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ORIGINAL ARTICLE

Xipho-pubic angle (XPA) correlates with patient's reported outcomes in a population of adult spinal deformity: results from a multi-center cohort study

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Abstract

Study design Retrospective multi-center cohort study.

Purpose Sagittal misalignment causes changes in the abdominal shape. Xipho-pubic angle (XPA) has been previously described to radiographically evaluate the shape of the abdominal cavity in patients with spine deformity. The aims of this study are to evaluate the correlation of XPA-to-spinopelvic sagittal parameters and to patients' health-related quality-of-life (HRQoL) scores.

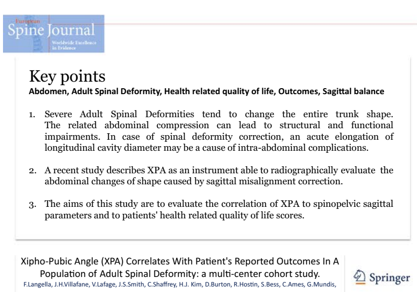
Methods 278 patients from a multi-center database with diagnosis adult spinal deformity (ASD) (one or more of: coronal Cobb angle > 20°, sagittal vertical axis (SVA) > 50 mm, pelvic tilt (PT) > 25°, and thoracic kyphosis > 60°) were included. Cut-off values for moderate and severe disability (ODI—Oswestry Disability Index—20 and 40%) were calculated. Pearson's correlation was tested between XPA and spinopelvic parameters and between XPA and HRQoL scores.

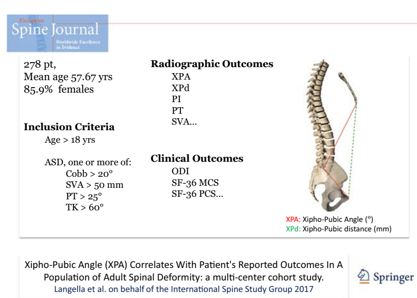
Results The cut-off value of XPA to identify ODI severe disability (40/100) was identified with XPA smaller than 103°; minimal (20/100) disability was identified by XPA greater than 113°. XPA showed strong correlation to sagittal spinopelvic parameters—PT, SVA, lumbar lordosis (LL), pelvic incidence (PI) minus LL—and to HRQoL scores—ODI, SF-36 PCS and SRS-22 activity and pain. XPA was the parameter with the strongest correlation to HRQoL scores.

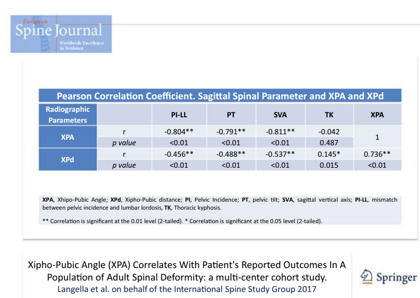
Conclusions Xipho-pubic angle reflects changes in spinal changes and has strong correlation to HRQoL and spinopelvic parameters. It can discriminate between patients with minimal, moderate, and severe disability as measured by ODI scores.

Graphical Abstract

These slides can be retrieved under Electronic Supplementary Material.







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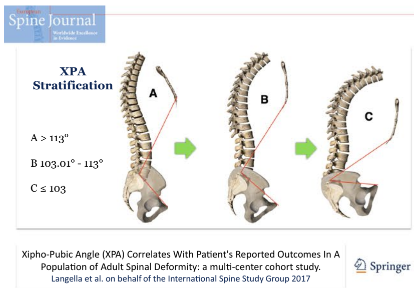

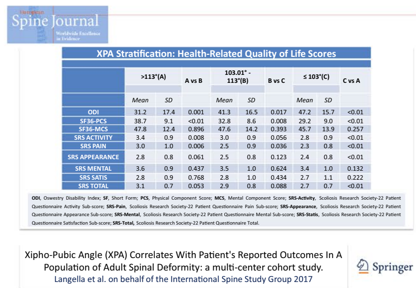

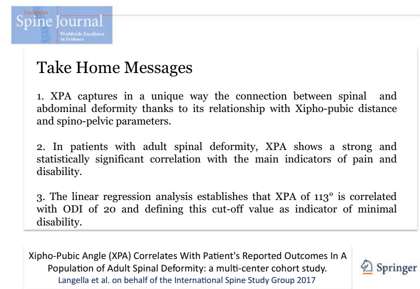

Keywords Abdomen · Health-related quality of life · Outcomes · Sagittal alignment · Spinal deformity

