BJR

OTHER

The effect of ethnicity on the age-related changes of spinopelvic characteristics: a systematic review

K. J. Lukas,
J. C. F. Verhaegen,
H. Livock,
E. Kowalski,
P. Phan,
G. Grammatopoulos

From The Ottawa Hospital, Ottawa, Canada

Aims

Spinopelvic characteristics influence the hip's biomechanical behaviour. However, to date there is little knowledge defining what 'normal' spinopelvic characteristics are. This study aims to determine how static spinopelvic characteristics change with age and ethnicity among asymptomatic, healthy individuals.

Methods

This systematic review followed the Preferred Reporting Items for Systematic Review and Meta-Analyses guidelines to identify English studies, including ≥ 18-year-old participants, without evidence of hip or spine pathology or a history of previous surgery or interventional treatment, documenting lumbar lordosis (LL), sacral slope (SS), pelvic tilt (PT), and pelvic incidence (PI). From a total of 2,543 articles retrieved after the initial database search, 61 articles were eventually selected for data extraction.

Results

When all ethnicities were combined the mean values for LL, SS, PT, and PI were: 47.4° (SD 11.0°), 35.8° (SD 7.8°), 14.0° (SD 7.2°), and 48.8° (SD 10°), respectively. LL, SS, and PT had statistically significant ($p < 0.001$) changes per decade at: –1.5° (SD 0.3°), –1.3° (SD 0.3°), and 1.4° (SD 0.1°). Asian populations had the largest age-dependent change in LL, SS, and PT compared to any other ethnicity per decade at: –1.3° (SD 0.3°) to –0.5° (SD 1.3°), –1.2° (SD 0.2°) to –0.3° (SD 0.3°), and 1.7° (SD 0.2°) versus 1.1° (SD 0.1°), respectively.

Conclusion

Ageing alters the orientation between the spine and pelvis, causing LL, SS, and PT to modify their orientations in a compensatory mechanism to maintain sagittal alignment for balance when standing. Asian populations have the largest degree of age-dependent change to their spinopelvic parameters compared to any other ethnicity, likely due to their lower PI.

Cite this article: *Bone Joint Res* 2023;12(4):231–244.

Keywords: Spinopelvic, Lumbar lordosis, Sacral slope, Pelvic tilt, Pelvic incidence

Article focus

- To determine the values of normal standing spinopelvic parameters in healthy cohorts.
- To evaluate how standing spinopelvic parameters change in healthy populations as they age.
- To evaluate the difference in standing spinopelvic parameters among different ethnicities.

Key messages

- Age affects the position of the pelvis and spine, adjusting their orientation in order to maintain sagittal balance when standing.
- Non-pathological Asian spines have the largest degree of changes to their spinopelvic parameter as they age compared to all other ethnicities currently documented in the literature.

Strengths and limitations

- This is a large systematic review, following Preferred Reporting Items for Systematic Review and Meta-Analyses guidelines.
- Datasets for some papers were incomplete due to unspecified age groups.

Correspondence should be sent to George Grammatopoulos; email: ggrammatopoulos@toh.ca

doi: 10.1302/2046-3758.124.BJR-2022-0335.R1

Bone Joint Res 2023;12(4):231–244.

- The majority of studies were conducted among Asian cohorts, which could lead to selection bias.

Introduction

The relationship between the lumbar spine and the adjacent pelvis is important to maintain appropriate sagittal balance when standing and during gait in humans.[1,2] The positional relationship between the lumbar spine and pelvis influences acetabular orientation, which is important for hip biomechanics in both native and replaced hips.[3] In pathological states of the spine, some compensatory mechanisms occur to regain sagittal balance, such as flexing the knees to tilt the femoral shafts, providing additional retroversion of the pelvis (increase in pelvic tilt).[4] These compensatory methods for sagittal balance can eventually lead to fatigue and further spinal deformity over time.[5] Compensation mechanisms of the spine and pelvis occur when patients with hip osteoarthritis (OA) move from a standing to a sitting position. Reduced femoroacetabular flexion (hip flexion) is compensated by an increased pelvic tilt (PT), and subsequently a decreased lumbar lordosis (LL) to maintain an upright position.[6] When hip flexion is restored with total hip arthroplasty (THA), these compensatory changes can be reversed.[7]

Ageing has been linked to many alterations of physiological and anatomical structures within the human body,[7–10] with most literature reporting that LL and hip flexion decrease during ageing.[3] Younger individuals have the capacity to better regulate their spinopelvic alignment,[8] while older individuals demonstrate inadequate compensation mechanisms at the spinopelvic junction due to restriction in range of motion at this level.[8,10] However, it is not well understood how these changes occur in the normal act of ageing among healthy individuals without hip or spinal pathology. Furthermore, whether these spinopelvic characteristics differ among ethnicities is unknown, due to the lack of comparative studies. To understand how pathological spinopelvic processes arise and how they can be addressed, it is important to first characterize how these characteristics change with normal ageing and between different ethnicities.

To better understand the role of the sagittal spinopelvic characteristics in the development of hip symptoms and surgical outcome, one needs to determine what 'normal' is and be able to predict how spinopelvic characteristics differ between age and ethnicity. The objective of this systematic review was to 1) define 'normal' age-related values of static spinopelvic parameters in a healthy population without hip or spinal pathology, and 2) compare whether and how these values differ between individuals of different ethnicities.

Methods

Search strategy. This systematic review protocol used the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) guidelines. The following databases were searched: MEDLINE, Embase, PubMed, CINAHL (EBSCO), and Cochrane Library (OVID Interface). Search terms were entered into three concepts: concept 1 included terms "spinopelvic adj2 parameter*", "pelvi* adj2 tilt*", "pelvi* angle", "pelvi* adj2 motion*", "sacral plateau*", and "sacral* slope*"; concept 2 included terms "postural* adj2 alignment*", "spine* adj2 alignment*", "pelvi* adj2 alignment*", sagittal* adj2 alignment*", "spine* adj2 lordosis*", "spine* adj2 curvature*", "postural* adj2 balanc*", and "sagittal* adj2 balanc*"; and concept 3 included terms "adult", "adults", "adulthood", "middle age", "middle-aged", "elderly", "senior", "seniors", "man", "men", "woman", and "women". Terms within each concept were combined using OR Boolean operator and the three concepts were combined with the AND Boolean operator. Terms were searched using title and abstracts.

Study eligibility criteria. Studies were included if they met the following criteria: 1) involving human participants; 2) written in the English language; 3) study type: randomized trials, longitudinal studies (i.e cohort and prospective studies); 4) included cohort age > 18 years old; 5) absence of hip or spine pathology, previous surgery, or interventional treatment of the included cohorts; 6) studies that documented standing lumbar spinopelvic characteristics including lumbar lordosis (LL), sacral slope (SS), pelvic tilt (PT), and pelvic incidence (PI).

Studies were excluded if they involved any of the following: 1) non-human studies, 2) non-English studies, 3) paediatric populations (≤ 18 years old), 4) secondary research methods (i.e. systematic reviews, case reports, letters, retrospective articles), 5) non-standing radiographs, 6) presences of hip or spine pathologies, 7) patient populations that had previous surgeries or treatment to these regions, 8) studies that did not distinguish between ages and measured spinopelvic parameters, and 9) studies that did not include two or more of the desired spinopelvic parameters.

All articles retrieved by database searches were uploaded to an online systematic review tool (Covidence, Australia), which removed duplicate articles. Articles were then appraised against the inclusion and exclusion criteria using a two-step technique. First, two reviewers (KJL, HL) independently screened the titles and abstracts, followed by full-text article review of all papers that both reviewers agreed upon from the initial screening. Conflicts were resolved by a third reviewer (EK).

The electronic database search identified 2,543 articles; of which 1,107 were duplicates and removed, leaving a total yield of 1,439 articles. Review of the titles and abstracts excluded a further 1,230 studies, leaving a remaining 201 for full-text review. Of these, 140 were excluded, leaving 61 articles from the original search (Figure 1).[10–68]

Data extraction. Data from included studies after the full-text screening were extracted by one reviewer and then another reviewer evaluated the completeness of the extracted data. Accumulatively, a total of 10,741 healthy

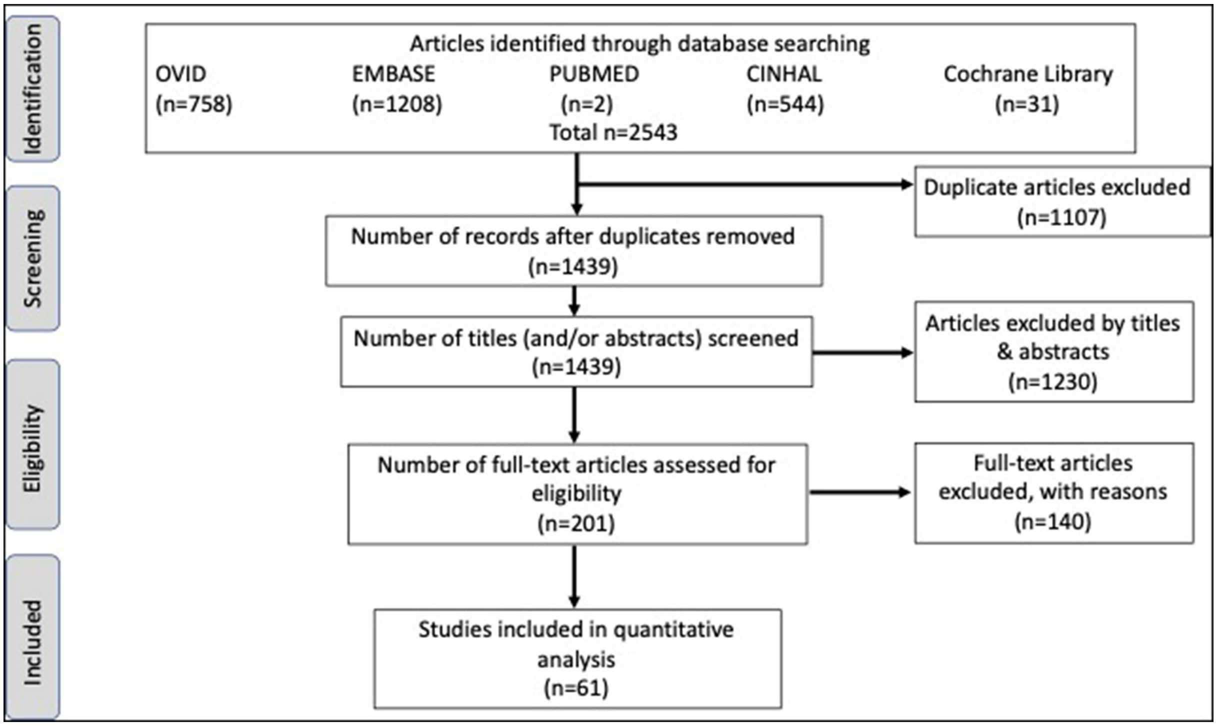

Fig. 1

Preferred Reporting Items for Systematic Review and Meta-Analyses flow diagram identifying search database involved and total amount of articles identified and screened.

patients were included in this systematic review, with the mean patient age stratified from 21 to 85 years old. The major ethnicities of our studies' cohorts were divided based off geographical regions which included: Asian (61%), North American (7%), South American (3%), European (21%), and Middle Eastern (8%). These geographical regions have previously been established in literature,[69] except for the Middle Eastern cohort which we included. Evaluation of the geographical regions underwent a binary analysis as there were too few cohorts from the geographical regions of: North America, South America, Europe, and Middle East.

