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Surgical technique

A Vertical Measurement System to Predict the Change in Leg Length in Total Hip Arthroplasty

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ABSTRACT

The management of leg lengths in total hip arthroplasty continues to challenge orthopaedic surgeons. The aim of this study is to test the reliability of a measuring device used to measure the resected femoral head and how the resulting intra operatively calculated change in leg length compares to the radiographically measured change in leg length. Four orthopaedic surgeons measured 20 femoral heads and the intra class coefficients of the raters were between 0.955 and 0.990 with a mean difference less 1 mm, indicating the reliability of the device. The 'actual' radiographic leg length correction of 50 patients and the 'predicted' intra operatively calculated correction was analysed with a linear regression model and 47 measurements were within 2 mm and the remaining 3 within 4 mm.

Introduction

Quality of life improvement after total hip arthroplasty is dependent on many variables including obtaining the correct leg length.

The process starts with clinical assessment and preoperative templating to assess the leg length discrepancy (LLD) and determine the desired correction.

Historically, the operative technique endeavors to reproduce the planned construct and prosthesis position using anatomic landmarks usually greater and lesser trochanters.

Having performed many thousand arthroplasties, the senior author remained frustrated that despite using a variety of recognized methods, he was unable to achieve leg length correction (LLC) to within 5 mm in all cases. In a retrospective review of 50 cases before this study, he found 33 cases corrected to within 5 mm, 15 cases in 6-10 mm, and more than 10 mm in 2 cases. This experience is not unique and has been highlighted by other authors [1-9].

Gross et al. [1] in 2016 concluded, "There is currently no viable option that provides accurate real time data to surgeons regarding leg length in a cost-effective manner."

We have therefore devised a system to predict and measure the change in leg length that works on the principle, previously described by Woolson et al. [2], that the difference in height between the excised bone and implant will precisely determine the leg length (Fig. 1).

The femoral implant height (y) is available from the manufacturer and (x) is the radius of the acetabulum. We have developed a measuring jig that determines the vertical height of the excised bone (b). This is a very precise measurement and is not dependent on anatomic variation (Fig. 2).

We were however surprised to learn of the significant differences in height between different implants. In some cases, the neck height remains the same between the smallest and largest implant, and in others, there is an incremental change. For example, the Corail (DePuy Synthes, Raynham, MA) size 8 stem and size 20 stem have the same vertical height, whereas the Summit (DePuy Synthes, Raynham, MA) size 1 and size 10 stems have a 9-mm difference.

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Changing the offset may or may not change the height depending on the design.

We have therefore developed a mobile device application (app) that has been populated by more than 1000 vertical height measurements of different sized implants from many of the major manufacturers. At surgery, the surgical technician is required to input the height of the excised bone into the app. The screenshot (Fig. 3) shows that the planned result is to lengthen the leg by 6 mm, and the intraoperatively predicted LLC is calculated as 5.9 mm.

If this is the desired correction, the surgeon can proceed with the knowledge that accurate LLC will be achieved.

If not, the implant size or position can then be adjusted to achieve the desired result.

This process is quick and simple and does not significantly impact surgical time.

The Vertical Measurement System (VMS) is the term used to describe the use of the measurement device (the jig) and the app intraoperatively.

The jig has been designed to measure the vertical height of the excised femoral bone that corresponds to the vertical height of the implanted construct as shown (Figs. 1 and 2).

The tool has a base plate angled to match the femoral neck osteotomy and a horizontal arm that slides on a calibrated vertical column to measure the vertical height of the excised bone. The device measures from the most superior aspect of the femoral head (superior reference point) to the intramedullary point on the medial calcar at the level of the femoral neck osteotomy (inferior reference point). This is the most reproducible point to compare vertical heights of the excised bone with the vertical height and position of the femoral stem.

The app contains a database of many femoral components. The engineering specifications of each femoral component were obtained from the relevant manufacturer. This enables the surgeon to determine the LLC with the trial components in situ. Adjustments can then be made. Fine-tuning can be done by changing head lengths. Major adjustments may require changing the stem size.

The app can be accessed free of charge at https://www.verticalmeasurementsystem.com/calculator/user_info and can be used on any smartphone.

