



The effect of low back pain on spine kinematics: A systematic review and meta-analysis

Aicha Errabity, Paul Calmels, Woo Suck Han, Rébecca Bonnaire, Romain Pannetier, Reynald Convert, Jérôme Molimard

► To cite this version:

Aicha Errabity, Paul Calmels, Woo Suck Han, Rébecca Bonnaire, Romain Pannetier, et al.. The effect of low back pain on spine kinematics: A systematic review and meta-analysis: Review. Clinical Biomechanics, 2023, 108, pp.106070. 10.1016/j.clinbiomech.2023.106070 . hal-04199538

HAL Id: hal-04199538

<https://imt-mines-albi.hal.science/hal-04199538>

Submitted on 8 Sep 2023

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

The effect of low back pain on spine kinematics: A systematic review and meta-analysis

Aicha Errabity^{a,b,*}, Paul Calmels^c, Woo-Suck Han^a, Rébecca Bonnaire^d, Romain Pannetier^b, Reynald Convert^b, Jérôme Molimard^a

^a Mines Saint-Etienne, Univ Lyon, Univ Jean Monnet, INSERM, U 1059 Sainbiose, Centre CIS, Saint-Etienne, France

^b Thuasne, BP243, 92307 Levallois-Perret, Cedex, France

^c Université Jean Monnet, Saint-Etienne, service de médecine physique et réadaptation - CHU-Saint Etienne, Lyon1, Université Savoie Mont-Blanc, Laboratoire Inter Universitaire de biologie de la Motricité, F-42023 Saint-Etienne, France

^d Institut Clément Ader (ICA), Université de Toulouse, CNRS, IMT Mines Albi, INSA, ISAE-SUPAERO, UPS Campus Jarlard, F-81013 Albi, France

ABSTRACT

Keywords:

Low back pain
Kinematics
Range of motion
Meta-analysis

Background: Although impairments in dorso-lumbar spine mobility have been previously reported in patients with low back pain, its exact mechanism is not yet clear. Therefore, the purpose of this systematic review and meta-analysis is to investigate and compare spinal kinematics between subjects with and without low back pain and identify appropriate tools to evaluate it.

Methods: The PubMed, Scopus and Web of Science databases were searched for relevant literature. The search strategy was mainly focused on studies investigating lumbar kinematics in subjects with and without low back pain during clinical functional tests, gait, sports and daily functional activities. Papers were selected if at least one of these outputs was reported: lumbar range of motion, lumbar velocity, lumbar acceleration and deceleration, lordosis angle or lumbar excursion.

Findings: Among 804 papers, 48 met the review eligibility criteria and 29 were eligible to perform a meta-analysis. Lumbar range of motion was the primary outcome measured. A statistically significant limitation of the lumbar mobility was found in low back pain group in all planes, and in the frontal and transverse planes for thoracic range of motion, but there is no significant limitation for pelvic mobility. The amount of limitation was found to be more important in the lumbar sagittal plane and during challenging functional activities in comparison with simple activities.

Interpretation: The findings of this review provide insight into the impact of low back pain on spinal kinematics during specific movements, contributing to our understanding of this relationship and suggesting potential clinical implications.

1. Introduction

Low back pain (LBP) is one of the most prevalent health problems in developed countries. It is estimated that up to 30% of the population will develop at least one episode of LBP during their lives (Rubin, 2007). The global prevalence over 1-month period of LBP was estimated to be 23.2% (Hoy et al., 2012), affecting both men and women of all ages (Rubin, 2007). LBP is associated with economic and social costs, which appears to be growing rapidly. In European countries, reported costs range from 0.1% to 2% of the gross domestic product (Williamson and Cameron, 2021), while estimates in the USA vary between US\$ 18.5 and

US\$28.2 billion (Maher et al., 2017). In fact, LBP is the leading cause of activity limitation and disability in the adult working population throughout much of the world. As an example, in France, the national health insurance estimated that LBP is a reason for 30% of work-related sick leaves of >6 months. Thus, 12.2 million working days were lost due to work-related LBP, generating a direct cost in this country of over 1 billion euros in 2017.

LBP typically affects the lower part of the spine, in particular the region of the lumbar vertebrae. More precisely, the pain is located below the costal margin and above the lower gluteal folds. (Koes et al., 2006). It must be qualified as a symptom of several different types of

pathological problems issues. In most cases, LBP is due to mechanical or non-specific conditions, and specific conditions as inflammation, fracture, malignancy, or infection must be identified. It is reported on clinical practice, that mechanical etiology represents 90% of LBP. In this case, LBP is classified into three categories: acute (< 6 weeks), subacute (> 6 and < 12 weeks) and chronic (> 12 weeks) (Van Tulder et al., 2006).

Despite the lack of evidence on the pain mechanisms in non-specific LBP (NSLBP), several earlier studies have indicated potential changes in lumbar spine biomechanics (Christe et al., 2016a; Gombatto et al., 2015; Van Hoof et al., 2012). Therefore, increasing our knowledge of the differences in the kinematic of the lumbar spine between individuals with and without LBP is imperative to better understand LBP mechanisms, and probably, for performing a more appropriate approach for diagnosis and treatment. A systematic review (Sedrez et al., 2019) reported significant differences in kinematic characteristics between subject with and without LBP during sit-to-stand-movement. Another systematic review (Arshad et al., 2019) showed significant differences among subjects without LBP in the range of motion (RoM) in the lumbar region in standing position consecutively to different typologies (age, sex). Muscular activation pattern was also studied during walking (Ghamkhar and Kahlaee, 2015), reporting that multifidus, erector spinae, external oblique, and rectus abdominus muscle activity levels were higher in LBP subjects during the gait phase.

Significant differences were observed in kinematic/kinetic measures between subjects with and without LBP while performing different daily functional activities; however, these indicators provide limited or inconsistent evidence in the clinical management of LBP patients (Papi et al., 2018). Additionally, a review with meta-analysis (Laird et al., 2014) systematically revealed differences among subject with and without LBP by examining lumbopelvic kinematics.

Given the current literature and its limitations, a comprehensive review and meta-analysis are needed to consolidate the available data and better understand the differences in lumbar spine movement between people with and without LBP.

The lumbar spine plays a crucial role in connecting the upper and lower parts of the body, facilitating the transmission of forces and coordinating all the movements. The analysis of lumbar spine movements in relation to the upper and lower back regions, may be important to better understand the compensatory strategies used by LBP patients, and potentially, to highlight therapeutic options, particularly in rehabilitation medicine.

Therefore, the objective of this study is to conduct a review and meta-analysis of relevant articles published until August 2022, with a specific focus on how LBP affects the movement of the lumbar spine during various activities of daily living. Additionally, we will consider the results reported for both the thoracic and pelvic regions. Secondary objectives include evaluating the employed methodologies and identifying key factors required to explain the relationship between LBP and spinal mobility.

2. Methods

2.1. Protocol

This systematic review was conducted following the PRISMA guidelines (Moher et al., 2009).

2.2. Eligibility criteria

Studies included were observational study design (cross-sectional). No priori restrictions were imposed regarding publication date, size or characteristic of the population or duration of LBP.

Studies are selected based on the following selection criteria:

- The presence of a comparator control group (subjects without LBP),
- Kinematic measurements were conducted on both LBP and control groups,
- Participants performed clinical functional test, gait in any situations, daily functional activity or any kind of sports activity,
- Movement of the lumbar spine in at least one anatomical plane was reported: the main relevant, outcomes were range of motion (RoM), velocity, acceleration/deceleration, lumbar lordosis angle.

Articles are excluded if they:

- Were longitudinal studies,
- Studied pathological causes and psychological factors of LBP,
- Studied the effect of stabilization exercises or other functional treatment on the lumbar spine kinematics,
- Reported kinematic characteristics of the entire trunk without specifying the movement in the lumbar spine,
- Reported muscular data as the only outcome result,
- Studied passive movement or only static (except comparison with movement)
- Were published in languages other than English,
- Included participants with induced LBP or pain-free.

2.3. Information sources and search strategies

This review of literature was conducted using PubMed, Scopus and Web of science databases. No complementary search was conducted (e.g. authors contacts, cited references, conference abstract, thesis etc).

The research formula was established in a collegial manner among the authors and verified by a senior researcher following the PRESS Guideline Evidence-Based Checklist. Two reviewers working independently conducted electronic searches. Intuitive problem keywords were optimized to “lumbar”, “lumbar spine”, “lower back”; “lower back pain”, “low back pain”, “lumbago”; possible outcomes to “motion*”, “mobility”, “movement*”, “biomechanic*”, “kinematic*”, “lordosis”, “excursion”, “velocity” or “acceleration”; comparator group to “control*”, “without”, “healthy”, “no history” or “compar*”. “muscl*”, “treat*” and “exercise*” were excluded to optimize the results.

Boolean logical operators [AND, OR, NOT] are used in searching databases in order to narrow our search results. The search string used was adapted to each database (Additional file 1).

Updates were done re-running the search formula with date filter. Last update was August 2022. All papers found by the databases were imported to Zotero reference management software.

2.4. Study selection and data extraction

First, duplicated studies were removed using Zotero “Find duplicates” functionality. Then, all papers retrieved from the databases were reviewed by two authors to eliminate non-articles (such as literature reviews, letters, or responses to publication) and no English language publication. They read titles and abstracts to eliminate irrelevant articles. If there was any hesitation, the full text was read to decide to include it or not. The excluded articles were categorized according to the reason for their non-inclusion and the eligible articles were retain.

The full texts of included articles were read by two authors who extracted data and another author checked the extraction for accuracy. The data were authors names, date of publication, population size (control and LBP subjects), population characteristic (sex, age, BMI), LBP characteristic (type, intensity and influence on the functional capacities), movement performed, measurement device used, spinal segment analyzed, main outcomes and overall result.

2.5. Quality assessment of included studies

The included studies were assessed for methodological quality. A checklist was developed from previously validated checklists (Downs and Black, 1998; Smith et al., 2018) and was adapted with the study designs of this present review. The checklist consists of 4 domains: participant characteristics, LBP characteristics, experimental measures-protocol, and outcomes- data presentation with a total of 18 items (Table 1). Each Item was scored as positive (+) if it met the criteria, negative (−) if not and (+/−) if the information is not sufficient. A weight was defined for each of answers as following, (+) = 1.0, (−) = 0.0 and (+/−) = 0.5. Then, after answering all the questions for each included study, a total score was calculated and a mid-point score (>50%) which corresponds to a total of 9 or more points was defined as a cutoff score to identify high-quality studies.

2.6. Data synthesis and analysis

The main analysis was conducted to assess the association of LBP

Table 1
Developed checklist for studies assessment quality.