The selected articles were assessed for inclusion of the following spinopelvic parameters: LL, SS, PT, and PI. The LL represents the angle between two lines drawn along the superior endplates of L1 and S1.[49,70] The SS represents the angle of the superior endplate of S1 to the horizontal.[59] The SS influences the position of the lumbar spine as it forms the base of the spine. The PT is defined as the angle between a line connecting the centre of the superior endplate of S1 and the centre of the femoral head and the vertical axis. The value denotes the spatial orientation of the pelvis, which varies according to position.[58] Lastly, PI represents the angle between a line connecting the centre of the superior endplate of S1 and the centre of the femoral head, and a line perpendicular to the superior endplate of S1. Historically, this anatomical parameter was believed to remain unchanged regardless of body position or age,[70] though recent papers identify that it may change with position in healthy populations.[71] Papers that did not differentiate between age groups for these values or express measurements taken in the standing position were not included, to avoid skewing the data when performing statistical analysis (Table I).

Statistical analysis. A qualitative analysis of covariance (ANCOVA) was performed on all data extracted from the 61 studies included (Table II). The data were first separated into individual spinopelvic parameters and then grafted on scatter plots based on age and numerical degrees of each parameter being measured (Figure 2). Identifiable markers were used to distinguish each study's majority geographical population on the scatter plots. These plots were used to assess for patterns with the extracted data. Then, a linear regression (SAS 9.4; SAS Institute, USA) was performed on each spinopelvic parameter, which included a 95% confidence limit with R-square, adjusted R-square, and mean square error (MSE) values calculated before being graphed on a fit plot with standard deviations (SDs). Subsequently, an analysis of variance was performed, which identified t-values and the presence of significant trends based on p-values less than 0.05.

Results

Of the 104 separate cohorts of groups evaluated, 93 reported on values of lumbar lordosis. The overall mean value for lumbar lordosis for all races and ages combined was 47.4° (SD 11.0°). Statistical regression of deviation groups identified lumbar lordosis decreased by 1.5°

Table I. Mean values with standard deviation of pelvic tilt, sacral slope, lumbar lordosis, and pelvic incidence for each of the included studies.

Author, Year	Total number of healthy participants	Majority ethnicity by geographical region	Age, yrs	Pelvic tilt	SD	Sacral slope	SD	Lumbar lordosis	SD	Pelvic incidence	SD
Zhou, 2020[11]	41	Asian	25	12.6	6.4	32.7	5.6	45.6	8	45.5	9.8
Zhou, 2020	33	Asian	35	10.4	5.5	35	6	48.9	9	45.3	5.9
Zhou, 2020	39	Asian	45	13.1	6.7	32.6	10	50.2	11.1	47	9.3
Zhou, 2020	43	Asian	55	14.9	7.1	31.4	5.8	49.1	8.6	46.8	9.5
Zhou, 2020	41	Asian	65	14.2	7.7	31.8	5.3	47.6	11.4	46.5	8.3
Zhou, 2020	21	Asian	75	14.6	4.9	30.8	7.9	47.5	12	45.4	9.3
Suh, 2014[12]	24	Asian	28.5	13.28	8.59	39.51	7.6	39.17	8.31	52.47	13.06
Lee, 2014[13]	40	Asian	40.1	13.5	5.9	35.5	5.9	39.3	6.8	48.3	5.5
Hong, 2010[15]	24	Asian	28.5	13.28	8.59	39.51	7.6	38.37	19.67	52.47	13.06
Suh, 2013[14]	24	Asian	-	13.28	8.59	39.52	7.6	39.17	8.31	52.47	13.06
Yeh, 2018[16]	114	Asian	30	11	8	34	9	49	12	45	11
Yeh, 2018	135	Asian	50	15	8	35	9	46	14	-	-
Yeh, 2018	143	Asian	70	19	10	31	10	40	17	-	-
Kang, 2010[17]	45	Asian	56.5	-	-	36	6	55.8	8.7	48.2	6.2
Kang, 2010	65	Asian	64	-	-	37.5	6.4	58.4	8.2	48.4	8.6
Kang, 2010	22	Asian	77	-	-	37.5	7.2	57.7	9	50.4	8.7
Weng, 2015[18]	64	Asian	58	12.9	6.2	32.8	7.8	48.7	10	46.3	9.3
Janssen, 2009[19]	60	European	26.6	11.5	6.2	40	7.1	58.5	9.6	51.5	10
Roussouly, 2006[20]	153	European	27	11.1	5.9	39.6	7.6	61.2	9.4	-	-
Kim, 2014[21]	184	Asian	21.2	9.9	6.5	36.6	7.3	52.2	9.2	46.5	7.7
Kim, 2014	158	Asian	63.8	11.3	6.4	36.8	6.7	57.3	8.8	48.2	8.5
Gerilmez, 2021[22]	75	Middle Eastern	34	12.38	7.12	34.43	8.87	57.92	10.45	46.86	10.84
Endo, 2014[23]	86	Asian	35.9	13.2	8.2	34.6	7.8	43.4	14.6	46.7	8.9
Weitkunat, 2016[24]	23	European	29.1	11.78	6.88	42.48	7.19	58.87	9.47	54.26	10.04
Ando, 2020[25]	286	Asian	64.5	17.8	8.7	30	8.1	43.5	12.2	47.8	11.5
Hammerberg, 2003[72]	50	North American	76.3	18	9.1	42	9.63	57	13.7	60.54	15.18
Chaléat-Valayer, 2011[26]	709	North American	36.8	13	6.8	39.6	7.9	42	11.2	50.65	12.1
Lee, 2013[27]	30	Asian	30.4	13.9	5.2	36.4	7	50.7	8.7	50.4	9.1
Tahvildari, 2020[28]	43	Middle Eastern	38.8	6.33	4.06	45.33	9.25	-	-	51.81	8.3
Zhou, 2022[29]	308	Asian	35	10.9	6.2	34.5	6.8	49	10	45.4	8.6
Zhou, 2022	127	Asian	50	12.9	6.8	34.2	8.1	50.7	10.2	47.1	8.5
Zhou, 2022	111	Asian	65	13.6	6.9	32.3	6.2	47.9	10	45.9	7.7
Iyer, 2016[30]	20	North American	25	13	10.4	38.5	7.6	59.8	11.1	45.2	15.2
Iyer, 2016	18	North American	35	11.1	9.6	39.8	19.5	60.8	15.3	50	10.4
Iyer, 2016	17	North American	45	12.7	7	36.4	7.6	57.2	10.5	49.1	9
Iyer, 2016	16	North American	55	13.7	7.6	38.1	8.1	36.19	11.2	51.2	13.5
Iyer, 2016	27	North American	65	17.4	7.2	35.3	10.7	56.4	9.8	51.7	10.2
Iyer, 2016	17	North American	75	18.8	7.8	30.1	9.6	46.7	15.9	48.9	13.9

Continued

Table I. Continued

Author, Year	Total number of healthy participants	Majority ethnicity by geographical region	Age, yrs	Pelvic tilt	SD	Sacral slope	SD	Lumbar lordosis	SD	Pelvic incidence	SD
Sun, 2020[31]	143	Asian	23	11.7	6.5	34.8	7.1	50.3	10	-	-
Asai, 2017[32]	170	Asian	45	11.5	6.9	-	-	47.9	9.1	53.5	10.35
Asai, 2017	256	Asian	55	14.4	6.6	-	-	45.2	11.8	48.75	10.05
Asai, 2017	418	Asian	65	15.5	6.8	-	-	45.2	12.8	49.45	10.15
Asai, 2017	407	Asian	75	16	7.5	-	-	39.3	15.9	50.1	10
Asai, 2017	210	Asian	85	19.7	8.4	-	-	44.5	12.7	49.85	11.15
Endo, 2016[33]	52	Asian	35.4	13.6	9.6	35	8.3	30.3	9	45.5	9.1
Menezes-Reis, 2018[34]	93	South American	-	9.5	7.5	36.4	6.6	49.5	11.2	45.9	9.7
Bakouny, 2017[35]	91	Middle Eastern	21.6	10.5	6.2	38	5.8	59.2	8.4	48.6	5.8
Boulay, 2006[36]	149	European	30.8	11.96	6.44	41.18	6.96	66.36	9.47	53.1	9
Endo, 2012[37]	50	Asian	31.5	9.9	7.6	33.32	11.24	33.32	11.25	47.2	10
Vaz, 2002[38]	112	European	32.5	12.3	5.9	39.4	9.3	46.5	11.1	51.7	11.5
Uehara, 2019[39]	97	Asian	55	13	6	34.5	8	47.5	11	47	9
Uehara, 2019	114	Asian	65	15.5	8	31	9.5	46	13.5	46.5	10.5
Uehara, 2019	109	Asian	75	19.5	8	31	9	43.5	13.5	51	10.5
Uehara, 2019	93	Asian	85	24	9	26.5	8.5	38	16	50	10
Yeganeh, 2020[1]	70	Middle Eastern	26.6	9.1	7.6	35.4	6.7	41.9	14.7	44.5	10.1
Moon, 2018[40]	16	Asian	29	15.7	-	35.3	-	37.1	-	51	-
Yang, 2014[41]	80	Asian	36.9	10.6	5.9	38.1	7	53	9.6	48.7	9.5
Oe, 2015[42]	36	Asian	55	13.9	7.65	32.9	7.45	41.45	10.65	46.85	9.1
Oe, 2015	174	Asian	65	15.35	7.2	31.7	8.65	42.45	13.45	45.45	10.1
Oe, 2015	311	Asian	75	18.5	8.5	30.5	10.35	40.95	15.05	48.6	11.8
Oe, 2015	135	Asian	85	22.6	10.45	27.35	10.7	35.75	17.5	49.95	10
Fader, 2018[43]	6	North American	36.5	-	-	37	5	52	14	44	5
Marty, 2002[44]	44	European	24	10.84	6.11	40.59	8.93	59.6	10.24	51.44	10.85
Thelen, 2017[45]	102	European	27.3	11.5	6.4	40.3	8.3	-	-	51.8	11.6
Yukawa, 2018[10]	101	Asian	25	12.15	7.35	40.95	8.25	50.9	10.85	54.1	10.1
Yukawa, 201	101	Asian	35	12.55	7.2	39.85	6.8	50.6	10.75	52.9	10.2
Yukawa, 2016	107	Asian	45	13.85	7.1	40.45	7.35	50.85	10.55	50.8	7.8
Yukawa, 2016	107	Asian	55	14.2	14.2	40.55	8.25	51	9.65	53	11.3
Yukawa, 2016	110	Asian	65	16.05	16.06	37.85	8.35	50.35	12	52	10.9
Yukawa, 2016	100	Asian	75	18.15	7.6	36.95	9.8	44.45	14.05	52	10.3
Bassani, 2019[46]	44	European	65	13.9	6.1	37.7	8.3	56.1	13.3	51.6	8.9
Bassani, 2019	83	European	75	16.5	6.5	37.6	10.6	56.8	12.5	54.1	12.8
Bassani, 2019	27	European	85	17.9	6.7	36.8	7.6	57.8	10.4	54.8	11.2
Lee, 2015[47]	77	Asian	31.7	-	-	33.4	8	47.3	9.8	45.6	45.6
Hu, 2018[48]	126	Asian	26.4	4.5	2.4	37.2	6.7	54	10	41.2	7.1
Chevillotte, 2018[49]	15	European	42.9	12.1	6.3	37.1	6.3	54.8	9.8	49.3	8.1

