A Vertical Measurement System to predict the change in leg length in Total Hip Arthroplasty.

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 independently, on four occasions. The intra class correlation coefficients were determined and the inter observer variation was measured using a general linear model and repeated measure design.
The 'actual' leg length correction was measured from the pre and post op radiographs of 50 patients and the 'predicted' leg length correction was determined by intra operative calculation. The 'actual' and 'predicted' measurement were analysed with a linear regression model.

The intra class coefficients of the raters were between 0.955 and 0.990 each with $p<0.001$. The mean differences between the observers' ratings were below 1 mm.
Forty seven of the 50 predicted measurements were within 2 mm of the actual radiographic measurement, two were 4 mm different and 1 was 3 mm different. Linear Regression (N=50) with 'Actual correction' as dependent and 'Predicted Correction' as independent variable did result in R= 0.889 (y= 0.83a+ 0.76).

The measuring device reliably measures the vertical height of the excised bone.
The intra operative calculation predicts leg length correction to within 4 mm of actual radiographic correction, and in 94% of the cases to within 2 mm of actual correction.

Keywords.
hip; arthroplasty; leg length

Introduction.

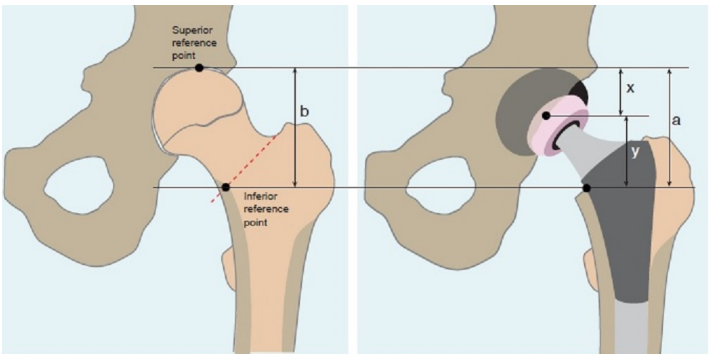
Quality of life improvement following Total Hip Arthroplasty (THA) is dependent on many variables including obtaining the correct leg length.

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

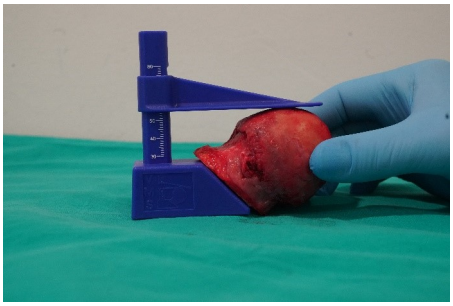
Historically the operative technique endeavours to reproduce the planned construct and prosthesis position utilizing anatomical landmarks usually greater and lesser trochanters.

Having performed many thousand arthroplasties the senior author remained frustrated that despite utilizing a variety of recognised methods, he was unable to achieve leg length correction (LLC) to within 5 mm in all cases. In a retrospective review of 50 cases prior to this paper he found 33 cases corrected to within 5 mm, 15 cases 6-10 mm and more than 10 mm in two cases. This experience is not unique and has been highlighted by other authors. (1-9)
Gross et al 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."(1)

We have therefore devised a system to predict and measure the change in leg length that works on the principle, previously described by Woolson, that the difference in height between excised bone and implant will precisely determine the leg length (Figure 1).(10)



