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Validity of a Smartphone Application (Sagittalmeter Pro) for the Measurement of Sagittal Balance Parameters

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■ OBJECTIVE: **The study was aimed to compare the validity, reproducibility, precision, and efficiency of a picture archiving and communication system (PACS) and a smartphone application, which is an educative app to easily measure sagittal balance parameters (SagittalMeter Pro), for measuring spinopelvic sagittal parameters.**

■ METHODS: **Three spine surgeons measured lumbar lordosis (LL), pelvic incidence (PI), sacral slope (SS), and pelvic tilt (PT) on standing posteroanterior radiographs of 30 patients using PACS and SagittalMeter Pro. Measurements were repeated a week after the original measurements. Intraobserver and interobserver variabilities and reliabilities of each parameter (LL, PI, SS, and PT) were calculated for both techniques. Comparisons were performed using the paired *t*-test. Results are expressed as mean ± standard deviation and *P* values of < 0.05 were considered significant.**

■ RESULTS: **PACS to SagittalMeter Pro differences between the mean absolute values of LL, PI, SS, PT were 0.50°, 0.82°, 0.81°, 0.34°, respectively, and intraobserver and interobserver variabilities were similar. Excellent intraobserver and interobserver reliabilities were obtained for PACS and SagittalMeter Pro as demonstrated by values >0.86 and >0.84, respectively. Measurement times for PACS and SagittalMeter Pro were 36.63 ± 7.55 and 14.57 ± 1.96 seconds, respectively, and this difference was significant (*P* = 0.001).**

■ CONCLUSIONS: **The study shows PACS and SagittalMeter Pro are equivalent in terms of their abilities to measure spinopelvic sagittal parameters, and that the time required to obtain measurements was significantly less for SagittalMeter Pro. We believe that SagittalMeter Pro may be helpful when planning spinal surgery.**

INTRODUCTION

Degenerative spine disease comprises a group of conditions characterized by loss of normal spinal structure and function, which usually affect the lumbar spine.[1] During the past 15 years, sagittal balance analysis has become an important factor before spine surgery.[2] Accurate and reproducible measurements are important, as poor measurements could lead to too little or overly aggressive planning and undesirable clinical results.

There is growing interest in the use of spinopelvic sagittal parameters to predict outcomes in patients with degenerative spinal disease.[3,4] Since it was first described by John Cobb in 1948, the Cobb angle[5] has been the gold standard for evaluating sagittal spinal deformities. In the past, we measured spinopelvic sagittal parameters using a wax pencil and a protractor on simple x-ray films, but at present, we obtain these values using the web-based picture archiving and communication system (PACS) (INFINIT Healthcare Co. Ltd., Seoul, South Korea). Smartphones are now been widely adopted for daily life and are being

Key words
- PACS
- Reliability
- SagittalMeter Pro
- Spinopelvic parameter
- Variability

Abbreviations and Acronyms
CI: Confidence interval
LL: Lumbar lordosis
PACS: Picture archiving and communication system
PI: Pelvic incidence
PT: Pelvic tilt
SD: Standard deviation
SS: Sacral slope

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increasingly used in clinical practice, which suggests that they could be used by surgeons to perform measurements. Therefore, physicians can no longer ignore the growing integration between smartphone technology and their clinical practice,[6] as smartphone applications can save time and can efficiently allow physicians to monitor patient's conditions during daily life.[7]

We used a smartphone application to obtain spinopelvic sagittal parameters before and during surgery. This application, which is called SagittalMeter Pro, was launched by Jean-Charles Le Heuc on February 2015, and is an educational application that allows sagittal balance parameters to be easily measured from sagittal plain radiographs (Figure 1). Using SagittalMeter Pro, surgeons can perform quick measurements on hard copy of digitized radiographs on the screen of a computer monitor without built-in measurement software. However, there is no evidence available about whether SagittalMeter Pro measurements are reliable.I It is of importance to assess the accuracy, precision, and validity of SagittalMeter Pro compared with those of the other PACSs before they are adopted widespread. Hence, we compared the validity, reproducibility, precision, and efficiency of spinopelvic sagittal parameters obtained using PACS and SagittalMeter Pro.