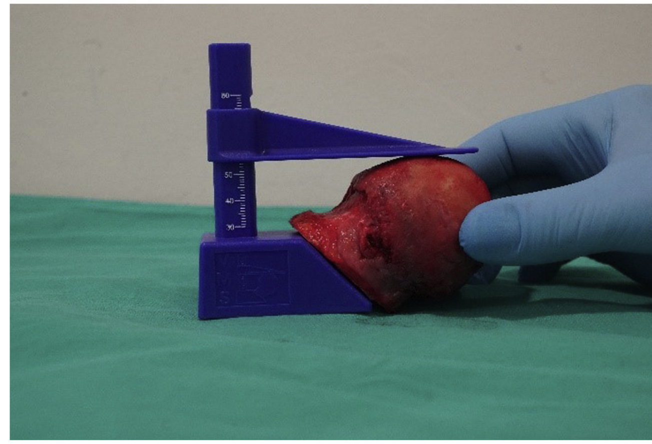

Figure 2. Measuring device with excised femoral head.

Surgical technique

The patient is assessed clinically in the office to differentiate between true and apparent LLD, and together with the radiographs, the surgeon determines the LLC required. This usually corresponds to the amount of bone and articular cartilage lost on the affected side. The final decision however may be influenced by other factors such as pelvic obliquity or preexisting leg length abnormalities. If this does not correlate with the patients' perceived difference, the patient is asked to stand on blocks until they feel that the LLD is corrected and this is considered.

Templating is performed to determine position, offset, and size of implants required to correct the leg length. The planned result and templated stem type and size are entered into the app (Fig. 3). The system is useful even if templating has not been undertaken, the difference being that the correction value will only be available intraoperatively once the trial implants are inserted.

The hip joint is opened via the operating surgeon's usual surgical approach, and the femoral neck osteotomy is performed at 45°. The measuring jig has a 45° angled base plate, and the osteotomy should match that angle. If the osteotomy is not at 45°

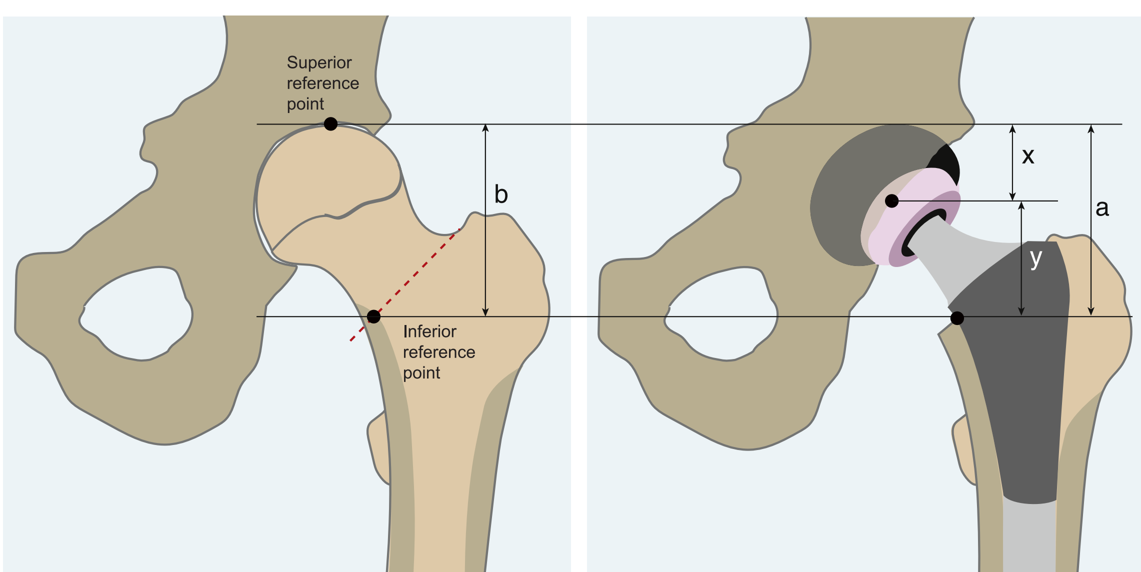

Figure 1. LLC = a-b.

