ARTICLE IN PRESS

Journal of Biomechanics ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Journal of Biomechanics

journal homepage: www.elsevier.com/locate/jbiomech
www.JBiomech.com

The effects of age and gender on the lumbopelvic rhythm in the sagittal plane in 309 subjects

Esther Pries [a,*,1], Marcel Dreischarf [a,1], Maxim Bashkuev [a], Michael Putzier [b], Hendrik Schmidt [a]

[a] Julius Wolff Institute, Charité–Universitätsmedizin Berlin, Germany
[b] Centre for Musculoskeletal Surgery–Universitätsmedizin Berlin, Germany

ARTICLE INFO

Article history:
Accepted 19 July 2015

Keywords:
Lumbopelvic rhythm
Lumbar lordosis
Sacrum orientation
Age
Gender

ABSTRACT

Frequent upper body bending is associated with low back pain (LBP). The complex flexion movement, combining lumbar and pelvic motion, is known as "lumbopelvic rhythm" and can be quantified by dividing the change in the lumbar spine curvature by the change in pelvic orientation during flexion movement (L/P ratio). This parameter is clinically essential for LBP prevention, for diagnostic procedures and therapy; however, the effects of age and gender, in detail, are unknown.

The Epionics SPINE system, utilizing strain-gauge technology and acceleration sensors, was used to assess lumbar lordosis and sacrum orientation during standing and lumbar angle and sacrum orientation during maximal upper body flexion in 309 asymptomatic subjects (age: 20–75 yrs; ♂: 134; ♀: 175). The effects of age and gender on these characteristics as well as on the resultant range of flexion (RoF) and lumbopelvic rhythm were investigated.

Aging significantly reduced lumbar lordosis by 8.2° and sacrum orientation by 6.6° during standing in all subjects. With aging, the lumbar RoF decreased by 7.7°, whereas the pelvic RoF compensated for this effect and increased by 7.0°. The L/P ratio decreased from 0.80 to 0.65 with age; however, this decrease was only significant in men. Gender affected sacrum orientation in standing and in flexion as well as the L/P ratio.

This study demonstrated the effects of age and gender on lordosis, sacrum orientation and lumbopelvic rhythm. These findings are of importance for the individual prevention of LBP, and provide a baseline for differentiating symptomatic from asymptomatic age- and gender-matched subjects.

1. Introduction

Frequent upper body bending is a risk factor for the development of low back pain (LBP) (Damkot et al., 1984; Hoogendoorn et al., 2000; Punnett et al., 1991). Therefore, physicians and physiotherapists have focused on understanding the complex pattern of this movement, which combines lumbar spine motion and pelvic rotation at the same time. During upper body bending, the lumbar spine and pelvis contribute differently to the total amount of motion in different phases of flexion movement, which is known as the "lumbopelvic rhythm". This rhythm can be quantified by dividing the change in the curvature of the lumbar spine by the change in pelvic orientation during flexion movement (the lumbopelvic (L/P) ratio). It has been shown that in young asymptomatic volunteers, the lumbar spine dominates in the early phase of flexion, whereas in the late flexion phase, the motion mainly arises from the pelvis (Dolan and Adams, 1993; Esola et al., 1996; Granata and Sanford, 2000; Kim et al., 2013; McClure et al.,1997a; Porter and Wilkinson, 1997; Tafazzol et al., 2014). Detailed knowledge about lumbopelvic motion is clinically essential for LBP prevention and diagnostic procedures and therapy (Laird et al., 2012, 2014) as well as for sophisticated biomechanical analyzes of upper body motion in computational models that aim to predict lumbar spine loading (Tafazzol et al., 2014). To establish an improved individualized and patient-specific approach, the effects of age and gender on the lumbopelvic rhythm must be understood. However, these effects remain elusive.