Domain	Item	Description
Participants characteristics	1. Age	Summary measure (e.g., range or mean and SD)
	2. Sex	Number or ratio male/female
	3. BMI	Summary measure (e.g., range or mean and SD)
	4. Groups features	both groups are comparable for age, sex, weight and height or BMI (no significant difference)
	5. Specific participant group	Specificity of both groups from a participation or activity (e.g., specific sport; military; ethnicity; etc.)
	6. History of LBP	Information regarding whether participants had previous history of LBP
LBP characteristics	7. Type	Etiology of LBP (e.g., non-specific, stenosis, etc.)
	8. Duration	Information about duration of LBP (acute, subacute or chronic)
	9. Pain intensity	Pain intensity level using a valid and reliable scale (e.g., Visual Analog Scale (VAS) or Numerical Pain Rating Scale (NPRS))
	10. Disability level	Disability level using a valid and reliable scale (e.g., Oswestry Disability Index (ODI) and Roland-Morris Disability Questionnaire (RMD))
Experimental measurements / protocol	11.Tasks	Movement tasks are clearly defined
	12. Segments analyzed	The spine segments clearly stated
	13. Groups measurements procedures	The measurement procedures applied to both groups are the same
	14. Equipment	The equipment and set-up clearly described
	15. Measurement location	The marker/sensors' locations accurately described (if applied)
Outcomes and data presentation	16. Main outcomes	The main outcomes of the study and how were calculated are stated
	17. Between group comparison	The statistical results of group comparisons were presented
	18. Simple size	Information about power calculation

with lumbar kinematics. We compared spine kinematics with and without LBP, particularly in the lumbar region, but also in the thoracic and pelvic region, if reported in the included studies. We synthesized the data qualitatively and quantitatively where possible.

Firstly, we grouped the studies into summary tables based on the type of movement performed to create homogenized subgroups of studies.

Secondly, for all studies with available data, the sample size, mean, and standard deviation (SD) for each kinematic spinal outcome measured in the frontal, sagittal, and transverse planes were extracted. The means and SD of lumbar, thoracic, and pelvic RoM data (°), angular velocity (°/s) were extracted if provided for the LBP and the control groups. A meta-analysis was then performed if there were two or more studies that reported differences in the same outcome between the two groups.

Continuous data are presented using standardized mean difference and 95% confidence interval (CI). The heterogeneity between studies was assessed for each outcome using the chi-square (χ^2) test with a significance level of $P < 0.1$. The I^2 statistic was employed to quantify the heterogeneity. If significant heterogeneity was detected ($P > 0.1$ and $I^2 > 50\%$), a random-effects model was used. Otherwise, a fixed-effects model was applied (when $P < 0.1$ and $I^2 < 50\%$). The meta-analysis was based only on the data reported in the articles, as no additional or missing data were obtained from the authors.

3. Results

3.1. Study selection

Out of 804 identified articles, 464 were left after removing duplicates. Following a rigorous screening process that evaluated titles, abstracts, and full texts, 48 articles were selected to be included in the review (Fig. 1).

3.2. Study characteristics

The included studies were published between 1989 and 2022. All were cross-sectional observational studies. Their characteristics are shown in additional file 2.

3.3. Population's characteristics

The sample size is ranging from 16 to 264 participants with a total of 2785 subjects (53.11% with LBP). The mean age ranged from 20 to 71.19 years for control and from 21 to 71.41 years for LBP participants, with a median age of 33 and 36.83 years, respectively. Six studies did not report the ratio men/women. On average, there were more men than women, especially in the LBP group. The mean BMI of the participants was reported in 32 studies, 17 studies (Christe et al., 2016b; Christe et al., 2017; Christe et al., 2020; Freddolini et al., 2014; Kim et al., 2014; Marich et al., 2017; Matheve et al., 2019; Miyakoshi et al., 2010; Pourahmadi et al., 2018; Pourahmadi et al., 2020; Rum et al., 2021; Sheikhhoseini et al., 2018; Tak et al., 2020; Tsang et al., 2017; Van Hoof et al., 2012; Zafereo et al., 2016; Zamiri et al., 2017) reported a mean BMI in the normal category ($18.5 \text{ Kg/m}^2 \leq \text{BMI} < 25 \text{ Kg/m}^2$) and 15 studies (Al-Eisa et al., 2006a; Al-Eisa et al., 2006b; Coyle et al., 2017; Gombatto et al., 2015; Gombatto et al., 2017; Haj et al., 2019; Hernandez et al., 2017; Hidalgo et al., 2012; Laird et al., 2018; Masharawi et al., 2020; Mitchell et al., 2017; Nagai et al., 2015; Sánchez-Zuriaga et al., 2011; Seraj et al., 2018; Shojaei et al., 2017) reported a BMI in the over-weight category ($25 \text{ Kg/m}^2 \leq \text{BMI} < 30 \text{ Kg/m}^2$).

3.4. LBP population characteristics

For 33 studies (Gombatto et al., 2015; Rum et al., 2021; Van Hoof et al., 2012)–(Akinpelu and Adeyemi, 1989; Basler et al., 2008; Boline

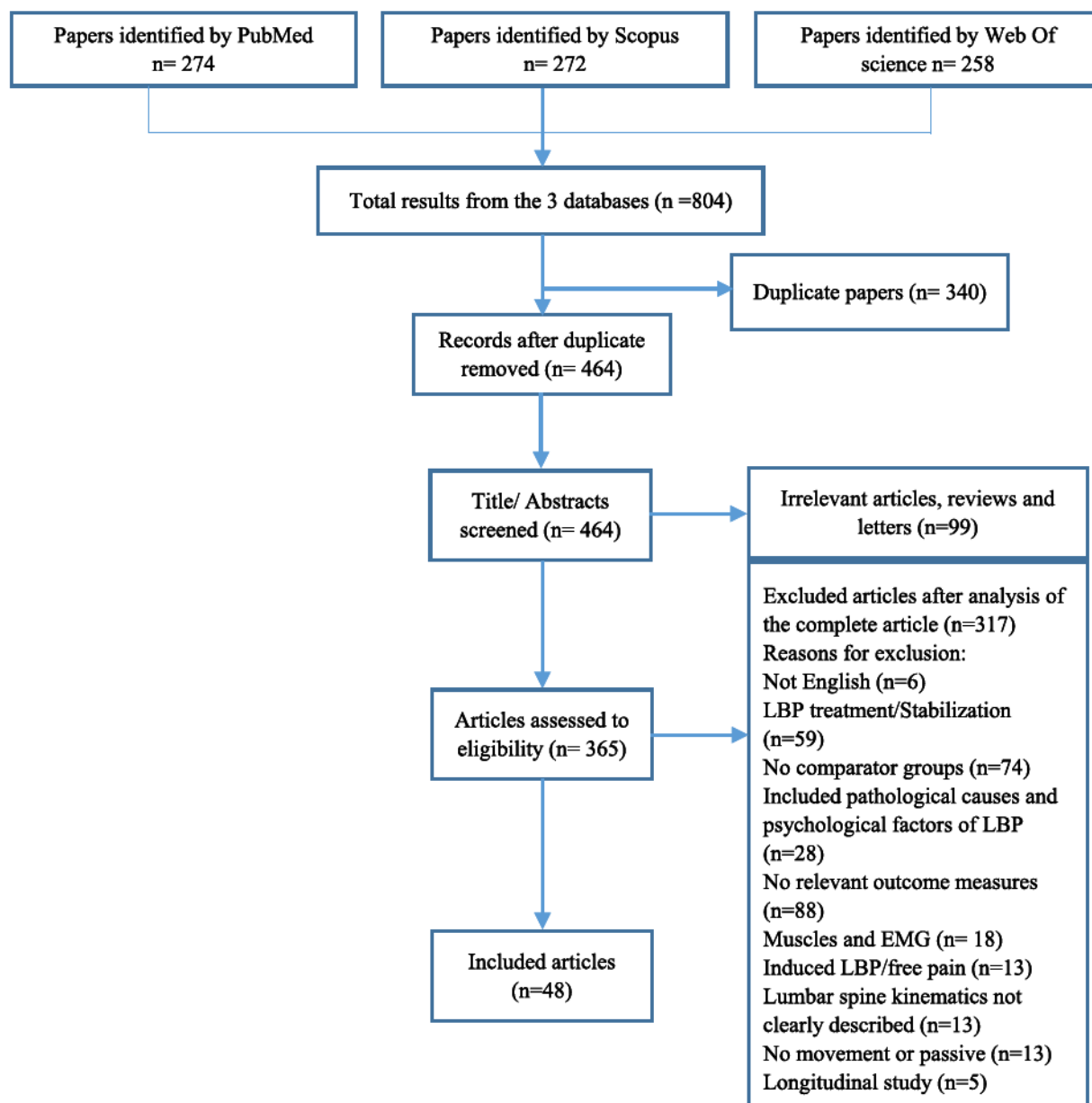


Fig. 1. Flow chart.

et al., 1992; Christe et al., 2016b; Christe et al., 2017; Coyle et al., 2017; Haj et al., 2019; Hidalgo et al., 2012; Kim et al., 2014; Laird et al., 2018; Lee et al., 2011a; Lee et al., 2011b; Marich et al., 2020; Masharawi et al., 2020; Miyakoshi et al., 2010; Papi et al., 2020; Seraj et al., 2018; Simonet et al., 2020; Sung, 2013; Vaisy et al., 2015; Wong and Lee, 2004) subjects had chronic LBP, for 5 (Freddolini et al., 2014; Nagai et al., 2015; Shojaei et al., 2017; Shum et al., 2005; Shum et al., 2007) acute to subacute LBP, and 10 remaining articles did not specify the type of LBP. A total of 35 studies (Basler et al., 2008; Christe et al., 2016b; Christe et al., 2017; Christe et al., 2020; Coyle et al., 2017; Freddolini et al., 2014; Gombatto et al., 2015; Gombatto et al., 2017; Haj et al., 2019; Hernandez et al., 2017; Hidalgo et al., 2012; Kim et al., 2014; Laird et al., 2018; Marich et al., 2017; Marich et al., 2020; Masharawi et al., 2020; Matheve et al., 2019; Mitchell et al., 2017; Nagai et al., 2015; Papi et al., 2020; Pourahmadi et al., 2018; Pourahmadi et al., 2020; Rum et al., 2021; Sheikhoseini et al., 2018; Shum et al., 2005; Shum et al., 2007; Simonet et al., 2020; Tak et al., 2020; Tsang et al., 2017; Vaisy et al., 2015; Van Hoof et al., 2012; Wildenbeest et al., 2022; Wong and Lee, 2004; Zamiri et al., 2017)

reported on pain intensity, measured by either the Visual Analog Scale VAS (18 over 50) or the Numerical Pain Rating Scale NPRS (17 over 50). 13 remaining studies did not report on the pain intensity. Reported mean pain intensity using the VAS or NPRS scale was transferred to a measurement scale of 0 to 10, and it was found to range from 1.42 to 6. The functional capacities was reported in 33 studies (Basler et al., 2008; Christe et al., 2016b; Christe et al., 2017; Christe et al., 2020; Coyle et al., 2017; Freddolini et al., 2014; Gombatto et al., 2015; Gombatto et al., 2017; Haj et al., 2019; Hernandez et al., 2017; Kim et al., 2014; Laird et al., 2018; Lee et al., 2011b; Marich et al., 2017; Marich et al., 2020; Masharawi et al., 2020; Matheve et al., 2019; Mitchell et al., 2017; Nagai et al., 2015; Papi et al., 2020; Pourahmadi et al., 2018; Pourahmadi et al., 2020; Rum et al., 2021; Sánchez-Zuriaga et al., 2011; Sheikhoseini et al., 2018; Shum et al., 2005; Shum et al., 2007; Simonet et al., 2020; Sung, 2013; Tsang et al., 2017; Vaisy et al., 2015; Wildenbeest et al., 2022; Wong and Lee, 2004); disability was measured using the Roland Morris Disability Questionnaire (RMDQ) or the Oswestry Disability Index (ODI); reported mean disability using (ODI) ranged from 1.66% to 45.5%.

