficients (ICC) were calculated based on 3 repeated measurements by a randomized effects model, using absolute concordance, completed with the upper and lower limits of the 95% CI, in order to determine reliability for each parameter (Landis & Koch, 1977). The ICC values were interpreted as poor (ICC less than 0.40), fair (ICC from 0.40 to 0.59), good (ICC from 0.60 to 0.74), and excellent (ICC from 0.75 to 1.0) (Hallgren, 2012). According to Portney and Watkins (Portney & Watkins, 2009), coefficients with an ICC higher than 0.90 may improve the correct reliability probability of the available clinical measurements. In addition, Cronbach's alpha, standard error of measurement (SEM) and minimum detectable change ($MDC = \sqrt{2} \times 1.96 \times SEM$) were analyzed according to Bland and Altman (Bland & Altman, 2010).

3. Results

3.1. Homogeneity of the groups

Forty subjects were recruited and divided into athletes with LPP (case group; n = 20) and healthy matched-paired athletes (control group; n = 20) with an age distribution from 20 to 65 years old. The sample included 40 male athletes with 10 (25%) moderate and 30 (75%) physical activity levels. There was not any statistical significant difference ($P > .05$) between both athletes with and without LPP for quantitative (Table 1) and categorical (Table 2) descriptive data, except for the RMDQ ($P = .002$) showing greater disability for athletes with LPP with respect to healthy athletes.

3.2. Diaphragm thickness and excursion comparison

Bilateral diaphragm thickness reductions at T^{ins} were shown as statistically significant ($P < .05$) with an effect size from moderate to large ($d = 0.63–1.07$) for athletes with LPP compared to healthy athletes. In addition, a statistically significant difference ($P = .01$) with a large effect size ($d = 1.00$) was shown for the thickness difference at T^{ins}-T^{exp} of the right hemi-diaphragm in athletes with LPP with respect to healthy athletes (Table 3). The rest of outcome measurements did not show any statistically significant difference ($P > .05$; $d = 0.06–0.50$).

3.3. Paradoxical breathing patterns and distributions

The Fisher exact test did not show statistically significant differences for the right ($P = .231$) and left ($P = .480$) hemi-diaphragm thickness differences (T^{ins}-T^{exp}) categorization as positive (+) and negative (−) values. Nevertheless, the negative (−) values seemed to be more prevalent in the right (Fig. 3A) and left (Fig. 3B) hemi-diaphragm thickness differences categorization for the athletes with bilateral LPP compared to healthy athletes as it was represented by dispersion graphs (Fig. 3) in order to determine paradoxical breathing patterns and distributions.

3.4. Multivariate predictive analysis

Multivariate regression analyses (Table 4) were performed for the prediction of bilateral hemi-diaphragm thickness (T^{ins}) and right hemi-diaphragm thickness difference (T^{ins}-T^{exp}) due to these outcome measurements were the only statistically significant differences between athletes with and without LPP (Table 3). The presence of LPP in athletes (group) was the only independent variable of all linear regression models which showed statistically significant differences ($P < .05$) to predict the right ($R^2 = 0.183$; $\beta = -0.067$; $F_{[1,38]} = 8.514$; $P = .006$) and left ($R^2 = 0.105$; $\beta = -0.054$; $F_{[1,38]} = 0.451$; $P = .042$) hemi-diaphragm thickness (T^{ins}) as well as the right hemi-diaphragm thickness difference (T^{ins}-T^{exp}; $R^2 = 0.161$;; $\beta = -0.048$; $F_{[1,38]} = 7.289$; $P = .010$). Thus, the rest of independent variables were excluded from the 3 prediction models due to dependent variables (right hemi-diaphragm thickness at T^{ins}; left hemi-diaphragm thickness at T^{ins}; and right hemi-diaphragm thickness difference at T^{ins}-T^{exp}) were not predicted or influenced by quantitative (age, sex, weight, height, BMI, IPAQ, RMDQ and Nijmegen scores) and categorical (IPAQ category, sport category, dominant side, handed throw side, foot jump side and smoker habit) descriptive data according to the pre-established parameters of in and out F probability (Pin = .05, Pout = .10).