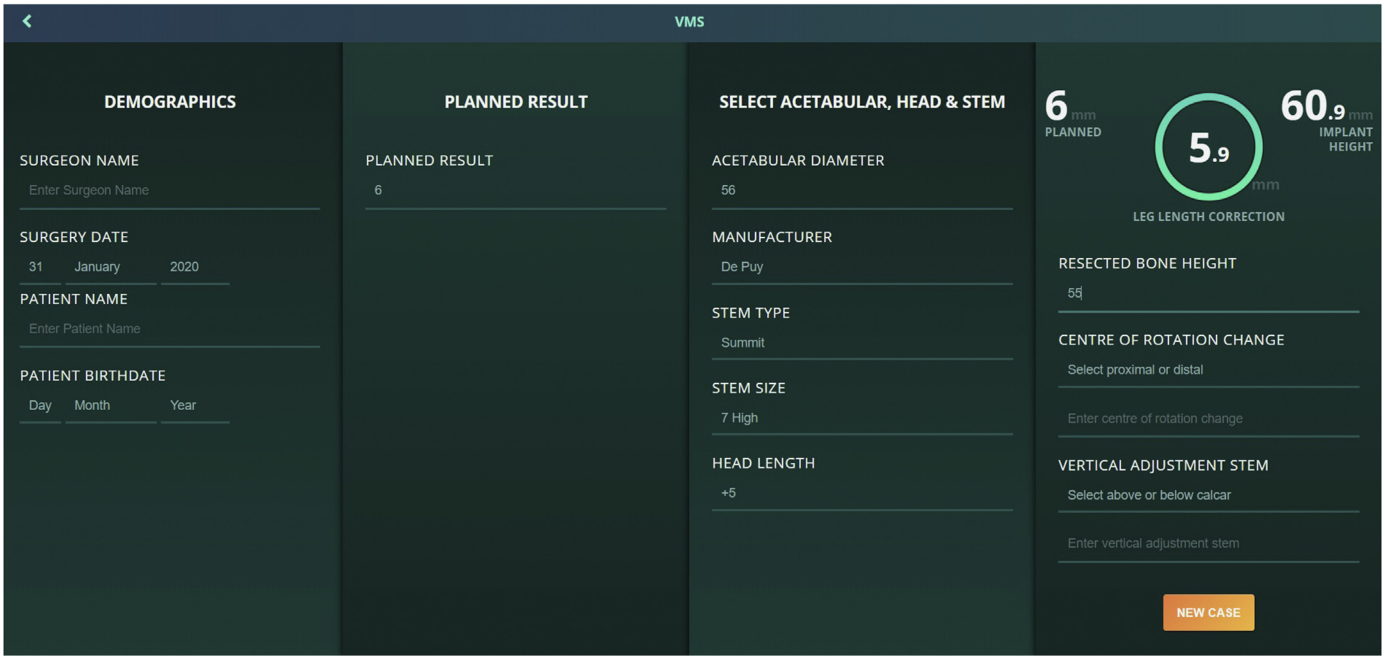

Figure 3. The mobile device application.

when using the measuring jig, the values will lose accuracy because of the rotation of the excised bone on the base plate. We used an aiming device to prevent this from occurring. The aiming device consists of a long arm that is orientated over the anatomic long axis of the femur and a short arm angled to ensure a 45° neck osteotomy (Fig. 4). Too vertical an osteotomy will overread and too horizontal will underread the vertical height of the excised bone. This amounts to approximately 1 mm per 5 degrees. The head height must be measured between the inferior and superior reference points (Figs. 1 and 2).

Determination of the acetabular diameter

The acetabular diameter can be predicted by the diameter of the femoral head and is confirmed by the first acetabular reamer that matches the acetabulum without reaming the superior acetabular bone.

Figure 4. Intraoperative utilisation of the femoral neck osteotomy guide.

The acetabular diameter is entered into the app, and the implant height will be displayed. The acetabulum is prepared, and the definitive acetabular component is implanted with definitive liner or trial liner as per the surgeon's preference – note that if the center of rotation is not changed, the acetabular component size will not alter the leg length and reaming to a bigger-than-anticipated acetabular size does not change the final calculation. Occasionally, a change in the center of rotation may be anticipated when templating or noted intraoperatively, and there is a data field in the app where this adjustment can be made.

The femur is prepared, the trial prosthesis is inserted, and the app is used to calculate LLC. If further neck is resected, this needs to be measured and added to the "Resected Bone Height" on the last screen of the app. If the correction is not appropriate, the femoral component size, offset, or position can be adjusted, or the modular femoral head length can be changed. It should be noted that certain femoral components change the vertical height between the standard and high offset stems and others do not. To accurately restore hip function, the leg length and lateral offset must both be addressed.

The hip is reduced and put through a range of motion to assess stability and tissue tension. Finally, the definitive femoral prosthesis is inserted, and the height above or below the inferior reference point at the medial calcar is measured and entered into the app. The final leg length will then be displayed and can be recorded for later comparison with clinical and radiographic measurements.

The aim of the study was to assess the reliability of the measuring device (the jig) and to compare the intraoperative "predicted" LLC with the "actual" radiographically measured correction.

The measuring tool was tested in a reliability study. Three consultant surgeons and one trainee were formally instructed on the use of the measuring device and individually in isolation measured the vertical height of 20 excised femoral heads at 4 different times. This gave 16 measurements per femoral head for a total of 320 measurements. The presentation sequence of each session was randomized. The intraobserver reliability was tested by calculating the intraclass correlation coefficients based on absolute (continuous) agreement. The differences between the 4 observers were tested using a general linear model in a repeated-measure design.