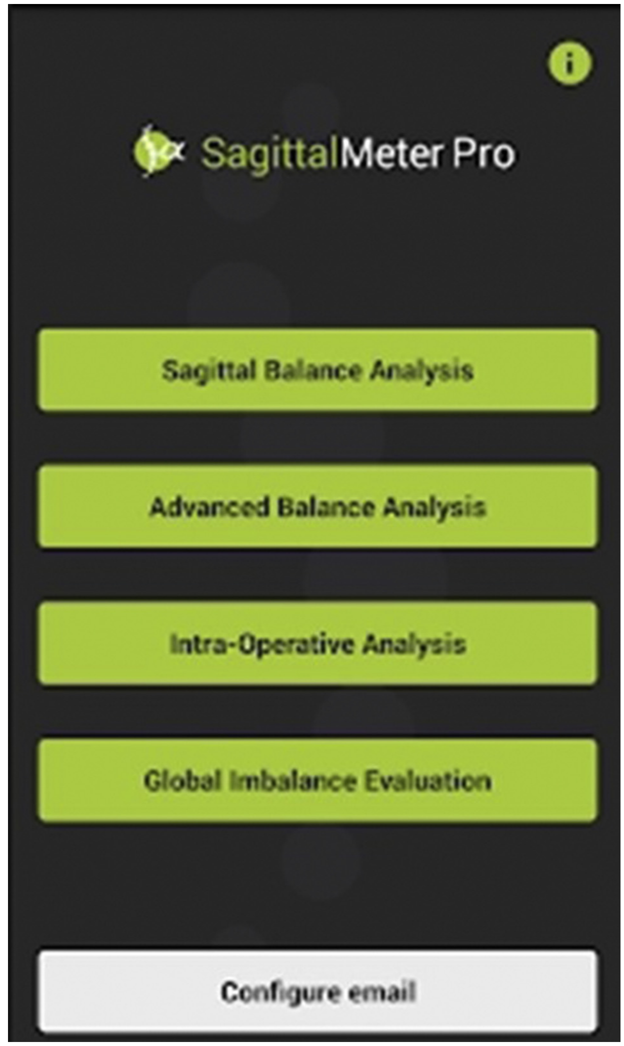

Figure 1. SagittalMeter Pro is produced by Jean-Charles Le Heuc.

METHODS

We chose, at random 30 patients, who underwent standing whole spine lateral radiography at our institute. Whole spine lateral radiographs were taken using a 14- × 17-inch cassette at a distance of 98.4 inches (250 cm) with the tube centered at the xiphoid process and subjects in a comfortable standing position with eyes forward and arms on clavicles, without magnification. We then measured lumbar lordosis (LL), pelvic incidence (PI), sacral slope (SS), pelvic tilt (PT), and recorded the time taken for each measurements using SagittalMeter Pro and PACS.

Three spine surgeons measured these parameters twice at a 1-week interval. To measure parameters using PACS (Figure 2), lines were drawn in the usual manner to measure Cobb angles. For example, LL was defined as the Cobb angle between the upper endplate of the L1 and S1.[8] PI was defined as the Cobb angle between the vertical line of the sacral plate and the line connecting the midpoint of the sacral plate to the midpoint of the bilateral femoral head center (bicoxofemoral axis).[9,10] SS was defined as the Cobb angle between the sacral plate and the horizontal plane.[11] PT was defined as the Cobb angle between the plumb line and the line connecting the midpoint of the sacral plate and the midpoint of the bilateral femoral head center.[9,10,12]

Parameters were measured using SagittalMeter Pro by placing a smartphone on sagittal radiographs (Figure 3) as follows: Step 1, place the superior border of the phone parallel to S1 plateau. Step 2, place the lateral border of the phone on the line between the center of S1 and the center of the appropriate femoral head. Step 3, place the superior border of the phone parallel to the L1 endplate. After each step, press confirm position button. The sagittal balance analysis is then performed automatically.

Statistical Analysis

Intraobserver variability was assessed by analyzing absolute differences between successive parameter measurements by the same observers using the same measurement tool. The 95% confidence intervals (CIs) for intraobserver variability were calculated using 1.96 × standard deviation (SD) intraobserver, where SD intraobserver is the SD of the intraobserver differences.[13,14] Interobserver variability (SD of the difference between measurements by 2 observers) was calculated using $\sqrt{2}$ × SD interobserver for a single measurement for each observer, where SD interobserver is the SD of interobserver differences.[13] The 95% CIs of interobserver variability were calculated using 2.09 × SD (t-distribution with 19 degrees of freedom).[13]

Interclass correlation coefficients were defined as follows: <0.40 was considered poor, 0.40—0.59 fair, 0.60—0.74 good, and 0.75—1.00 excellent.[15]