Continued

Table I. Continued

Author, Year	Total number of healthy participants	Majority ethnicity by geographical region	Age, yrs	Pelvic tilt	SD	Sacral slope	SD	Lumbar lordosis	SD	Pelvic incidence	SD
El Rayes, 2017[50]	95	Middle Eastern	26	11.11	7.9	39.85	7.1	-	-	51.34	1.135
Attali, 2019[51]	50	European	34	12	-	40	-	58	-	51	-
Hasegawa, 2020[52]	50	Asian	52.2	13.6	1.2	39.8	1.2	52.9	2.2	53.4	1.4
Sohn, 2016[53]	32	Asian	35	12.5	-	34.8	-	54	-	46.4	-
Sohn, 2016	32	Asian	45	12.1	-	35.1	-	55.5	-	46.9	-
Sohn, 2016	32	Asian	55	10.7	-	35.2	-	54.1	-	46	-
Sohn, 2016	32	Asian	75	17.3	-	35.5	-	51.9	-	46.4	-
Hey 2019[54]	60	Asian	21	16.4	8.1	32.4	7.4	44.8	13	48.9	9.3
Arima 2018[55]	50	Asian	57	14	6.5	33.1	10	44.3	14.5	46.1	10.4
Arima 2018	84	Asian	67	17.3	8.5	33.1	10	44.3	14.5	47.9	12.6
Lee, 2011[56]	86	Asian	28.19	11.5	5.3	36.3	7.6	49.6	9.6	47.8	9.3
Bhosale, 2019[57]	130	Asian	34.49	12.32	5.41	39.17	6.26	-	-	51.52	6.74
Zhou, 2020[58]	140	Asian	23.2	11.9	6.2	35.4	7	50.5	9.4	46.58	6.14
Pratali, 2018[59]	44	South American	31.5	11.5	5.5	36.9	6.6	55.3	8.8	48.6	7.9
Ding, 2019[60]	12	Asian	57.4	13.47	3.63	35.5	4.64	46.59	7.14	-	-
Araújo, 2014[61]	57	European	-	15.2	-	39.8	-	64	-	55.4	-
Araújo, 2014	194	European	-	17	-	37.7	-	61.2	-	55.4	-
Oe, 2020[62]	162	Asian	-	-	-	-	-	-	-	-	-
Machino, 2020[63]	50	Asian	45	17.3	8.65	32.35	8.6	46.3	10.55	-	-
Machino, 2020	73	Asian	55	22.35	8.55	27.6	6.65	42.15	11.3	-	-
Machino, 2020	145	Asian	75	21.8	8.8	27.15	8.25	42.2	11.85	-	-
Roussouly, 2005[64]	160	European	33	11.99	6.46	39.92	8.17			-	-
Cho, 2017[65]	252	Asian	32.2	9.4	6.7	37.8	5.8	48.3	10.2	45.1	7.5
Hu, 2019[66]	249	Asian	35	10.05	7.23	-	-	44.07	9.15	42.85	9.82
Hu, 2019	86	Asian	55	12.85	9.05	-	-	41.95	10.9	43.95	11.3
Hu, 2019	165	Asian	75	17.3	9.2	-	-	39.63	13	45.05	12.83
Suzuki, 2017[67]	25	Asian	26.9	7.7	9.5	35.9	8.7	-	-	47.25	10.06
Laouissat, 2017[68]	296	European	27	13	7	39	3	58	10	53	7

Any articles with multiple age groups with separated data values were assessed independently as single groups and added to the table.
Empty columns are due to articles either having no data or not separating their mean values by ages groups for the desired parameter.
SD, standard deviation.

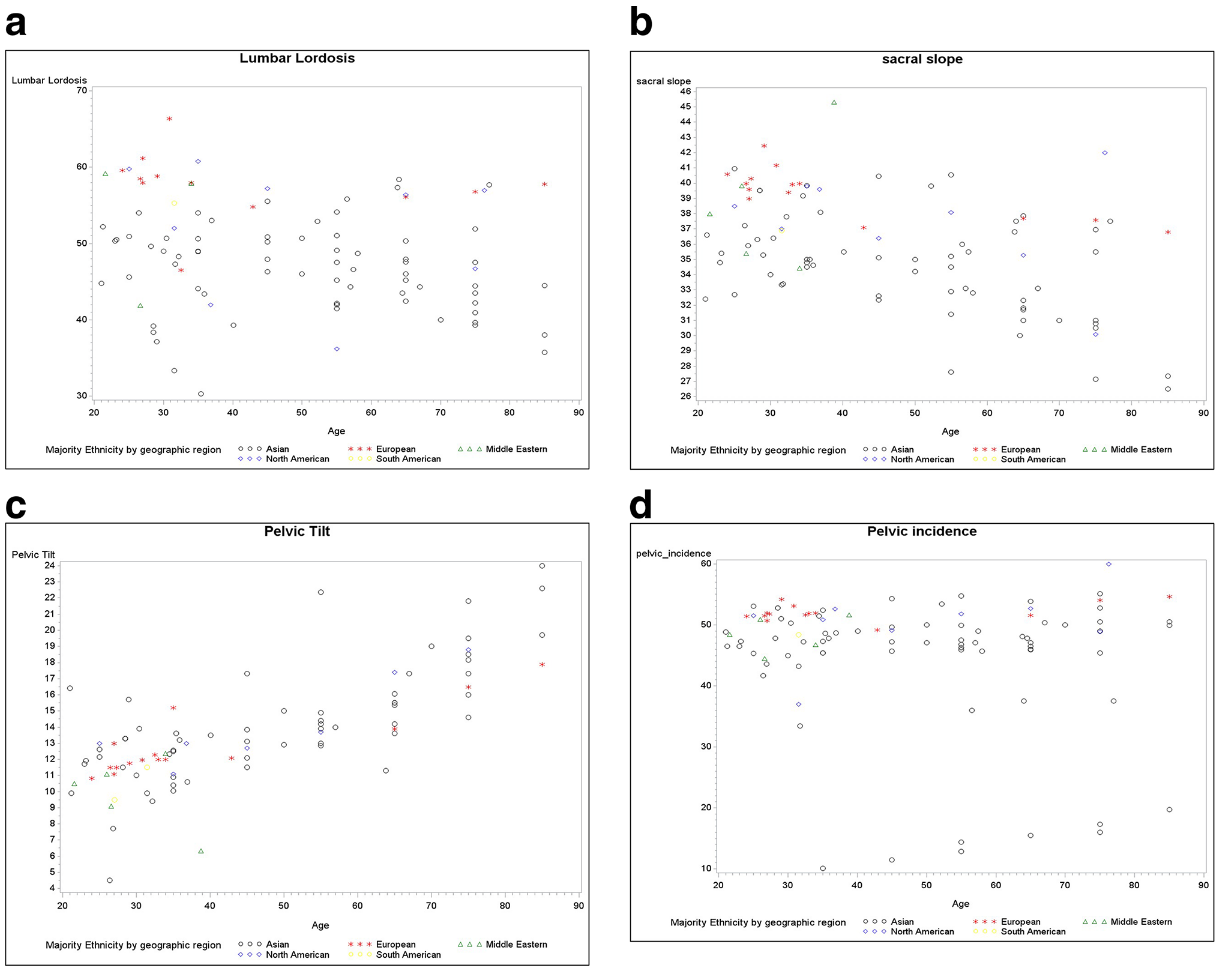

Fig. 2

Scatter plots of a) pelvic tilt, b) pelvic incidence, c) sacral slope, and d) lumbar lordosis.

Table II. List of items for data extraction.

Category	Items for data extraction
Study characteristics	Author and date of publication
	Journal
	Study design
Population characteristics	Number of patients
	Patient's age at evaluation: may be divided into groups
	First and second ages of measuring if measured more than once
	Patient's sex
	Patient's ethnicity
Parameters of interest	Sacral slope values
	Lumbar lordosis values
	Pelvic tilt values
	Pelvic incidence

(SD 0.3°) per decade (p < 0.001). A fit plot and variable analysis identified noticeable trends between ethnicities (Figure 3). Asian populations had steeper trends than all others. Among younger Asian populations (aged 20 to 30 years) the mean value for LL was lower than all other ethnicities (53° (SD 2.1°) vs 54° (SD 4.0°); p < 0.001, ANCOVA). These values subsequentially decreased at a rate of 1.3° (SD 0.3°) per decade compared to all other ethnicities where LL decreased at a rate of 0.5° (SD 1.3°) per decade (Figure 4).