For a sophisticated understanding of the lumbopelvic rhythm, the analysis of the lumbar spine and pelvis during standing and in full flexion is a prerequisite. Although there is a strong anatomical correlation between lumbar lordosis and pelvic morphology (Barrey et al., 2007; Vaz et al., 2002), several studies have

* Correspondence to: Julius Wolff Institute, Charité – Universitätsmedizin Berlin, Augustenburger Platz 1, 13353 Berlin, Germany. Tel.: +49 30 2093 46049; fax: +49 2093 46001.
E-mail address: esther.pries@charite.de (E. Pries).
[1] The authors contributed equally to this work.

http://dx.doi.org/10.1016/j.jbiomech.2015.07.030
0021-9290/

investigated the effects of age and gender on lumbar lordosis and the pelvis separately. The majority of studies found either no differences (Jackson and McManus, 1994; Vialle et al., 2005) or a decrease in lordosis during aging (Gelb et al., 1995; Korovessis et al., 1998). Studies that have examined gender-related differences have reported either slightly greater lordosis in females (Schroder et al., 2014) or no significant differences at all (Gelb et al., 1995; Korovessis et al., 1998; Vaz et al., 2002). Studies on the effects of gender and age on pelvic morphology have not identified any gender-related differences in parameters such as pelvic incidence and pelvic tilt (Vaz et al., 2002) and have reported only weak correlations between age and pelvic tilt (Korovessis et al., 1998; Mac-Thiong et al., 2011). Investigations on upper body flexion have focused mainly on the spine, demonstrating a reduction in the spinal range of motion with increasing age (Dvorak et al., 1995; Intolo et al., 2009; Troke et al., 2005). The effect of gender on lumbar motion is still controversially discussed, with partly more or less motion in males than in females (McGregor et al., 1995; Russell et al., 1993; Troke et al., 2001; Van Herp et al., 2000). However, only a few studies have investigated age- and gender-specific differences in lumbopelvic rhythm to elucidate potential deviations in the interaction between the lumbar spine and the pelvis during flexion movement. Only Dolan and Adams (1993) examined the effect of aging, however in sitting and found no effect of age on lumbopelvic rhythm. Gender-related effects were only investigated by Esola et al. (1996), who did not find any significant differences between males and females. Due to these findings, most subsequent studies neglected the impact of age and gender or included sample sizes that were too small to explore these fundamental effects (Table 1).

Therefore, this study aimed to investigate, in a large asymptomatic cohort, the effects of age and gender initially on lumbar angle and sacrum orientation during standing and in upper body flexion as well as in particular on the resultant lumbopelvic rhythm by employing a novel motion capture device.

It was hypothesized that

1. Age and gender significantly affect lumbar angle and sacrum orientation in standing and during flexion.
2. As a consequence, age and gender specifically affect the resultant L/P ratio for full flexion and for single phases of the flexion process.

2. Materials and methods

2.1. Measurement system

The Epionics SPINE system (Epionics Medical GmbH, Potsdam, Germany) was used to measure lumbar spinal shape and motion as well as sacrum orientation (as a representation of pelvic orientation) and rotation in the sagittal plane (Fig. 1a). The system consisted of two flexible sensor strips that utilize strain gauge sensors located alongside flexible circuit board strips. These provided a sensitive measure of electrical resistance, and thus the aperture angles (Fig. 1a middle), in accordance with the curvature in each of the twelve 2.5-cm-long segments (Epionics segments: S1–S12). During a measurement, the sensor strips were inserted into two hollow plasters attached to the back paravertebrally, 7.5 cm away from the spinal column on each side. The Epionics segments detected the local back curvature by means of lumbar lordosis (similar to the X-ray assessment of lordosis introduced by Cobb (1948)), as illustrated in Fig. 1a (middle). The resultant segmental angles were derived from the measured segmental radius as follows:

$$\text{Angle in degrees} = (\text{arc length} \times 360)/(2\pi \times \text{radius}).$$