The independent samples t-test and the paired t-test were used to analyze normally distributed data, and the Mann-Whitney rank test was used for non-normally distributed data. The statistical analysis was performed using SPSS version 18.0.0

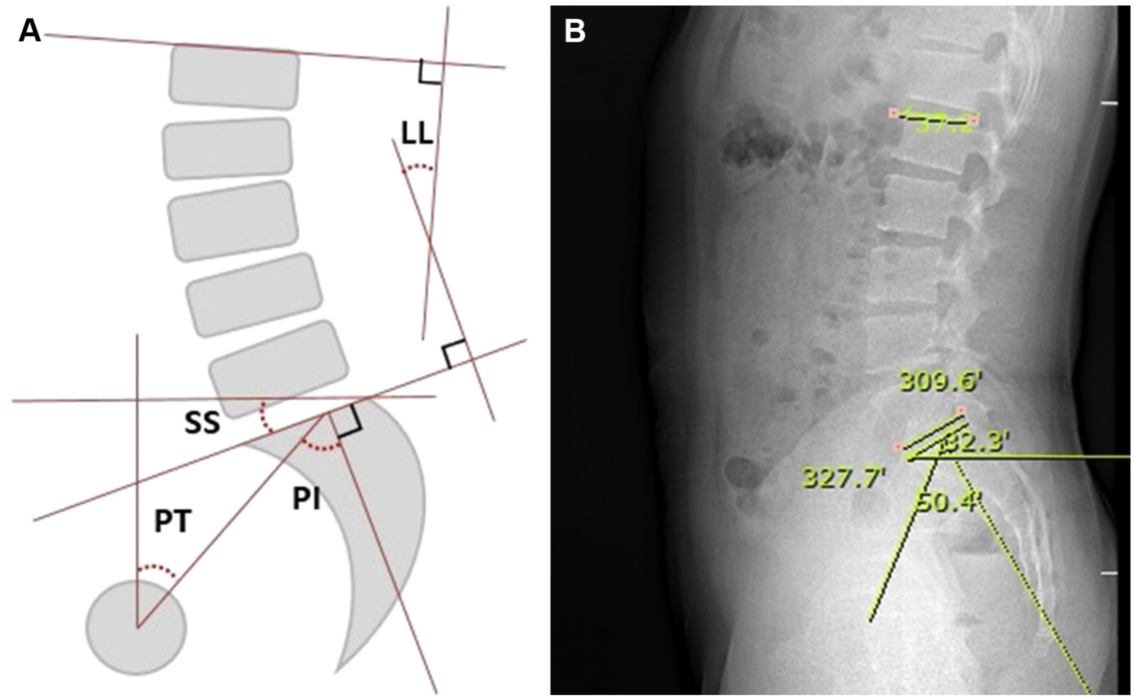

Figure 2. Spinopelvic sagittal parameter measurements using PACS. (**A**) Simplified illustration. LL, lumbar lordosis; SS, sacral slope; PT, pelvic tilt; PI, pelvic incidence. (**B**) Actual measurement.

(IBM Corporation, Chicago, Illinois, USA). Results are presented as mean ± SDs, and statistical significance was accepted for P values of <0.05.

RESULTS

A total of 30 patients were selected at random. They consisted of 17 women and 13 men and a mean overall age was 50.86 ± 17.63 years (range, 20–78 years). By PACS, average LL, PI, SS, and PT angles were 43.83° ± 11.67°, 54.32° ± 10.35°, 36.01° ± 8.73°, and 18.70° ± 7.85°, respectively, and corresponding SagittalMeter Pro values were 44.33° ± 11.37°, 53.50° ± 11.72°, 35.20° ± 8.39°. and 18.36° ± 9.18°, respectively. Differences between these values were not statistically significant (LL, $P = 0.866$; PI, $P = 0.775$; SS, $P = 0.714$; PT, $P = 0.878$). Mean spinopelvic sagittal parameter measurement times for PACS and SagittalMeter Pro were 36.63 ± 7.55 and 14.57 ± 1.96 seconds, respectively, and this difference was statistically significant ($P = 0.001$). Actual mean differences between LL, PI, SS, PT, and measuring times were 0.50°, 0.82°, 0.81°, 0.34°, and 22.06 seconds, respectively (Figure 4).