The mean value for SS for all ethnicities and ages combined was 35.8° (SD 7.8°). Sacral slope changed significantly from the young to the elderly patient groups (p < 0.001, ANCOVA), with a mean decrease of 1.3° (SD 0.3°) per decade (Figure 4) (Table III). The decrease in SS with ageing occurred at a higher rate among the Asian population in comparison to the other ethnic groups (1.2° (SD 0.2°) vs 0.3° (SD 0.3°) per decade; p < 0.001, ANCOVA). Among the younger (20 to 30 years old) Asian population, SS values were lower than among other ethnicities at (37.8° (SD 1.7°) vs 40° (SD 0.9°); p < 0.001, ANCOVA). There was a larger trend in negative covariance in the Asian populations, corresponding with a larger reciprocal change in their mean SS compared to other races with ageing (Figure 4).

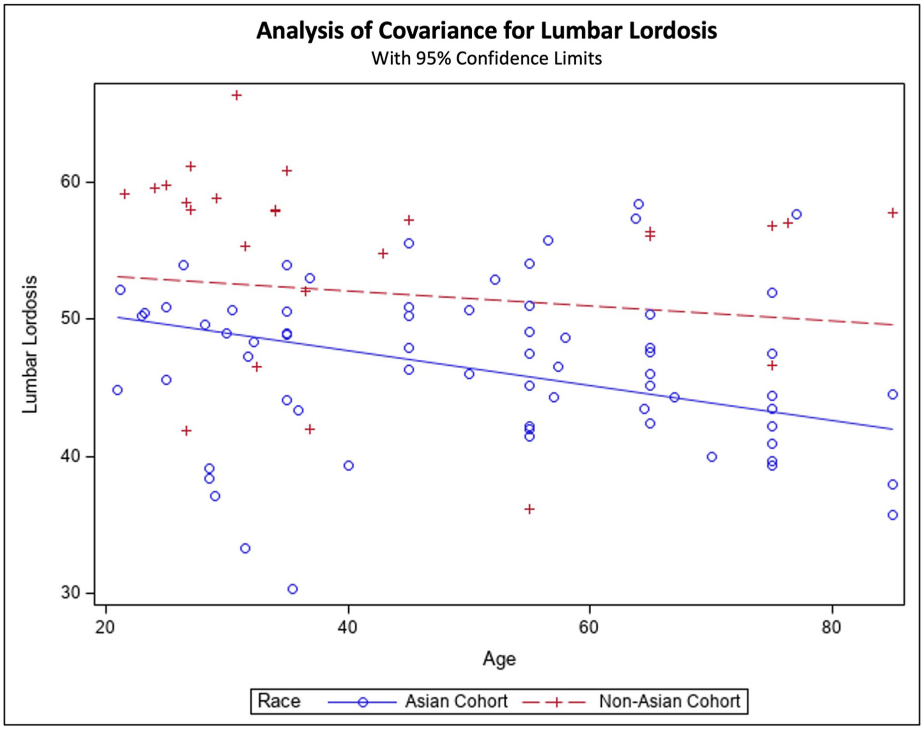

Fig. 3

Fit plot comparing measured lumbar lordosis from literature, with 95% confidence limits identified and regression values for Asian vs non-Asian cohorts.

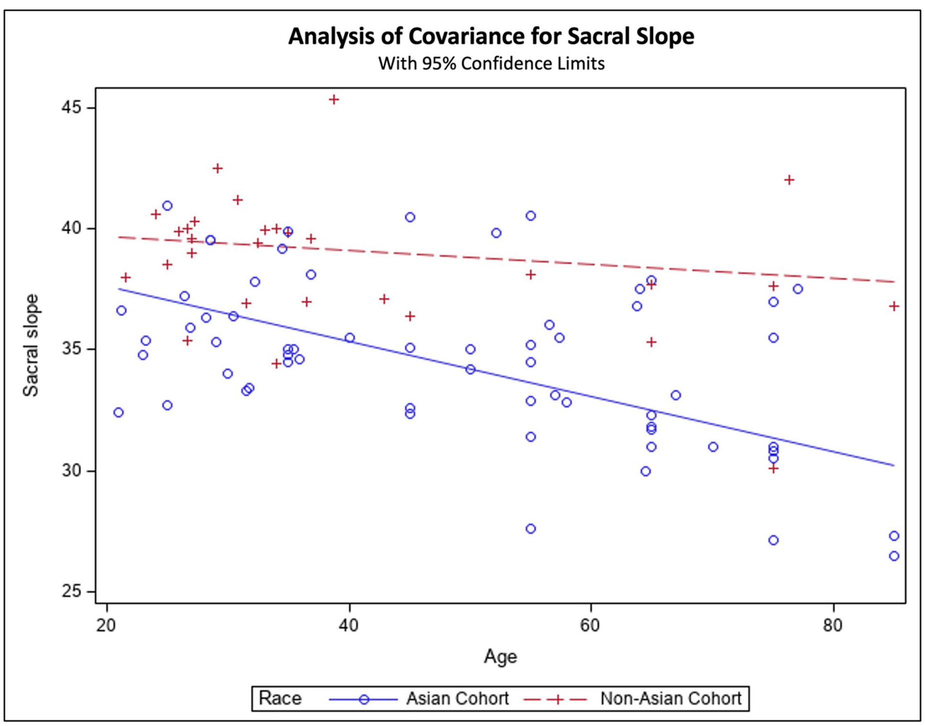

Fig. 4

Fit plot comparing measured sacral slope from literature, with 95% confidence limits identified and regression values for Asian vs non-Asian cohorts.

Table III. Calculated regression values for spinopelvic parameters divided into three groups: combined ethnicities, Asian ethnicity, and other ethnicities (which include all ethnicities accept Asian). The age-dependent parameter estimate column represents the projected rate of change per year.

Variable	Age-dependent parameter estimate per decade, °	SD	t-value	p-value
Combined ethnicities				
Pelvic tilt	1.4326	0.1089	9.67	< 0.001
Lumbar lordosis	–1.5136	0.3269	–4.63	< 0.001
Sacral slope	–1.3005	0.2725	–7.54	< 0.001
Pelvic incidence	0.155	0.1588	0.98	0.332
Asian ethnicities				
Pelvic tilt	1.6848	0.1743	9.67	< 0.001
Lumbar lordosis	–1.3414	0.3284	–4.08	<0.001
Sacral slope	–1.1929	0.2065	–5.78	< 0.001
Pelvic incidence	0.4919	0.1964	2.5	0.016
Other ethnicities				
Pelvic tilt	1.0892	0.131	8.31	< 0.001
Lumbar lordosis	–0.5285	1.3094	–0.4	0.691
Sacral slope	–0.2691	0.2657	–1.01	0.323
Pelvic incidence	0.8201	0.319	2.57	0.018

SD, standard deviation.

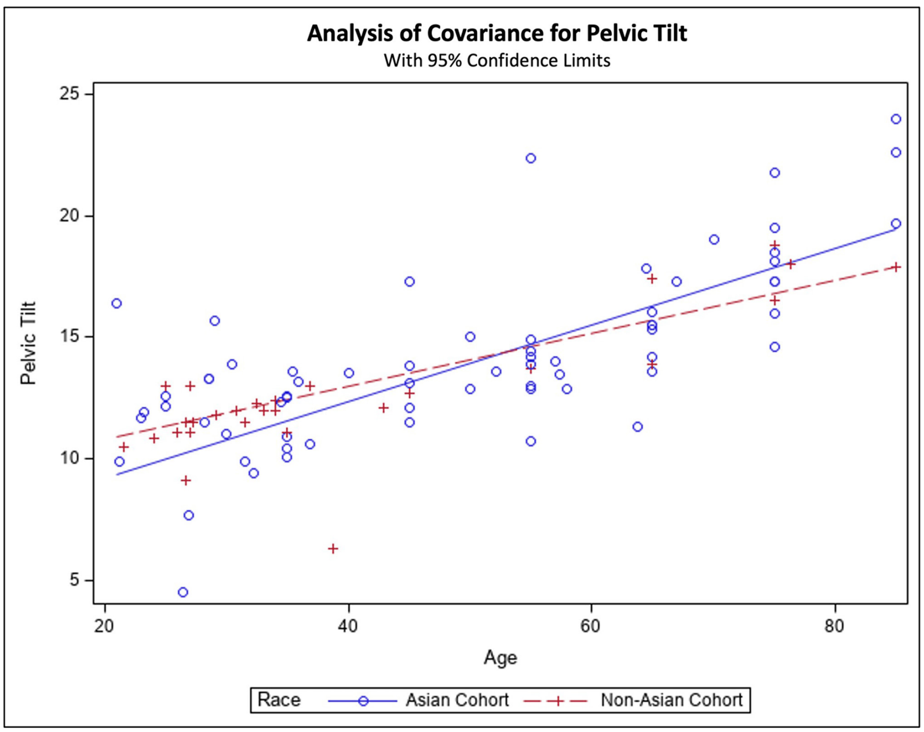

Fig. 5

Fit plot comparing measured pelvic tilt from literature, with 95% confidence limits identified and regression values for Asian vs non-Asian cohorts.

The overall mean value of PT was 14.0° (SD 7.2°). There was a significant increase of 1.4° (SD 0.1°) in PT per decade ($p < 0.001$, ANCOVA) (Figure 5). The Asian cohort of patients showed the largest degree of age-dependent change in PT compared to all other ethnicities (1.7° (SD 0.2°) vs 1.1° (SD 0.1°) per decade; $p < 0.001$, ANCOVA) (Table III). In the 20- to 30-year-old cohorts, Asian populations had a lower PT mean value in comparison to other ethnicities at (6.0° (SD 0.7°) vs 8.5° (SD 1.3°); $p = 0.083$, ANCOVA). All ethnicities have positive covariance trends, although the rate of progression of PT is greater in Asian populations, which intercept and then surpass the mean values of all other races in the latter half of the fifth decade of life (Figure 5).