3.5. Movement tasks performed

Clinical functional tests (as forward bending, side bending, backward bending, or twisting) were reported in 23 studies (Akinpelu and Adeyemi, 1989; Al-Eisa et al., 2006a; Al-Eisa et al., 2006b; Basler et al., 2008; Boline et al., 1992; Coyle et al., 2017; Haj et al., 2019; Hidalgo et al., 2012; Kim et al., 2014; Laird et al., 2018; Lee et al., 2011a; Masharawi et al., 2020; Mazloui et al., 2021; Miyakoshi et al., 2010; Nagai et al., 2015; Seraj et al., 2018; Shojaei et al., 2017; Tak et al., 2020; Tsang et al., 2017; Vaisiy et al., 2015; Wong and Lee, 2004; Zafereo et al., 2016; Zamiri et al., 2017); daily functional tests (as sitting to stand, standing to sit, stepping, lifting, picking up an object, ...) in 15 studies (Christe et al., 2016b; Christe et al., 2020; Freddolini et al., 2014; Gombatto et al., 2017; Hernandez et al., 2017; Lee et al., 2011b; Marich et al., 2017; Matheve et al., 2019; Mitchell et al., 2017; Pourahmadi et al., 2018; Pourahmadi et al., 2020; Sánchez-Zuriaga et al., 2011; Shum et al., 2005; Shum et al., 2007; Wildenbeest et al., 2022); walking trials in 4 studies (Christe et al., 2017; Gombatto et al., 2015; Rum et al., 2021; Simonet et al., 2020); sports activities (as bat swinging, cycling, and squatting) in 4 studies (Oshikawa et al., 2020; Sheikhoseini et al., 2018; Sung, 2013; Van Hoof et al., 2012); both daily functional activity and clinical functional test in 1 study (Marich et al., 2020), and both daily functional activities and walking tests in 1 study (Papi et al., 2020).

3.6. Measurement devices used

Lumbar spine kinematics were analyzed using a large number of available measuring tools; the optoelectronic camera systems are the most widely used (25 studies) (Al-Eisa et al., 2006a; Al-Eisa et al., 2006b; Christe et al., 2016b; Christe et al., 2017; Christe et al., 2020; Gombatto et al., 2015; Gombatto et al., 2017; Hernandez et al., 2017; Hidalgo et al., 2012; Kim et al., 2014; Marich et al., 2017; Marich et al., 2020; Mitchell et al., 2017; Oshikawa et al., 2020; Papi et al., 2020; Pourahmadi et al., 2018; Pourahmadi et al., 2020; Rum et al., 2021; Sánchez-Zuriaga et al., 2011; Seraj et al., 2018; Sheikhoseini et al., 2018; Simonet et al., 2020; Sung, 2013; Wildenbeest et al., 2022; Zamiri et al., 2017), with a variable number of cameras ranging from 1 to 14 and different types of 3D optoelectronic motion systems (VICON™, Oxford, UK, OPTOTRAK™, Corvallis, USA, QUALISYS™, Göteborg, Sweden...) are used. The number and the positions of markers are included in all studies. Electromagnetic measurement systems (3SPACE FASTRAK; Polhemus Inc., USA) are used in 4 studies (Freddolini et al., 2014; Shum et al., 2005; Shum et al., 2007; Wong and Lee, 2004), tri-axial electro-goniometer in 2 studies (Haj et al., 2019; Masharawi et al., 2020), inclinometer in 3 studies (Coyle et al., 2017; Nagai et al., 2015; Tak et al., 2020) and inertial sensors in 7 studies (Laird et al., 2018; Lee et al., 2011a; Lee et al., 2011b; Matheve et al., 2019; Mazloui et al., 2021; Shojaei et al., 2017; Tsang et al., 2017). The positions of the measuring sensors as well as other measuring devices were also reported. Other measuring devices were used as: one body guard monitoring system (Van Hoof et al., 2012), 1 Epionics™ spine system (Epionics Medical GmbH, Potsdam, Germany) (Vaisiy et al., 2015), 1 skin-surface device (the ValedoShape, idiag AG, Fehraltorf, Switzerland) (Zafereo et al., 2016), 1 ultrasound topometry using the device CMS 20S (Zebiris, Isny, Germany) (Basler et al., 2008), 1 computerized measurement device of surface curvature (SpinalMouse®; Idiag, Volkswill, Switzerland) (Miyakoshi et al., 2010) and 1 Skin-marking method (Akinpelu and Adeyemi, 1989).

3.7. Outcome measured

27 studies (Akinpelu and Adeyemi, 1989; Basler et al., 2008; Boline et al., 1992; Coyle et al., 2017; Gombatto et al., 2015; Gombatto et al., 2017; Hernandez et al., 2017; Matheve et al., 2019; Mazloui et al., 2021; Mitchell et al., 2017; Nagai et al., 2015; Oshikawa et al., 2020; Pourahmadi et al., 2018; Pourahmadi et al., 2020; Sheikhoseini et al.,

2018; Shum et al., 2005; Shum et al., 2007; Simonet et al., 2020; Sung, 2013; Tak et al., 2020; Tsang et al., 2017; Van Hoof et al., 2012; Wildenbeest et al., 2022; Wong and Lee, 2004) reported kinematics only in the lumbar spine region. Lumbar kinematics associated with thoracic kinematics was reported in 10 studies (Christe et al., 2020; Hidalgo et al., 2012; Papi et al., 2020; Sánchez-Zuriaga et al., 2011), with pelvic kinematics in 8 studies (Kim et al., 2014; Laird et al., 2018; Lee et al., 2011a; Marich et al., 2017; Marich et al., 2020; Vaisiy et al., 2015; Zamiri et al., 2017), and with both pelvic and thoracic kinematics in 3 studies (Lee et al., 2011b; Rum et al., 2021; Shojaei et al., 2017).

45 studies (Akinpelu and Adeyemi, 1989; Al-Eisa et al., 2006a; Al-Eisa et al., 2006b; Basler et al., 2008; Boline et al., 1992; Christe et al., 2016b; Christe et al., 2017; Christe et al., 2020; Coyle et al., 2017; Gombatto et al., 2015; Gombatto et al., 2017; Haj et al., 2019; Hernandez et al., 2017; Hidalgo et al., 2012; Kim et al., 2014; Laird et al., 2018; Lee et al., 2011a; Lee et al., 2011b; Marich et al., 2017; Marich et al., 2020; Masharawi et al., 2020; Matheve et al., 2019; Mazloui et al., 2021; Mitchell et al., 2017; Miyakoshi et al., 2010; Nagai et al., 2015; Oshikawa et al., 2020; Papi et al., 2020; Pourahmadi et al., 2018; Rum et al., 2021; Sánchez-Zuriaga et al., 2011; Sheikhoseini et al., 2018; Shojaei et al., 2017; Shum et al., 2005; Shum et al., 2007; Simonet et al., 2020; Sung, 2013; Tak et al., 2020; Tsang et al., 2017; Vaisiy et al., 2015; Van Hoof et al., 2012; Wildenbeest et al., 2022; Wong and Lee, 2004; Zafereo et al., 2016; Zamiri et al., 2017) reported RoM, 12 studies (Christe et al., 2016b; Haj et al., 2019; Hidalgo et al., 2012; Lee et al., 2011a; Masharawi et al., 2020; Oshikawa et al., 2020; Pourahmadi et al., 2018; Shojaei et al., 2017; Shum et al., 2005; Shum et al., 2007; Tsang et al., 2017; Vaisiy et al., 2015) angular velocity measurements, 4 studies (Haj et al., 2019; Masharawi et al., 2020; Shojaei et al., 2017; Tsang et al., 2017) lumbar acceleration, 5 studies (Freddolini et al., 2014; Miyakoshi et al., 2010; Pourahmadi et al., 2020; Seraj et al., 2018; Simonet et al., 2020) lumbar lordosis angle and 2 studies (Freddolini et al., 2014; Miyakoshi et al., 2010) thoracic kyphosis angle.

3.8. Methodological quality of included studies

The quality assessment of included studies is presented in additional file 3. The rating ranged from 7 to 18, with a median score of 15. Overall, 47 out of 48 of included studies were rated as high quality (≥ 9).

3.9. Summary of findings

The results of the selected studies were qualitatively summarized according to the movement performed to determine whether the outcome measures in patients with LBP compared to controls, decrease, increase or show no significant difference additional file 4.

3.10. Effect of LBP on lumbar kinematics

3.10.1. Lumbar range of motion (RoM)

Sagittal plane: 37 studies investigated lumbar RoM in the sagittal plane, of which 22 studies (Akinpelu and Adeyemi, 1989; Basler et al., 2008; Coyle et al., 2017; Hernandez et al., 2017; Hidalgo et al., 2012; Laird et al., 2018; Lee et al., 2011a; Lee et al., 2011b; Matheve et al., 2019; Mazloui et al., 2021; Miyakoshi et al., 2010; Oshikawa et al., 2020; Pourahmadi et al., 2018; Sánchez-Zuriaga et al., 2011; Shojaei et al., 2017; Shum et al., 2005; Shum et al., 2007; Sung, 2013; Tak et al., 2020; Vaisiy et al., 2015; Wong and Lee, 2004; Zamiri et al., 2017) showed limited mobility in the LBP group, 1 showed increased mobility (Kim et al., 2014), 9 studies reported no significant influence of LBP (Gombatto et al., 2015; Marich et al., 2020; Nagai et al., 2015; Rum et al., 2021; Sheikhoseini et al., 2018; Tsang et al., 2017; Wildenbeest et al., 2022; Zafereo et al., 2016) and 5 studies (Christe et al., 2016b; Christe et al., 2020; Gombatto et al., 2017; Mitchell et al., 2017; Papi et al., 2020) divided the lumbar spine into 2 regions and reported different results between the upper and lower lumbar spine.

A meta-analysis of 18 high-quality studies that reported means and SD of lumbar flexion in the sagittal plane found a significant reduction of the RoM in subjects with LBP ($P < 0.00001$; $-1.26 [-1.65, -0.88]$). From 8 studies that reported data on lumbar extension a meta-analysis confirmed that a significant limitation of the RoM is associated with LBP ($P = 0.003$; $-0.73 [-1.22, -0.24]$) (Fig. 2).

