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Correlation between torsobarography and surface topography for spinal analysis

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Abstract: Surface topography systems are used in radiation-free monitoring and screening of scoliosis. This study examines the correlations of anatomical landmarks and parameters between torsobarography in a supine position and conventional surface topography in a standing position in 40 subjects. Overall, moderate correlations were observed between the two approaches, with a maximum Pearson correlation coefficient |r| of 0.63. Nonetheless, surface differences persist, which may be linked to both measurement inaccuracies and the variation in gravitational load across postures. These findings indicate that torsobarography holds potential as a complementary or alternative tool for radiation-free scoliosis assessment.

I. Introduction

Scoliosis progression is accompanied by measurable changes in trunk surface topography (ST) [1]. To reduce radiographic imaging, ST systems are recommended for monitoring and screening scoliotic deformities [1]. These methods capture the dorsal trunk surface and derive morphological characteristics of the spine and adjacent structures (e.g., rib cage deformations) in a standing position. Quantification is based on anatomical landmarks in the frontal, sagittal, and transverse planes, which can be defined either manually or automatically [2]. In contrast, torsobarography (TB) infers anatomical associations from the dorsal surface pressure distribution acquired in the supine position [3], [4]. Compared to conventional ST, TB enables measurements without requiring undressing (improving compliance) and supports broad clinical applicability (e.g., wheelchair users). Previous studies have shown that TB parameters correlate moderately with the Cobb angle [4] and its corresponding severity classification [5]. Due to differences in gravitational loading, spinal and surrounding structures adopt a distinct alignment in the supine posture, affecting anatomical structures such as the frontal curvature angle [6]. Strong correlations indicate a largely linear relationship between standing and supine measures, supporting the use of a linear mapping. Therefore, the aim of this study is to assess the correspondence between conventional ST (standing) and TB (supine) by analyzing correlations between parameters extracted from each method.

II. Material and methods

A total of 40 subjects participated in the study (age: 27.8 ± 4 years; height: 174 ± 9 cm; weight: 72 ± 13.2 kg), the majority without known musculoskeletal disorders [3]. Two participants had previously diagnosed, non-surgically treated scoliosis that was still present. For each subject, ten pressure images were recorded using a high-resolution pressure mapping system (LX100:100.160.05, XSENSOR Technology Corporation, Calgary, Canada). To ensure statistical independence, subjects were repositioned on the sensor surface after each recording using a standardized protocol [3]. Subsequently, depth images of the dorsal trunk were recorded in a standing position using rasterstereography (Formetric 4D, DIERS International GmbH, Wiesbaden, Germany).

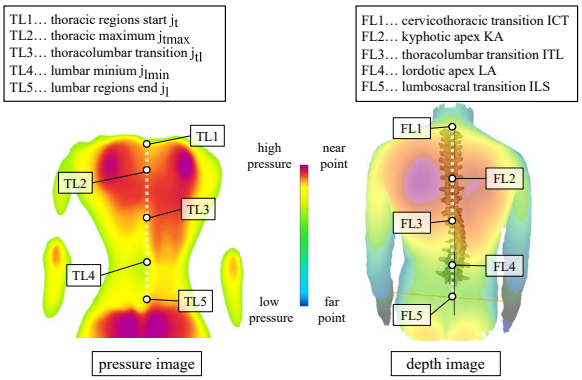

Figure 1. Landmarks of TB (according to [3]) and rasterstereography (according to [7]) for a scoliotic subject.

For each TB measurement, five landmarks along the longitudinal body axis (TL1 to TL5, Fig. 1) and 41 parameters describing dorsal trunk surface morphology (defined in [3], [4]) were automatically extracted from the pressure images. The DIERS formetric 4D system similarly provided 132 automatically extracted parameters, including five landmarks (FL1 to FL5, Fig. 1). TL and FL landmarks are system-specific and reproducible [3], [7] but not anatomically identical. To account for the repeated-measures structure of the TB data, a nonparametric subject-level bootstrap was performed. For each of the 1000 bootstrap resamples, one TB measurement was randomly drawn from the ten available repetitions per subject, and the extracted parameters were correlated with the

corresponding rasterstereographic parameters. For each landmark or parameter pair, the mean Pearson correlation coefficient ($|r|$), the standard deviation (SD), and the 95 % confidence interval (CI) were determined. Correlations were interpreted according to [8] as negligible ($|r| < 0.1$), weak (0.1–0.4), moderate (0.4–0.7), strong (0.7–0.9), and very strong (0.9–1.0).