Introduction

The ideal spinal sagittal alignment is the spinal shape that allows to maintain the standing position with minimal energy expenditure [1]. Adult spinal deformity (ASD), a disease progressively increasing with population aging [2], is characterized by a wide range of radiographic and clinical patterns [3]. Its severity is conditioned by the severity of sagittal (and to a lesser extent, coronal) spinal misalignment [4, 5]. In these conditions, spinal standing position reflects the interaction between the sagittal deformity and compensatory mechanisms aimed to maintain the correct alignment. The complete absence of compensatory mechanisms with the consequent sagittal deformity is mostly related to difficulties in activities of daily living [6]. This condition, global kyphosis, is characterized by loss of lumbar lordosis and increase of thoracic kyphosis [7].

These severe deformities tend to change the entire trunk shape. Several researches have been done in the past decade to establish the correlation between spine balance and changes in the shape of the abdominal cavity [8, 9].

Abdominal compression related to the spinal deformity seems to lead to intra-abdominal complications including gastrointestinal reflux and nausea [8, 9]. The surgical procedures aimed to correct spinal deformity are first aimed to achieve the optimal spinal alignment [10], but, when investigated, digestive functions tend to improve as well [11].

Langella et al. [12] recently described a radiographic parameter, XPA, initially developed to evaluate the effect of correction of sagittal deformity on the abdominal shape and on the abdominal fascial tension. This parameter has shown a fair-to-excellent test retest reliability and possesses validity to discriminate between preoperative and postoperative radiographs in patients undergoing successful surgery for sagittal misalignment. As a basis for future use of the parameter to explore the implications of abdominal shape in spinal deformity, this study aims to evaluate the correlation of XPA to other well known and validated sagittal parameters of use in clinical practice. In addition, this study aims to assess the association of XPA value to health-related quality of life.

Methods

Study design

This is a cohort retrospective multi-center study. Patients were enrolled in 11 centers from the United States following institutional review board (IRB) approval at each site. The database includes adult spinal deformity (ASD) patients with the following inclusion criteria: age > 18 years and radiographic ASD (one or more of: coronal Cobb angle > 20°, sagittal vertical axis > 50 mm, pelvic tilt > 25°, and thoracic kyphosis > 60°). Exclusion criteria for the database were scoliosis due to neuromuscular, infectious, malignant aetiologies, previous surgery, or main trauma on the sternum. The population was properly stratified in three groups representing minimal, moderate, and severe disability.

Outcomes

Clinical data

Patients' demographics included age, gender, and body mass index (BMI). Patients reported outcomes (PRO) were obtained at baseline and included Oswestry Disability Index (ODI), the Scoliosis Research Society-22 Patient Questionnaire (SRS-22r), Short-Form-36 (SF-36) Mental (MCS) and Physical (PCS) Component Scores [13–15].

Radiographic data

Full-length standing spine radiographs were used to assess patients' deformity. Radiographs were measured using dedicated and validated software (Spineview®, ENSAM

Paris Tech, Paris, France) [16]. Radiographic analysis was performed at a central location by independent researchers. Radiographic parameters included sagittal vertical axis (SVA), pelvic tilt (PT), and pelvic incidence minus lumbar lordosis (PI−LL) [4]. The XPA was measured on the sagittal plane as the angle between the line drawn from the posterior superior corner of S1 endplate and to the anterior border of the xiphisternal joint and the line drawn from the posterior superior corner of S1 and the superior border of pubic symphysis [12]. The Xipho-pubic distance (XPd) was measured as the distance between the anterior border of the xiphisternal joint and the superior border of the pubic symphysis.

Statistical analysis

All data were statistically analyzed using SPSS (SPSS Inc. Version 22.0; Armonk, NY: IBM Corp. USA). A stepwise linear regression, with the ODI as the independent variable and XPA as dependent variable, was performed to create cut-off values of XPA corresponding to two different degrees of disability (ODI: severe 40/100 and minimal 20/100).

Pearson correlations were calculated to assess the relationships between XPA, XPd, and all sagittal parameters. Furthermore, the correlations between XPA other radiographic sagittal parameters (PI−LL, PT, and SVA) and health-related quality-of-life scores were evaluated.

Independent-samples *t* test was used to determine the differences between the groups built on XPA cut-off values (Groups: “A”, “B”, and “C”) in terms of radiographic sagittal parameters, XPd, and HRQoL-related scores. A value of p less than 0.05 was considered to be statistically significant.

