VALIDATION OF THE SMARTPLAN BALANCE* MOBILE APPLICATION TO MEASURE SAGITTAL PARAMETERS OF THE SPINE

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Objective. To assess the inter- and intra-expert reliability of measurements of spinopelvic parameters using the SmartPlan Balance mobile application.

Material and Methods. The following spinopelvic parameters were measured on postural radiographs of patients with degenerative spine diseases: pelvic index (PI), pelvic tilt (PT), sacral slope (SS), total lumbar lordosis (LL), and lower lordosis L4–S1 (LowLL). The measurements were performed by three experts using the SmartPlan Balance mobile application and the Radiant DICOM Viewer desktop program. The values obtained by the mobile application and by the computer program were compared. The inter-rater reliability of the measurements obtained using SmartPlan Balance was calculated. After repeated measurements of parameters using the SmartPlan Balance, the intra-rater reliability was calculated for each expert.

Results. No statistically significant differences were found when comparing consecutive measurements of all experts for each parameter with each tool (Radiant DICOM Viewer and SmartPlan Balance); $p > 0.05$. The Pearson correlation coefficient ranged from 0.83 to 0.95 (PI: $r = 0.956$; PT: $r = 0.912$; SS: $r = 0.865$; GLL: $r = 0.943$; LowLL: $r = 0.839$) regardless of the specific expert or method. The inter- and intra-rater reliability of measurements by the SmartPlan Balance application had excellent or good reliability: the most stable and highest value of the intra- and interclass correlation index (ICC) was determined for the LowLL parameter (0.85–0.92), and the lowest ICC consistency values were found for the PT parameter (0.75–0.81).

Conclusion. Measurements of spinopelvic parameters using SmartPlan Balance demonstrate high reliability and reproducibility, comparable to the standard desktop program. The use of the SmartPlan Balance mobile application is recommended in the daily practice of each spine surgeon, particularly in surgical planning, intraoperative parameter measurements, and analysis of non-digital radiographs.

Key words: sagittal balance; spinopelvic relationships; mobile application; software.

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Degenerative diseases of the spine are characterized by asymmetric loss of intervertebral disc height, especially in the anterior sections, and facet hypertrophy of the facet joints resulting in the flattening of lumbar lordosis and impaired spinopelvic relationships [1]. In order to improve the patients' quality of life, these relationships require surgical correction [2]. To assess the volume of the correction required, the sagittal balance parameters should be calculated for each patient at the pre-operative planning, as well as in the early and late postoperative periods to objectify the achieved results and to evaluate the changes over time [3].

Currently, the great majority of radiological images are predominantly recorded digitally rather than on film. Digitalization in medicine has led to the development of software for viewing radiological images (Radiant Dicom Viewer, PACS, Surgimap, etc.); each one allows for the drawing of different angles significantly accelerating the analysis of the sagittal balance in comparison to manual measurements on film. This software is an accurate, reliable, and standard technique for calculating radiological parameters [4]. However, they have one significant limitation: they cannot be used for intraoperative calculation of radiological parameters on the monitor.

Considering the active implementation of smartphones into daily clinical practice of a physicians [5], including spinal surgery [6, 7], we have developed a mobile application for more convenient, fast and, most importantly, intraoperative calculation of sagittal balance parameters. SmartPlan Balance is a smartphone application for measurement and predictive calculation of the sagittal balance parameters of the spinopelvic complex. This application allows to measure the basic (PI, SS, PT, LL) and additional sagittal balance parameters (SCA, SSA, Lordosis C2–C7, C7 Slope, Occipito C2), as well as the full balance integrated index (FBI). All measurements are stored in the database.

** The application is available on the Android platform via the QR code provided at the end of the article.*

To implement the application in the daily practice of a spinal surgeon, one should ensure its equivalence to standard software in terms of the accuracy of calculating sagittal parameters.

The objective was to assess the inter- and intra-rater reliability of measurements of the spinopelvic parameters using the SmartPlan Balance application.