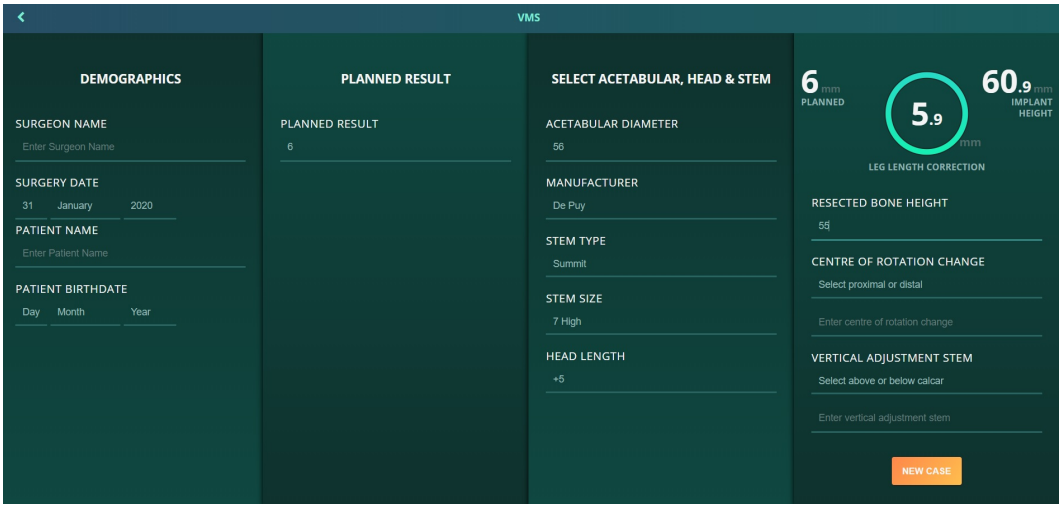
The femoral implant height (y) is available from the manufacturer and (x) is the radius of the acetabulum. We have developed a measuring jig that determines the vertical height of the excised bone (b). This is a very precise measurement and is not dependant on anatomical variation (Figure 2).



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 smallest and largest implant and in others there is an incremental change. For example, the De Puy Corail size 8 stem and size 20 stem have the same vertical height whereas the De Puy Summit size 1 and size 10 stem have a 9 mm difference.

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 over 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 (Figure 3) shows that the planned result is to lengthen the leg by 6 mm and the intraoperatively predicted leg length correction is calculated as 5.9 mm.



If this is the desired correction, the surgeon can proceed with the knowledge that accurate leg length correction 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 on surgical time.

The Vertical Measurement System (VMS) is the term used to describe the use of the measurement device (The Jig) and The App intra operatively.

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 (Figure 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 to 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 was obtained from the relevant manufacturer. This enables the surgeon to determine the leg length correction with the trial components in situ. Adjustments can then be made. Fine tuning can be made 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.

Surgical Technique

The patient is assessed clinically in the office in order to differentiate between true and apparent LLD, and together with the radiographs the surgeon determines the leg length correction 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 pre-existing 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 is entered into the App (Figure 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 degrees. The measuring jig has a 45° angled base plate and the osteotomy should match that angle. If the osteotomy is not at 45°, when using the measuring jig the values will lose accuracy due to the rotation of the excised bone on the base plate. We utilize an aiming device to prevent this occurring. The aiming device consists of a long arm that is orientated over the anatomical long axis of the femur, and a short arm angled to ensure a 45° neck osteotomy (Figure 4).

Too vertical an osteotomy will over read and too horizontal will under read the vertical height of the excised bone. This amounts to approximately 1 mm per 5. The head height must be measured between the inferior and superior reference points (Figure 1 and 2).

Determine the acetabular diameter. This can be predicted by the diameter of the femoral head and is confirmed by the first acetabular reamer that matches the acetabulum without reaming superior acetabular bone.
Enter the acetabular diameter into the App and the implant height will be displayed. Prepare the acetabulum and implant the definitive acetabular component with definitive liner or trial liner as per surgeon 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 center of rotation may be anticipated when templating or noted intra operatively and there is a data field in the App where this adjustment can be made.

Prepare the femur, insert the trial prosthesis and use the App to calculate leg length correction. 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 changed. It should be noted that certain femoral components change the vertical height between standard and high offset stems, and others do not. To accurately restore hip function leg length and lateral offset must both be addressed.