The VMS was tested by a comparative design. In 50 consecutive total hip arthroplasties, the LLD was measured preoperatively radiologically at the time of templating. Templating was performed using a digital picture archive and communication system radiograph system (AGFA IMPAX Orthopaedic planning tool v3.0). A standardized pelvic radiograph was taken with a marker placed at the level of the greater trochanter to scale the image. LLD was measured from the inferior aspect of the tear drop to the most prominent aspect of the lesser trochanter as described by Woolson et al. [2]. Postoperatively at 6 weeks, a standardized pelvic radiograph was taken, and the leg lengths were measured radiologically using the same technique. An example of a preoperative radiograph with digital templating (Fig. 5) and a postoperative radiograph (Fig. 6) is shown. The difference between the preoperatively and postoperatively measured LLD was recorded as the “actual” LLC, and in this case, it was 6 mm. The use of the VMS intraoperatively gave a number which was recorded as the “predicted” LLC, and in this case, it was 5.9 mm (Fig. 3). The predicted and actual LLC were analyzed with a linear regression model.

The interobserver reliability results are summarized (Fig. 7), with the mean difference of all observations shown with the black line at 0.81 mm and the 95% confidence interval shown with the dashed line. The intraclass coefficients of the raters were between 0.955 and 0.990 each with $P < .001$. The mean differences between the observers' ratings were lesser than 1 mm except for raters 1 and 4. None of the differences were significant from zero (Table 1).

The postoperative actual radiographically measured correction was between 0 and 4mm of the predicted correction. It is evident that the mean is affected by 3 outliers: The predicted correction of samples 37 and 43 underestimated the actual correction by 4 mm. The predicted correction of sample 15 overestimated the actual correction by 3 mm (Fig. 8). The difference between the actual and predicted correction of the remaining 47 cases varied between zero and 2 mm. A linear regression (N = 50) with “actual correction” as a dependent and “predicted correction” as an independent variable did result in R = 0.889 (y = 0.83a + 0.76).

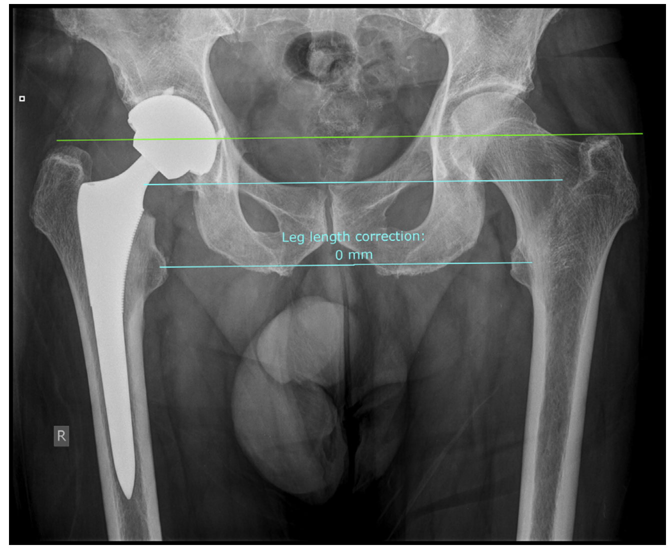

Figure 6. Post operative radiograph showing equal leg lengths.