3.5. Intra-rater reliability

Based on 3 repeated measurements, an excellent reliability was shown for the right hemi-diaphragm thickness at T^{ins} (ICC [95% CI] = 0.949 [0.914–0.941]; Cronbach $\alpha = 0.950$; SEM = 0.053; MDC = 0.148) and T^{exp} (ICC = 0.962 [0.935–0.979]; Cronbach $\alpha = 0.965$; SEM = 0.023; MDC = 0.064), left hemi-diaphragm thickness at T^{ins} (ICC = 0.939 [0.898–0.966]; Cronbach $\alpha = 0.939$; SEM = 0.062; MDC = 0.173) and T^{exp} (ICC = 0.961 [0.934–0.978]; Cronbach $\alpha = 0.960$; SEM = 0.027; MDC = 0.074), right hemi-diaphragm excursion at T^{ins} (ICC = 0.971 [0.951–0.984]; Cronbach $\alpha = 0.971$; SEM = 0.027; MDC = 0.808) and T^{exp} (ICC = 0.963 [0.937–0.979]; Cronbach $\alpha = 0.963$; SEM = 0.725; MDC = 2.009).

4. Discussion

To the authors' knowledge, this is the first case-control study that assesses the diaphragm thickness and excursion during normal breathing by RUSI comparing athletes with LPP with

Table 1
Quantitative descriptive data for athletes with LPP, healthy athletes and total sample.

Quantitative data	Total group (n = 40)	LPP athletes (n = 20)	Healthy athletes (n = 20)	*P*-Value
Age (years)	24.00 ± 7.00 (20–35)	26.00 ± 7.75 (20–35)	23.00 ± 7.25 (20–35)	.277[b]
Weight (kg)	77.41 ± 9.04 (53–96)	77.11 ± 10.37 (53–94)	77.72 ± 7.76 (65–96)	.833[a]
Height (m)	1.81 ± 0.06 (1.68–1.95)	1.82 ± 0.07 (1.69–1.94)	1.81 ± 0.06 (1.68–1.95)	.718[a]
BMI (kg/m^2)	23.84 ± 2.68 (17.31–26.30)	23.84 ± 3.40 (17.31–26.30)	23.70 ± 1.97 (20.10–25.80)	.799[b]
IPAQ (METS/min/week)	4266.00 ± 3042.75 (1737–19272)	4899.00 ± 4936.00 (2072–19272)	3471.00 ± 2499.00 (1737–10560)	.072[b]
RMDQ	0.00 ± 2.75 (0–10)	2.00 ± 4.00 (0–10)	0.00 ± 0.00 (0–3)	**.002**[b]
Nijmegen	8.00 ± 9.00 (0–23)	7.00 ± 14.25 (0–23)	8.50 ± 6.75 (1–15)	.678[b]

Abbreviations: BMI, body mass index; IPAQ, International Physical Activity Questionnaire; LPP, lumbo-pelvic pain METs, metabolic equivalent index per week; RDMQ, Roland-Morris Disability Questionnaire.
For all analyses, $P < .05$ (for a confidence interval of 95%) was considered as statistically significant (**bold**).
[a] Mean ± standard deviation and range (min - max) as well as Student's *t*-test for independent samples were used according to parametric distributions (Shapiro-Wilk test showing a *P*-value ≥ .05).
[b] Median ± interquartile range and range (min - max) as well as Mann-Whitney *U* test were applied according to non-parametric distributions (Shapiro-Wilk test showing a *P*-value < .05).

Table 2
Categorical descriptive data for athletes with LPP, healthy athletes and total sample.

Categorical data		Total group (n = 40)	LPP athletes (n = 20)	Healthy athletes (n = 20)	*P*-Value
IPAQ category[c]	Moderate	10 (25%)	3 (15%)	7 (35%)	.273[a]
	Vigorous	30 (75%)	17 (85%)	13 (65%)	
Sport category	Basketball	16 (40%)	10 (50%)	6 (30%)	.614[b]
	Soccer	9 (22.5%)	4 (20%)	5 (25%)	
	Volleyball	2 (5%)	1 (5%)	1 (5%)	
	Fitness	13 (32.5%)	5 (25%)	8 (40%)	
Dominant side	Right	32 (80%)	17 (85%)	15 (75%)	.695[a]
	Left	8 (20%)	3 (15%)	5 (25%)	
Handed throw side	Right	33 (82.5%)	18 (90%)	15 (75%)	.407[a]
	Left	7 (17.5%)	2 (10%)	5 (25%)	
Foot jump side	Right	13 (32.5%)	6 (30%)	7 (35%)	1.00[a]
	Left	27 (67.5%)	14 (70%)	13 (65%)	
Smoker habit	Yes	9 (22.5%)	4 (20%)	5 (25%)	1.00[a]
	No	31 (77.5%)	16 (80%)	15 (75%)	