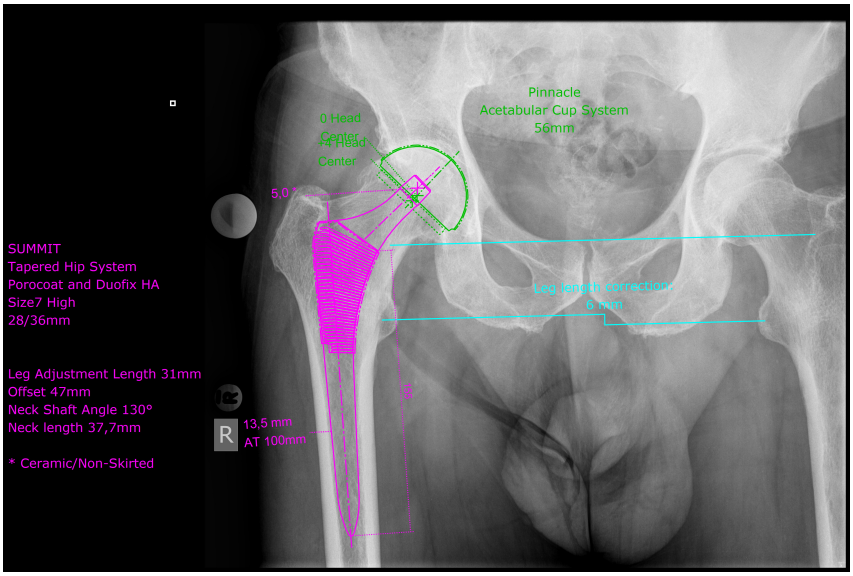
Reduce the hip and put it through a range of motion to assess stability and tissue tension. Finally insert the definitive femoral prosthesis and measure the height above or below the inferior reference point at the medial calcar and enter this into the App. The final leg length will then be displayed and can be recorded for later comparison with clinical and radiographic measurements.

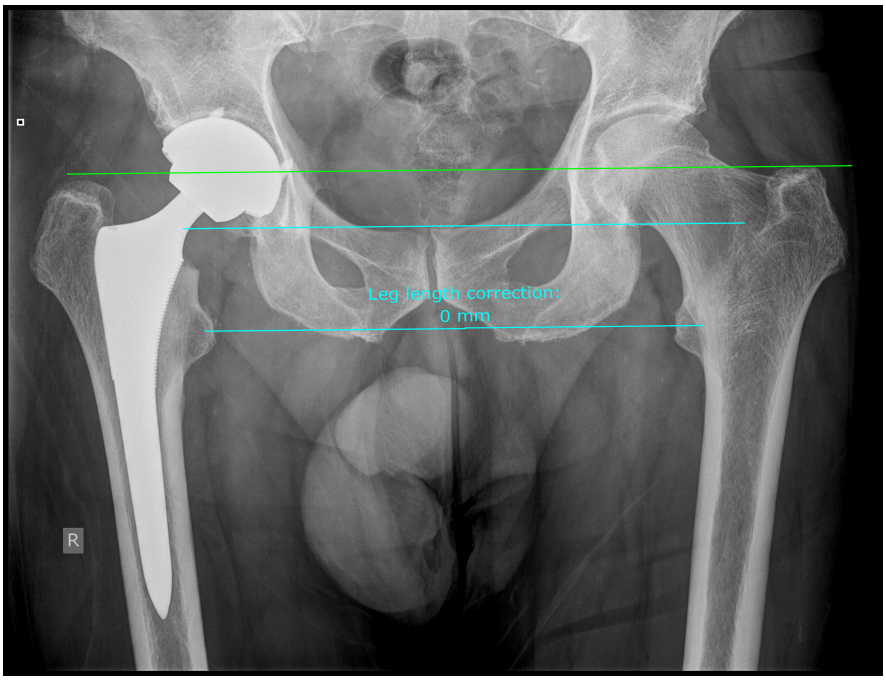
The aim of the study was to assess the reliability of the measuring device (The Jig) and to compare the intra operative 'predicted' leg length correction to the 'actual' radiographically measured correction.