III. Results and discussion

Predominantly moderate correlations were observed for the landmarks, reaching up to $|r| = 0.63$ (TL2–FL1) in the thoracic region and $|r| = 0.59$ (TL5–FL4) in the lumbar region (Fig. 2). Only FL5-related correlations were weak, with a maximum $|r| = 0.32$. Contrary to expectations, the strongest correlations did not occur along the diagonal of the correlation matrix but rather appeared with an offset. For example, the mean correlation of TL3–FL2 ($|r| = 0.63$) exceeded that of the anatomically matched pair TL2–FL2 ($|r| = 0.47$).

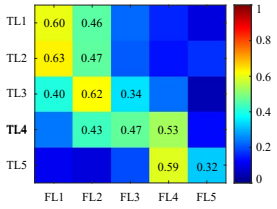

Figure 2. Mean $|r|$ correlation matrix comparing landmarks between a randomly selected TB measurement and the single rasterstereography measurement

As shown in Table 1, moderate correlations were observed between the TB and rasterstereography parameters characterizing trunk morphology. The highest mean correlation was found for trunk torsion F1, reaching $|r| = 0.63$ (T1–F1). This was followed by the mean correlation between the TB lordosis angle T2 and the rasterstereography lordosis angle F4, which reached $|r| = 0.53$. Pressure symmetry scores (T4, T5) showed moderate correlations with the surface rotation parameters (F2, F3) of up to $|r| = 0.52$ (T4–F2).

Table 1. Correlation between TB parameters (as defined in [3], [4]) and rasterstereography parameters (described in [2], [7]) for trunk morphology with $|r| \geq 0.4$

Feature descriptions
T1…Variance of the estimated frontal spine FC_2, [mm²]
T2…Inclination of the estimated frontal spine FC_7, [-]
T3…Torsobarography lordosis angle SC_2, [°]
T4…Total COP deviation along the symmetry axis TS_1, [mm]
T5…Ratio of the MPI between both body halves TS_2, [-]
T6…Lateral curvature angle of COP curve TBA, [°]
F1…Trunk torsion, [°]
F2…Surface rotation RMS, [°]
F3…Surface rotation RMS, T4-DM, [°]
F4…Lordosis angle ITL-ILS (max), [°]
F5…Scoliosis angle, [°]

Feature		MEAN $\|r\|$	SD $\|r\|$	95 % CI $\|r\|$
T1	F1	0.63	0.12	[0.39, 0.82]
T3	F4	0.53	0.08	[0.36, 0.67]
T4	F2	0.52	0.08	[0.35, 0.67]
T2	F1	0.50	0.11	[0.28, 0.69]
T4	F3	0.48	0.08	[0.32, 0.64]
T6	F3	0.48	0.06	[0.36, 0.59]
T6	F2	0.41	0.06	[0.30, 0.53]
T5	F3	0.40	0.10	[0.20, 0.60]
T6	F5	0.40	0.08	[0.23, 0.54]

The representative TB parameter for frontal curvature angle T6 exhibited multiple correlations of $|r| \geq 0.4$ with rasterstereographic parameters associated with scoliosis. The confidence intervals of $|r|$ demonstrated that substantially higher correlations may occur across bootstrap samples (e.g., $|r| = 0.82$ for TL1–FL1).

While both methods are highly reproducible [3], [7], system-specific and intraindividual variability remain. Moreover, biomechanical differences between supine and standing positions, including soft-tissue displacement and altered gravitational loading, affect spinal alignment and thereby the derived parameters. Overall, the results show that linear mapping is feasible but limited, suggesting that TB reflects structural trends of conventional ST but not the full posture-independent anatomical relationships.

IV. Conclusions

This study demonstrated that TB parameters and landmarks correlate moderately with those obtained from conventional ST. However, moderate correspondence is insufficient to monitor posture-independent anatomical changes, highlighting the need to better understand soft-tissue and spinal shifts between supine and standing positions. Such insights could complement static spinal assessments with dynamic information to support individualized scoliosis treatment planning.

Author's Statement

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