Frontal plane: 20 studies reported lumbar RoM in the frontal plane, of which 13 reported no significant difference between the LBP and control groups (Al-Eisa et al., 2006a; Al-Eisa et al., 2006b; Coyle et al., 2017; Gombatto et al., 2015; Gombatto et al., 2017; Kim et al., 2014; Lee et al., 2011b; Mazloumi et al., 2021; Mitchell et al., 2017; Oshikawa et al., 2020; Rum et al., 2021; Sung, 2013; Wildenbeest et al., 2022), 3 studies reported a limitation of the lumbar mobility in the frontal plane (Nagai et al., 2015; Vaisy et al., 2015; Wong and Lee, 2004) and in 4 studies which take into consideration 2 distinct regions, the upper and lower lumbar spine, inconsistent results were reported (Christe et al., 2017; Christe et al., 2020; Hernandez et al., 2017; Papi et al., 2020).

A meta-analysis was performed on 10 studies that reported lumbar lateral flexion data in the frontal plane, including some studies that distinguished left and right flexion without significant differences. The results showed that lateral flexion in the frontal plane was significantly

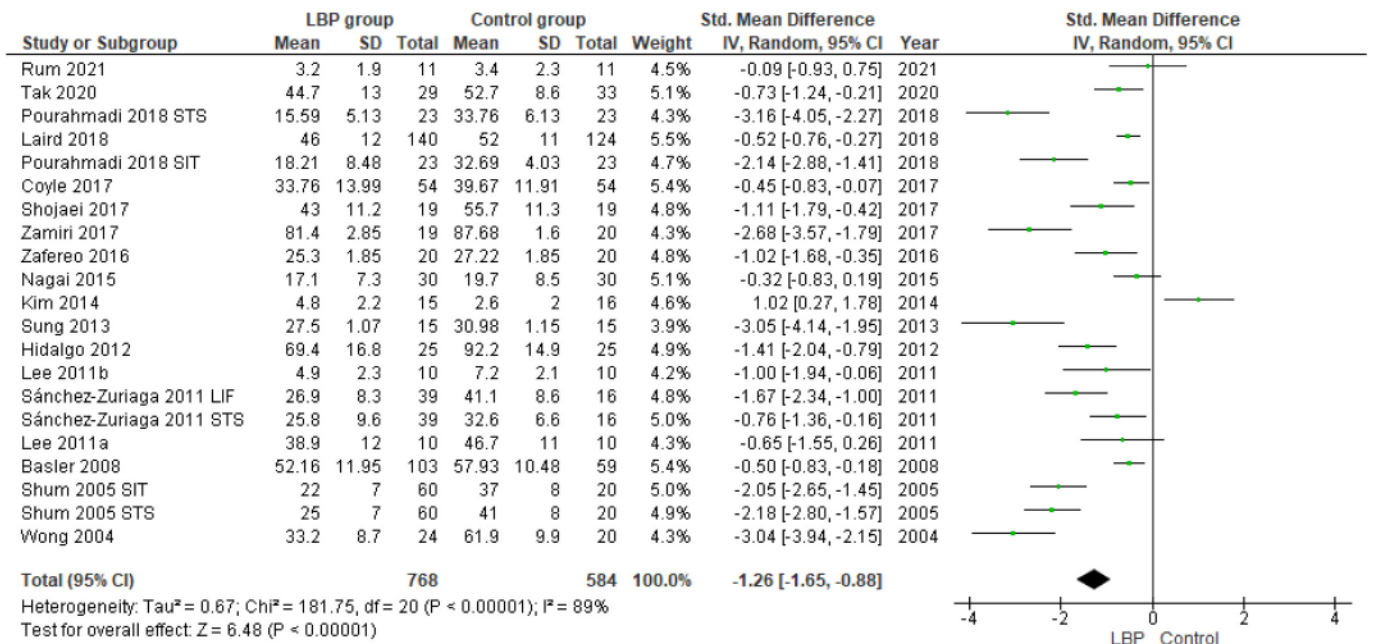
lower in the LBP group ($P = 0.0004$; $-0.97 [-1.51, -0.43]$) (Fig. 3).

Transverse plane: 23 studies reported lumbar RoM in the transverse plane in which 11 studies (Boline et al., 1992; Christe et al., 2017; Christe et al., 2020; Gombatto et al., 2015; Gombatto et al., 2017; Haj et al., 2019; Masharawi et al., 2020; Mitchell et al., 2017; Shum et al., 2007; Vaisy et al., 2015; Wong and Lee, 2004) reported a decreased rotation in the LBP group, 2 studies (Hernandez et al., 2017; Papi et al., 2020) reported inconsistent results between the lower and upper lumbar spine, and 1 study (Rum et al., 2021) reported increased mobility in LBP group. The remaining studies reported no significant difference between the two groups (Al-Eisa et al., 2006a; Al-Eisa et al., 2006b; Kim et al., 2014; Lee et al., 2011b; Mazloumi et al., 2021; Nagai et al., 2015; Oshikawa et al., 2020; Sung, 2013; Wildenbeest et al., 2022).

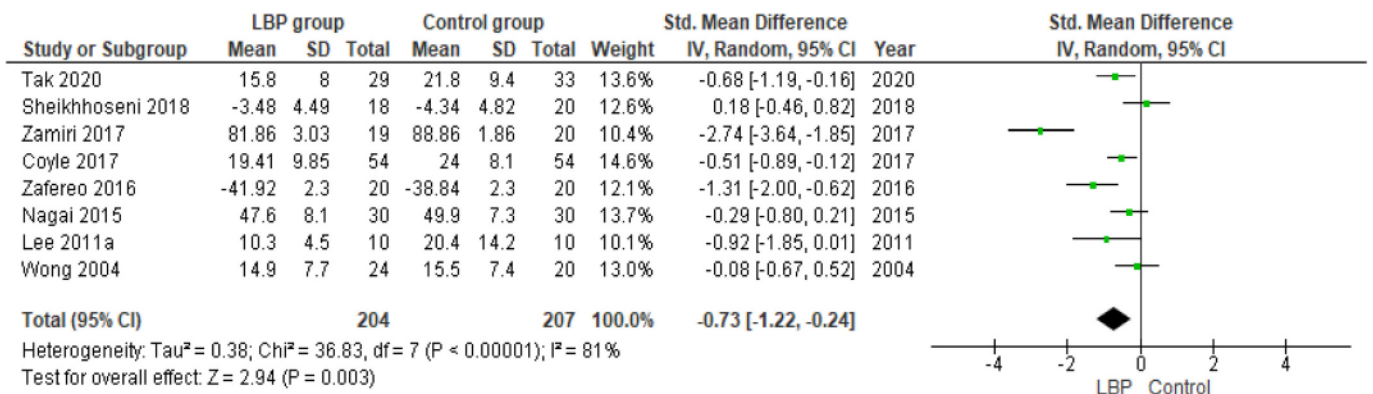
A meta-analysis on 12 studies that reported mean and SD data showed that LBP is associated with limited rotation ($P = 0.004$; $-0.56 [-0.94, -0.18]$). (Fig. 4).

3.10.2. Lumbar spine angular velocity

12 studies reported lumbar angular velocity; 9 of them reported that the LBP group adopted a reduced lumbar angular velocity (Freddolini et al., 2014; Hidalgo et al., 2012; Lee et al., 2011a; Marich et al., 2017;



(A) Flexion



(B) Extension

Fig. 2. Forest plots of studies investigating the association between LBP and lumbar sagittal RoM (STS: Sit-to-stand; SIT: Stand-to-sit; LIF: Lifting).

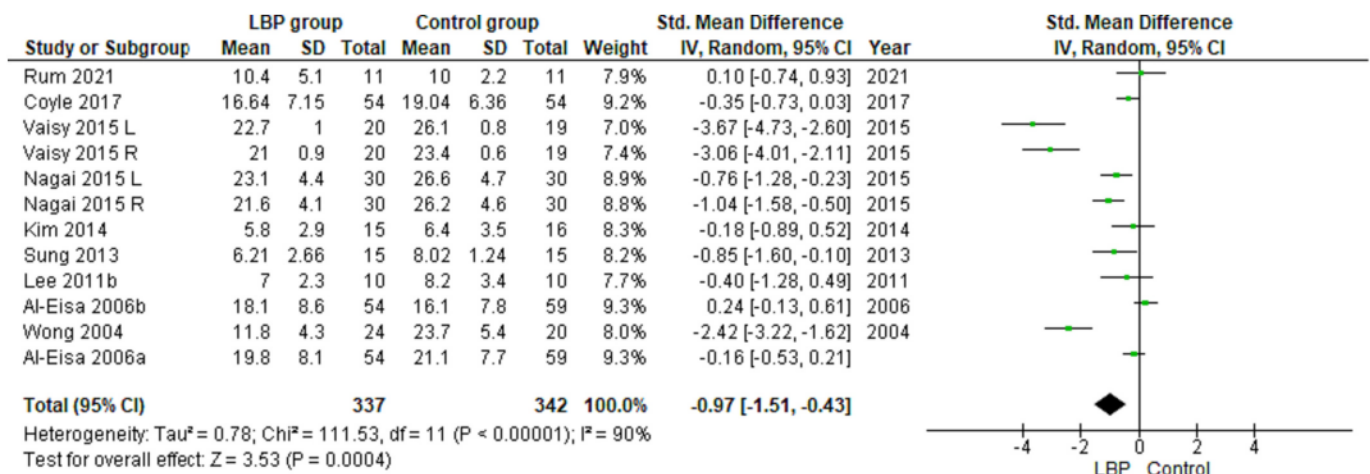


Fig. 3. Forest plots of studies investigating the association between LBP and lumbar frontal RoM (L: Left side bending; R: Right side bending).