Material and Methods

The main sample included patients with degenerative diseases of the spine of different severity. A total of 30 subjects with postural radiological images were randomly selected. A patient's correct position is extremely important to obtain reliable results while performing postural radiographic images of the spine. All postural radiological images were performed according to the following standard: the patient was in a standing position, with knee and hip joints in a neutral comfortable position. The arms are flexed at the shoulder and elbow joints with the hands placed on the contralateral clavicles; standing with support was unacceptable. The following basic spinopelvic parameters were calculated using the radiological images: pelvic incidence (PI), pelvic tilt (PT), sacral slope (SS), total lumbar lordosis L1–S1 (LL), and lower lordosis L4–S1 (LowLL).

The measurements were carried out in the SmartPlan Balance mobile application and in the Radiant DICOM Viewer software for viewing radiological images [8].

The parameters were calculated in the SmartPlan Balance mobile application using the following algorithm: the first stage involved placing the upper edge of the smartphone parallel to the S1 endplate; the second stage involved placing the lateral edge of the smartphone on the line between the S1 center and the center of the corresponding femoral head; and the third stage involved placing the upper edge of the smartphone parallel to the L1 endplate. After each stage, the position confirmation button was pressed on the smartphone. Following all stages, the application automatically analyzes the sagittal balance (Fig. 1). The parameters were calculated in the Radiant DICOM Viewer in a standard way (Fig. 2) [9].

The measurements for the entire series of radiological images were performed by three spinal surgeons (expert specialists) with at least five years of experience.

First, the experts were trained to measure spinopelvic parameters, with an inter-rater agreement of ⩾0.80 achieved for at least 10 subjects not included in the main sample. Disagreements in terms of the measured values were resolved by discussion and consensus.

To determine the inter-rater reliability, three experts independently measured the parameters for the subjects of the main sample using the SmartPlan Balance application. To determine the intra-rater reliability, the same three experts repeated their measurements for the subjects of the main sample using the SmartPlan Balance application two weeks later.

Statistical analysis. The source data were checked for normality (normal distribution) using the Kolmogorov-Smirnov test. The distribution of continuous and discrete quantitative variables in the sample is provided as the mean value and standard deviation ($M \pm SD$). To determine the strength and direction of the linear relationship between two continuous variables, the Pearson correlation coefficient was used (0.75–1.00 – very strong; 0.50–0.74 – strong; 0.25–0.49 – medium; 0.00–0.24 – weak). To calculate the inter- and intra-rater reliability of measurements of the sagittal balance parameters, the intra- and interclass correlation coefficient (ICC) was used. To determine the statistical significance for differences in mean values, the Student's t-test was used. The null hypothesis in statistical tests was rejected at a significance level of $p < 0.05$.

Results

A comparison was made for the spinopelvic parameters (PI, PT, SS, LL, LowLL) measured using SmartPlan Balance and Radiant DICOM Viewer (Table 1).

These spinopelvic parameters determined by SmartPlan Balance and Radiant DICOM Viewer had comparable values ($p > 0.05$).

The parameter values obtained from SmartPlan Balance and Radiant DICOM Viewer demonstrated strong positive association (Table 2).

The Pearson correlation coefficient ranged from 0.83 (LowLL value) to 0.95 (PI value), regardless of a particular expert or method; it indicates a strong relationship between the parameters for two measurement techniques.

When calculating the intra-rater reliability of measurements of the spinopelvic parameters using the SmartPlan Balance application, the ICC was calculated for each expert (Table 3).

The ICC value varied from 0.75 (PT by the expert 2) to 0.93 (SS by the expert 3), indicating high and very high measurement reliability depending on the parameter. The most stable and highest ICC value was determined for LowLL (L4–S1) and was 0.85-0.92; the lowest ICC value was obtained for PT (0.75–0.81; Fig. 3).

When calculating the inter-rater reliability for measured values of the spinopelvic parameters using the SmartPlan Balance application, the ICC was calculated: one common model was used considering all measurements performed by each expert simultaneously (Table 4).

All parameters had very high and high inter-rater reliability (ICC > 0.81): the lowest values were registered for PT (ICC = 0.81), and the highest – for LowLL (L4–S1; ICC = 0.92; Fig. 4).