The lower end of each strip was aligned with the posterior superior iliac spine, which was approximately in line with the first sacral vertebra. A tri-axial accelerometer was located at this end, allowing the system to determine the sacrum orientation as depicted in Fig. 1a. This acceleration sensor determined the spatial orientation of the sensor relative to the vertical direction of the earth's gravitational field. The sensor strips were connected to a storage unit (size: 12.5 cm × 5.5 cm; mass: 80 g) that collected data with a frequency of 50 Hz. The system's sensor strips exhibit high accuracy and repeatability (ICC > 0.98) with test–retest reliability ICC values of > 0.98. Previous studies confirmed the suitability of the system for assessing lumbar and pelvic motion (Consmuller et al., 2012a, b; Pries et al., 2015).

2.2. Ethics

The Ethics Committee of the Charité – Universitätsmedizin Berlin approved this study (Registry number EA4/011/10). All of the volunteers were informed of the study's procedure, and they signed a written consent granting their permission to conduct the measurements.

2.3. Subjects

This study examined data obtained from 429 subjects from a previously published cohort on the measurement of lumbar spinal posture and motion (Consmuller et al., 2012a). These subjects had no pain in the lower back or in the pelvis in the six months prior to the measurements and no history of spinal or pelvic surgery. Recent studies, such as those by Adams et al. (1986), Guermazi et al. (2006), and Stokes et al. (1987) as well as our own validation studies, have found a significant correlation between lumbar lordosis assessed via the back shape and radiologically determined lordosis only for subjects with a body mass index (BMI) < 26.0 kg/m². Therefore, to ensure valid results with a strong correlation between back shape and underlying spinal structures, 106 volunteers with a BMI higher than 26.0 kg/m² were excluded from the study. Moreover, 14 subjects were excluded due to missing sacrum orientation values caused by a malfunction in the acceleration sensors, resulting in 309 evaluated subjects (175 females; 134 males) with a mean age of 38.4 ± 14.0 yrs (38.2 yrs for females, 38.5 yrs for males). The mean height was 173.0 ± 9.5 cm (167.4 cm for females, 180.3 cm for males), the mean weight was 67.5 ± 10.1 kg (61.4 kg, 75.5 kg) and the mean BMI was 22.5 ± 2.0 kg/m² (21.9 kg/m², 23.2 kg/m²). The volunteers were classified by gender and assigned to three age groups: 20–35 yrs (n = 155), 35–50 yrs (n = 100) and > 50 yrs (n = 54).

2.4. Measurement protocol

All of the volunteers were measured five times during relaxed upright standing after being equipped with the Epionics SPINE system. From this upright reference position, maximum upper body flexion was performed five times at the volunteers' preferred velocity while keeping the knees extended (Fig. 1a).

Table 1
Literature values for asymptomatic subjects (f = females; m = males) from previously published studies and data regarding their lumbar and pelvic ranges of flexion (RoF) and lumbopelvic ratios (L/P ratios). L/P ratios for full flexion are calculated by dividing the maximum lumbar RoF by the maximum pelvic RoF. The results of the current study are shown for comparison.

Author	Mean age (yrs)	Age range (yrs)	Measurement technique	Subjects	Gender	Lumbar RoF (deg)	Pelvic RoF (deg)	L/P ratio
Mayer et al. (1984)	31.0	19–51	Inclinometer + X-ray	13	6f/7m	55.0	66.0	0.83
Esola et al. (1996)	27.5	–	3D optoelectric motion analysis	21	8f/13m	43.0	70.0	0.61
Porter and Wilkinson (1997)	26.0	18–36	3D motion analysis	17	17m	68.6	58.3	1.18
Kim et al. (2013)	23.8	–	3D motion capture system	16	–	48.5	56.6	0.86
Tafazzol et al. (2014)	25.3	–	Inertial tracking device	8	8m	60.2	53.0	1.14
Range						**43.0–68.6**	**53.0–70.0**	**0.61–1.18**
Current study	38.4	20–75	Epionics SPINE system	309	175f/134m	52.1	72.1	0.72