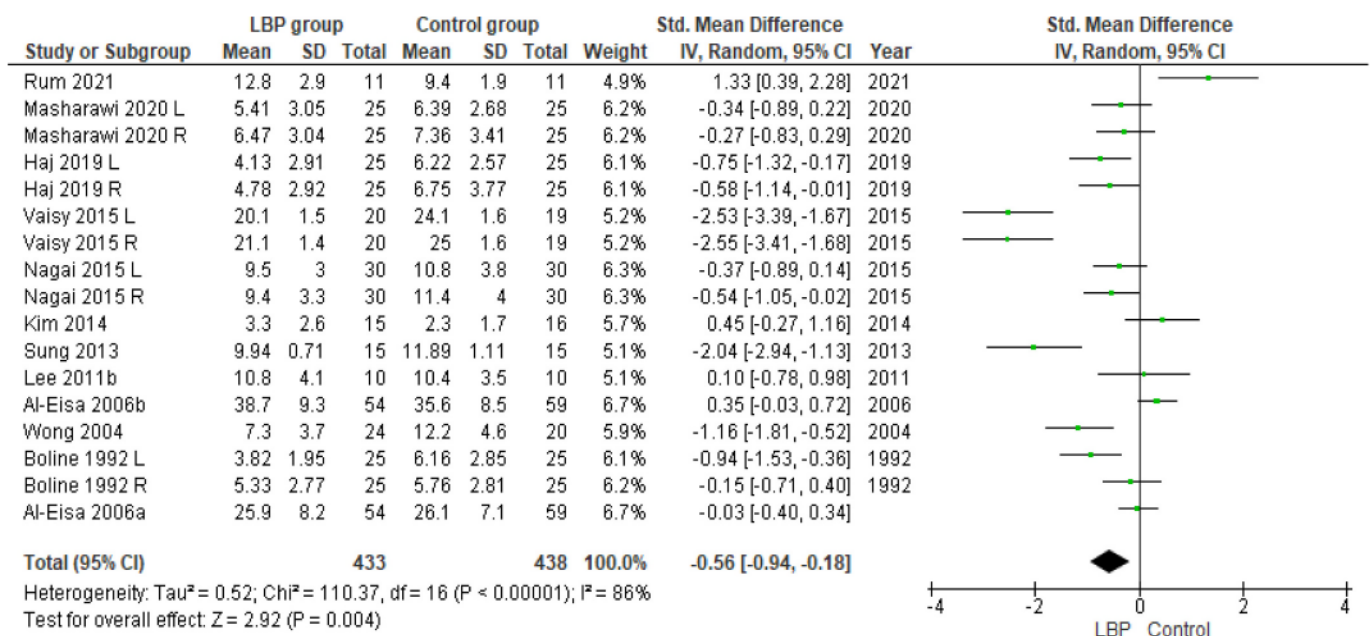


Fig. 4. Forest plots of studies investigating the association between LBP and lumbar Transverse RoM.

Sheikhhosseini et al., 2018; Shojaei et al., 2017; Shum et al., 2005; Shum et al., 2007; Vaisy et al., 2015) and one reported an increase (Oshikawa et al., 2020) in the sagittal plane. Two studied (Haj et al., 2019; Seraj et al., 2018) reported a decreased lumbar velocity in the transverse plane.

A meta-analysis performed on five studies reported a significant decrease of lumbar angular velocity in the sagittal plane with LBP ($P < 0.00001$); $-1.70 [-2.33, -1.08]$ (Fig. 5).

Another meta-analysis was also performed on 2 studies (Haj et al., 2019; Seraj et al., 2018) that reported lumbar angular velocity in the

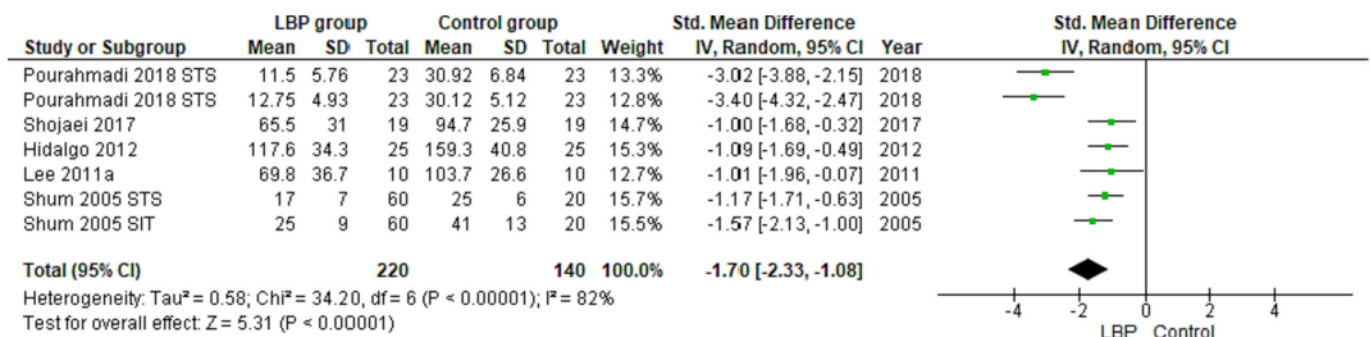


Fig. 5. Forest plots of studies investigating the association between LBP and lumbar sagittal angular velocity.

transverse plane and showed a significantly reduced rotation velocity in LBP group ($P < 0.0001$); $-0.63 [-0.91, -0.34]$ (Fig. 6).

3.10.3. Additional lumbar kinematics

Three studies (Freddolini et al., 2014; Pourahmadi et al., 2020; Simonet et al., 2020) found a decrease in lumbar lordosis angle in the LBP group, one (Seraj et al., 2018) showed no significant difference, and one reported an increase (Miyakoshi et al., 2010). Similarly, a decrease in lumbar spine acceleration during different movements was reported in 4 studies (Haj et al., 2019; Masharawi et al., 2020; Shojaei et al., 2017; Tsang et al., 2017). The reported data were not sufficient to perform a meta-analysis.

3.11. Effect of LBP on thoracic and pelvic spine kinematics

3.11.1. Thoracic spine RoM

Thoracic RoM was studied during a total of 16 different movements in 13 studies in at least one plane of motion.

Sagittal plane: 9 studies analyzed thoracic RoM in the sagittal plane, of which 4 reported no significant difference between groups (Lee et al., 2011b; Miyakoshi et al., 2010; Rum et al., 2021; Zafereo et al., 2016), 2 reported a decrease in LBP group thoracic ROM. Three studies (Freddolini et al., 2014; Matheve et al., 2019; Papi et al., 2020) studied during three different movements the RoM of the upper and lower thoracic spine separately, and reported inconsistent results between the two regions.

Frontal plane: 7 studies analyze thoracic RoM in the frontal plane, of which 4 reported no significant difference between the two groups (Al-Eisa et al., 2006b; Christe et al., 2017; Lee et al., 2011b; Rum et al., 2021), one a decrease in the LBP group (Al-Eisa et al., 2006a). Two studies dissociate upper and lower thoracic regions during different movements (Christe et al., 2020; Papi et al., 2020) and showed no significant difference between the groups.

Transverse plane: 8 studies analyzed thoracic RoM in the transverse plane, of which 4 reported no significant difference, 2 studies reported a decrease in RoM in LBP group (Al-Eisa et al., 2006a; Al-Eisa et al., 2006b) and two reported different results between the upper and lower thoracic regions (Christe et al., 2020; Papi et al., 2020).

A meta-analysis performed on 6 studies (Al-Eisa et al., 2006a; Al-Eisa et al., 2006b; Lee et al., 2011b; Rum et al., 2021; Sánchez-Zuriaga et al., 2011; Shojaei et al., 2017; Zafereo et al., 2016) that reported thoracic spine RoM data, showed no significant difference between LBP and control groups in the sagittal plane ($p = 0.32$; $-0.34 [-1.00, 0.33]$). In the frontal and transverse planes, RoM was significantly decreased in LBP group ($p = 0.03$; $-0.27 [-0.52, -0.03]$, $p = 0.03$; $-0.25 [-0.48, 0.02]$, respectively) (Fig. 7).

3.11.2. Pelvic spine RoM

A total of 10 studies analyzed pelvic RoM in at least one of the movement planes.

Sagittal plane: 9 studies reported pelvic RoM in the sagittal plane, of which 4 reported a decrease in pelvic RoM in the LBP group (Laird et al., 2018; Lee et al., 2011a; Vaisy et al., 2015; Zamiri et al., 2017), only one

reported an increase (Kim et al., 2014) and 4 studies reported no significant difference between the two groups (Lee et al., 2011b; Marich et al., 2020; Oshikawa et al., 2020; Rum et al., 2021).

Frontal plane: 3 studies reported pelvic RoM with no significant difference between groups (Lee et al., 2011b; Oshikawa et al., 2020; Rum et al., 2021).

Transverse plane: 1 study reported an increase of RoM in LBP group (Shojaei et al., 2017) and 3 reported no significant difference (Lee et al., 2011b; Oshikawa et al., 2020; Rum et al., 2021).

A meta-analysis performed on 6 studies (Gombatto et al., 2015; Hoy et al., 2012; Laird et al., 2018; Sheikhoseini et al., 2018; Shojaei et al., 2017; Zamiri et al., 2017) showed no significant difference between groups in the sagittal, frontal and transverse plane ($p = 0.08$; $-0.83 [-1.77, 0.11]$, $p = 0.86$; $0.06 [-0.55, 0.66]$, $p = 0.16$; $0.83 [-0.34, 1.99]$, respectively) (Fig. 8).

4. Discussion

4.1. Overview

This literature review aimed to determine how LBP affects spinal kinematics. 48 articles were finally selected. The selection is closer to (Laird et al., 2014) with 5 common sources out of 48 and 3 out of 29 in the meta-analysis.

Out of the 48 articles, 47 showed high quality and eligible for meta-analysis. Most of the studies focused on the kinematics of lumbar spine during various movements.

The results of the studies were analyzed qualitatively to determine if subjects with LBP showed different outcomes compared to control group depending on the movement being performed. When possible, a meta-analysis was performed to quantitatively synthesize the findings and determine the level of mobility limitation in subjects with LBP.

4.2. Relation between lumbar kinematics and LBP

The meta-analysis confirmed the results of the qualitative analysis, demonstrating a significant limitation of movement in LBP group, especially in the sagittal plane, and particularly during flexion, which was the most frequently studied movement. The limitation was also significant in the transverse and frontal planes even though the qualitative analysis found lower mobility in only some studies.

Some studies investigated lumbar spine kinematics with a partition of upper and lower segments, showing inconsistent results between LBP and controls in both segments. In addition, although the search strategy primarily focused on articles that analyzed the lumbar spine as the region most affected by LBP, some studies also included thoracic or pelvic kinematics, with statistically significant differences between the control and LBP groups in the thoracic segment in the frontal and transversal planes, but not in the pelvic segment. Results in the upper and lower thoracic parts did not conclude on a significant difference. This highlights the need for more studies on spinal motion to evaluate the contribution of lumbar segments, as well as the thoracic and pelvic junctions.

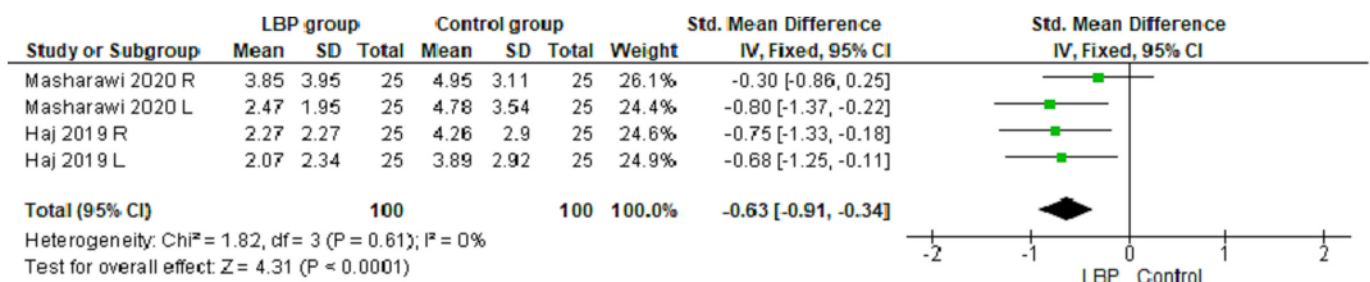


Fig. 6. Forest plots of studies investigating the association between LBP and lumbar transversal angular velocity.