Discussion

Calculation of actual and theoretical sagittal balance parameters is an integral part of planning a spinal surgical intervention. Planning spinal surgery, we always clearly understand what sagittal balance parameters we want to obtain in each specific case. Until recently, it seemed to be impossible to assess the adequacy of the achieved correction of the spinopelvic relationships during surgery (the result of surgical treatment in terms of balance parameters was

evaluated in the postoperative period on control radiological images).

Currently, applications are actively being implemented in medical settings. In addition to electronic textbooks and guidelines, more and more field-specific applications are developed that are designed for different medical specialists. For example, Meng et al. [10] concluded that a smartphone is equivalent to a protractor in terms of the accuracy of measuring the hallux valgus angle. Smartphones are also successfully used in spine medicine to measure Cobb angles in idiopathic scoliosis in adolescents [11], as well as in kinesiology for dynamic assessment of the degree of thoracic vertebrae rotation when turning the torso [12].

A group of Russian authors has developed SmartPlan Balance mobile application, which allows assessing the sagittal balance parameters directly in the operating room using a smartphone on the image intensifier screen, and this is a huge advantage compared to well-known and standard software for viewing radiological images. SmartPlan Balance is a modified and improved version of SpinoMeter application. Unlike the prototype, the modified version allows measuring the actual parameters of the sagittal balance, as well as target values considering the age of patients.

In this study, we demonstrated the full comparability of obtained measurements using the above-mentioned mobile application and standard stationary software for viewing radiological images: there were just slight differences in the values of the spinopelvic parameters. A similar study was conducted comparing the results of sagittal parameter measurements using the SpinoMeter mobile app and the SurgiMap software [13]; the authors reported complete comparability of measurements performed by two tools. Another similar study was conducted comparing Sagittalmeter Pro mobile app and PACS desktop program [7]; the authors concluded that the measurements performed using these two program were completely equivalent. Despite the comparable results, Sagittalmeter Pro has a significant limitation: the app does not save the results of prior examinations. SmartPlan Balance app is free of this disadvantage: identification data for each examined patient may be entered. All results are stored in a database, which can be uploaded to a PC in tabular form, if required.

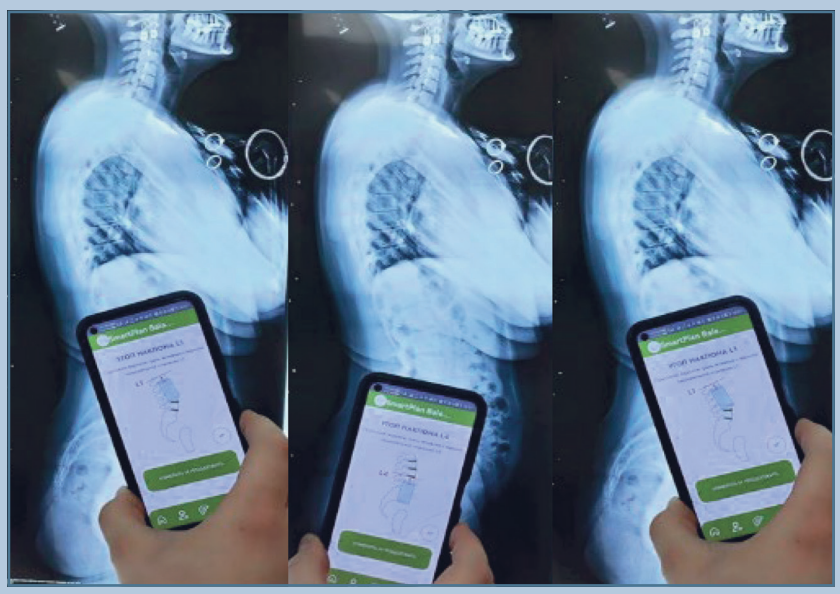

Fig. 1
An example of calculating the main spinopelvic parameters in the SmartPlan Balance application

In this study, we confirmed very high and high inter- and intra-rater agreement in measuring all analyzed spinopelvic parameters using SmartPlan Balance; it indicates high reliability and reproducibility of the results. It should be mentioned that the lowest reliability was determined for PT measurement (intra-rater reliability: 0.78, inter-rater reliability: 0.81). There is a fairly simple explanation: in SmartPlan Balance, PT is calculated as the difference between PI and SS because of geometric considerations. Thus, in the SmartPlan Balance, the total error from measuring PI and SS is accumulated.