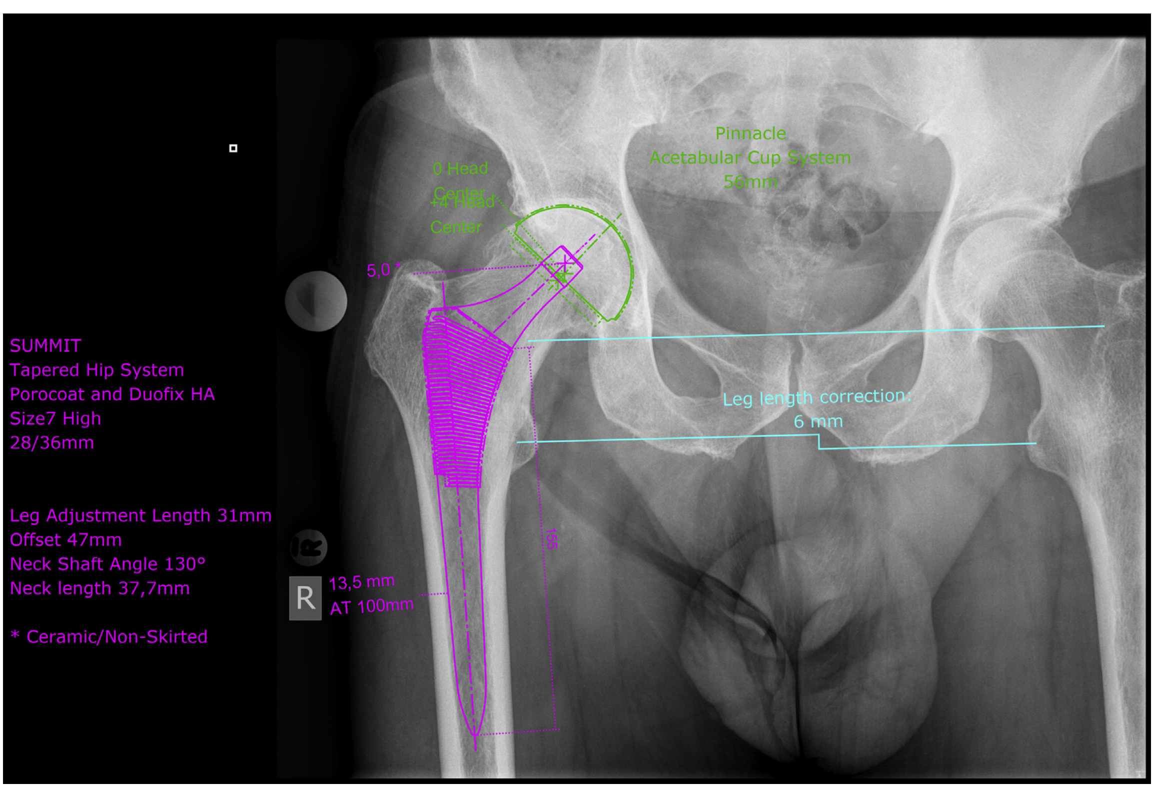

Figure 5. Preoperative template showing 6 mm LLD.

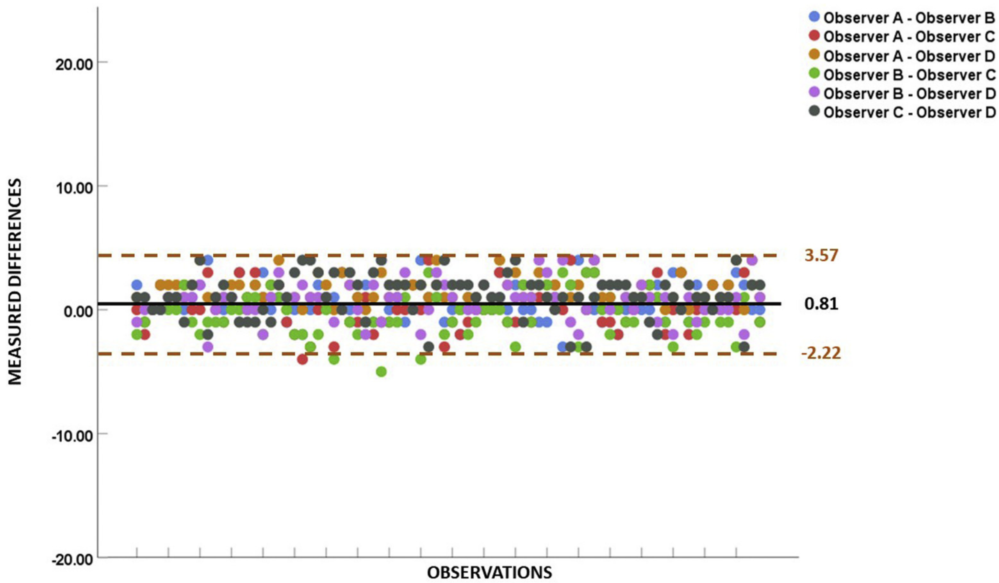

Figure 7. Measured femoral head differences with mean and 95% confidence interval.

Discussion

It is surprising that achieving correct leg length after total hip arthroplasty remains difficult. In 1997, Ranawat and Rodriguez [3] reported the incidence of LLD after primary total hip replacement (THR) to be up to 27%, and in 2013, Whitehouse et al. [4] found a LLD greater than 10 mm in 21.5% of 191 patients.

LLC after THR is not only difficult to achieve but also difficult to measure. The strength of the system that we have developed is that we can measure correction to within 4 mm in all cases. The weakness is that small errors are possible at each step: (1) the angle of the osteotomy, (2) measurement of the resected bone height, (3) measurement of the prosthesis position, and (4) radiological measurement. These may compound up to 4 mm as shown in the 3 outliers (Fig. 8). One of the outlier radiographs is shown (Figs. 9 and 10). Preoperatively, the right leg was 9 mm short, and postoperatively, the radiograph shows that it has been lengthened by 5 mm and remains 4 mm short (Fig. 10). On the app, the planned result was 9 mm and the "predicted" LLC was 9.1 mm (Fig. 11). The intraoperative "predicted" LLC is therefore 4 mm different from the "actual" radiographic correction. Although this is our worst result, it is still well within acceptable limits.