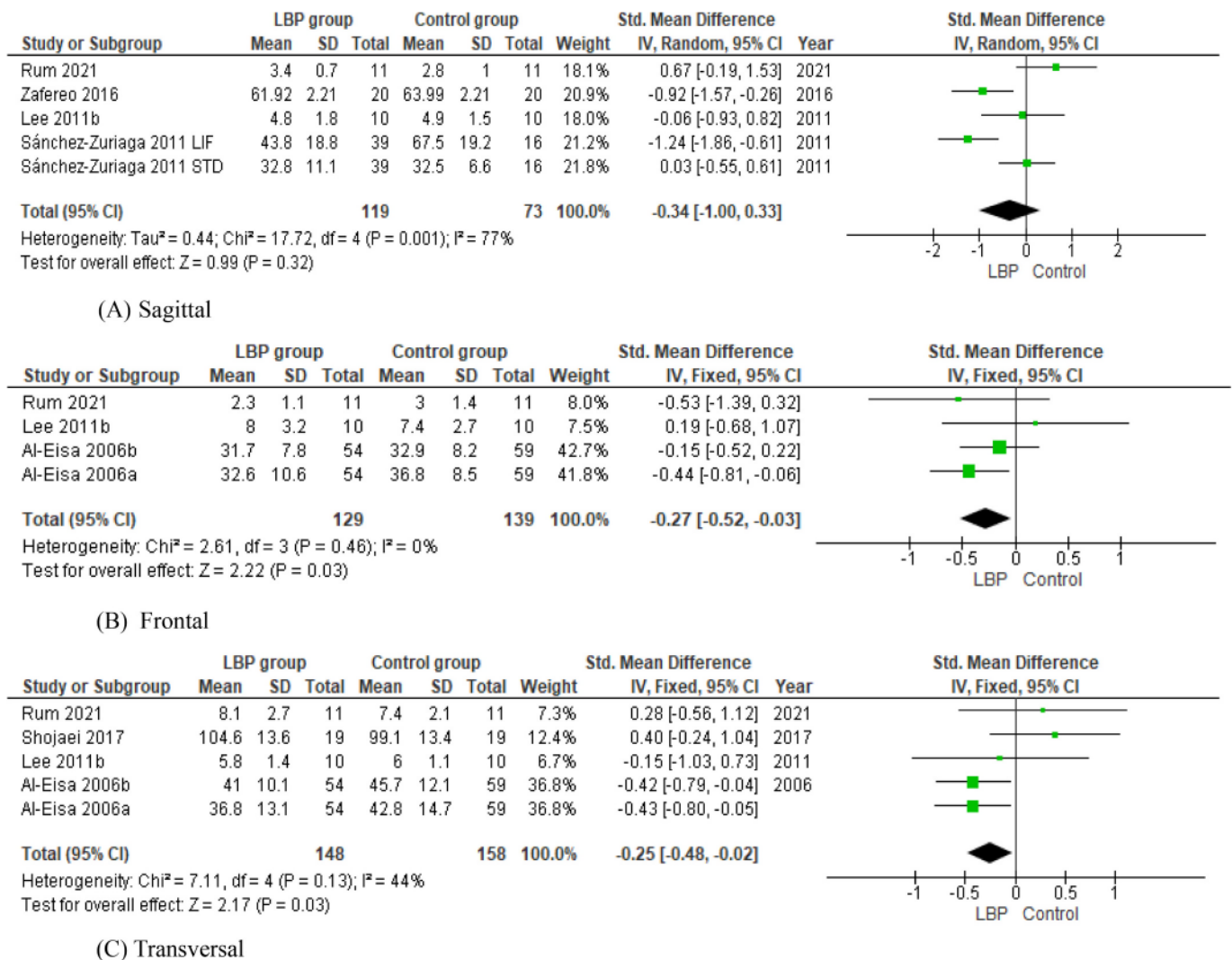


Fig. 7. Forest plots of studies investigating the association between LBP and Thoracic ROM.

Certain studies reported significant differences between LBP and control groups in terms of velocity of movement, deceleration and acceleration, asymmetry in lumbar movement, and coordination between the lumbar spine and hip joint. However, some of these studies did not find any difference in total lumbar range of motion (RoM) between the two groups. These findings suggest that focusing only on RoM may not provide enough information to show a difference between the control and LBP groups. Instead, movement speed, asymmetry, and coordination between segments may be better indicators of the impact of LBP on the kinematics of the spine.

Additionally, it is interesting to investigate the association between mobility limitations in LBP patients and the level of functional limitations reported on self-administered questionnaires such as the Oswestry Disability Index (ODI). In a study (Marich et al., 2017), it was found that the amount of lumbar excursion in the early phase of movement was greater in LBP subjects and high levels of functional limitation (ODI (0–100%): 33.8 (8.7)) than in LBP subjects with low levels of functional limitation (ODI (0–100%): 12.0 (4.4)) and control subjects during different daily functional activities.

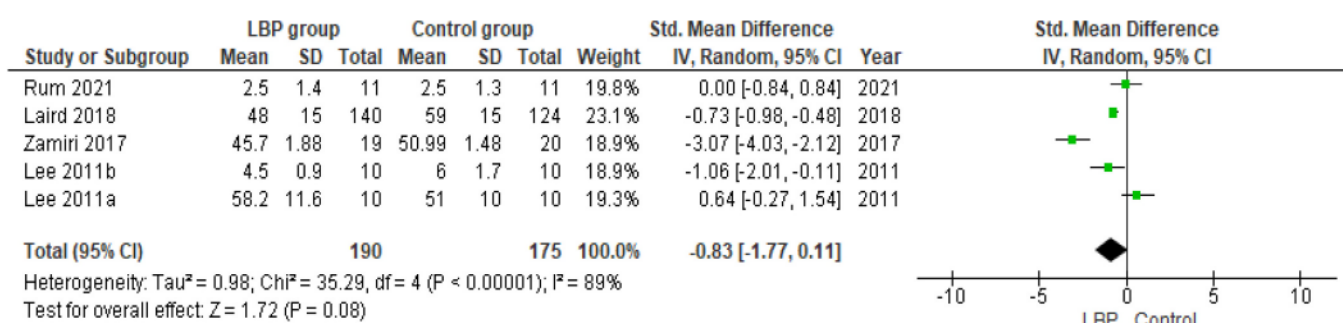
Overall, although the kinematic parameters vary across the selected studies, the lumbar mobility reduction in terms of RoM and velocity may be explained by pain or muscle defense, and an habitual movement pattern as the result of the LBP condition (Hernandez et al., 2017; Mitchell et al., 2017). However, based on this review and data analyses, we cannot establish any relationship between lumbar kinematics, pain

intensity, and duration of LBP, as these factors are not indicated in the included studies. Additionally, there is insufficient analysis to establish any relationship with muscular strength or power of the spine or trunk. However, we can consider that an analysis of muscular activity (neurophysiological activity, strength, power, ...) could be relevant and associated, but difficult. Muscle activity in LBP has been extensively studied, but the results remain contradictory regarding whether the observed changes in muscle activity are causes or consequences of LBP.

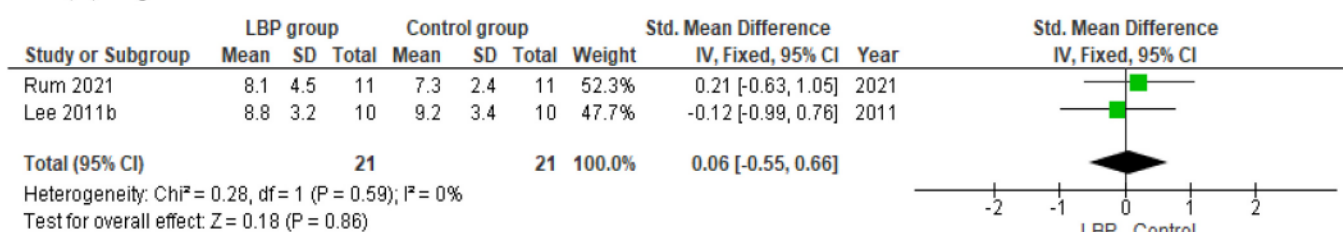
4.3. Performed movements or activities and spine kinematics methodology

There are various activities used to analyze lumbar movements, and the comparison between the results obtained showed more significant differences between the control and LBP groups when high effort is required (such as cycling) compared to a light activity (such as walking). In the sagittal plane, the most significant differences were found in studies investigating sit-to-stand or stand-to-sit activity (Pourahmadi et al., 2018; Shum et al., 2005), squatting sport activity (Sung, 2013) or cycling (Zamiri et al., 2017), and the lowest during walking activity (Rum et al., 2021).

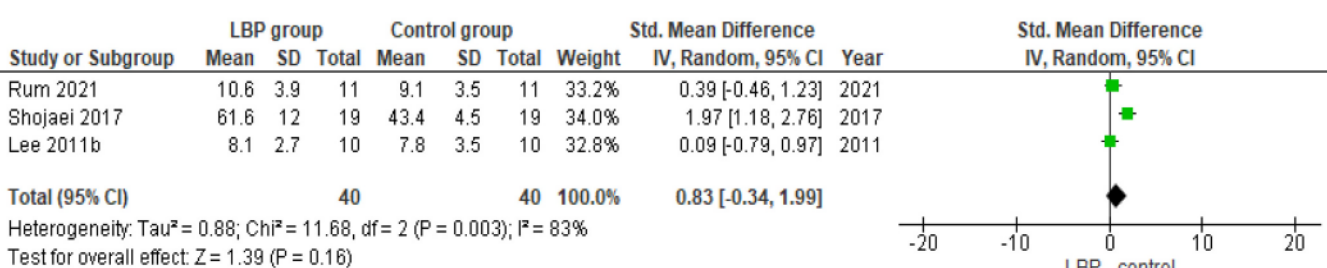
Therefore, it seems particularly relevant to assess daily functional activities, as they are a real challenge for people with LBP. Step-up activities have proven to be relevant for studying standardized movements and increasing the difficulty (for example, by changing the height of the step) (Christe et al., 2020). Movements that allow postural changes, such



(A) Sagittal



(B) Frontal



(C) Transversal

Fig. 8. Forest plots of studies investigating the association between LBP and pelvic RoM.

as sit to stand or stand to sit, could increase the number of measures differing between the control and LBP groups.

Moreover, a variety of noninvasive instruments and measurement methodologies were used in the studies to collect kinematics data. The 3D optical motion capture system, considered the gold standard instrument for motion analysis, is the most widely used tool. This system has been shown to be able to accurately assess the kinematics of several joints simultaneously and identify differences between its different subregions in different planes, providing comprehensive biomechanical information regarding global movement strategies.