Abbreviations: METs, metabolic equivalent index per week; IPAQ, International Physical Activity Questionnaire; LPP, lumbo-pelvic pain.
For all analyses, $P < .05$ (for a confidence interval of 95%) was considered as statistically significant.
[a] Frequency and percentage (%) as well as Fisher exact test were used.
[b] Frequency and percentage (%) as well as Chi-squared test (χ^2) were used.
[c] Physical activity levels were divided into moderate (<1500 METs/min/week) or vigorous (≥1500 METs/min/week) according to IPAQ. METS were calculated as total index of metabolic equivalents per minute/week for different physical activity levels (Craig et al., 2003).

Table 3
Diaphragm thickness and excursion data for athletes with LPP, healthy athletes and total sample.

Outcome measurements (cm)	Total group (n = 40)	LPP athletes (n = 20)	Healthy athletes (n = 20)	*P*-Value LPP vs healthy	Effect size (*d*)
Right hemi-diaphragm thickness (T^{ins})	.20 ± 0.07 (0.06–0.36)	0.16 ± 0.07 (0.06–0.35)	0.23 ± 0.06 (0.08–0.36)	.006[a]	1.07
Right hemi-diaphragm thickness (T^{exp})	0.12 ± 0.04 (0.05–0.21)	0.11 ± 0.04 (0.05–0.21)	0.13 ± 0.04 (0.06–0.21)	.154[a]	0.50
Right hemi-diaphragm thickness (T^{ins}-T^{exp})	0.07 ± 0.06 (−0.03 − 0.21)	0.05 ± 0.05 (−0.03 − 0.17)	0.10 ± 0.05 (0–0.21)	**.010**[a]	1.00
Left hemi-diaphragm thickness (T^{ins})	0.14 ± 0.12 (0.08–0.39)	0.13 ± 0.12 (0.08–0.36)	0.20 ± 0.10 (0.11–0.39)	**.015**[b]	0.63
Left hemi-diaphragm thickness (T^{exp})	0.12 ± 0.08 (0.07–0.28)	0.12 ± 0.07 (0.07–0.18)	0.14 ± 0.10 (0.08–0.28)	.211[b]	0.23
Left hemi-diaphragm thickness (T^{ins}-T^{exp})	0.04 ± 0.06 (−0.06 − 0.18)	0.03 ± 0.06 (−0.06 − 0.18)	0.06 ± 0.06 (−0.02 − 0.18)	.192[a]	0.50
Right hemi-diaphragm excursion (T^{ins})	14.17 ± 1.55 (9.07–16.61)	13.93 ± 1.55 (9.07–16.18)	14.41 ± 1.55 (10.42–16.61)	.327[a]	0.30
Right hemi-diaphragm excursion (T^{exp})	17.56 ± 0.88 (14.55–20.51)	17.44 ± 0.98 (15.03–20.51)	17.84 ± 1.27 (2.70–7.90)	.157[b]	0.35
Right hemi-diaphragm excursion (T^{ins}-T^{exp})	−3.35 ± 1.14 (−6.12 to −1.41)	−3.38 ± 1.13 (−5.96 to −1.72)	−3.31 ± 1.17 (−6.12 to −1.41)	.865[a]	0.06

Abbreviations: LLP, lumbo-pelvic pain; T^{ins}, maximum relaxed inspiration; T^{exp}, maximum relaxed expiration; T^{ins}-T^{exp}, differences between maximum relaxed inspiration and maximum relaxed inspiration.
For all analyses, $P < .05$ (for a confidence interval of 95%) was considered as statistically significant (**bold**).
[a] Mean ± standard deviation and range (min - max) as well as Student's *t*-test for independent samples were used according to parametric distributions (Shapiro-Wilk test showing a *P*-value ≥ .05).
[b] Median ± interquartile range and range (min - max) as well as Mann-Whitney *U* test were applied according to non-parametric distributions (Shapiro-Wilk test showing a *P*-value < .05).