The combined mean value for PI for all races and ages was 48.8° (SD 10°). Variable analysis and fit plot of the pelvic incidence showed notable difference between the Asian cohort and the non-Asian cohorts (45° (SD 0.9°)

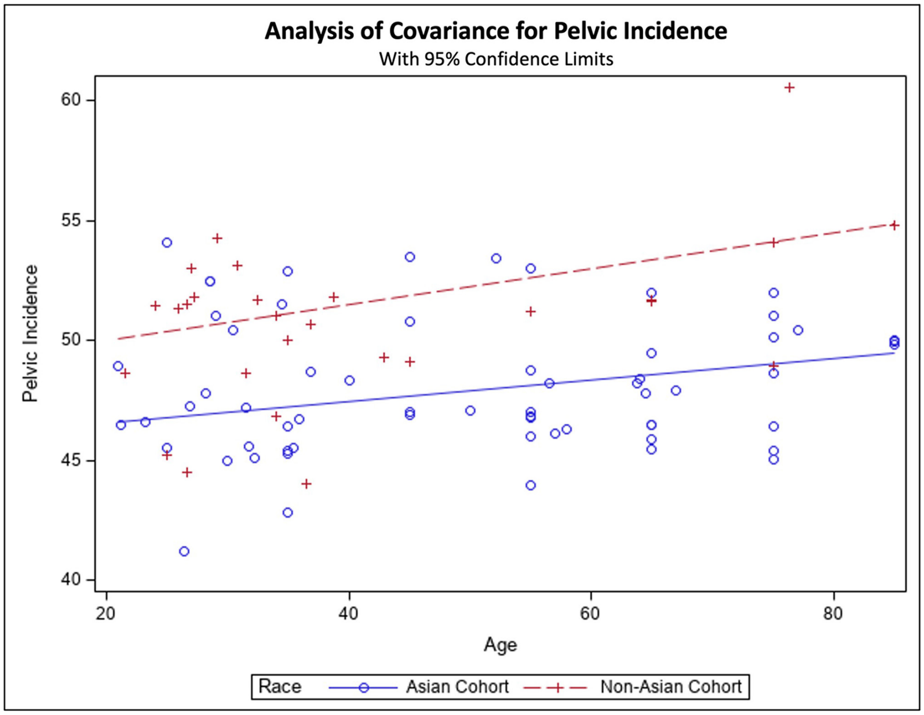

Fig. 6

Fit plot comparing measured pelvic incidence from literature, with 95% confidence limits identified and regression values for Asian vs non-Asian cohorts.

vs 48.5° (SD 1.8°); p ≤ 0.001, ANCOVA). There was no variance between the rate of change among ethnicities (Figure 6), with all races expressing a gradual increase to their PI by 0.2° (SD 0.1°) per decade.

Further analysis was performed to evaluate for any confounding effect based on sex. Several studies reported sex distribution by age category,[11,73] which were used for the proportional analysis of males and females, illustrating no differences in sex distribution between age groups (Supplementary Tables i to vii).

Discussion

Despite the heightened interest in using spinopelvic characteristics in preoperative planning of hip[3] and spinal procedures,[74] data that determine 'normal' changes in spinopelvic characteristics with ageing are limited. With an ever increasing and ageing population, what these expected changes are in normal and disease states are likely to influence surgical practice.[2,6,11,18] This systematic review of cross-sectional data showed that, among individuals without a history of hip or spinal pathology, spinopelvic characteristics change with age, and furthermore demonstrate ethnicity-related differences. This is of relevance as surgeons aim to understand the hip-spine pathomechanics across the spectrum of hip pathology, ranging from the young adult hip (suffering from impingement and/or dysplasia), to the elderly patient with hip-spine syndrome (requiring hip or spine surgery). A normal lumbar lordosis of 47.4° (SD 11.0°) was found among all age groups and ethnicities, and an overall mean value of pelvic tilt of 14.0° (SD 7.2°). With healthy ageing, one can expect a very small decrease of 1.5° (SD 0.3°) per decade in lumbar lordosis, which is accompanied by minimal increase of 1.4° (SD 0.1°) in pelvic tilt and minimal reduction (1.3° (SD 0.3°)) in sacral slope. Ethnicity contributes to the rate at which spinopelvic characteristics change, with Asian populations showing the largest degree of change. This is likely to be due to the difference in the pelvic incidence among groups: Asian pelves have lower PI, compared to other ethnicities. According to certain preoperative THA planning algorithms for cup orientation, patients with lower PI would require more acetabular anteversion/anteinclination to accommodate for a greater degree of flexion required by the hip.[2] However, such practice of purposely increasing cup anteversion during THA might in time lead to an excessive anteversion/anteinclination, leading to increased risk of posterior impingement and anterior instability with increasing age. In healthy ageing, the rate of change is small and unlikely to be significant over a decade or two.[75,76] However, it may be significant over a span of three or four decades (i.e. arthroplasty performed in patients below 50, reflecting 10% to 15% of practice), as dynamic standing cup orientation, particularly anteversion, is likely to change by 2° to 5° as pelvic tilt increases by 3° to 7°.[77] Furthermore, in the presence of lumbar degeneration the rate of change might be greater,[78,79] and thus the risk of developing an adverse pelvic posture leading to abnormal mechanics and instability may be greater, as previously reported.[80]

Sagittal balance reflects the effort that is needed to maintain upright sagittal position.[81] Lumbar lordosis is a critical determinant of sagittal balance. Progressive forward displacement of the centre of mass due to loss of lumbar lordosis is associated with an increased risk of falls.[82–85] This is often associated with compensatory demand on the hips and thoracolumbar regions to maintain balance.[86] It has been reported that LL decreases with age, corresponding to a decline in quality of life.[53,87–92] Degenerative loss of disc height, osteoporotic wedge fractures, and weakening paraspinal muscles in advancing age contribute to decrease in lordosis.[87,93–96] This reduction in LL has been identified as an "evolutionary weak point" of bipedal organisms.[10] The consequence is an increased likelihood of deviating outside an individual's cone of economy, and subsequently an increased effort to maintain upright standing posture.[10,87] In this systematic review, we found that standing LL gradually changes over the course of normal ageing, at a generalized rate of 1.5° (SE 0.3°) decrease per decade, thus the rate of change in non-pathological states is very low and a loss of lordosis is more likely to be associated with underlying pathology. As the curvature of the lumbar lordosis decreases with age,[87,93–95] there is a corresponding decrease in SS, with the sacrum showing a tendency towards posterior inclination affecting sagittal alignment and thus contributing to sagittal imbalance.[97,98] Clinically, a decrease in LL, with an associated decreased SS and increased posterior PT, leads to a decrease of anterior acetabular hip coverage.[95,99,100] In native hips, this increases the load on the anterior labrum, risking a labral tear and subsequent cartilage wear, and thereby contributing to the development of hip osteoarthritis.[100] In patients with total hip arthroplasty (THA), this increased posterior pelvic tilt increases acetabular version, which can be protective against posterior THA instability,[101] but also increase risk of posterior impingement and anterior instability. This has been shown to be of significance in patients presenting with late dislocation post-THA.[80]

Data on differences in spinopelvic characteristics among ethnicities are very scarce. Zhu et al[87] identified significant differences in adult spinopelvic parameters between Chinese and Caucasian populations, finding sacral slope and pelvic incidence to be significantly smaller among the Chinese cohort than the Caucasian cohort. Similarly, we found LL, SS, and PI to be smaller among Asian cohorts compared to all other cohorts, a difference that increased with older ages. Zhu et al[87] underlined the importance of appreciating differences in ethnicity-related spinopelvic characteristics with surgical planning with regard to the value of LL for sagittal decompensation or the association of spinopelvic characteristics with spinal surgery outcome.[102,103] Twin studies identified that heritability greatly influenced standing LL measurements.[96] These studies confer heritability of genetics on spinal curvature and spinopelvic orientation. Lonner et al[99] and Wang and Sun[97] also concluded that ethnicity may influence spinopelvic parameters, and they found that LL, PT, and PI were significantly greater in African-American populations compared to Caucasian populations. As described by Roussouly et al,[4] sagittal balance in ageing is associated with forward flexion of the spine for which to maintain balance, the body compensates with pelvic retroversion (leading to increased PT and decreased SS), achieved through hip extension. That ability to retrovert the pelvis is proportional to PI; patients with lower PI, given the limited offset of the sacrum from the femoral heads, can only achieve small compensation through retroversion for sagittal imbalance. Inversely, patients with high PI can more widely achieve pelvic retroversion restoring sagittal balance; however this manoeuvre is limited by hip joint extension and leads those individuals to perform the next method of balance correction through knee flexion. Given the close relationship between spinal morphology, PI, and the compensatory mechanisms to achieve sagittal balance, Roussouly and Pinheiro-Franco[4] developed a classification integrating four types of ageing spines based on their pelvic parameters and associated compensatory mechanisms. These could explain the variations seen in the Asian population. For example, one could hypothesize that, with an overall lower PI and lumbar lordosis, the Asian population would fit well the type 1 spines of the Roussouly and Pinheiro-Franco classification. In the presence of a kyphotic event, those patients would use their limited retroversion abilities faster, explaining the large degree of age-dependent change in PT while seeking increased LL. Those trends require further prospective studies to be better understood.

Most studies included only static spinopelvic measurements. One previous cross-sectional study among asymptomatic volunteers examined the effect of ageing on static and dynamic spinopelvic characteristics.[3] While they found that lumbar spine lost its flexion to a greater extent than the hip, and the hip's relative contribution to overall sagittal movement increased, the only age-dependent static (standing) parameter they found was LL, while PI, PT, and SS were not different among age groups.[3] The mean PT in that study (13°) was similar to the mean PT in this systematic review (14°).[3] We found changes in static spinopelvic characteristics with ageing to be rather small, on average 1° to 1.5° per decade. This might be attributed to the inclusion of exclusively 'healthy' asymptomatic cohorts. As PT reflects sagittal balance, it is unsurprising that in a well-functioning cohort, there was appropriate sagittal balance and transfer of load. Subanalysis illustrated no confounding effect on our findings based on sex as there was no difference in male and female ratios among different age groups. The effect of sex on spinopelvic characteristics has been reported previously, with conflicting results on whether characteristics differ or not.[3,7,87,104–108] Verhaegen et al[3] reported on both standing and deep-flexed seated spinopelvic characteristics among asymptomatic individuals, and reported no differences in standing spinopelvic characteristics between sexes.[33] However, the authors identified that men exhibited less hip flexion, presumably due to morphological differences between males and females,[3] such as a smaller femoral head neck offset and lower combined femoral and acetabular version. This decrease in hip flexion leads to the increase in posterior PT in a sitting position among males.

