Dose-response relationship between spino-pelvic alignment determined by sagittal modifiers and back pain-specific quality of life

Ryoji Tominaga1,2,3 · Noriaki Kurita3,4,5 · Yoshiyuki Kokubun6 · Takuya Nikaido2 · Miho Sekiguchi2 · Koji Otani2 · Masumi Iwabuchi1 · Osamu Shirado1 · Shunichi Fukuhara5,7 · Shin-ichi Konno2

Abstract

Purpose To determine whether abnormalities of the sagittal modifiers (SMs) of the Scoliosis Research Society (SRS)-Schwab classification truly reflect back pain (BP)-specific quality of life (QOL), it is necessary to examine their dose–response relationships and to determine clinically impactful thresholds for declines in BP-specific QOL. This study aimed to analyse the continuous dose–response relationship between each SM and BP-specific QOL.

Methods This cross-sectional study, using data from a Japanese population-based cohort study, included 519 community-dwelling residents aged ≥ 50 years who participated in the annual health examination. The participants completed the Roland–Morris Disability Questionnaire (RDQ) on BP-specific QOL. Spino-pelvic alignment based on SMs was assessed by whole-spine X-ray examinations. We fitted general linear models with or without nonlinear terms to estimate the dose–response relationship between each SM and BP-specific QOL.

Results Pelvic tilt, pelvic incidence minus lumbar lordosis (PI-LL), and sagittal vertical axis showed dose–response relationships with BP-specific QOL measured as the RDQ score. PI-LL was most likely to predict a minimally clinically important RDQ score when its value exceeded the 90th percentile. A nonlinear relationship between PI-LL and the BP-specific QOL score was found. RDQ increased when PI-LL exceeded 10°.

Conclusion PI-LL might be the most sensitive of the three modifiers of the SRS-Schwab classification for determining BP-specific QOL. Moreover, BP-specific QOL worsens rapidly when the compensatory mechanism against malalignment exceeds a critical value. Therefore, we suggest that traditional classifications and surgical strategies should be re-examined regarding the dose-dependent abnormalities of the SMs to develop a more reliable classification strategy.

Keywords Sagittal alignment · Spino-pelvic alignment · Pelvic tilt · Pelvic incidence · Lumbar lordosis · Sagittal vertical axis
Introduction

To evaluate the indications for the treatment of degenerative changes and post-traumatic deformities of the spine, an accurate radiographic assessment of the whole-spine is required. The importance of this assessment lies in the concept of ‘cone of economy’ that states that energy consumption is minimised when the centre of gravity of the body is maintained in a cone centred on the trunk [1]. Spinal deformities due to degenerative changes and post-traumatic deformities increase the energy consumption required to maintain the centre of gravity within this cone [2]. However, once these deformities disrupt the compensatory mechanism for maintaining the centre of gravity, symptoms such as pain, disability, and psychological distress appear [3, 4].

The Scoliosis Research Society (SRS)-Schwab classification is one of the most widely used to classify adult spinal deformities [5]. This classification comprises four coronal curve types and three sagittal modifiers (SMs) (pelvic tilt [PT], pelvic incidence [PI] minus lumbar lordosis [LL] [PI-LL], and sagittal vertical axis [SVA] as global alignment [GA]); these SMs are widely used as treatment benchmarks [6], and they have been reported to be more correlated with back pain (BP)-specific quality of life (QOL) scores than coronal alignment [3, 4, 7]. However, previous studies which demonstrated this correlation could only show the degrees of linearity of the relationships between the SMs and BP-specific QOL. Therefore, quantifying the shapes and magnitudes of the continuous relationships between the SMs and BP-specific QOL is clinically important to determine impactful thresholds for declines in BP-specific QOL among community-dwelling individuals, including those with and without deformities.

This study aimed to analyse such relationships using a sub-cohort of the Locomotive Syndrome and Health Outcome in Aizu Cohort Study (LOHAS). We hypothesised that each SM would have a similar degree of dose–response relationship to BP-specific QOL.