However, the main problem with these methods is the lack of a consistent approach to spine measurement, especially with respect to marker placement. Nevertheless, most of the spine models used in the included studies were tested and found to be valid and reliable for measuring kinematics and identifying patients with LBP (Gombatto et al., 2015; Mitchell et al., 2017)–(Gombatto et al., 2017).

Electromagnetic tracking systems, which are based on tracking the position and orientation of body segments using receivers within an electromagnetic field, were also used. This type of system has proven to be a good alternative to optical 3D systems because it offers great possibilities for fast and accurate acquisition of 3D kinematic data.

Some clinical inertial sensor systems consisting of accelerometers, magnetometers, and gyroscopes were also used as a reliable alternative and because they can also be applied to multi-body segments and have been able to provide 3D kinematics during specific motions. They can be

considered of great interest for kinematics measurement because of their small size, low cost, reliability, and proven good performance compared to standard systems such as electromagnetic tracking and optical systems, which are complex and expensive.

Additional different instruments were used in the remaining studies (12 out of 48), but less information on their accuracy and reliability was provided.

In general, the results of this review confirmed that the kinematics of the lumbar spine, particularly in the sagittal plane, are the most affected by LBP and the most important parameter to study. However, despite the limited number of studies, thoracic and pelvic RoM, and probably, lumbo-thoracic junctions, must also be considered.

4.4. Limitations of the review

Although the search was constructed to be as homogeneous as possible, with strict eligibility criteria and a methodological approach that included an assessment of overall quality and a meta-analysis based on reported results, several limitations must be considered.

First, the heterogeneity between studies, including sample size and population characteristics (age, BMI, gender, etc.), remains a potential bias. As a primary drawback, it was impossible to extract any relationship between population characteristics and spinal kinematics.

Second, the characteristics of LBP, such as duration, pain intensity, functional abilities, and potential osteo-articular types of lesions, differ

or are missing. Thus, a more restricted but well-documented clinical form of LBP is recommended for future work. A small number of studies reported interesting data for the thoracic and pelvic spine, highlighting the interest in associated above and below spinal segments in future studies.

Third, the lack of standardized methods for measuring spinal kinematics, in terms of instruments used, marker positions, and sites considered, makes it complicated to draw conclusions with high reliability, even when considering the same movement performed.

Moreover, despite the evidence of mobility limitations in LBP patients, this review did not highlight the cause-and-effect relationship between this limitation and LBP.

5. Conclusion

The present review investigated lumbar kinematics in individuals with and without LBP, revealing a significant reduction in lumbar range of motion (RoM), particularly in the sagittal plane, among those with LBP. The meta-analysis further supports these findings, confirming the decrease in lumbar RoM in individuals with LBP across all planes, but not necessarily in all planes for thoracic and pelvic range of motion. It emphasizes the importance of considering complex daily activities involving different spinal segments and planes when assessing and managing LBP, taking into account parameters such as RoM, velocity, acceleration.

While this review provides valuable insights into the impact of LBP on spinal kinematics during specific movements, it is important to acknowledge its limitations. Further research is then needed to address these limitations and strengthen our understanding in this area.

Fundings

This work was supported by the French National Association of Research and Technology (ANRT) under grant number 2020/0110.

CRediT authorship contribution statement

Aicha Errabity: Conceptualization, Methodology, Data curation, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. **Paul Calmels:** Conceptualization, Supervision, Formal analysis, Methodology, Writing – review & editing. **Woo-Suck Han:** Conceptualization, Data curation, Writing – review & editing. **Rébecca Bonnaire:** Conceptualization, Data curation. **Romain Pannetier:** Conceptualization, Data curation. **Reynald Convert:** Conceptualization, Writing – review & editing. **Jérôme Molimard:** Conceptualization, Methodology, Supervision, Data curation, Formal analysis, Resources, Writing – review & editing.

Declaration of Competing Interest

None.

Acknowledgments

The authors would like to thank Ms. Stéphanie Villet for her comments and valuable feedback.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.clinbiomech.2023.106070>.

References

Akinpelu, A.O., Adeyemi, A.I., 1989. Range of lumbar flexion in chronic low back pain. *Cent. Afr. J. Med.* 35 (7), 430–432.

- Al-Eisa, E., Egan, D., Deluzio, K., Wassersug, R., 2006a. Effects of pelvic skeletal asymmetry on trunk movement: three-dimensional analysis in healthy individuals versus patients with mechanical low back pain. *Spine* 31 (3), E71–E79. <https://doi.org/10.1097/01.brs.0000197665.93559.04>.
- Al-Eisa, E., Egan, D., Deluzio, K., Wassersug, R., 2006b. Effects of pelvic asymmetry and low back pain on trunk kinematics during sitting: a comparison with standing. *Spine* 31 (5), E135–E143. <https://doi.org/10.1097/01.brs.0000201325.89493.5f>.
- Arshad, R., Pan, F., Reitmaier, S., Schmidt, H., 2019. Effect of age and sex on lumbar lordosis and the range of motion. A systematic review and meta-analysis. *J. Biomech.* 82, 1–19.
- Basler, H.-D., Luckmann, J., Wolf, U., Quint, S., 2008. Fear-avoidance beliefs, physical activity, and disability in elderly individuals with chronic low back pain and healthy controls. *Clin. J. Pain* 24 (7), 604–610. <https://doi.org/10.1097/AJP.0b013e31816b54f6>.
- Boline, P.D., Keating, J.C., Haas, M., Anderson, A.V., 1992. Interexaminer reliability and discriminant validity of inclinometric measurement of lumbar rotation in chronic low-back pain patients and subjects without low-back pain. *Spine* 17 (3), 335–338. <https://doi.org/10.1097/00007632-199203000-00015>.
- Christe, G., Redhead, L., Legrand, T., Jolles, B.M., Favre, J., 2016a. Multi-segment analysis of spinal kinematics during sit-to-stand in patients with chronic low back pain. *J. Biomech.* 49 (10), 2060–2067. <https://doi.org/10.1016/j.jbiomech.2016.05.015>.
- Christe, G., Redhead, L., Legrand, T., Jolles, B.M., Favre, J., 2016b. Multi-segment analysis of spinal kinematics during sit-to-stand in patients with chronic low back pain. *J. Biomech.* 49 (10), 2060–2067. <https://doi.org/10.1016/j.jbiomech.2016.05.015>.
- Christe, G., Kade, F., Jolles, B.M., Favre, J., 2017. Chronic low back pain patients walk with locally altered spinal kinematics. *J. Biomech.* 60, 211–218. <https://doi.org/10.1016/j.jbiomech.2017.06.042>.
- Christe, G., Rochat, V., Jolles, B.M., Favre, J., 2020. Lumbar and thoracic kinematics during step-up: comparison of three-dimensional angles between patients with chronic low back pain and asymptomatic individuals. *J. Orthop. Res.* 38 (6), 1248–1256. <https://doi.org/10.1002/jor.24575>.
- Coyle, P.C., Velasco, T., Sions, J.M., Hicks, G.E., 2017. Lumbar mobility and performance-based function: an investigation in older adults with and without chronic low back pain. *Pain Med. Malden Mass* 18 (1), 161–168. <https://doi.org/10.1093/pm/pnw136>.
- Downs, S.H., Black, N., 1998. The feasibility of creating a checklist for the assessment of the methodological quality both of randomised and non-randomised studies of health care interventions. *J. Epidemiol. Community Health* 52 (6), 377–384.
- Freddolini, M., Strike, S., Lee, R., 2014. Dynamic stability of the trunk during unstable sitting in people with low back pain. *Spine* 39 (10), 785–790. <https://doi.org/10.1097/BRS.0000000000000296>.
- Ghamkhar, L., Kahlae, A.H., 2015. Trunk muscles activation pattern during walking in subjects with and without chronic low back pain: a systematic review. *PM&R* 7 (5), 519–526.
- Gombatto, S.P., Brock, T., DeLork, A., Jones, G., Madden, E., Rinere, C., 2015. Lumbar spine kinematics during walking in people with and people without low back pain. *Gait Posture* 42 (4), 539–544. <https://doi.org/10.1016/j.gaitpost.2015.08.010>.
- Gombatto, S.P., et al., 2017. Differences in kinematics of the lumbar spine and lower extremities between people with and without low back pain during the down phase of a pick up task, an observational study. *Musculoskelet. Sci. Pract.* 28, 25–31. <https://doi.org/10.1016/j.msksp.2016.12.017>.
- Haj, A., Weisman, A., Masharawi, Y., 2019. Lumbar axial rotation kinematics in men with non-specific chronic low back pain. *Clin. Biomech.* 61, 192–198. <https://doi.org/10.1016/j.clinbiomech.2018.12.022>.
- Hernandez, A., Gross, K., Gombatto, S., 2017. Differences in lumbar spine and lower extremity kinematics during a step down functional task in people with and people without low back pain. *Clin. Biomech.* 47, 46–52. <https://doi.org/10.1016/j.clinbiomech.2017.05.012>.
- Hidalgo, B., Gilliaux, M., Poncin, W., Detrembleur, C., 2012. Reliability and validity of a kinematic spine model during active trunk movement in healthy subjects and patients with chronic non-specific low Back pain. *J. Rehabil. Med.* 44 (9), 756–763. <https://doi.org/10.2340/16501977-1015>.
- Hoy, D., et al., 2012. A systematic review of the global prevalence of low back pain. *Arthritis Rheum.* 64 (6), 2028–2037.
- Kim, S.-H., Kwon, O.-Y., Yi, C.-H., Cynn, H.-S., Ha, S.-M., Park, K.-N., 2014. Lumbopelvic motion during seated hip flexion in subjects with low-back pain accompanying limited hip flexion. *Eur. Spine J.* 23 (1), 142–148. <https://doi.org/10.1007/s00586-013-2973-4>.
- Koes, B.W., Tulder, Van, Thomas, S., 2006. Diagnosis and treatment of low back pain. *Bmj* 332 (7555), 1430–1434.
- Laird, R.A., Gilbert, J., Kent, P., Keating, J.L., 2014. Comparing lumbo-pelvic kinematics in people with and without back pain: a systematic review and meta-analysis. *BMC Musculoskelet. Disord.* 15 (1), 1–13.
- Laird, R.A., Keating, J.L., Kent, P., 2018. Subgroups of lumbo-pelvic flexion kinematics are present in people with and without persistent low back pain. *BMC Musculoskelet. Disord.* 19 (1) <https://doi.org/10.1186/s12891-018-2233-1>.
- Lee, J.K., Desmoulin, G.T., Khan, A.H., Park, E.J., 2011a. A portable inertial sensing-based spinal motion measurement system for low back pain assessment. In: *Annu. Int. Conf. IEEE Eng. Med. Biol. Soc. IEEE Eng. Med. Biol. Soc. Annu. Int. Conf.*, 2011, pp. 4737–4740. <https://doi.org/10.1109/IEMBS.2011.6091173>.
- Lee, J.K., Desmoulin, G.T., Khan, A.H., Park, E.J., 2011b. Comparison of 3D spinal motions during stair-climbing between individuals with and without low back pain. *Gait Posture* 34 (2), 222–226. <https://doi.org/10.1016/j.gaitpost.2011.05.002>.