The angle of the femoral neck osteotomy needs to match the 45° angle of the base plate on the measuring device. A step cut may be performed, provided that the angle at the inferior reference point is 45°. Anatomic coxa vara or coxa valga will not incur an error, provided the neck osteotomy is at 45°. Measurement errors of the resected bone height most likely will occur if care is not taken to measure from the inferior reference point.

In acetabular dysplasia, the center of rotation may be difficult to maintain. The surgeon needs to recognize this and enter it into the app. Although this is not a precise measurement, it can be anticipated from preoperative templating and needs to be taken into account regardless of what method the surgeon uses to judge leg lengths. Errors in measurement of the final position of the definitive femoral stem above the inferior reference point on the medial calcar can be minimized by using an angled ruler.

There is some controversy regarding the functional morbidity associated with LLD. Some authors found little correlation between LLD and patient outcomes [5,6].

Conversely, it has been proposed that even small discrepancies are associated with functional impairment and pain [7,8].

Despite patient satisfaction being multifactorial, LLD remains a leading cause of litigation against orthopaedic surgeons [9,10].

The treatment of LLD adds to the economic burden, ranging from a shoe raise up to revision surgery costing up to $29,000 [11].

In a review article in 2013, Desai et al. [12] concluded that LLD is a common and recognizable complication of THR surgery. The authors categorized all the various methods of managing LLD into perioperative templating, intraoperative measurement techniques and complex mathematical calculations, and the use of ultrasound probes.

In a more recent 2016 article, Gross et al. [1] reviewed several methods developed to manage leg length, which they divided into

Table 1
Pairwise comparison of raters.

(I) rater	(J) rater	Mean height difference (I-J) over time	Standard error	Sig.[a]	95% confidence interval for difference[a]	
					Lower bound	Upper bound
1	2	0.825	1.455	1.000	−3.118	4.768
	3	0.863	1.455	1.000	−3.080	4.805
	4	1.612	1.455	1.000	−2.330	5.555
2	3	0.037	1.455	1.000	−3.905	3.980
	4	0.787	1.455	1.000	−3.155	4.730
3	4	0.750	1.455	1.000	−3.193	4.693

Based on estimated marginal means.
[a] Adjustment for multiple comparisons: Bonferroni.

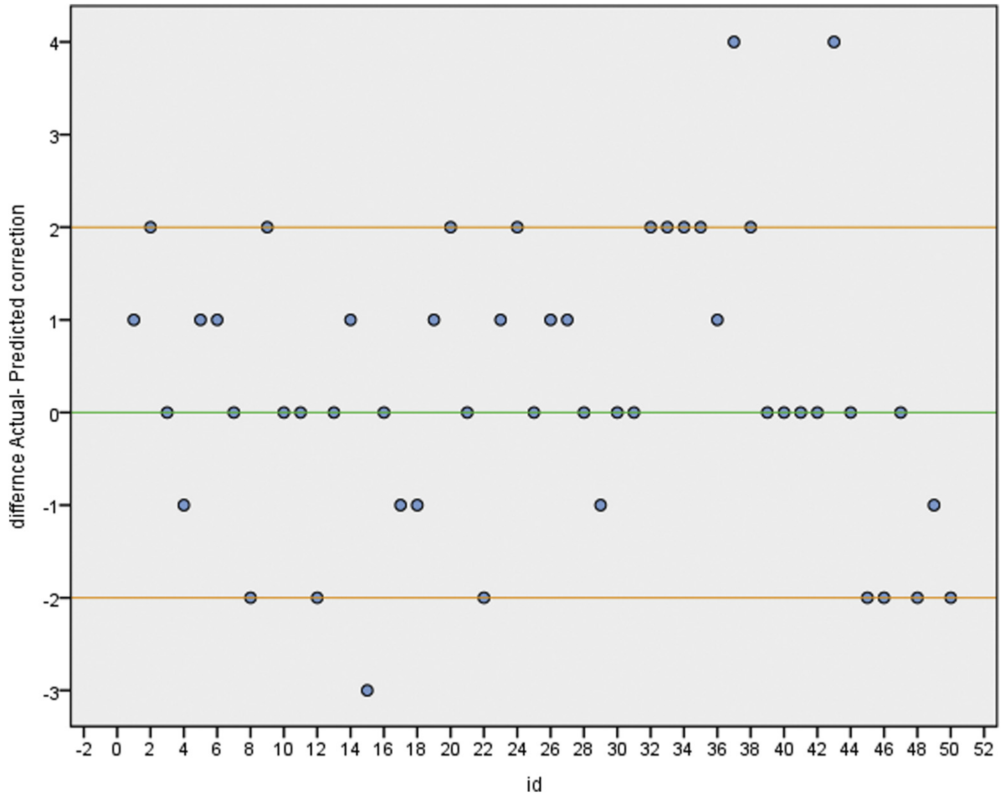

Figure 8. The difference between actual and predicted correction of the 50 patients.