Materials and methods

Study setting

This cross-sectional study was a secondary analysis of the LOHAS, involving residents from Tadami and Minami-aizu in Fukushima Prefecture, Japan, and was conducted according to the STROBE guidelines. Details regarding the setting and baseline characteristics of the study have been reported previously [8]. This study included residents aged ≥ 50 years who participated in the annual health examination conducted during 2010. We did not set any exclusion criteria. The Research Ethics Committee of our institute approved the study protocol (no. 673), and written informed consent was obtained from all participants.

Definition of spino-pelvic alignment and radiographic evaluation

Spino-pelvic alignment (SPA) based on sagittal parameters was assessed by a whole-spine X-ray examination performed with participants in the standing position and their hands on the supraclavicular fosse [9]. We measured the following SPA characteristics using Surgimap Spine software (Nemaris Inc., USA): LL, PT, PI, PI-LL, and SVA. Each SPA characteristic was defined as follows [10]: LL, the angle between the L1 superior endplate and upper sacral plate; PT, the angle between the vertical reference line and the line connecting the midpoint of the sacral plate to the centre of the femoral heads; PI, the angle between the line perpendicular to the sacral plate and the line connecting the midpoint of the sacral plate to the centre of the femoral heads; PI-LL, PI minus LL; and SVA, the horizontal distance between the posterosuperior point of the S1 vertebral body and a vertical plumb line drawn from the centre of the C7 vertebral body. Measurements were performed by two independent examiners (R.T. and Y.K). Intra- and inter-rater measurement reliabilities were excellent (Supplementary file 1).

Outcome measurements: RDQ

The Roland–Morris Disability Questionnaire (RDQ) is a BP-specific QOL scale [11]. It is a self-administered questionnaire to measure disability caused by a low BP. It comprises 24 items; the total score is calculated based on the number of positive (yes) responses given. A high RDQ score indicates low QOL [12]. The RDQ is extremely useful in any situation when the expected level of dysfunction in participants is low; therefore, it may be more useful in primary care settings than the Oswestry disability index [13]. The questionnaire was completed by each patient at the time of their annual health examination.

Measurements of potential confounders

We selected potential confounders according to the epidemiological definition of variables determining both (1) the exposure (SMs) and (2) outcome (RDQ). After considering the clinical perspective and existing evidence [14], confounders of the association between SMs and RDQ included demographic characteristics such as age, sex, and underlying degenerative diseases (degenerative spondylolisthesis or isthmic spondylolisthesis), as well as surgical history. An experienced spine surgeon (K.O.) reviewed all radiographs and classified them according to these pathologies. We also
obtained the spinal surgery history according to the whole-
spine radiograph.

Calculations

Statistical analyses

Statistical analyses were conducted using Stata/SE software
version 15 (Stata Corp., College Station, TX, USA). Participant
characteristics were described using summary statistics. The distributions of PT, PI-LL, SVA as GA, and RDQ score are shown using histograms. To estimate the continuous dose–response relationships between the RDQ score and indices of SMs (PT, PI-LL, and SVA), linear regression models were fitted with robust standard errors. Age, sex, underlying spinal disease (none, degenerative spondylolisthesis, or isthmic spondylolisthesis), and surgical history (none, spinal fixation, or hip arthroplasty) were included as covariates in the models (Model 1). Additionally, according to the multivariable linear regression models, the mean RDQ scores predicted by the nonlinear or linear exposure variables were visually presented. We also examined the associations between the indices of SMs categorised by the SRS-Schwab classification and the RDQ score (Model 2). Details are presented in the Supplementary file 2. P < 0.05 was considered statistically significant.

Results

Descriptive statistics

Among 840 individuals who were included in the study, 615 (73.2%) participated in the RDQ survey. After excluding 96 participants with incomplete responses or missing confounding variables, 519 (61.8%) participants were included in the primary analysis (Fig. 1).

Table 1 summarises the characteristics of the study participants. Histograms of PT, PI-LL, and SVA are presented in Fig. 2. The median and interquartile range of the RDQ score were 0 and 0–3, respectively. The score of 305 (58.8%) patients was zero, and the maximum score was 22. The RDQ scores had a right-skewed distribution (Fig. 3).