- Maier, C., Underwood, M., Buchbinder, R., 2017. Non-specific low back pain. *Lancet Lond. Engl.* 389 (10070), 736–747. [https://doi.org/10.1016/S0140-6736\(16\)30970-9](https://doi.org/10.1016/S0140-6736(16)30970-9).
- Marich, A.V., Hwang, C.-T., Salsich, G.B., Lang, C.E., Van Dillen, L.R., 2017. Consistency of a lumbar movement pattern across functional activities in people with low back pain. *Clin. Biomech.* 44, 45–51. <https://doi.org/10.1016/j.clinbiomech.2017.03.004>.
- Marich, A.V., Hwang, C.-T., Sorensen, C.J., van Dillen, L.R., 2020. Examination of the lumbar movement pattern during a clinical test and a functional activity test in people with and without low Back pain. *PM R* 12 (2), 140–146. <https://doi.org/10.1002/pmrj.12197>.
- Masharawi, Y., Haj, A., Weisman, A., 2020. Lumbar axial rotation kinematics in an upright sitting and with forward bending positions in men with nonspecific chronic low Back pain. *Spine* 45 (5), E244–E251. <https://doi.org/10.1097/BRS.0000000000003265>.
- Matheve, T., De Baets, L., Bogaerts, K., Timmermans, A., 2019. Lumbar range of motion in chronic low back pain is predicted by task-specific, but not by general measures of pain-related fear. *Eur. J. Pain* 23 (6), 1171–1184. <https://doi.org/10.1002/ejp.1384>.
- Mazloui, A., Kazemi, Z., Abedzadeh, S., Foroushani, A.R., 2021. Design and fabrication of portable motion recorder: comparing lumbar kinematics in workers with and without low back pain in assembly line of a car manufacturing industry. *J. Health Saf. Work* 11 (1), 55–71.
- Mitchell, K., et al., 2017. Differences in lumbar spine and lower extremity kinematics in people with and without low back pain during a step-up task: a cross-sectional study. *BMC Musculoskelet. Disord.* 18 (1) <https://doi.org/10.1186/s12891-017-1721-z>.
- Miyakoshi, N., Kasukawa, Y., Ishikawa, Y., Nozaka, K., Shimada, Y., 2010. Spinal alignment and mobility in subjects with chronic low back pain with walking disturbance: a community-dwelling study. *Tohoku J. Exp. Med.* 221 (1), 53–59. <https://doi.org/10.1620/tjem.221.53>.
- Moher, D., et al., 2009. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement (Chinese edition). *J. Chin. Integr. Med.* 7 (9), 889–896.
- Nagai, T., et al., 2015. Lumbar spine and hip flexibility and trunk strength in helicopter pilots with and without low back pain history. *Work Read. Mass* 52 (3), 715–722. <https://doi.org/10.3233/WOR-152192>.
- Oshikawa, T., Kaneoka, K., Morimoto, Y., Akuzawa, H., 2020. Comparison of lumbar kinematics with a history of low Back pain during baseball hitting. *Int. J. Sports Med.* 41 (2), 119–127. <https://doi.org/10.1055/a-1014-3041>.
- Papi, E., Bull, A.M.J., McGregor, A.H., 2018. Is there evidence to use kinematic/kinetic measures clinically in low back pain patients? A systematic review. *Clin. Biomech.* 55, 53–64. <https://doi.org/10.1016/j.clinbiomech.2018.04.006>.
- Papi, E., Bull, A.M.J., McGregor, A.H., 2020. Alteration of movement patterns in low back pain assessed by statistical parametric mapping. *J. Biomech.* 100 <https://doi.org/10.1016/j.jbiomech.2019.109597>.
- Pourahmadi, M.R., et al., 2018. Test-retest reliability of sit-to-stand and stand-to-sit analysis in people with and without chronic non-specific low back pain. *Musculoskelet. Sci. Pract.* 35, 95–104. <https://doi.org/10.1016/j.msksp.2017.11.001>.
- Pourahmadi, M., et al., 2020. Effect of chronic low Back pain on lumbar spine lordosis during sit-to-stand and stand-to-sit. *J. Manipulative Physiol. Ther.* 43 (2), 79–92. <https://doi.org/10.1016/j.jmpt.2018.11.028>.
- Rubin, D.L., 2007. Epidemiology and risk factors for spine pain. *Neurol. Clin.* 25 (2), 353–371.
- Rum, L., Brasiliano, P., Vannozzi, G., Laudani, L., Macaluso, A., 2021. Non-specific chronic low back pain elicits kinematic and neuromuscular changes in walking and gait termination. *Gait Posture* 84, 238–244. <https://doi.org/10.1016/j.gaitpost.2020.12.005>.
- Sánchez-Zuriaga, D., López-Pascual, J., Garrido-Jaén, D., de Moya, M.F.P., Prat-Pastor, J., 2011. Reliability and validity of a new objective tool for low back pain functional assessment. *Spine* 36 (16), 1279–1288. <https://doi.org/10.1097/BRS.0b013e3181f471d8>.
- Sedrez, J.A., de Mesquita, P.V., Gelain, G.M., Candotti, C.T., 2019. Kinematic characteristics of sit-to-stand movements in patients with low Back pain: a systematic review. *J. Manipulative Physiol. Ther.* 42 (7), 532–540. <https://doi.org/10.1016/j.jmpt.2018.12.004>.
- Seraj, M.S.M., Sarrafzadeh, J., Maroufi, N., Takamjani, I.E., Ahmadi, A., Negahban, H., 2018. The ratio of lumbar to hip motion during the trunk flexion in patients with mechanical chronic low back pain according to O'Sullivan classification system: a cross-sectional study. *Arch. Bone Jt. Surg.* 6 (6), 560–569.
- Sheikhhoseini, R., Alizadeh, M.-H., Salavati, M., O'Sullivan, K., Shirzad, E., Movahed, M., 2018. Altered lower limb kinematics during jumping among athletes with persistent low back pain. *Ann. Appl. Sport Sci.* 6 (2), 23–30. <https://doi.org/10.29252/aassjournal.6.2.23>.
- Shojaei, I., Salt, E.G., Hooker, Q., Van Dillen, L.R., Bazrgari, B., 2017. Comparison of lumbo-pelvic kinematics during trunk forward bending and backward return between patients with acute low back pain and asymptomatic controls. *Clin. Biomech.* 41, 66–71. <https://doi.org/10.1016/j.clinbiomech.2016.12.005>.
- Shum, G.L.K., Crosbie, J., Lee, R.Y.W., 2005. Effect of low back pain on the kinematics and joint coordination of the lumbar spine and hip during sit-to-stand and stand-to-sit. *Spine* 30 (17), 1998–2004. <https://doi.org/10.1097/01.brs.0000176195.16128.27>.
- Shum, G.L.K., Crosbie, J., Lee, R.Y.W., 2007. Movement coordination of the lumbar spine and hip during a picking up activity in low back pain subjects. *Eur. Spine J.* 16 (6), 749–758. <https://doi.org/10.1007/s00586-006-0122-z>.
- Simonet, E., et al., 2020. Walking and running with non-specific chronic low back pain: what about the lumbar lordosis angle? *J. Biomech.* 108 <https://doi.org/10.1016/j.jbiomech.2020.109883>.
- Smith, J.A., Hawkins, A., Grant-Beuttler, M., Beuttler, R., Lee, S.-P., 2018. Risk factors associated with low back pain in golfers: a systematic review and meta-analysis. *Sports Health* 10 (6), 538–546.
- Sung, P.S., 2013. A compensation of angular displacements of the hip joints and lumbosacral spine between subjects with and without idiopathic low back pain during squatting. *J. Electromyogr. Kinesiol. Off. J. Int. Soc. Electrophysiol. Kinesiol.* 23 (3), 741–745. <https://doi.org/10.1016/j.jelekin.2013.02.003>.
- Tak, J.R., Weerink, M., Barendrecht, M., 2020. Judokas with low back pain have lower flexibility of the hip-spine complex: a case-control study. *Phys. Ther. Sport* 45, 30–37. <https://doi.org/10.1016/j.ptsp.2020.06.003>.
- Tsang, S.M.H., Szeto, G.P.Y., Li, L.M.K., Wong, D.C.M., Yip, M.M.P., Lee, R.Y.W., 2017. The effects of bending speed on the lumbo-pelvic kinematics and movement pattern during forward bending in people with and without low back pain. *BMC Musculoskelet. Disord.* 18 (1) <https://doi.org/10.1186/s12891-017-1515-3>.
- Vaisy, M., Gizzi, L., Petzke, F., Consmüller, T., Pfingsten, M., Falla, D., 2015. Measurement of lumbar spine functional movement in low Back pain. *Clin. J. Pain* 31 (10), 876–885. <https://doi.org/10.1097/AJP.0000000000000190>.
- Van Hoof, W., Volkaerts, K., O'Sullivan, K., Verschueren, S., Dankaerts, W., 2012. Comparing lower lumbar kinematics in cyclists with low back pain (flexion pattern) versus asymptomatic controls - field study using a wireless posture monitoring system. *Man. Ther.* 17 (4), 312–317. <https://doi.org/10.1016/j.math.2012.02.012>.
- Van Tulder, M., et al., 2006. European guidelines for the management of acute nonspecific low back pain in primary care. *Eur. Spine J.* 15 (Suppl. 2), s169.
- Wildenbeest, M.H., Kiers, H., Tuijt, M., van Dieën, J.H., 2022. Associations of low-back pain and pain-related cognitions with lumbar movement patterns during repetitive seated reaching. *Gait Posture* 91, 216–222. <https://doi.org/10.1016/j.gaitpost.2021.10.032>.
- Williamson, O.D., Cameron, P., 2021. The global burden of low Back pain. *International Association for the Study of Pain (IASP) 09*. <https://www.iasp-pain.org/resources/fact-sheets/the-global-burden-of-low-back-pain/>.
- Wong, T.K.T., Lee, R.Y.W., 2004. Effects of low back pain on the relationship between the movements of the lumbar spine and hip. *Hum. Mov. Sci.* 23 (1), 21–34. <https://doi.org/10.1016/j.humov.2004.03.004>.
- Zafereo, J., Wang-Price, S., Brown, J., Carson, E., 2016. Reliability and comparison of spinal end-range motion assessment using a skin-surface device in participants with and without low Back pain. *J. Manipulative Physiol. Ther.* 39 (6), 434–442. <https://doi.org/10.1016/j.jmpt.2016.05.008>.
- Zamiri, S., Yazdi, M.J.S., Mehravar, M., Takamjani, I.E., Ahmadi, A., Maroufi, N., 2017. The relationship between prolonged sitting position and adaptive alterations in lumbar spine and pelvic range of motion in cyclists with chronic low back pain. *World Fam. Med.* 15 (10), 23–27. <https://doi.org/10.5742/MEWFM.2017.93132>.