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 four different times. This gave 16 measurements per

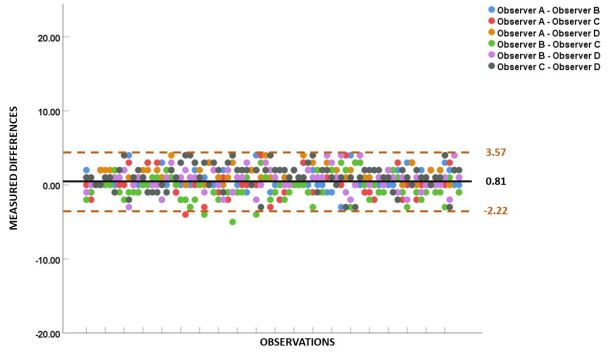
femoral head for a total of 320 measurements. The presentation sequence of each session was randomised. The intra-observer reliability was tested by calculating the intraclass correlation coefficients based on absolute [continuous] agreement. The differences between the four observers was tested using a general linear model in a repeated measure design.

The VMS was tested by a comparative design. In 50 consecutive total hip arthroplasties the leg length discrepancy was measured preoperatively radiologically at the time of templating. Templating was performed using a digital PACS x-ray system (AGFA IMPAX Orthopaedic planning tool v3.0). A standardised pelvic x-ray was taken with a marker placed at the level of the greater trochanter to scale the image. Leg length discrepancy was measured from the inferior aspect of the tear drop to the most prominent aspect of the lesser trochanter as described by Woolson.(10) Post operatively at 6 weeks a standardised pelvic xray was taken and the leg lengths measured radiologically using the same technique. An example of a pre op xray with digital templating (Figure 5) and the post op xray (Figure 6) is shown. The difference between the pre op and post op measured leg length discrepancy was recorded as the “actual” leg length correction (LLC) and in this case it was 6 mm. Use of the VMS intra operatively gave a number which was recorded as the “predicted” LLC and in this case was 5.9 mm (Figure 3). The predicted and actual LLC were analysed with a linear regression model.





The inter observer reliability results are summarised (Figure 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.



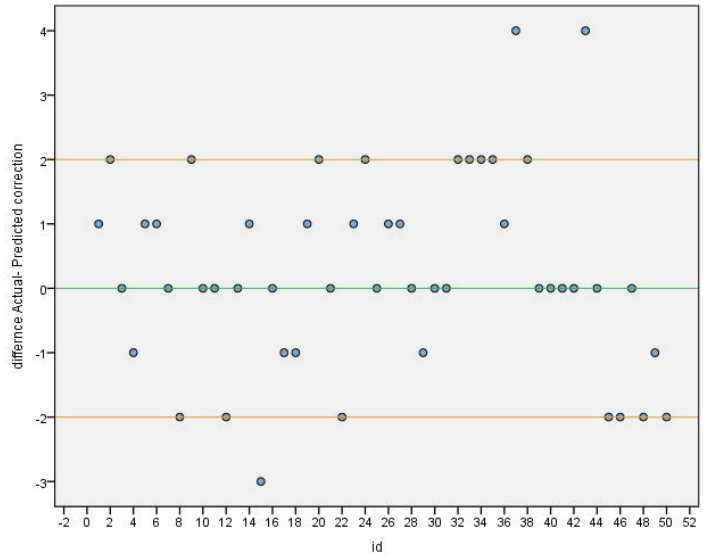
The intra class coefficients of the raters were between 0.955 and 0.990 each with p<0.001. The mean differences between the observers' ratings were below 1 mm except for rater 1 and 4. None of the differences were significant from zero (Table 1).