2 categories: intraoperative mechanical methods and computer-assisted navigation. They stated that, "Current methods for managing leg length and offset during hip arthroplasty are either inaccurate and susceptible to error or are cumber-some, expensive and lengthen surgical time. There is currently no viable option that provides accurate, real-time data to surgeons…." and, "As such, we hypothesize that a procedural gap exists in hip arthroplasty…"

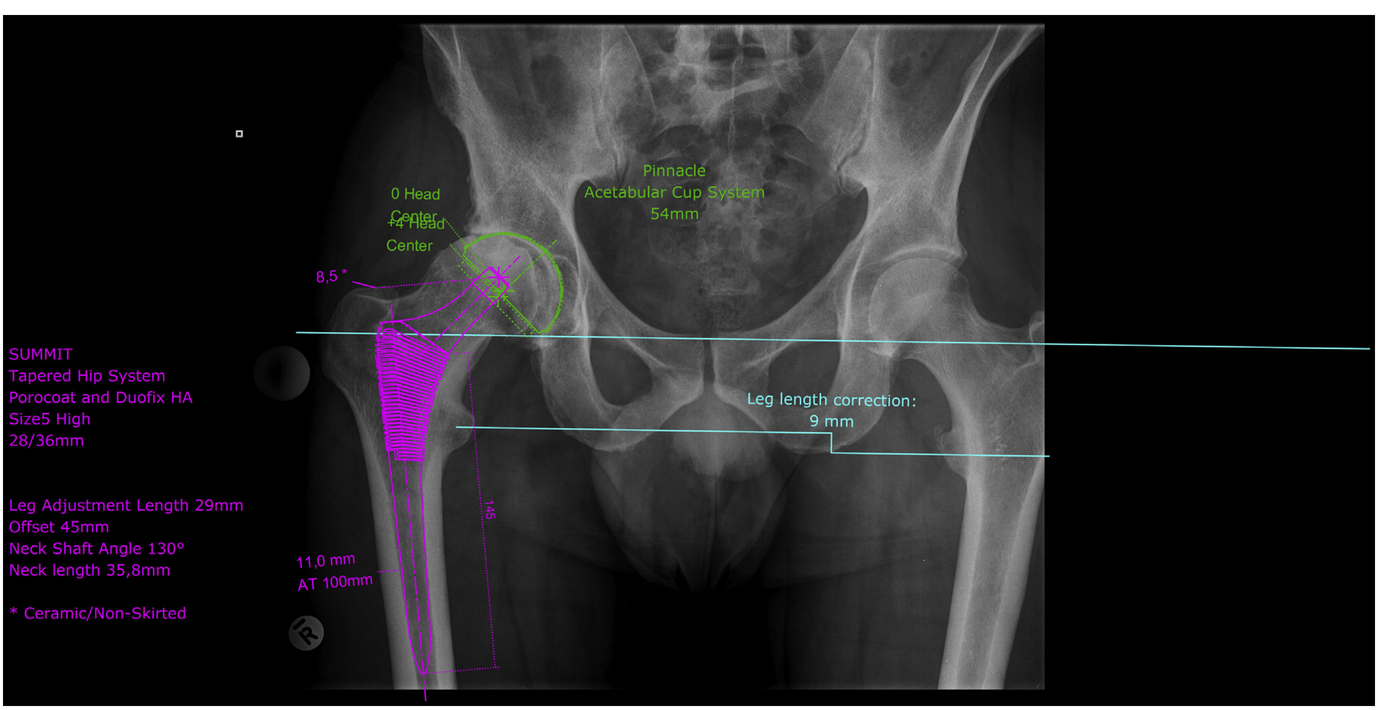

Figure 9. Pre operative with 9 mm LLD.