respect to healthy matched-paired controls showing that the diaphragm muscle may play a key role as a deep muscular stabilizer of the "core" in athletes with bilateral LPP in line with the prior suggestions raised by other authors (Celli, 1989; Hruska, 1997; Huxel Bliven & Anderson, 2013; Terada et al., 2016). Our results showed that athletes who suffered from bilateral LPP presented bilateral diaphragm thickness reductions at T^{ins} and thickness difference at T^{ins}-T^{exp} of the right hemi-diaphragm. Nevertheless, there were not differences for diaphragm excursion between both athletes with and without LPP. The lack of prior RUSI studies assessing diaphragm thickness and excursion between athletes with and without bilateral LPP hinders the comparison with our study. Despite the comparison between MRI and RUSI studies may present bias, our findings are in line with prior MRI studies which showed a thinner diaphragm in subjects with LPP (Vostatek et al., 2013), but our study is in contrast with other conclusions for reduced respiratory diaphragm excursion (Vostatek et al., 2013) as well as smaller excursion and higher position of the diaphragm (Kolář et al., 2012) in subjects with LPP. These differences may be due to the sample of our study was entirely composed by athletes or the different measurement approaches (MRI versus RUSI). In addition, the LPP presence in athletes is the only variable that predicted bilateral diaphragm thickness reductions at T^{ins} and thickness difference at T^{ins}-T^{exp} of the right hemi-diaphragm. According to our statistical analyses and findings about the 3 prediction models, the combined effects of LPP presence (group) with the rest of independent variables such as demographics and anthropometric variables did not influence the prediction of these dependent variables (bilateral thicknesses of diaphragm muscle at T^{ins} and right hemi-diaphragm difference at T^{ins}-T^{exp}) due to these independent variables were excluded from the prediction model (Pin = .05, Pout = .10).

4.1. Reliability and measurement errors

Despite we reported an excellent reliability (ICC and Cronbach α varied from 0.939 to 0.971) for the RUSI outcome measurements (Hallgren, 2012), the statistically significant differences between athletes with and without LPP (Table 3) should be considered with caution according to the SEM and MDC of these measures (Bland & Altman, 2010). Indeed, the statistically significant differences between both groups for the right and left hemi-diaphragm thickness values at T^{ins} (0.07 cm for both hemi-diaphragms) were greater