(I) rater	(J) rater	Mean height difference (I-J) over time	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	.825	1.455	1.000	-3.118	4.768
	3	.863	1.455	1.000	-3.080	4.805
	4	1.612	1.455	1.000	-2.330	5.555
2	3	.037	1.455	1.000	-3.905	3.980
	4	.787	1.455	1.000	-3.155	4.730
3	4	.750	1.455	1.000	-3.193	4.693

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

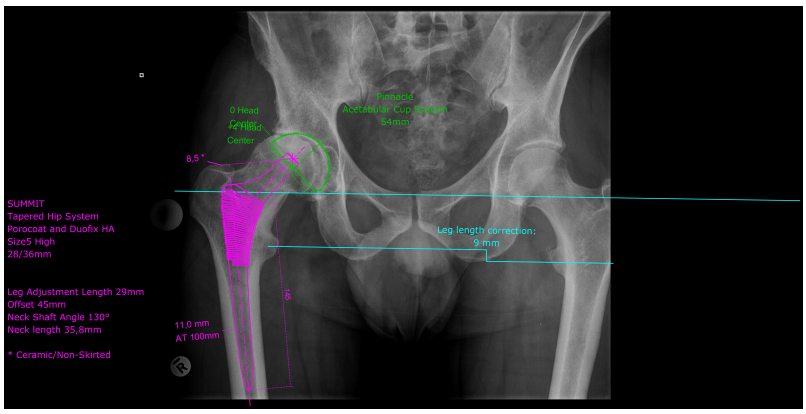
The postoperative actual radiographically measured correction was between 0 and 4mm of the predicted correction. It is evident that the mean is affected by three outliers: The predicted correction of sample 37 and 43 underestimated the actual correction by 4 mm. The predicted correction of sample 15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

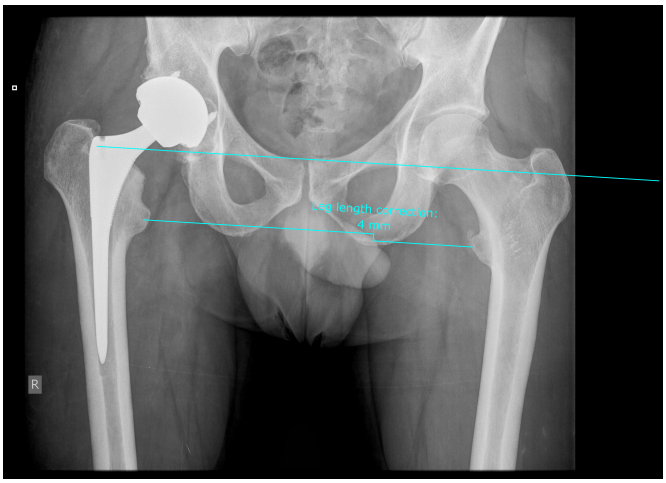


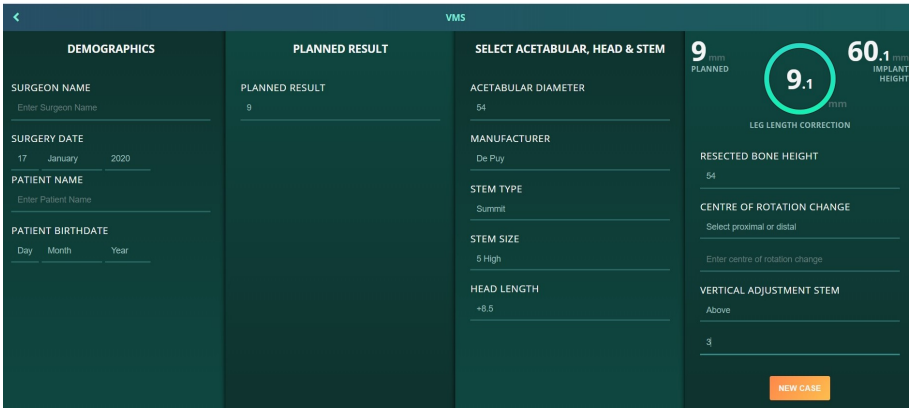
Discussion.

It is surprising that achieving correct leg length following total hip arthroplasty remains difficult. In 1997 Ranawat and Rodriguez (2) reported the incidence of LLD after primary THR to be up to 27% and in 2013 Whitehouse et al (3) found a LLD greater than 10 mm in 21.5% of 191 patients.