Several limitations can be identified for our study. First, incomplete data extraction was present in several studies as some of the values were not separated based on age. In these studies, mean values for all age groups were incorporated into a single value, which made it impossible to determine the average values of these parameters were in different decades of life. Second, we did not perform any methodological assessment of the studies, as most assessment tools primarily evaluate whether authors in a study have been blinded. Since we sought to identify normal healthy patients who had no medical interventions and no pathological states, participants and researchers would not be privy to blinded treatment arms as intervention would naturally not be given. Third, most studies (72/104) were conducted among Asian populations, while the remaining studies included a wide variety of ethnicities; differences in values between different ethnicities were not specified. This creates a potential for selection bias during data interpretation and statistical analysis with possible larger trends identified in the Asian population. Lastly, we evaluated all spinopelvic parameters based on static standing positions. Therefore, our study can only comment on the static standing positions of these parameters; further evaluation of how age influences dynamic spinopelvic characteristics is required.

In summary, this systematic review aimed to define normal standing ranges of spinopelvic changes in different ethnicities as they age in healthy populations. As populations age, their pelvis and spines change their orientation to maintain sagittal balance when standing. Non-pathological Asian spines have the largest degree of changes to their LL, SS, and PT as they age compared to all other ethnicities currently documented in the literature. This is possibly due to the lower PI and LL, however further prospective studies are required.

Supplementary material

Tables of studies reporting on the sex distribution by age to assess the confounding effect of sex.

References

1. **Yeganeh A**, **Moghtadaei M**, **Ameri Mahabadi E**, **Mahdavi SM**, **Pirani A**, **Safdari F**. Sagittal spinopelvic alignment in asymptomatic Iranian adults aged 18 to 40 years. *Arch Iran Med*. 2020;23(6):391–396.
2. **Rivière C**, **Hardijzer A**, **Lazennec JY**, **Beaulé P**, **Muirhead-Allwood S**, **Cobb J**. Spine-hip relations add understandings to the pathophysiology of femoro-acetabular impingement: A systematic review. *Orthop Traumatol Surg Res*. 2017;103(4):549–557.
3. **Verhaegen JCF**, **Innmann M**, **Alves Batista N**, **et al**. Defining "normal" static and dynamic spinopelvic characteristics: A cross-sectional study. *JB JS Open Access*. 2022;7(3):e22.00007.
4. **Roussouly P**, **Pinheiro-Franco JL**. Biomechanical analysis of the spino-pelvic organization and adaptation in pathology. *Eur Spine J*. 2011;20 Suppl 5(Suppl 5):609–618.
5. **Schwab F**, **Lafage V**, **Patel A**, **Farcy JP**. Sagittal plane considerations and the pelvis in the adult patient. *Spine (Phila Pa 1976*). 2009;34(17):1828–1833.
6. **Innmann MM**, **Merle C**, **Gotterbarm T**, **Ewerbeck V**, **Beaulé PE**, **Grammatopoulos G**. Can spinopelvic mobility be predicted in patients awaiting total hip arthroplasty? A prospective, diagnostic study of patients with end-stage hip osteoarthritis. *Bone Joint J*. 2019;101-B(8):902–909.
7. **Innmann MM**, **Merle C**, **Phan P**, **Beaulé PE**, **Grammatopoulos G**. Differences in spinopelvic characteristics between hip osteoarthritis patients and controls. *J Arthroplasty*. 2021;36(8):2808–2816.
8. **Amabile C**, **Pillet H**, **Lafage V**, **Barrey C**, **Vital JM**, **Skalli W**. A new quasi-invariant parameter characterizing the postural alignment of young asymptomatic adults. *Eur Spine J*. 2016;25(11):3666–3674.
9. **Otayek J**, **Bizdikian AJ**, **Yared F**, **et al**. Influence of spino-pelvic and postural alignment parameters on gait kinematics. *Gait Posture*. 2020;76:318–326.
10. **Yukawa Y**, **Kato F**, **Suda K**, **Yamagata M**, **Ueta T**, **Yoshida M**. Normative data for parameters of sagittal spinal alignment in healthy subjects: an analysis of gender specific differences and changes with aging in 626 asymptomatic individuals. *Eur Spine J*. 2018;27(2):426–432.
11. **Zhou S**, **Xu F**, **Wang W**, **Zou D**, **Sun Z**, **Li W**. Age-based normal sagittal alignment in Chinese asymptomatic adults: establishment of the relationships between pelvic incidence and other parameters. *Eur Spine J*. 2020;29(3):396–404.
12. **Suh DH**, **Hong JY**, **Suh SW**, **Park JW**, **Lee SH**. Analysis of hip dysplasia and spinopelvic alignment in cerebral palsy. *Spine J*. 2014;14(11):2716–2723.
13. **Lee JS**, **Suh KT**, **Kim JI**, **Goh TS**. Analysis of sagittal balance of ankylosing spondylitis using spinopelvic parameters. Internet. *J Spinal Disord Tech*. 2014;27(3):E94–8.
14. **Suh SW**, **Suh DH**, **Kim JW**, **Park JH**, **Hong JY**. Analysis of sagittal spinopelvic parameters in cerebral palsy. *Spine J*. 2013;13(8):882–888.
15. **Hong JY**, **Suh SW**, **Modi HN**, **Park JW**, **Park JH**. Analysis of sagittal spinopelvic parameters in achondroplasia. *Spine (Phila Pa 1976*). 2011;36(18):E1233–9.
16. **Yeh K-T**, **Lee R-P**, **Chen I-H**, **et al**. Are there age- and sex-related differences in spinal sagittal alignment and balance among Taiwanese asymptomatic adults? *Clin Orthop Relat Res*. 2018;476(5):1010–1017.
17. **Kang KB**, **Kim YJ**, **Muzaffar N**, **Yang JH**, **Kim YB**, **Yeo ED**. Changes of sagittal spinopelvic parameters in normal Koreans with age over 50. *Asian Spine J*. 2010;4(2):96–101.
18. **Weng W-J**, **Wang W-J**, **Wu M-D**, **Xu Z-H**, **Xu L-L**, **Qiu Y**. Characteristics of sagittal spine-pelvis-leg alignment in patients with severe hip osteoarthritis. *Eur Spine J*. 2015;24(6):1228–1236.
19. **Janssen MMA**, **Drevelle X**, **Humbert L**, **Skalli W**, **Castelein RM**. Differences in male and female spino-pelvic alignment in asymptomatic young adults: a three-dimensional analysis using upright low-dose digital biplanar X-rays. *Spine (Phila Pa 1976)*. 2009;34(23):E826–32.
20. **Roussouly P**, **Gollogly S**, **Noseda O**, **Berthonnaud E**, **Dimnet J**. The vertical projection of the sum of the ground reactive forces of a standing patient is not the same as the C7 plumb line. *Spine*. 2006;31(11):E320–E325.
21. **Kim YB**, **Kim YJ**, **Ahn Y-J**, **et al**. A comparative analysis of sagittal spinopelvic alignment between young and old men without localized disc degeneration. *Eur Spine J*. 2014;23(7):1400–1406.
22. **Gerilmez A**, **Naderi S**. A novel perspective for analyzing craniocervical sagittal balance and horizontal gaze. *World Neurosurg*. 2021;149:e924–e930.
23. **Endo K**, **Suzuki H**, **Nishimura H**, **Tanaka H**, **Shishido T**, **Yamamoto K**. Characteristics of sagittal spino-pelvic alignment in Japanese young adults. *Asian Spine J*. 2014;8(5):599–604.
24. **Weitkunat T**, **Buck FM**, **Jentzsch T**, **Simmen HP**, **Werner CML**, **Osterhoff G**. Influence of high-heeled shoes on the sagittal balance of the spine and the whole body. *Eur Spine J*. 2016;25(11):3658–3665.
25. **Ando K**, **Kobayashi K**, **Nakashima H**, **et al**. Poor spinal alignment in females with obesity: The Yakumo study. *J Orthop*. 2020;21:512–516.
26. **Chaléat-Valayer E**, **Mac-Thiong JM**, **Paquet J**, **Berthonnaud E**, **Siani F**, **Roussouly P**. Sagittal spino-pelvic alignment in chronic low back pain. *Eur Spine J*. 2011;20 Suppl 5(Suppl 5):634–640.
27. **Lee CS**, **Park SJ**, **Chung SS**, **Lee KH**. The effect of simulated knee flexion on sagittal spinal alignment: novel interpretation of spinopelvic alignment. *Eur Spine J*. 2013;22(5):1059–1065.
28. **Pourabbas Tahvildari B**, **Masroori Z**, **Erfani MA**, **Solooki S**, **Vosoughi AR**. The impact of spino-pelvic parameters on pathogenesis of lumbar disc herniation. *Musculoskelet Surg*. 2022;106(2):195–199.
29. **Zhou S**, **Sun Z**, **Li W**, **Zou D**, **Li W**. The pelvic incidence stratified sagittal spinopelvic alignment in asymptomatic Chinese population with different age groups. *Global Spine J*. 2022;12(8):1821–1826.
30. **Iyer S**, **Lenke LG**, **Nemani VM**, **et al**. Variations in sagittal alignment parameters based on age: A prospective study of asymptomatic volunteers using full-body radiographs. *Spine (Phila Pa 1976)*. 2016;41(23):1826–1836.

