Repeatability and Reproducibility of the A-Palp as a 2D/3D Spine Digitization Tool

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Summary

This study contributes to the validation of the A-Palp digitizing method as a tool to quantify spinal curvatures. In ten volunteers, three spinal palpations were realized with the A-Palp by two examiners and repeated one week apart. Thoracic kyphosis and lumbar lordosis were computed using 3 methods. Repeatability and reproducibility were assessed using ICC, Bland-Altman plots and RSME. All methods provided excellent results, with the tangent method displaying the highest reliability for both curvatures.

Introduction

Back conditions, such as chronic low back pain and scoliosis in young individuals, require regular monitoring in the pre- and post-operative phases to evaluate the progression of the condition and objectively assess surgical outcomes. Costly or ionizing diagnostic tools (MRI, X-rays, EOS) are often used. To address these limitations, the A-palp, a non-invasive spinal digitization tool, was developed. Its 2D validity, repeatability, and reproducibility have been demonstrated [1,2]. However, evaluating the effect of temporal variability through measurements taken at different time points is essential to ensure its reliability and long-term integration into routine clinical practice.

Methods

Ten healthy subjects aged 35 years and older participated in the study. Each subject attended two sessions one week apart. Two examiners systematically performed three spine measurements during each session. Thoracic kyphosis and lumbar lordosis angles were assessed using three methods: tangent (Tm), circle-fit (Cm), and trigonometric (Trm) [2]. Data were collected using the A-palp technique [1] with a 14-camera optoelectronic system (T40s, VICON, Oxford, UK; sampling rate: 100Hz). Retro-reflective markers were placed on anatomical landmarks, and additional landmarks were palpated using the A-Palp. This protocol generated a 3D model of the spine by tracking spinous processes from the external occipital prominence to S2. Intraclass correlation coefficients (ICC) with 95% confidence intervals (CI) were calculated and Bland-Altman plots were produced to assess within- and between-examiner and between-session repeatability. Root mean square errors (RMSE) were calculated to compare sagittal spinal curves within and between examiners, as well as over time.

Results and Discussion

Bland-Altman analysis (Figure 1) showed similar mean biases across the different methods over a one-week time interval, with Tm exhibiting the narrowest limits of agreement, indicating slightly reduced variability. The Cm and Trm, while showing slightly greater dispersion and a small number of outliers, demonstrated overall good consistency and reliable reproducibility across most measurements.

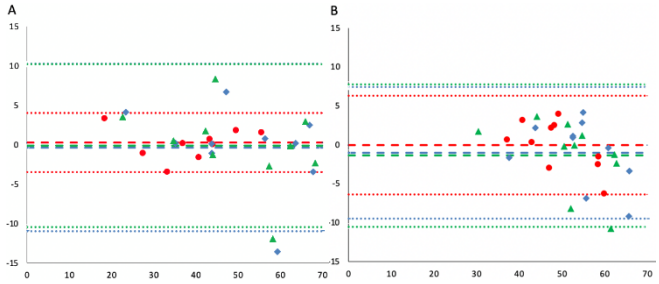

Figure 1: Bland Altman Plot of Lumbar Lordosis (A) and Thoracic Kyphosis (B) Reproducibility with Three Measurement Methods Over Time.

For lumbar lordosis, the Tm achieved the highest ICC and tightest CI, reflecting superior precision. For thoracic kyphosis, the Tm showed high reliability, being more consistent compared to other methods (Table 1). The RMSE analyzed sagittal curve similarity using the A-Palp method. Intra-examiner RMSE was 5.9% (SD = 1.5), inter-examiner RMSE was 6.7% (SD = 3.1), and RMSE over one week increased slightly to 5.4% (SD = 2.7), remaining within acceptable limits.

Conclusions

These findings confirm the reliability of all three methods for evaluating spinal curvature, with the Tm showing superior precision and consistency. The RMSE analysis supports the A-Palp tool's reliability over time. Future research will compare A-Palp-derived curves with radiographic imaging to validate its clinical use.

References

[1] Salvia P et al. (2009). *Gait Posture* **29**: 587-90.
[2] Salvia P et al. (2022). *Comput Methods Biomech Biomed Eng Imaging Vis* 2077236.

Table 1: Intra-Rater Reliability of Lumbar Lordosis and Thoracic Kyphosis Over Time (ICC [95% CI])

	Tm	Cm	Trm
Lumbar lordosis	0.993 [0.999; 0.986]	0.966 [0.996; 0.936]	0.968 [0.996; 0.941]
Thoracic kyphosis	0.968 [0.995; 0.920]	0.940 [0.993; 0.888]	0.943 [0.993; 0.893]