Leg length correction following total hip replacement 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 three outliers (Figure 8). One of the outliers xrays is shown (Figure 9 and 10). Preoperatively the right leg is 9 mm short and post operatively shows that it has been lengthened by 5 mm and remains 4mm short (Figure 10). On the App the planned result is 9 mm and the 'predicted' LLC is 9.1mm (Figure 11). The intra-operative 'predicted' LLC is therefore 4 mm different to 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°. Anatomical 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 pre-op 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 minimised 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. (4, 11)
Conversely it has been proposed that even small discrepancies are associated with functional impairment and pain. (5, 6)
Despite patient satisfaction being multifactorial, leg length discrepancy remains a leading cause of litigation against orthopaedic surgeons. (7, 8)
The treatment of LLD adds to the economic burden, ranging from a shoe raise up to revision surgery costing up to $29 000. (12)

In a review article in 2013 Desai et al concluded that LLD is a common and recognisable complication of THR surgery.(9) The authors categorised all the various methods of managing LLD into perioperative templating, intra operative measurement techniques and complex mathematical calculations and the use of ultrasound probes.

In a more recent 2016 article Gross et al reviewed several methods developed to manage leg length, which they divided into two categories; Intra operative 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…"(1)

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

<u>Summary</u>
The measuring device reliably measures the vertical height of the excised bone.
The VMS predicts leg length correction to within 4 mm of actual radiographic correction, and in 94% of the cases to within 2 mm of actual correction.

Acknowledgement.
Dr Roopam Dey for help with statistics.

References.

1. Gross A, Muir JM. Identifying the procedural gap and improved methods for maintaining accuracy during total hip arthroplasty. Med Hypotheses. 2016;94:93-8.

2. Ranawat CS, Rodriguez JA. Functional leg-length inequality following total hip arthroplasty. J Arthroplasty. 1997;12(4):359-64.
3. Whitehouse MR, Stefanovich-Lawbuary NS, Brunton LR, Blom AW. The impact of leg length discrepancy on patient satisfaction and functional outcome following total hip arthroplasty. J Arthroplasty. 2013;28(8):1408-14.
4. Plaass C, Clauss M, Ochsner PE, Ilchmann T. Influence of leg length discrepancy on clinical results after total hip arthroplasty--a prospective clinical trial. Hip Int. 2011;21(4):441-9.
5. Gurney B. Leg length discrepancy. Gait Posture. 2002;15(2):195-206.
6. Parvizi J, Sharkey PF, Bissett GA, Rothman RH, Hozack WJ. Surgical treatment of limb-length discrepancy following total hip arthroplasty. J Bone Joint Surg Am. 2003;85(12):2310-7.
7. Hofmann AA, Skrzynski MC. Leg-length inequality and nerve palsy in total hip arthroplasty: a lawyer awaits! Orthopedics. 2000;23(9):943-4.
8. Patterson DC, Grelsamer R, Bronson MJ, Moucha CS. Lawsuits After Primary and Revision Total Knee Arthroplasty: A Malpractice Claims Analysis. J Am Acad Orthop Surg. 2017;25(10):e235-e42.
9. Desai AS, Dramis A, Board TN. Leg length discrepancy after total hip arthroplasty: a review of literature. Curr Rev Musculoskelet Med. 2013;6(4):336-41.
10. Woolson ST, Hartford JM, Sawyer A. Results of a method of leg-length equalization for patients undergoing primary total hip replacement. J Arthroplasty. 1999;14(2):159-64.
11. White TO, Dougall TW. Arthroplasty of the hip. Leg length is not important. J Bone Joint Surg Br. 2002;84(3):335-8.
12. Grosso P, Snider M, Muir JM. A Smart Tool for Intraoperative Leg Length Targeting in Total Hip Arthroplasty: A Retrospective Cohort Study. Open Orthop J. 2016;10:490-9.