31. **Sun Z**, **Zhou S**, **Jiang S**, **Zou D**, **Yu M**, **Li W**. Variations of sagittal alignment in standing versus sitting positions under the Roussouly classification in asymptomatic subjects. *Global Spine J*. 2022;12(5):772–779.
32. **Asai Y**, **Tsutsui S**, **Oka H**, **et al**. Sagittal spino-pelvic alignment in adults: The Wakayama Spine Study. *PLoS One*. 2017;12(6):e0178697.
33. **Endo K**, **Suzuki H**, **Sawaji Y**, **et al**. Relationship among cervical, thoracic, and lumbopelvic sagittal alignment in healthy adults. *J Orthop Surg (Hong Kong*). 2016;24(1):92–96.
34. **Menezes-Reis R**, **Bonugli GP**, **Salmon CEG**, **Mazoroski D**, **Herrero CFP da S**, **Nogueira-Barbosa MH**. Relationship of spinal alignment with muscular volume and fat infiltration of lumbar trunk muscles. *PLoS One*. 2018;13(7):e0200198.
35. **Bakouny Z**, **Assi A**, **Massaad A**, **et al**. Roussouly's sagittal spino-pelvic morphotypes as determinants of gait in asymptomatic adult subjects. *Gait Posture*. 2017;54:27–33.
36. **Boulay C**, **Tardieu C**, **Hecquet J**, **et al**. Sagittal alignment of spine and pelvis regulated by pelvic incidence: standard values and prediction of lordosis. *Eur Spine J*. 2006;15(4):415–422.
37. **Endo K**, **Suzuki H**, **Nishimura H**, **Tanaka H**, **Shishido T**, **Yamamoto K**. Sagittal lumbar and pelvic alignment in the standing and sitting positions. *J Orthop Sci*. 2012;17(6):682–686.
38. **Vaz G**, **Roussouly P**, **Berthonnaud E**, **Dimnet J**. Sagittal morphology and equilibrium of pelvis and spine. *Eur Spine J*. 2002;11(1):80–87.
39. **Uehara M**, **Takahashi J**, **Ikegami S**, **et al**. Sagittal spinal alignment deviation in the general elderly population: a Japanese cohort survey randomly sampled from a basic resident registry. *Spine J*. 2019;19(2):349–356.
40. **Moon MS**, **Lee H**, **Kim ST**, **Kim SJ**, **Kim MS**, **Kim DS**. Spinopelvic orientation on radiographs in various body postures: Upright standing, chair sitting, Japanese style kneel sitting, and Korean style cross-legged sitting. *Clin Orthop Surg*. 2018;10(3):322–327.
41. **Yang X**, **Kong Q**, **Song Y**, **Liu L**, **Zeng J**, **Xing R**. The characteristics of spinopelvic sagittal alignment in patients with lumbar disc degenerative diseases. *Eur Spine J*. 2014;23(3):569–575.
42. **Oe S**, **Togawa D**, **Nakai K**, **et al**. The influence of age and sex on cervical spinal alignment among volunteers aged over 50. *Spine (Phila Pa 1976)*. 2015;40(19):1487–1494.
43. **Fader RR**, **Tao MA**, **Gaudiani MA**, **et al**. The role of lumbar lordosis and pelvic sagittal balance in femoroacetabular impingement. *Bone Joint J*. 2018;100-B(10):1275–1279.
44. **Marty C**, **Boisaubert B**, **Descamps H**, **et al**. The sagittal anatomy of the sacrum among young adults, infants, and spondylolisthesis patients. *Eur Spine J*. 2002;11(2):119–125.
45. **Thelen T**, **Thelen P**, **Demezon H**, **Aunoble S**, **Le Huec J-C**. Normative 3D acetabular orientation measurements by the low-dose EOS imaging system in 102 asymptomatic subjects in standing position: Analyses by side, gender, pelvic incidence and reproducibility. *Orthop Traumatol Surg Res*. 2017;103(2):209–215.
46. **Bassani T**, **Galbusera F**, **Luca A**, **Lovi A**, **Gallazzi E**, **Brayda-Bruno M**. Physiological variations in the sagittal spine alignment in an asymptomatic elderly population. *Spine J*. 2019;19(11):1840–1849.
47. **Lee SH**, **Son ES**, **Seo EM**, **Suk KS**, **Kim KT**. Factors determining cervical spine sagittal balance in asymptomatic adults: correlation with spinopelvic balance and thoracic inlet alignment. *Spine J*. 2015;15(4):705–712.
48. **Hu PP**, **Yu M**, **Liu XG**, **Chen ZQ**, **Liu ZJ**. How does the sagittal spinal balance of the scoliotic population deviate from the asymptomatic population? *BMC Musculoskelet Disord*. 2018;19(1):36.
49. **Chevillotte T**, **Coudert P**, **Cawley D**, **et al**. Influence of posture on relationships between pelvic parameters and lumbar lordosis: Comparison of the standing, seated, and supine positions. A preliminary study. *Orthop Traumatol Surg Res*. 2018;104(5):565–568.
50. **El Rayes J**, **Kreichati G**, **Sassine S**. Lumbar morphotypes analysis in a population of asymptomatic young adults about 94 subjects. *LMJ*. 2017;65(3):162–166.
51. **Attali V**, **Clavel L**, **Rouch P**, **et al**. Compensation of respiratory-related postural perturbation is achieved by maintenance of head-to-pelvis alignment in healthy humans. *Front Physiol*. 2019;10:APR.
52. **Hasegawa K**, **Okamoto M**, **Hatsushikano S**, **et al**. Compensation for standing posture by whole-body sagittal alignment in relation to health-related quality of life. *Bone Joint J*. 2020;102-B(10):1359–1367.
53. **Sohn S**, **Chung CK**, **Kim YJ**, **et al**. Sagittal spinal alignment in asymptomatic patients over 30 years old in the Korean population. *Acta Neurochir (Wien*). 2017;159(6):1119–1128.
54. **Hey HWD**, **Tan KA**, **Chin BZ**, **Liu G**, **Wong HK**. Comparison of whole body sagittal alignment during directed vs natural, relaxed standing postures in young, healthy adults. *Spine J*. 2019;19(11):1832–1839.
55. **Arima H**, **Togawa D**, **Hasegawa T**, **et al**. Hypertension is related to positive global sagittal alignment: A cross-sectional cohort study. *Asian Spine J*. 2019;13(6):895–903.
56. **Lee CS**, **Chung SS**, **Kang KC**, **Park SJ**, **Shin SK**. Normal patterns of sagittal alignment of the spine in young adults radiological analysis in a Korean population. *Spine (Phila Pa 1976*). 2011;36(25):E1648–54.
57. **Bhosale S**, **Pinto D**, **Srivastava S**, **Purohit S**, **Gautham S**, **Marathe N**. Measurement of spinopelvic parameters in healthy adults of Indian origin - A cross sectional study. *J Clin Orthop Trauma*. 2020;11(5):883–888.
58. **Zhou S**, **Sun Z**, **Li W**, **et al**. The standing and sitting sagittal spinopelvic alignment of Chinese young and elderly population: does age influence the differences between the two positions? *Eur Spine J*. 2020;29(3):405–412.
59. **Pratali RR**, **Nasreddine MA**, **Diebo B**, **Oliveira C**, **Lafage V**. Normal values for sagittal spinal alignment: a study of Brazilian subjects. *Clinics (Sao Paulo*). 2018;73:e647.
60. **Ding Y**, **Liu B**, **Qiao H**, **et al**. Can knee flexion contracture affect cervical alignment and neck tension? A prospective self-controlled pilot study. *Spine J*. 2020;20(2):251–260.
61. **Araújo F**, **Lucas R**, **Alegrete N**, **Azevedo A**, **Barros H**. Individual and contextual characteristics as determinants of sagittal standing posture: A population-based study of adults. *Spine J*. 2014;14(10):2373–2383.
62. **Oe S**, **Yamato Y**, **Hasegawa T**, **et al**. Deterioration of sagittal spinal alignment with age originates from the pelvis not the lumbar spine: a 4-year longitudinal cohort study. *Eur Spine J*. 2020;29(9):2329–2339.
63. **Machino M**, **Ando K**, **Kobayashi K**, **et al**. Differences of lumbopelvic sagittal parameters among community-dwelling middle-age and elderly individuals: Relations with locomotor physical function. *J Clin Neurosci*. 2020;73:80–84.
64. **Roussouly P**, **Gollogly S**, **Berthonnaud E**, **Dimnet J**. Classification of the normal variation in the sagittal alignment of the human lumbar spine and pelvis in the standing position. *Spine (Phila Pa 1976*). 2005;30(3):346–353.
65. **Cho Y**. Evaluation of global sagittal balance in Koreans adults. *J Korean Neurosurg Soc*. 2017;60(5):560–566.
66. **Hu Z**, **Man GCW**, **Yeung KH**, **et al**. 2020 Young Investigator Award Winner: Age- and sex-related normative value of whole-body sagittal alignment based on 584 asymptomatic Chinese adult population from age 20 to 89. *Spine (Phila Pa 1976)*. 2020;45(2):79–87.
67. **Suzuki H**, **Endo K**, **Sawaji Y**, **et al**. Radiographic assessment of spinopelvic sagittal alignment from sitting to standing position. *Spine Surg Relat Res*. 2018;2(4):290–293.
68. **Laouissat F**, **Sebaaly A**, **Gehrchen M**, **Roussouly P**. Classification of normal sagittal spine alignment: refounding the Roussouly classification. *Eur Spine J*. 2018;27(8):2002–2011.
69. **Sinclair ST**, **Emara AK**, **Orr MN**, **Klika AK**, **Piuzzi NS**. The influence of geographic region on hip and knee arthroplasty literature from 1988 to 2018. *J Am Acad Orthop Surg Glob Res Rev*. 2021;5(6):e20.00260.
70. **Drazin D**, **Hussain M**, **Harris J**, **et al**. The role of sacral slope in lumbosacral fusion: a biomechanical study. *J Neurosurg Spine*. 2015;23(6):754–762.
71. **Place HM**, **Hayes AM**, **Huebner SB**, **Hayden AM**, **Israel H**, **Brechbuhler JL**. Pelvic incidence: a fixed value or can you change it? *Spine J*. 2017;17(10):1565–1569.
72. **Hammerberg EM**, **Wood KB**. Sagittal profile of the elderly. *J Spinal Disord Tech*. 2003;16(1):44–50.
73. **Pratali RR**, **Nasreddine MA**, **Diebo B**, **Oliveira C**, **Lafage V**. Normal values for sagittal spinal alignment: A study of Brazilian subjects. *Clinics (Sao Paulo*). 2018;73:e647.
74. **Arima H**, **Dimar JR**, **Glassman SD**, **Yamato Y**, **Matsuyama Y**, **Mac-Thiong JM**. Differences in lumbar and pelvic parameters among African American, Caucasian and Asian populations. *Eur Spine J*. 2018;27(12):2990–2998.
75. **Ishida T**, **Inaba Y**, **Kobayashi N**, **et al**. Changes in pelvic tilt following total hip arthroplasty. *J Orthop Sci*. 2011;16(6):682–688.
76. **Cotter BD**, **Innmann MM**, **Dobransky JS**, **Merle C**, **Beaulé PE**, **Grammatopoulos G**. Does functional cup orientation change at minimum of 10 years after primary total hip arthroplasty? *J Arthroplasty*. 2020;35(9):2507–2512.
77. **Ranawat CS**, **Ranawat AS**, **Lipman JD**, **White PB**, **Meftah M**. Effect of spinal deformity on pelvic orientation from standing to sitting position. *J Arthroplasty*. 2016;31(6):1222–1227.
78. **Suzuki H**, **Inaba Y**, **Kobayashi N**, **Ishida T**, **Ike H**, **Saito T**. Postural and chronological change in pelvic tilt five years after total hip arthroplasty in patients with developmental dysplasia of the hip: A three-dimensional analysis. *J Arthroplasty*. 2016;31(1):317–322.