When using other mobile applications, high and very high agreement was also obtained. For example, very high inter-rater reliability values were obtained for Sagittalmeter Pro, from 0.84 to 0.93 [7]. The presented data evidence that SmartPlan Balance matches competing solutions in technical performance, and in

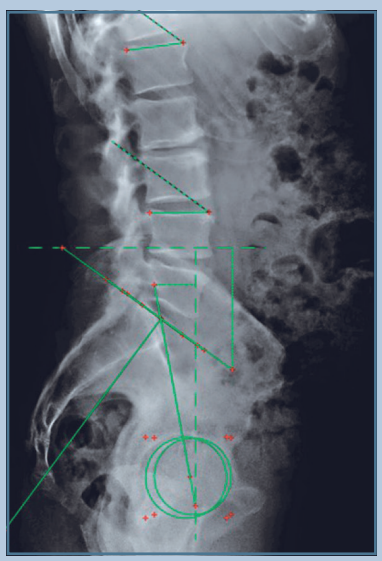

Fig. 2
An example of calculating the main spinopelvic parameters in the Radiant DICOM Viewer software: the PI, PT, SS parameters were calculated using the Angle tool; the LL parameter was calculated using the Cobb angle tool

Table 1
Mean values and standard deviations of sagittal balance parameters

Parameter	Radiant DICOM Viewer	SmartPlan Balance	*p*-value
PI	55.1 ± 13.7	53.8 ± 12.0	0.12
PT	20.1 ± 8.7	23.7 ± 8.2	0.08
SS	34.3 ± 6.9	30 ± 7.2	0.21
GLL	46.7 ± 12.4	49.4 ± 10.5	0.67
LowLL (L4–S1)	24.7 ± 10.0	25.4 ± 9.7	0.07

Table 2
Association of spinopelvic parameter values determined by SmartPlan Balance and Radiant DICOM Viewer

Parameter	Pearson's correlation coefficient (*r*)	Degree of agreement	Strength of correlations
PI	0.956	Very high agreement	Very strong
PT	0.912	Very high agreement	Very strong
SS	0.865	High agreement	Very strong
GLL	0.943	Very high agreement	Very strong
LowLL (L4–S1)	0.839	High agreement	Strong

Table 3
Intra- and interclass correlation coefficient (3.1) for calculating intra-rater reliability for each expert

Parameter	Expert 1	Expert 2	Expert 3	Reliability
PI	0.9123	0.8567	0.9234	Very high
PT	0.7890	0.7543	0.8123	High
SS	0.9012	0.8678	0.9345	Very high
GLL	0.8765	0.9123	0.8901	High
LowLL (L4–S1)	0.9234	0.8567	0.9012	Very high

Table 4
Intra- and interclass correlation coefficient (2.1) for calculating inter-rater reliability

Parameter	ICC	Reliability
PI	0.8765	High
PT	0.8123	High
SS	0.9012	Very high
GLL	0.8901	High
LowLL (L4–S1)	0.9234	Very high

some cases even surpasses the similar analogues.

We have found a number of advantages when u sing SmartPlan Balance: first, is user-friendly and rapidly provides measurement results, and second, it is a highly reliable and easily accessible tool that can be used in any conditions, including in the operating room.

Additional advantages of the SmartPlan Balance application include the calculation of theoretical (target) parameters of the sagittal balance for a particular patient, storage of measurement results in the mobile phone repository and the option to export the data to a spreadsheet, the parameters measurement regardless of lighting and without using the phone camera, references on sagittal balance parameters, step-by-step guidance for each parameter, and intuitive interface. The application can be downloaded vis QR code below (available on Android).