Results

Population

A total of 278 patients with a mean age 57.67 ± 13.39, BMI of 26.58 ± 5.15, and 85.9% of females were included in the study. Overall, mean ODI 41.11 ± 17.73, SF36 MSC 46.77 ± 13.52 and SF36 PCS 32.87 ± 9.80, and SRS-22 total score 2.89 ± 0.73. Patients had a mean XPA 103° ± 16.46, XPd 411.4 mm ± 61.63, PI 54.78 ± 12.57, PI−LL 15.21° ± 19.43, PT 24.13° ± 10.43, SVA 59.88 mm ± 71.96, LL 39.58° ± 20.81, T10-L2 − 14.06° ± 17.23, TK (Thoracic Kyphosis) –36.52° ± 18.43, and T1PA (T1 Pelvic Angle) 22° ± 12.81 (Table 1).

Table 1 Baseline demographics

	Minimum	Maximum	Mean	Standard deviation
Descriptive statistics				
Age	20	84	57.67	13.39
BMI	17	46	26.58	5.15
HRQoL scores				
ODI	0	84	41.11	17.73
SF36-MCS	11	71	46.77	13.52
SF36-PCS	9	59	32.87	9.80
SRS total	1	4	2.89	0.73
Radiographic parameters				
XPA (°)	63	150	103.66	16.46
XPd (mm)	213	547	411.4	61.63
PI (°)	12	92	54.78	12.57
PI−LL (°)	− 36	69	15.21	19.43
PT (°)	− 6	53	24.13	10.43
SVA (mm)	− 84	294	59.88	71.96
LL (°)	− 12	92	39.58	20.81
T10–L2 (°)	− 70	24	− 14.06	17.23
TK (T2–T12) (°)	− 99	11	− 36.52	18.43
T1PA	− 9	62	22.33	12.81

Data are expressed as means, standard deviations (SD), and minimum and maximum values

BMI body mass index, *ODI* Oswestry Disability Index, *SF-36 MCS* Short-Form-36 mental component summary, *SF-36 PCS* Short-Form-36 physical component summary, *SRS-total* Scoliosis Research Society-22 Patient Questionnaire, *XPA* xipho-pubic angle, *XPd* xipho-pubic distance, *PI* pelvic incidence, *PT* pelvic tilt, *SVA* sagittal vertical axis, *PI–LL* mismatch between pelvic incidence and lumbar lordosis, *T10–L2* thoracolumbar junction, *TK (T2–T12)* thoracic kyphosis, *T1PA* T1 pelvic angle (lordotic angles are expressed in + values and kyphotic angles are expressed in − values)

Correlation analysis

Sagittal parameters

The Pearson correlation analysis demonstrated that all sagittal parameters as PI−LL, SVA, PT, and XPA had a significant correlation with XPd (XPA: $r = 0.736$ p value < 0.01).

The XPA was highly correlated with all the other sagittal parameters: SVA ($r = -0.811$), pelvic tilt ($r = -0.791$), and pelvic incidence minus lumbar lordosis ($r = -0.804$), with p value < 0.01 (Table 2).

HRQoL

The Pearson correlation showed significant correlation of XPA and XPd with the indicators of pain and disability (ODI, SF-36 PCS, SRS activity, and SRS pain). All reported correlations were statistically significant, at a $p < 0.01$ level.

Table 2 Values of Pearson correlation coefficient between the different radiographic parameters and XPA and XPd

Radiographic parameters	PI−LL	PT	SVA	TK	XPA
Pearson correlation coefficient: sagittal spinal parameter and XPA and XPd					
XPA					
r	− 0.804**	− 0.791**	− 0.811**	− 0.042	1
p value	< 0.01	< 0.01	< 0.01	0.487	
XPd					
r	− 0.456**	− 0.488**	− 0.537**	0.145*	0.736**
p value	< 0.01	< 0.01	< 0.01	0.015	< 0.01

XPA xhipo-pubic angle, *XPd* xipho-pubic distance, *PI* pelvic incidence, *PT* pelvic tilt, *SVA* sagittal vertical axis, *PI−LL* mismatch between pelvic incidence and lumbar lordosis, *TK* thoracic kyphosis

** Correlation is significant at the 0.01 level (two-tailed). * Correlation is significant at the 0.05 level (two-tailed)

Xipho-pubic angle was more strongly correlated than PI−LL, PT, T1PA, and SVA with most scores of pain and disability scores (exception made of the stronger correlation of SVA with SF-36 MCS) (Table 3).