79. **Okanoue Y**, **Ikeuchi M**, **Takaya S**, **Izumi M**, **Aso K**, **Kawakami T**. Chronological changes in functional cup position at 10 years after total hip arthroplasty. *HIP Int*. 2017;27(5):477–482.
80. **Heckmann N**, **McKnight B**, **Stefl M**, **Trasolini NA**, **Ike H**, **Dorr LD**. Late dislocation following total hip arthroplasty: Spinopelvic imbalance as a causative factor. *J Bone Joint Surg Am*. 2018;100-A(21):1845–1853.
81. **Kobayashi T**, **Chiba H**, **Jimbo S**, **et al**. Clinical, physical, and radiographic analyses of lumbar degenerative kyphosis and spondylolisthesis among community-based cohort. *Eur Spine J*. 2016;25(8):2384–2389.
82. **Bsat S**, **Frei H**, **Beaulé PE**. The acetabular labrum: a review of its function. *Bone Joint J*. 2016;98-B(6):730–735.
83. **Diebo BG**, **Henry J**, **Lafage V**, **Berjano P**. Sagittal deformities of the spine: factors influencing the outcomes and complications. *Eur Spine J*. 2015;24 Suppl 1:S3–15.
84. **Park SH**. Tools for assessing fall risk in the elderly: a systematic review and meta-analysis. *Aging Clin Exp Res*. 2018;30(1):1–16.
85. **Moon JW**, **Shinn JK**, **Ryu D**, **Oh SY**, **Shim YS**, **Yoon SH**. Pelvic incidence can be changed not only by age and sex, but also by posture used during imaging. *Korean J Spine*. 2017;14(3):77–83.
86. **Oliveira LM**, **Roizenblatt S**, **Silva FD**, **Roizenblatt A**, **Fernandes ARC**, **Szejnfeld VL**. Relationship of the sacral slope with early gait derangements in robust older women. *Adv Rheumatol*. 2021;61(1):35.
87. **Zhu Z**, **Xu L**, **Zhu F**, **et al**. Sagittal alignment of spine and pelvis in asymptomatic adults: norms in Chinese populations. *Spine (Phila Pa 1976)*. 2014;39(1):E1–6.
88. **Boulay C**, **Tardieu C**, **Hecquet J**, **et al**. Sagittal alignment of spine and pelvis regulated by pelvic incidence: standard values and prediction of lordosis. *Eur Spine J*. 2006;15(4):415–422.
89. **Sparrey CJ**, **Bailey JF**, **Safaee M**, **et al**. Etiology of lumbar lordosis and its pathophysiology: a review of the evolution of lumbar lordosis, and the mechanics and biology of lumbar degeneration. *Neurosurg Focus*. 2014;36(5):E1.
90. **Mendoza-Lattes S**, **Ries Z**, **Gao Y**, **Weinstein SL**. Natural history of spinopelvic alignment differs from symptomatic deformity of the spine. *Spine (Phila Pa 1976)*. 2010;35(16):E792–8.
91. **Yokoyama K**, **Kawanishi M**, **Yamada M**, **et al**. Age-related variations in global spinal alignment and sagittal balance in asymptomatic Japanese adults. *Neurol Res*. 2017;39(5):414–418.
92. **Le Huec JC**, **Hasegawa K**. Normative values for the spine shape parameters using 3D standing analysis from a database of 268 asymptomatic Caucasian and Japanese subjects. *Eur Spine J*. 2016;25(11):3630–3637.
93. **Sohn S**, **Chung CK**, **Kim YJ**, **et al**. Sagittal spinal alignment in asymptomatic patients over 30 years old in the Korean population. *Acta Neurochir (Wien)*. 2017;159(6):1119–1128.
94. **Le Huec JC**, **Thompson W**, **Mohsinaly Y**, **Barrey C**, **Faundez A**. Sagittal balance of the spine. *Eur Spine J*. 2019;28(9):1889–1905.
95. **Shimizu M**, **Kobayashi T**, **Chiba H**, **et al**. Adult spinal deformity and its relationship with height loss: a 34-year longitudinal cohort study. *BMC Musculoskelet Disord*. 2020;21(1):422.
96. **Lee ES**, **Ko CW**, **Suh SW**, **Kumar S**, **Kang IK**, **Yang JH**. The effect of age on sagittal plane profile of the lumbar spine according to standing, supine, and various sitting positions. *J Orthop Surg Res*. 2014;9(1):11.
97. **Wang Q**, **Sun CT**. Characteristics and correlation analysis of spino-pelvic sagittal parameters in elderly patients with lumbar degenerative disease. *J Orthop Surg Res*. 2019;14(1):127.
98. **Bayartai M-E**, **Ferreira PH**, **Pappas E**, **et al**. Genetic and environmental effects on lumbar posture, flexibility and motion control in healthy adults. *Musculoskelet Sci Pract*. 2020;50:102253.
99. **Lonner BS**, **Auerbach JD**, **Sponseller P**, **Rajadhyaksha AD**, **Newton PO**. Variations in pelvic and other sagittal spinal parameters as a function of race in adolescent idiopathic scoliosis. *Spine (Phila Pa 1976)*. 2010;35(10):E374–7.
100. **Okuda T**, **Fujita T**, **Kaneuji A**, **Miaki K**, **Yasuda Y**, **Matsumoto T**. Stage-specific sagittal spinopelvic alignment changes in osteoarthritis of the hip secondary to developmental hip dysplasia. *Spine (Phila Pa 1976)*. 2007;32(26):E816–9.
101. **Yang G**, **Li Y**, **Zhang H**. The influence of pelvic tilt on the anteversion angle of the acetabular prosthesis. *Orthop Surg*. 2019;11(5):762–769.
102. **Lee SH**, **Kim KT**, **Suk KS**, **Lee JH**, **Seo EM**, **Huh DS**. Sagittal decompensation after corrective osteotomy for lumbar degenerative kyphosis: classification and risk factors. *Spine (Phila Pa 1976)*. 2011;36(8):E538–44.
103. **Lafage V**, **Ames C**, **Schwab F**, **et al**. Changes in thoracic kyphosis negatively impact sagittal alignment after lumbar pedicle subtraction osteotomy: A comprehensive radiographic analysis. *Spine (Phila Pa 1976)*. 2012;37(3):E180–7.
104. **Dreischarf M**, **Albiol L**, **Rohlmann A**, **et al**. Age-related loss of lumbar spinal lordosis and mobility--A study of 323 asymptomatic volunteers. *PLoS One*. 2014;9(12):e116186.
105. **Janssen MMA**, **Drevelle X**, **Humbert L**, **Skalli W**, **Castelein RM**. Differences in male and female spino-pelvic alignment in asymptomatic young adults: a three-dimensional analysis using upright low-dose digital biplanar X-rays. *Spine (Phila Pa 1976)*. 2009;34(23):E826–32.
106. **Vialle R**, **Levassor N**, **Rillardon L**, **Templier A**, **Skalli W**, **Guigui P**. Radiographic analysis of the sagittal alignment and balance of the spine in asymptomatic subjects. *J Bone Joint Surg Am*. 2005;87-A(2):260–267.
107. **Mac-Thiong JM**, **Roussouly P**, **Berthonnaud E**, **Guigui P**. Age- and sex-related variations in sagittal sacropelvic morphology and balance in asymptomatic adults. *Eur Spine J*. 2011;20 Suppl 5(Suppl 5):572–577.

Author information:
- K. J. Lukas, MB, BCH, BAO, BSc, Orthopaedic Surgery Resident
- P. Phan, MD, FRCSC, Orthopaedic Surgeon
  Division of Orthopaedic Surgery, The Ottawa Hospital, Ottawa, Canada.
- J. C. F. Verhaegen, MD, Orthopaedic Surgeon (Clinical Fellow), Division of Orthopaedic Surgery, The Ottawa Hospital, Ottawa, Canada; University Hospital Antwerp, Edegem, Belgium; Orthopedic Center Antwerp, Antwerp, Belgium.
- H. Livock, BSc, MSc, Research Coordinator, Division of Orthopaedic Surgery, Children's Hospital of Eastern Ontario Research Institute, Ottawa, Canada.
- E. Kowalski, BSc, MSc, PhD, Researcher, PhD Student of Biomechanics, Ottawa Hospital Research Institute, Ottawa, Canada.
- G. Grammatopoulos, MBBS, Bsc, DPhil(Oxon), FRCS (Tr&Orth), Staff Orthopaedic Surgeon, Associate Professor, Division of Orthopaedic Surgery, The Ottawa Hospital, Ottawa, Canada; University of Ottawa, Ottawa, Canada.

Author contributions:
- K. J. Lukas: Conceptualization, Data curation, Formal analysis, Methodology, Writing – original draft.
- J. C. F. Verhaegen: Methodology, Formal analysis, Writing – original draft.
- H. Livock: Data curation, Methodology, Project administration.
- E. Kowalski: Data curation, Formal analysis, Conceptualization, Methodology.
- P. Phan: Writing – review & editing.
- G. Grammatopoulos: Conceptualization, Formal analysis, Methodology, Supervision, Writing – review & editing.

Funding statement:
- The authors received no financial or material support for the research, authorship, and/or publication of this article.

ICMJE COI statement:
- P. Phan reports a research grant and consulting fees from Stryker, unrelated to this study.

Acknowledgements:
- The authors would like the thank the statisticians at the Ottawa Hospital Research Institute for their contributions on the statistical results. The authors also thank the University of Ottawa Library department for their assistance creating the search criteria for this systematic review.

Open access funding:
- The authors confirm that the open access fee for this study was self-funded.