Intraobserver Variability

The mean intraobserver difference for LL as determined by PACS and SagittalMeter Pro were 0.27° ± 3.14° (95% CI 6.15°) and 0.96° ± 3.10° (95% CI 6.07°). The mean intraobserver difference for PI as determined by PACS and SagittalMeter Pro were 1.36° ± 2.43° (95% CI 4.76°) and 1.36° ± 2.61° (95% CI 5.11°). The mean intraobserver difference for SS as determined by PACS and SagittalMeter Pro were 1.09° ± 2.23° (95% CI 4.37°) and 1.00° ± 2.20° (95% CI 4.31°). The mean intraobserver difference for PT as determined by PACS and SagittalMeter Pro were 2.31° ± 2.33° (95% CI 4.56°) and 0.30° ± 2.40° (95% CI 4.80°), respectively (Table 1). These results indicated that the intraobserver variability of SagittalMeter Pro is equivalent to that of PACS.

Interobserver Variability

Based on a single reading by each observer, the SD of a LL was 3.07° for PACS and 3.01° for SagittalMeter Pro. The interobserver error (SD of the difference between measurements by 2 observers) was 4.32° for PACS and 4.24° for SagittalMeter Pro. The 95% CIs for interobserver error were ±6.41 and ±6.29 for PACS and SagittalMeter Pro, respectively. Other measurements were specified in Table 2.

Interrater Reliability

The intraobserver reliabilities of LL, PI, SS, and PT, as determined by PACS and SagittalMeter Pro were 0.98, 0.98, 0.97, and 0.97, and 0.96, 0.95, 0.92, and 0.93, respectively, and the interobserver reliabilities of LL, PI, SS, and PT by PACS and SagittalMeter Pro were 0.93, 0.86, 0.88, and 0.90, and 0.93, 0.84, 0.87, and 0.93, respectively (Tables 1 and 2). Consistently, intraobserver and interobserver correlation coefficients of all parameters showed excellent reproducibility. An intraclass