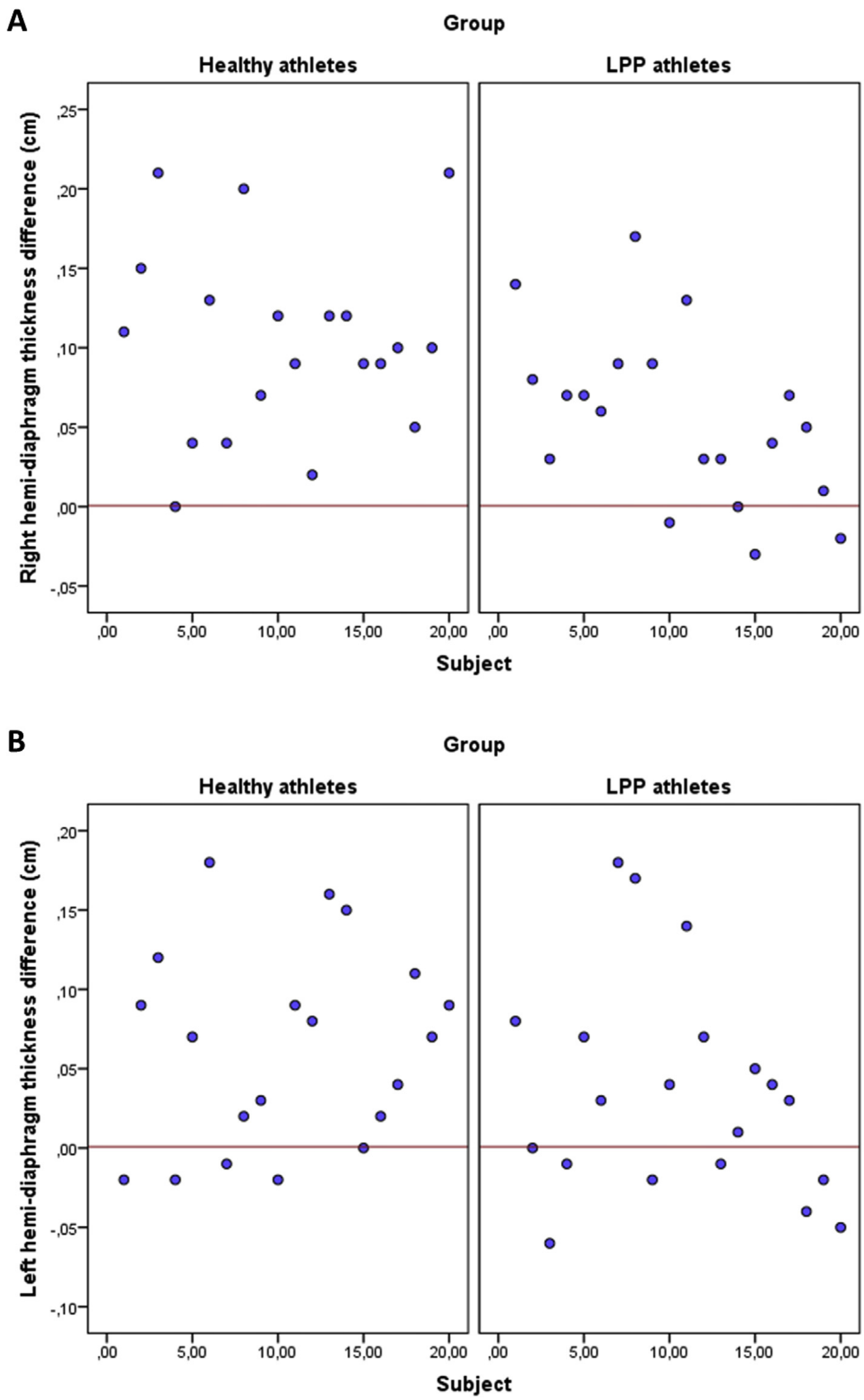

Fig. 3. Dispersion graphs of the right (Fig. 3A) and left (Fig. 3B) hemi-diaphragm thickness differences (T^{ins}-T^{exp}) categorization for the athletes with LPP compared to healthy athletes in order to determine paradoxical breathing patterns and distributions. *Abbreviations:* LLP, lumbo-pelvic pain; T^{ins}-T^{exp}, differences between maximum relaxed inspiration and maximum relaxed inspiration.

than the SEM (0.053 and 0.062 cm) but lower than the MDC (0.148 and 0.173 cm), respectively. These values were in line with the measurement error reported previously in the literature (Harper et al., 2013). Thus, these calculations were conducted according to the proper reliability analysis recommended to determine measurement error in outcome measurements relevant in sports medicine (Atkinson & Nevill, 1998).

4.2. Paradoxical breathing patterns

Due to there were not statistically significant differences for paradoxical breathing patterns and distributions (Fig. 3), the presence of negative (−) values did not seem to be bilaterally more frequent in the right and left hemi-diaphragm thickness for differences categorization in athletes with bilateral LPP with respect

Table 4
Multivariate predictive analysis for bilateral hemi-diaphragm thickness (T^{ins}) and right hemi-diaphragm thickness difference (T^{ins}-T^{exp}) for athletes with LPP and healthy athletes.

Parameter	Model	R^2 change	Model R^2
Right hemi-diaphragm thickness (T^{ins})	0.237 −0.067[c] Group	0.183[b]	0.183
Left hemi-diaphragm thickness (T^{ins})	0.217 −0.054[c] Group	0.105[a]	0.105
Right hemi-diaphragm thickness (T^{ins}-T^{exp})	0.103 −0.048[c] Group	0.161[b]	0.161

Abbreviations: LLP, lumbo-pelvic pain; T^{ins}, maximum relaxed inspiration; T^{ins}-T^{exp}, differences between maximum relaxed inspiration and maximum relaxed inspiration.
[a] *P*-value < .05 for a 95% confidence interval was shown.
[b] *P*-value < .01 for a 95% confidence interval was shown.
[c] Multiplay: Group (healthy athletes = 0; LPP athletes = 1).

to healthy matched paired athletes. Further studies with higher sample sizes are necessary in order to study the presence of paradoxical breathing patterns in athletes with LPP.