Furthermore, a statistically significant relationship between the XPA and XPd and age of patients was found (age: XPA $r = -0.439$ and XPd $r = -0.344$ for both $p < 0.01$) (Table 3).

Stratification of XPA

XPA cut-off values

The regression analysis, performed using XPA and ODI, was obtained with an $r^2 = 0.18$:

$$\text{XPA} = 119,991 + -0.397264 * (\text{ODI}).$$

On the basis of this regression, the deformity threshold for XPA was found to be 103° when ODI is equal to 40/100 and 113° when ODI is 20/100.

Categorization using XPA

Of the 278 patients, 83 (29.9%) had XPA ≥ 113° (group "A"), 63 (22.7%) had XPA between 103.01° and 113° (group "B") and 132 (47.5%) with a value of XPA < 103° (group "C").

Table 3 Values of Pearson correlation coefficient between HRQoL scores and XPA, XPd, and main sagittal radiographic parameters

Clinical parameters	ODI	SF-36 PCS	SF-36 MCS	SRS activity	SRS pain	AGE
Pearson correlation coefficient: HRQoL and XPA and XPd						
XPd						
r	− 0.267**	0.254**	0.073	0.229**	0.188**	− 0.344**
p value	< 0.001	< 0.001	0.227	< 0.001	0.002	< 0.001
XPA						
r	− 0.428**	0.448**	0.118	0.331**	0.361**	− 0.439**
p value	< 0.001	< 0.001	0.05	< 0.001	< 0.001	< 0.001
T1PA						
r	0.374**	− 0.398**	− 0.104	− 0.295**	− 0.297**	0.415**
p value	< 0.001	< 0.001	0.083	< 0.001	< 0.001	< 0.001
PI−LL						
r	0.343**	− 0.354**	− 0.118*	− 0.281**	− 0.298**	0.322**
p value	< 0.001	< 0.001	0.049	< 0.001	< 0.001	< 0.001
PT						
r	0.285**	− 0.303**	− 0.037	− 0.220**	− 0.248**	0.357**
p value	< 0.001	< 0.001	0.537	< 0.001	< 0.001	< 0.001
SVA						
r	0.399**	− 0.417**	− 0.147*	− 0.300**	− 0.279**	0.378**
p value	< 0.001	< 0.001	0.014	< 0.001	< 0.001	< 0.001

XPd xipho-pubic distance, *XPA* xipho-pubic angle, *T1PA* T1 pelvic angle, *PI−LL* mismatch between pelvic incidence and lumbar lordosis, *PT* pelvic tilt, *SVA* sagittal vertical axis, *ODI* Oswestry Disability Index, *SF-36 PCS* Short-Form-36 physical component summary, *SF-36 MCS* Short-Form-36 mental component summary, *SRS-Activity* Scoliosis Research Society-22 Patient Questionnaire Activity Subscore, *SRS-Pain* Scoliosis Research Society-22 Patient Questionnaire Pain Subscore

** Correlation is significant at the 0.01 level (two-tailed). * Correlation is significant at the 0.05 level (two-tailed)

Comparisons between Groups

Differences statistically significant were seen comparing the three groups in terms of XPd (all, $p < 0.01$), sagittal spinal parameters (PI−LL, PT, and SVA: all, $p < 0.01$), and PRO of pain or disability (ODI, SF-36 PCS, SRS activity, and SRS pain: all, $p < 0.01$). Detailed comparisons are available in Tables 4 and 5.

Discussion

This study aims primarily to evaluate the correlation of XPA to other well-known and validated sagittal parameters of use in clinical practice and to assess the association between XPA and health-related quality of life.

Spinal alignment

The abdominal and pelvic muscles play an important role as spine stabilizer during the standing position and active motion [17]. The spinal and abdominal deformity seems influenced each other.

Previous studies have focused on the relationship between the sagittal spinal alignment and the quality of life. One of the first studies was performed by Glassman et al. In particular, it was established that positive sagittal balance predicts clinical symptoms and significant sagittal imbalance was directly related to pain and disability [18]. At the same time, the previous investigations failed to demonstrate a significant influence of coronal imbalance in HRQoL measurements [3].