Outcome data

The association between PT and the RDQ score is presented in Table 2. A nonlinear relationship was not supported (Model 1, P for nonlinearity = 0.076). A 1-standard deviation (SD) increase in PT was associated with a 0.45-point
(95% confidence interval [CI], 0.04–0.86) higher RDQ score. The predicted RDQ score by PT value is shown in Fig. 4. In Model 2, PT > 30° was not associated with higher RDQ scores (mean difference, 1.28 points; 95% CI, −0.17–2.74) compared with PT < 20°.

The association between PI-LL and the RDQ score is presented in Table 3. A nonlinear relationship was evident (Model 1, \(P\) for nonlinearity = 0.041). The predicted RDQ score by PI-LL value is shown in Fig. 5. When PI-LL exceeded 10°, the RDQ score sharply elevated. For example, at a PI-LL of 40°, the RDQ score was 4.6 points (95% CI, −0.17–2.74) compared with PI-LL ≤ 10°.

The association between SVA as GA and the RDQ score is presented in Table 4. A nonlinear relationship was not supported (Model 1, \(P\) for nonlinearity = 0.340). A 1-SD increase in SVA was associated with 0.61-point (95% CI, 0.18–1.05) higher RDQ scores. The predicted RDQ score by SVA value is shown in Fig. 6. In Model 2, SVA > 95 mm was not associated with higher RDQ scores (mean difference, 2.20 points; 95% CI, −0.28–4.68) compared with SVA < 40 mm.

The RDQ scores predicted by the percentiles of three modifiers are presented in Table 5. Among the scores predicted by the 90th percentiles of the three modifiers, only...
those predicted by PI-LL exceeded 3 points (3.06 points; 95% CI, 2.25–3.87). Additionally, the point estimate of the RDQ score predicted by the 95th percentile of PI-LL demonstrated the highest score among those predicted by the 95th percentiles of the three modifiers (3.78 points; 95% CI, 2.51–5.06).

**Discussion**

Among the dose–response relationships of the three SMs (PT, PI-LL, and SVA) with BP-specific QOL, PI-LL showed a distinctive nonlinear relationship. Additionally, only PI-LL-based SRS-Schwab classification category was associated with a worse BP-specific QOL. These findings suggest that PI-LL might be the most sensitive modifier determining BP-specific QOL among the three SMs.

Our findings partially agree with those of previous studies showing the correlations between the SMs of the SRS-Schwab classification with both BP-specific and general health-related QOL measurements [3, 4, 7]. However, although the relationships between the SMs and BP-specific QOL are not new concepts, we believe that our findings fill a gap in the literature. First, we were able to validate independent associations between the three SMs as continuous predictors and BP-specific QOL after adjustments for likely confounders. Second, this study revealed the clinical impact of the high values of three SMs on RDQ scores: participants with more than 95th percentile values of PT, PI-LL, or SVA have RDQ scores of ≥3 points on average, which corresponds to the minimally clinically important difference in the RDQ score [15]. In other words, the three SMs can be used to screen 5% of community-dwelling elderly individuals to identify people with disabilities affected by BP. Third, potential superiority of the PI-LL for evaluating BP-specific QOL impairment reinforces the recent evidence that PI is the only constant parameter providing key information about adult spino-pelvic degeneration [6, 16]. For example, the global alignment and proportion score based on PI is a tool for predicting the likelihood of mechanical complications after corrective surgery for patients with spinal deformity [6].

Interestingly, the finding that RDQ scores increased when PI-LL exceeded 10° may suggest that BP-specific QOL...
worsens rapidly when the compensatory mechanism against malalignment exceeds a critical value. This finding is the first empiric demonstration of the concept of the ‘cone of economy’ [1]: it is maintained within a particular range in sagittal alignment (e.g. within 10° in PI-LL); however, when it fails (e.g. > 10° in PI-LL), patient symptoms and health-related outcomes worsen rapidly. Collectively, our findings may suggest the need to revisit the traditional classifications and strategies for spinal surgeries such as instrumented fusion surgery based on a more reliable classification.