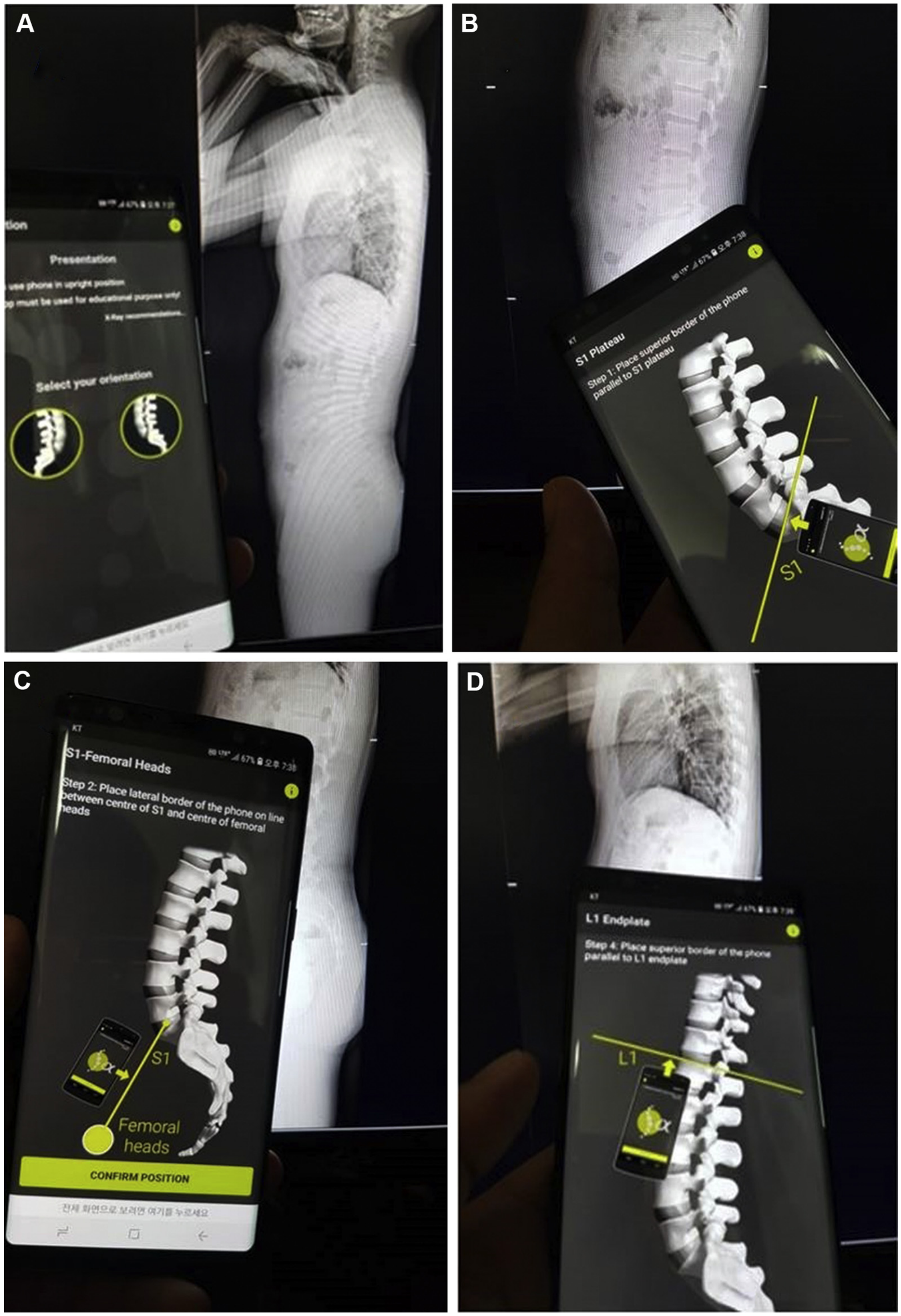

Figure 3. Spinopelvic sagittal parameter measurements using SagittalMeter Pro. Measurements were performed using several steps. (**A**) Determine the orientation before measurement. **(B)** Place superior border of the phone paralle1 to the S1 plateau. (**C**) Place the lateral border of the phone on the line between the center of S1 and the center of femoral heads. (**D)** Place the superior border of the phone parallel to the L1 endplate.

Figure 4. Mean differences between PACS and SagittalMeter Pro measurements. The only significant difference found was between measurement times ($P = 0.001$). LL, lumbar lordosis; SS, sacral slope; PT, pelvic tilt; PI, pelvic incidence.

correlation coefficient of >0.80 is considered to show very high reliability among raters.[7]

Intraoperative Usefulness

In addition, benefit of SagittalMeter Pro is that the surgeon can take the C-arm during surgery to assess the parameter that has been calibrated on the spot by SagittalMeter Pro (Figure 5). For example as a case presentation, a 69-year-old woman was treated with multilevel interbody and posterior pedicle screw fixations for multilevel bilateral foraminal stenosis and flat back syndrome. Preoperative spinopelvic sagittal parameters were evaluated by SagittalMeter Pro (Figure 5A). During surgery, we can calibrate and adjust sagittal parameters easily by using only SagittalMeter Pro (Figure 5B). Postoperative spinopelvic sagittal

Table 1. Intraobserver Variabilities and Reliabilities of PACS and SagittalMeter Pro measurements

	PACS				SagittalMeter Pro			
	Variability		Reliability		Variability		Reliability	
	MAD ±SD	95% CI	ICC	95% CI	MAD ±SD	95% CI	ICC	95% CI
LL	0.27° ± 3.14°	6.15	0.98	(0.95, 0.99)	0.96° ± 3.10°	6.07°	0.96	(0.91, 0.98)
PI	1.36° ± 2.43°	4.76	0.98	(0.95, 0.98)	1.36° ± 2.61°	5.11°	0.95	(0.89, 0.97)
SS	1.09° ± 2.23°	4.37	0.97	(0.95, 0.99)	1.00° ± 2.20°	4.31°	0.92	(0.84, 0.96)
PT	2.31° ± 2.33°	4.56	0.97	(0.93, 0.98)	0.30° ± 2.40°	4.70°	0.93	(0.85, 0.96)

MAD, mean absolute difference; SD, standard deviation; ICC, intraclass correlation coefficient; CI, confidence interval; LL, lumbar lordosis; SS, sacral slope; PT, pelvic tilt; PI, pelvic incidence.

Table 2. Interobserver Variabilities and Reliabilities of PACS and SagittalMeter Pro measurements

	PACS				SagittalMeter Pro			
	Variability		Reliability		Variability		Reliability	
	MAD ± SD	95% CI	ICC	95% CI	MAD ± SD	95% CI	ICC	95% CI
LL	0.58 ± 4.32	6.41°	0.93	(0.85, 0.96)	0.10° ± 4.24°	6.29	0.93	(0.86, 0.97)
PI	2.44 ± 3.59	5.32°	0.86	(0.70, 0.93)	0.70° ± 3.93°	5.83	0.84	(0.66, 0.92)
SS	0.34 ± 3.22	4.77°	0.88	(0.76, 0.95)	0.50° ± 3.14°	4.66	0.87	(0.73, 0.94)
PT	3.04 ± 3.21	4.76°	0.90	(0.80, 0.95)	0.26° ± 3.35°	4.97	0.93	(0.85, 0.97)

MAD, mean absolute difference; SD, standard deviation; ICC, intraclass correlation coefficient; CI, confidence interval; LL, lumbar lordosis; SS, sacral slope; PT, pelvic tilt; PI, pelvic incidence.

parameters were well balanced (**Figure 5C**). These steps were done rapidly and with ease, whether done by students or early surgical residents.