Conclusion

The measurements of spinopelvic parameters using SmartPlan Balance application demonstrate high reliability and reproducibility, comparable to the standard desktop program. The use of the SmartPlan Balance mobile application is recommended in the daily practice of each spine surgeon, particularly in surgical planning, intraoperative parameter measurements, and analysis of non-digital radiographs.

Moreover, this application is currently the first and only Russian developed application for calculating sagittal parameters of the spine. Considering the broad applicability of smartphones in both everyday life and medical practice, we consider this application a valuable addition to a spinal surgeon's toolkit.

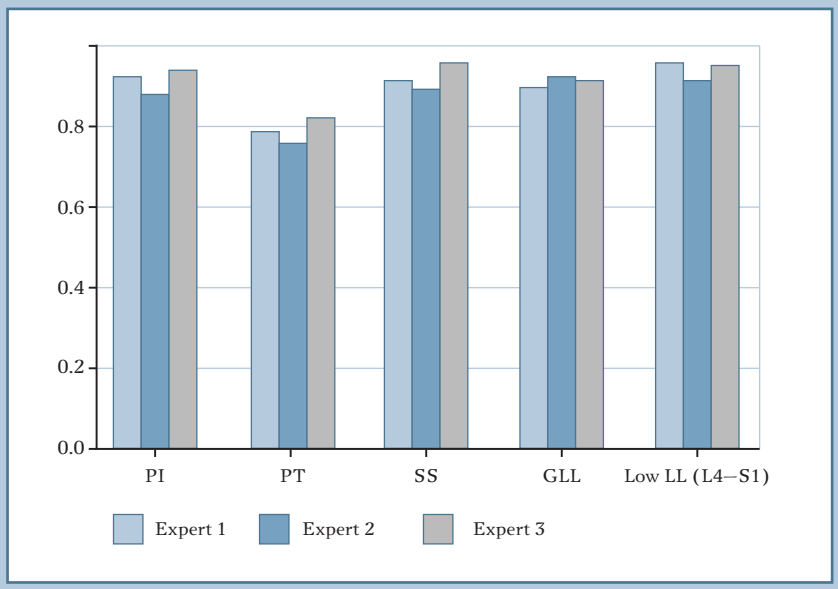

Fig. 3
Graphic representation of the intra- and interclass correlation coefficient (3.1) for calculating intra-rater reliability

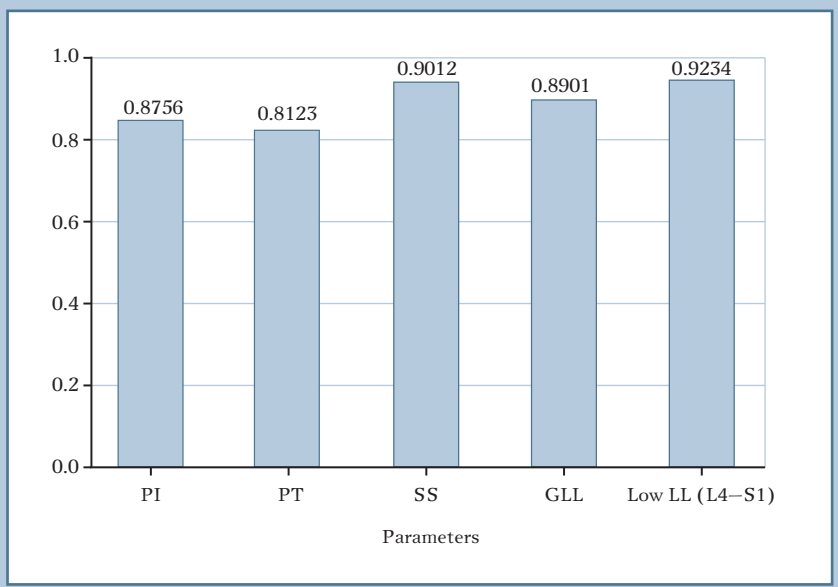

Fig. 4
Graphic representation of the intra- and interclass correlation coefficient (3.1) for calculating inter-rater reliability

The study had no sponsors. The authors declare that they have no conflict of interest.
The study was approved by the local ethics committees of the institutions.
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