The loss of lumbar lordosis tends to activate compensatory mechanism to maintain the erect position by limiting the muscle effort. The following loss of compensatory

Table 4 Groups' comparisons: radiographic parameters

	> 113° (A)		A vs. B	103.01°–113° (B)		B vs. C	≤ 103° (C)		C vs. A
	Mean	SD		Mean	SD		Mean	SD	
XPA stratification: sagittal spinal parameters									
XPd (mm)	462.9	37.9	< 0.01	424.8	49.8	< 0.01	372.5	51.6	< 0.01
PT (°)	14.3	6.8	< 0.01	22.4	5.9	< 0.01	31.2	8.5	< 0.01
PI–LL (°)	− 3.2	11.4	< 0.01	10.1	11.7	< 0.01	29.2	15.0	< 0.01
SVA (°)	− 3.8	36.1	< 0.01	34.1	40.2	< 0.01	112.2	61.0	< 0.01

XPd, xipho-pubic distance, *PT* pelvic tilt, *PI−LL* mismatch between pelvic incidence and lumbar lordosis, *SVA* sagittal vertical axis

Table 5 Groups' comparisons: HRQoL scores

	> 113° (A)		A vs. B	103.01°–113° (B)		B vs. C	≤ 103° (C)		C vs. A
	Mean	SD		Mean	SD		Mean	SD	
XPA stratification: health-related quality-of-life scores									
ODI	31.2	17.4	0.001	41.3	16.5	0.017	47.2	15.7	< 0.01
SF36-PCS	38.7	9.1	< 0.01	32.8	8.6	0.008	29.2	9.0	< 0.01
SF36-MCS	47.8	12.4	0.896	47.6	14.2	0.393	45.7	13.9	0.257
SRS activity	3.4	0.9	0.008	3.0	0.9	0.056	2.8	0.9	< 0.01
SRS pain	3.0	1.0	0.006	2.5	0.9	0.036	2.3	0.8	< 0.01
SRS appearance	2.8	0.8	0.061	2.5	0.8	0.123	2.4	0.8	< 0.01
SRS mental	3.6	0.9	0.437	3.5	1.0	0.624	3.4	1.0	0.132
SRS statis	2.8	0.9	0.768	2.8	1.0	0.434	2.7	1.1	0.222
SRS total	3.1	0.7	0.053	2.9	0.8	0.088	2.7	0.7	< 0.01

ODI Oswestry Disability Index, *SF* Short Form, *PCS* physical component score, *MCS* mental component score, *SRS* Scoliosis Research Society, *SRS-Activity* Scoliosis Research Society-22 Patient Questionnaire Activity Subscore, *SRS-Pain* Scoliosis Research Society-22 Patient Questionnaire Pain Subscore, *SRS-Appearance* Scoliosis Research Society-22 Patient Questionnaire Appearance Subscore, *SRS-Mental* Scoliosis Research Society-22 Patient Questionnaire Mental Subscore, *SRS-Statis* Scoliosis Research Society-22 Patient Questionnaire Satisfaction Subscore, *SRS-Total* Scoliosis Research Society-22 Patient Questionnaire Total mechanism, related to the patients aging, leads to global misalignment and pain or disability. Overall, when corrective surgery is performed, calculation of ideal lordosis and kyphosis on the basis of pelvic incidence and age is a reliable method to predict good postoperative alignment [19, 20].

Lafage et al. [5] in a recent study described a new radiographic parameter to investigate the correlation between sagittal deformity and HRQoL. This study demonstrated that T1 pelvic angle had the strongest correlation compared to T1 tilt and lumbar lordosis to HRQoL. These strongest relations to quality of life were attributed to the concomitant increase of PT and SVA that occurred in patients with T1 pelvic angle increasing [21].

In our study, XPA has shown substantial and statistically significant correlation with well-defined sagittal spinal parameters. Overall, decrease in XPA is associated with increase in terms of PT and SVA with loss of lumbar lordosis. This pattern of spinal changing is extremely correlated with sagittal impairment and clinical disability [22].

Interestingly, of all the sagittal parameters considered in this study, XPA is the one with the strongest correlation to pain and disability scores (ODI, SF36-PCS, SRS-22 activity, and SRS pain). This stronger correlation could be explained by the fact that XPA reflects not only sagittal parameter changing, but also abdominal compression, and this abdominal distortion could influence patients HRQoL measurements.

Abdominal changes

Xipho-pubic angle was built to provide an instrument able to evaluate the abdominal changes of shape caused by sagittal misalignment and its correction. The angular parameter avoids radiographic calibration usage.