DISCUSSION

Parameters measured by PACS and SagittalMeter Pro were similar and differences did not deviate beyond ±3°. Generally, measurement differences did not exceed, or even approach, the 3—5° range of intraobserver and interobserver variation considered acceptable according to current norms a standard protractor,[16-19] and thus, are not considered to be clinically meaningful. This also agrees with the margins of error when measuring the angle determined by a previous study.[20]

Variability analysis showed that the intraobserver and interobserver variabilities of PI and PT measurements by PACS were more than those of LL and SS (intraobserver variability by PACS: PI, 1.36° ± 2.43°; PT, 2.31° ± 2.33°; interobserver variability by PACS: PI, 2.44° ± 3.59°; PT, 3.04° ± 3.21°). We believe this was due to difficulty in determining the midpoint of the bicoxofemoral axis. Therefore, the measurement of pelvic parameters was relatively more variable compared with LL and SS, which measured the Cobb angle between the endplates of the vertebral bodies.

Intraobserver and interobserver correlation coefficients of all parameters showed excellent reproducibility. Not surprisingly, interobserver reliability was poorer than the intraobserver reliability, presumably due to consistent individual methodologic differences.[15]

Several articles related to the usefulness and accuracies of smartphone applications have been published. Meng et al[21] concluded that the smartphone is equivalent to the protractor in terms of the accuracy of hallux valgus angle measurements and that measurement times were shorter. Qiao et al[15] reported that smartphone measurements of Cobb angles showed excellent reliability and accuracy compared with manual measurements in adolescent idiopathic scoliosis, and Furness et al[22] concluded that a smartphone application (Compass) provides a reliable means of measuring thoracic spine rotation and that the measurements obtained showed had more intraobserver and interobserver reproducibilities than those obtained using an universal goniometer. Furthermore, because Compass application and universal goniometer measurements are known to be positively correlated, these findings support the use of either device in clinical practice for the measurement of thoracic rotation. Allam et al[23] concluded that a smartphone containing the integrated Tiltmeter and Cobbmeter applications is equivalent to the Oxford Cobbmeter for measurement of the Cobb angle in adolescent idiopathic scoliosis. It has also been suggested that these integrated applications might be useful for spine surgeons, especially in hospitals where PACS and Oxford Cobbmeter are unavailable.

We need to emphasize at this point that changing the tool used to obtain measurements does not change the spirit and the purpose, which provides a point of reference during the course of a treatment and a basis for evaluating techniques.[24] We recognize that many surgeons will choose to continue using wax pencils and the PACS system. The present study was not undertaken to replace the standard protractor, wax pencil, and PACS, but rather to validate the use of the SagittalMeter Pro smartphone application as a clinically reliable, precise, and efficient tool.[7] However, SagittalMeter Pro has many benefits. First, it is easily used and provides values quickly, and second, it is highly reliable, readily accessible tool that can be used anywhere (especially during surgery).

CONCLUSION

We conclude that the SagittalMeter Pro is equivalent to the PACS in terms of its ability to measure spinopelvic sagittal parameters, and that it offers the facility of rapid measurements. This smartphone application is likely to be useful when planning spinal deformity surgery. To our knowledge, this is the first validation study to be conducted on SagittalMeter Pro for the measurement of radiographic spinopelvic sagittal parameters. Because of the widespread use of smartphones by spine surgeons, we believe that these types of smartphone applications will be found useful in the spine surgery field.

Figure 5. Photographs showing spinopelvic sagittal parameter measurements using the SagittalMeter Pro application during surgery. A 69-year-old woman was treated with multilevel interbody and posterior pedicle screw fixations for multilevel bilateral foraminal stenosis and flat back syndrome. Measurements were performed using SagittalMeter Pro. (**A**) preoperative; (**B**) intraoperative; and (**C**) postoperative results.

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