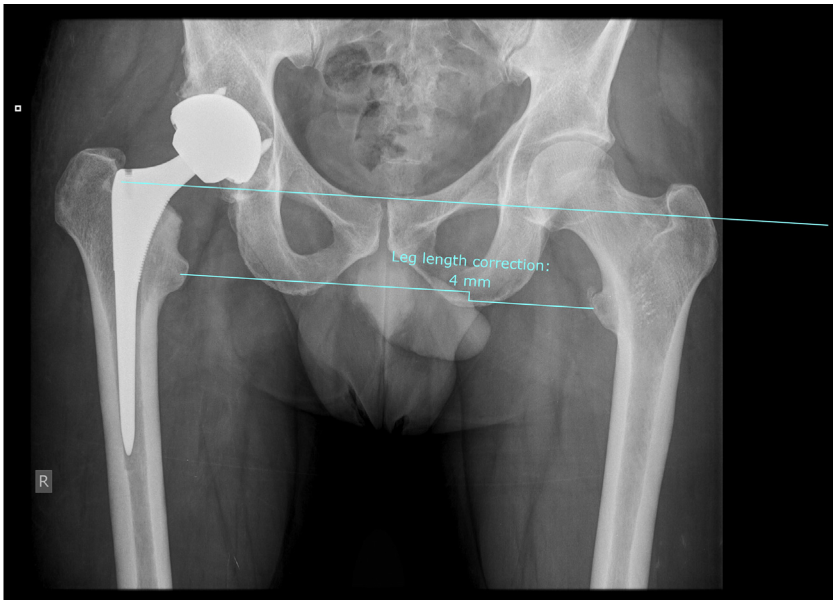

Figure 10. Post operative under correction with residual 4 mm LLD.

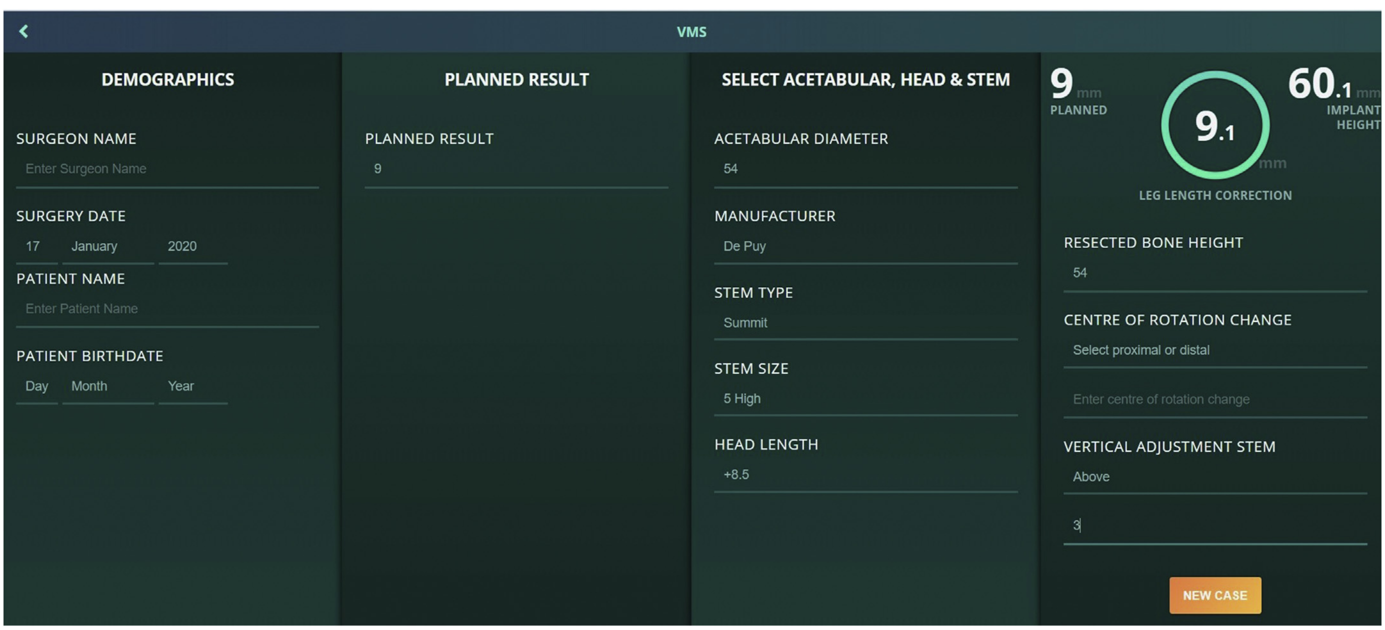

Figure 11. The calculator showing the intra operative 'predicted' correction of 9.1 mm.

We have therefore endeavored to fill this procedural gap by developing a cost-effective, simple-to-use, and unobtrusive technology in managing leg length.

Summary

The measuring device reliably measures the vertical height of the excised bone.

The VMS predicts LLC to within 4 mm of actual radiographic correction and in 94% of the cases to within 2 mm of actual correction.

Conflict of interest

The authors have not received any financial assistance; they have funded all research, development, and manufacturing costs themselves. Some of the authors have shares in a company manufacturing the device.

Acknowledgment

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