Patients with severe spine deformity as patients with ankylosing spondylitis (AS) are often affected by severe impairment of digestive functions. This condition was considered as probably due to severe thoracolumbar kyphosis with compression of abdominal viscera and can present with a variety of symptoms as difficult digestion nausea and gastroesophageal reflux [9].

In this study, XPA quantifies changes in abdominal shape. Our results confirmed that changes in spinal shape due to adult deformity modify the abdominal morphology.

Ji et al. [23] for the first time evaluated the abdominal changes that occurred after surgical procedures aimed to correct thoracolumbar kyphosis, consisting in a significant increase of the longitudinal diameter of the abdominal cavity.

The abdominal stretch due to surgical corrective procedures seems to impact also on aortic size diameter [24]. A significant difference was seen in terms of size due to aortic lengthening in patients treated for thoracolumbar kyphosis. Furthermore, the possible risk of abdominal complications related to aortic damage due to the acute elongation of longitudinal cavity diameter was elucidated. In both studies, any gastrointestinal function was not evaluated.

According to Liu et al. [11], improvement in terms of digestive function was observed in patients surgically treated for kyphotic spinal deformity. Restoring the abdominal volume and reducing the visceral compression seemed related to the improvement of digestive function.

More recently, Krishankumar and Lenke in a case report study [25] proposed a new term, “Sternum-Into-Abdomen”, to define a patient affected by severe spinal kyphosis and abdominal compression. The result of multiple fractures severely reduced abdominal cavity up to cause gastrointestinal dysfunction and weight loss.

According to our results, XPA could an appropriate instrument to measure the abdominal deformities in patients affected by spinal disorders.

In accordance with our results, it can be hypothesized that patients affected by more severe degrees of sagittal deformity, i.e., patients with global kyphosis, could have greater gastrointestinal and lung condition. A shorter XPd was seen in patients with the lowest values of XPA (“C” group). Reduced XPd intuitively has an impact on the abdominal shape.

We can summarize that patients with lower values of XPA have lower values of XPd and, at the same time, greater sagittal spinal deformity; this condition could reflect abdominal compression and visceral distortion.

Potential advantages using XPA

XPA have shown behaviour directly influenced by the main sagittal parameters changing as PI−LL, PT, and SVA. XPA seems extremely correlated with XPd and demonstrates to have a better relationship with HRQoL compared to other sagittal parameters.

Limitations

This is a retrospective study of a cohort not specifically incepted to evaluate this parameter. Thus, bias in the evaluation of correlations of XPA to other sagittal parameters and HRQoL cannot be excluded.

Though a relevant number of patients have been included, these numbers do not consent extensive investigation of other correlations. Furthermore, the linear regression analysis demonstrated significant but modest correlations among ODI and XPA, accounting for only 18% of the ODI variability ($r^2 = 0.18$). It can be argued that this low value of r^2 suggests lack of clinical relevance. This limitation is strictly related to the nature of r^2 and the nature of the variables compared (radiographic variables and clinical variables which are by nature multifactorial). Even using large databases, it is usual to find similar magnitudes of r^2 in this area of the research when a radiographic parameter is matched with a clinical outcome. Some examples are T1PA and HRQoL ($r^2 = 0.19$) [26] or FeV1 and scoliosis ($r^2 = 0.1853$) [27].

Different morphologies of the sternum from patient to patient, as highlighted in the literature [28], may have a significant impact on the observed XPA. Similarly, concomitant coronal spinal deformity could introduce a distortion factor on the ability of XPA to exactly reflect the abdominal shape. In addition, we did not provide any direct evaluation of the abdominal shape, volume or pressure, or a clinical evaluation of the visceral functions.

Finally, XPA is influenced by the age of patients (it is not clear to us whether this is only due to the correlation between XPA and spinal shape). An independent effect of age on XPA (not correlated with spinal shape) could not be confirmed or ruled out by this study.

Conclusion

Spinal deformity clearly affects the abdominal shape in terms of xipho-pubic distance and xipho-pubic angle.

XPA is an instrument to measure the impact of spinal deformity on abdominal cavity due to its direct relationship with abdominal wall length and spinal shape.

Furthermore, XPA is parameter strongly related to XPd, sagittal spinopelvic parameters, and HRQoL scores. The regression analysis shows that XPA of 113° is correlated with ODI of 20 and defining this cut-off value as indicator of minimal disability.

Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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