This study has several strengths. First, this is the first survey to focus on the shapes of the continuous dose–response relationships (i.e. not only correlation) between the three SMs and BP-specific QOL independent of the important confounders. Second, our data were thoroughly retrieved from a large population in the community. Recent studies have shown that sagittal alignment is widely involved not only in spinal deformity but also in many spinal disorders such as degenerative disc disease, osteoporosis, and facet joint arthritis [17–19]. An evaluation of sagittal alignment

Fig. 5 The Roland-Morris Disability Questionnaire (RDQ) score predicted using the continuous pelvic incidence minus lumbar lordosis (PI-LL) value: Using the multivariable linear model with restricted cubic spline including age, sex, underlying degenerative disease, and surgical history, the adjusted mean RDQ score for PI-LL was predicted. The left vertical axis shows the adjusted RDQ score. The black solid line indicates point estimates of the RDQ score. The dotted lines indicate 95% confidence intervals. Grey bars indicate the frequency at which the PI-LL values were observed. The right vertical axis shows the frequency of each grey bar. The red vertical lines indicate the boundary for the Scoliosis Research Society-Schwab classification

Table 4 Association of SVA as GA with RDQ (N=515)

| SVA (mm) | Model 1 based on continuous predictors | Model 2 based on the Schwab classification |
|----------|----------------------------------------|------------------------------------------|
| Per 30   | 0.54 (0.15–0.92)                       | 0.67 (− 0.11–1.44)                       |
| Per 1 SD | 0.61 (0.18–1.05)                       | 2.20 (− 0.28–4.68)                       |
| Covariates |                                    |                                          |
| Age      |                                        |                                          |
| Per 5 years | 0.57 (0.35–0.80)                       | 0.60 (0.38–0.83)                        |
| Per 10 years | 1.15 (0.69–1.60)                      | 1.21 (0.76–1.66)                        |
| Women versus men | 1.06 (0.42–1.70) | 1.03 (0.39–1.67) |

SVA: Sagittal vertical axis; GA: Global alignment; RDQ: Roland–Morris disability questionnaire; SD: standard deviation; CI: confidence interval

Linear regression models with robust standard errors were fitted. Both Models 1 and 2 included age, sex, underlying degenerative diseases (degenerative spondylolisthesis/isthmic spondylolisthesis), and surgical history (spinal fixation or hip arthroplasty).

Bold values represent statistically significant difference (P value < 0.05)

Fig. 6 The Roland-Morris Disability Questionnaire (RDQ) score predicted using the continuous sagittal vertical axis (SVA) value: Using the multivariable linear model including age, sex, underlying degenerative disease, and surgical history, the adjusted mean RDQ score for SVA as global alignment (GA) was predicted. The left vertical axis shows the adjusted RDQ score. The black solid line indicates point estimates of the RDQ score. The dotted lines indicate 95% confidence intervals. Grey bars indicate the frequency at which the GA values were observed. The right vertical axis shows the frequency of each grey bar. The red vertical lines indicate the boundary for the Scoliosis Research Society-Schwab classification.

worsens rapidly when the compensatory mechanism against malalignment exceeds a critical value. This finding is the first empiric demonstration of the concept of the ‘cone of economy’ [1]: it is maintained within a particular range in sagittal alignment (e.g. within 10° in PI-LL); however, when it fails (e.g. > 10° in PI-LL), patient symptoms and health-related outcomes worsen rapidly. Collectively, our findings may suggest the need to revisit the traditional classifications and strategies for spinal surgeries such as instrumented fusion surgery based on a more reliable classification.

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is not limited to corrective surgery for patients with spinal deformity; it should also be considered when treating localised spinal disorders [20]. During our study, alignment and QOL data were evaluated at the individual level via whole-spine radiographs and a questionnaire. Therefore, our findings reflect the actual general community setting and are applicable to other populations with any type of lumbar disease.