Considering the thickness of the diaphragm evaluated by trans-costal RUSI approach, a first dysfunctional pattern of diaphragm activation was occasionally observed and the thickness of the diaphragm was partially modified in the subcostal space (Video 2). Nevertheless, the caliper measurement was always carried out in the center of the intercostal space by drawing a line from the caudal edge of the 11th rib to the cranial edge of the 12th rib (Harper et al., 2013).

Supplementary video related to this article can be found at https://doi.org/10.1016/j.ptsp.2019.03.015.

The second abnormal pattern of diaphragm activation corresponded to the thinning of the diaphragm during inspiration and the thickness increase during expiration (Video 3). This phenomenon may be described as an inversion of the normal pattern of activation that could be compatible with the presence or description of paradoxical breathing as a plausible hypothesis (Fayssoil et al., 2018). The increase of the diaphragm thickness may be observed due to a reduction of the intercostal space and passive stacking of the interposed structures (intercostal and diaphragm muscles).

Supplementary video related to this article can be found at https://doi.org/10.1016/j.ptsp.2019.03.015.

Finally, a third activation pattern described previously in the literature observed a diaphragm thinning in a specific region of the intercostal space and a non-deformable hyperechogenic image during ventilation that could be compatible with a diaphragmatic “herniation” or an increase in the presence of connective tissue or fibrosis (Groth & Andrade, 2010; Nason et al., 2012).

4.3. Future studies and clinical implications

Our findings may suggest that diaphragm reeducation could be a main focus of intervention related to athletic performance, prevention and rehabilitation. Indeed, a prior clinical trial has reported that inspiratory muscle training may facilitate the proprioceptive involvement of trunk postural control in subjects who suffered from LPP and may be an useful rehabilitation tool in LPP subjects (Janssens et al., 2015). In addition to this intervention, the use of RUSI could be recommended as a biofeedback tool for diaphragm reeducation (Henry & Teyhen, 2007). Thus, future randomized clinical trials should use RUSI as a feedback tool for diaphragm activation pattern reeducation as a promising technique during normal breathing rehabilitation in subjects who suffered from LPP.

4.4. Limitations

Some limitations should be acknowledged regarding the present study. First of all, the consecutive sampling method used for recruitment of participants should be considered for future studies. Second, all trans-costal measurements were collected in the mid-axillary line of the last intercostal space between the 11th and 12th ribs but some subjects showed the appearance of the pulmonary pleura during the maximum relaxed inspiration and the costophrenic angle generated an image artefact that hindered the outcome measurements. In addition, regarding this intercostal space, the diaphragm seemed to present a smaller thickness than in the rest of the intercostal spaces at resting basal breathing status (Harper et al., 2013). Third, trans-hepatic RUSI measurements presented an open or closed sub-costal angle which provided difficulties to stabilize the probe at 45° of inclination angle in order to direct the ultrasound view to the posterior margin of the diaphragmatic dome, which showed the highest excursion variability. Nevertheless, all measurements were collected at 45° inclination angle at the lower edge of the anterior costal angle coinciding with the midclavicular line (Testa et al., 2011). Finally, some of our RUSI outcome measurements did not reach the MDC values and may be influenced by measurement errors (Atkinson & Nevill, 1998).

5. Conclusions

Athletes who suffered from LPP presented a reduced diaphragm thickness compared to healthy matched-paired athletes. Therefore, these novel findings may suggest that diaphragm reeducation could be a main focus of intervention related to athletic performance, prevention and rehabilitation. Nevertheless, these findings should be considered with caution due to the possible influence of the RUSI measurement errors of the diaphragm activation during normal breathing.

Conflicts of interest and Source of Funding

There are no conflicts of interest or Source of Funding.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ptsp.2019.03.015.

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