Despite these strengths, our study has some limitations. First, unmeasured factors leading to sagittal malalignment might have affected the results. Inter-vertebral disc degeneration, osteoporotic vertebral fractures, and trunk muscle mass are clinically important and might affect the relationship between sagittal alignment and BP-specific QOL [21]. Second, causality could not be assessed because of the cross-sectional nature of our study. However, the impact of altered SPA on BP-specific QOL is biologically plausible, and we believe that reverse causation is unlikely to occur given the traditional mechanisms of health-related QOL, in which biological changes in alignment and symptoms such as BP lead to a decline in function and perceived well-being [22]. Decreased LL triggers spinal deformity and causes sagittal imbalance, as reflected by an increased PI-LL value and SVA. Sagittal plane imbalance shifts the body towards the periphery of the ‘cone of economy’. Consequently, several compensatory mechanisms are deployed to help re-centre the body over the pelvis and to maintain an upright posture. When these compensatory mechanisms fail, efficiency performing daily living activities and QOL decline, and disruption of sagittal alignment leads to further decrease in QOL. Third, because the setting of this study was rural, the results may not be applicable to people living in urban areas. However, sagittal alignment parameters in this study were comparable to those of other Japanese cohort studies (Supplementary file 3) [23–25]. Therefore, our participants may represent the general Japanese population, and the findings may be reasonably applicable to all. Fourth, cervical spine alignment and lower limb joint alignment were not evaluated. Patients with deformity experienced changes in their alignment from the cervical spine to the ankle and used compensatory mechanisms to correct the imbalance.

**Table 5** Predicted RDQ score by centiles of PT, PI-LL, and SVA

|        | PT Degree (°) | Point estimates | 95% CI | PI-LL Degree (°) | Point estimates | 95% CI | SVA mm | Point estimates | 95% CI |
|--------|---------------|----------------|--------|----------------|----------------|--------|--------|----------------|--------|
| 5 percentile | 4 | 1.57 | (0.94–2.19) | −15 | 1.95 | (1.24–2.67) | −24.3 | 1.26 | (0.60–1.92) |
| 10 percentile | 7 | 1.71 | (1.18–2.24) | −11 | 1.85 | (1.31–2.39) | −13.5 | 1.45 | (0.91–2.00) |
| 50 percentile | 16 | 2.14 | (1.79–2.49) | 4 | 1.75 | (1.30–2.20) | 24.1 | 2.13 | (1.79–2.46) |
| 90 percentile | 31 | 2.85 | (2.13–3.58) | 23 | 3.06 | (2.25–3.87) | 67.0 | 2.89 | (2.21–3.57) |
| 95 percentile | 34 | 2.99 | (2.15–3.83) | 31 | 3.78 | (2.51–5.06) | 85.9 | 3.23 | (2.33–4.13) |

RDQ: Roland–Morris disability questionnaire; PT: pelvic tilt; PI-LL: pelvic incidence minus lumbar lordosis; SVA: sagittal vertical axis; CI: confidence interval

Using separately the multivariable linear models including age, sex, underlying degenerative disease, and surgical history (i.e. Model 2 in Tables 2, 3, 4), adjusted mean RDQ score by centiles of each modifier was predicted.

**Conclusion**

PT, PI-LL, and SVA showed dose–response relationships with BP-specific QOL measured as the RDQ score among community-dwelling adults. Among the three modifiers of the SRS-Schwab classification, PI-LL might be the most sensitive for determining BP-specific QOL. Moreover, the new finding of a nonlinear relationship between PI-LL and the RDQ score found during our survey might potentially bring new insight to the classification and corrective surgery strategies for spinal disorders.

**Supplementary Information** The online version contains supplemental material available at https://doi.org/10.1007/s00586-021-06965-3.

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**Authors’ contributions** RT, NK, MS, KO took part in conceptualisation. RT and NK involved in methodology. RT, NK, YK took part in formual analysis and investigation. RT and NK involved in writing—original draft preparation. YK, TN, MS, KO, MI, OS, SF, SK participated in writing—review and editing. MS, KO, SF, SK participated in funding acquisition. MS, KO, SF, SK took part in resources. MI, OS, SF, SK involved in supervision.

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**Declarations**

**Conflict of interest** The authors have no relevant financial or non-financial interests to disclose.
Ethical approval All procedures performed in this study involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

Availability of data and material The datasets generated and/or analysed during the current study are available from the corresponding author on reasonable request.

Consent to participate Informed consent was obtained from all individual participants included in the study.

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