ARTHROPLASTY

Does the intra-operatively measured leg length correction compare to the post-operative radiograph in total hip replacement surgery?

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Abstract

Background: This study aims to analyse the accuracy of the Vertical Measurement System™ (VMS) in assessing the leg length correction (LLC) during total hip arthroplasty (THA) by comparing the intra-operative measurements to the radiographic measurements obtained six weeks post-operatively.

Patients and methods: A prospective cohort study was conducted in which patients undergoing primary THA were enrolled at two centres in Cape Town, over a period of 19 weeks. THAs were performed by four surgeons. Pre-operative leg length discrepancy (LLD) measurements were obtained in 92 patients. The VMS was used to predict intra-operative LLC, and this measurement was compared to the post-operative LLC measured on the six-week follow-up X-ray. These measurements were statistically compared using the Mann–Whitney U test.

Results: The difference between the intra-operative VMS calculation and the six-week radiological measurement was not significant ($p>0.05$), with the difference in their mean values being 0.1±3.3 mm. In the cohort, 82% of the patients (n=75) were within 5 mm of the target LLC, and 96% of patients (n=88) were within 10 mm of the target LLC. The mean absolute residual LLD at six weeks was 3.2±3.1 mm.

Conclusion: The intra-operative LLC measurement obtained using the VMS accurately predicts the six-week post-operative radiographic LLC measurement.

Level of evidence: Level 4

Keywords: total hip replacement, leg length discrepancy, leg length correction, vertical measurement system, comparative study, longitudinal study

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Introduction

Total hip arthroplasty (THA) is one of the most successful orthopaedic operations, with high patient satisfaction and low revision rates.[1] Accurate leg length correction (LLC) in THA is imperative for a good clinical outcome. Therefore, equalisation of leg length remains one of the primary objectives of THA. Nevertheless, leg length inequality remains a recognised complication of the procedure.[2,3] Leg length discrepancy (LLD) accounts for 5% of all medical errors, as per the Joint Commission on Accreditation of Healthcare Organizations (JCAHO),[4] and remains one of the leading causes of litigation against orthopaedic surgeons in the USA.[5] The complications of LLD after THA include sciatic, femoral and peroneal nerve palsy, hip or low back pain, abnormal gait and posture, and aseptic loosening.

The incidence of LLD after THA has been reported to range from 1% to 27%,[6] with some studies reporting values of LLD from 3 mm to 70 mm (mean 3–17 mm).[2] Small discrepancies may be a source of dissatisfaction for some patients; however, several studies have shown that up to 10 mm of LLD may be well tolerated by most patients. Leaving the operated leg short seems to be more acceptable to patients than lengthening the operated leg, since patients can detect relatively small increases in length, and are particularly unhappy if they have to wear a shoe raise on the contralateral, unoperated side.[7]

The importance of attempting to equalise leg length is recognised among all orthopaedic surgeons in all sub-specialties, not just arthroplasty surgeons. This is attested to by the large amount of literature on LLD in THA. In order to mitigate the occurrence of LLD after THA, various methods have been used. These include pre-operative templating,[8-10] a wide range of intra-operative techniques, such as measurements from a fixed point on the pelvis using a suture or ruler, to drilling Steinman pins or K-wires into a point in the pelvis.[11] More recently, computer navigation has been used.[12,13] In order to achieve consistent LLC, the surgeon needs to be familiar with the various surgical techniques and the accuracy of these in the clinical or operative setting.

The objective of this study was to assess the accuracy of a method we use to quantify the LLC intra-operatively, namely the Vertical Measurement System™ (VMS), and compare it to six-week post-operative X-rays. The basic principle of this system is that the difference in vertical height between the excised femoral head and neck, and the combined vertical height of the implants, determines the change in leg length. Our hypothesis was that the LLC measured using the intra-operative VMS method would equal the post-operative radiological measurement.

Patients and methods

A prospective cohort study was conducted at two hospitals in the Western Cape, South Africa. Patients who were booked for THA were invited to participate, after careful explanation of the study design and methods. Informed consent for the study was obtained from all patients. Inclusion criteria were all patients undergoing primary THA, as per standard protocols utilised in the arthroplasty units at the two hospitals. Exclusion criteria were THAs performed for trauma (fractures of the femoral neck or pelvis) and revision THA. Patients were recruited between May and October 2019, over a period of 19 weeks.

Pre-operative assessment

Prior to surgery (at the routine pre-operative clinic visit), clinical assessment of the true and apparent leg length was performed to exclude other causes of LLD such as hip adduction, abduction or flexion contractures, or knee flexion contractures. Digital X-rays were obtained using the Philips IntelliSpace PACS Enterprise system. A standard AP pelvis standing X-ray, scaled using a radiological sphere marker at the level of the greater trochanter, was used for planning. OrthoView Digital Planning software was used for pre-operative templating, sizing and positioning of implants and calculation of the pre-operative radiological LLD. The method described by Woolson,[8] using the distance measured between a line drawn at the inferior aspect of each acetabular teardrop (the reference line) and the medial vertex of each lesser trochanter, was used to measure LLD *(Figure 1)*.[8] The three possible pelvic reference points include the inferior aspect of the obturator foramen, the ischial tuberosities, and the acetabular teardrop. The teardrop is the most reproducible and accurate when calculating limb length discrepancy.[9] This measurement, in combination with the clinical assessment of LLD, was used to inform the intra-operative LLC to be achieved.

Intra-operative measurement and calculation

The THAs were performed by four surgeons at two hospitals. Each THA proceeded in the routine manner, utilising the modified Hardinge or direct anterior approach. Implanted components

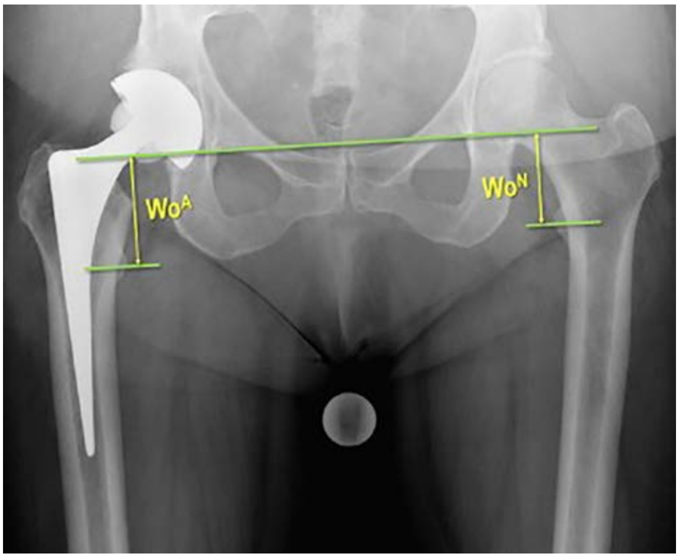

Figure 1. The method used by Woolson to measure LLD. A reference inter-teardrop line is drawn between the most inferior aspect of each teardrop. The distance to the medial vertex of each lesser trochanter is measured (Wo^A and Wo^N)

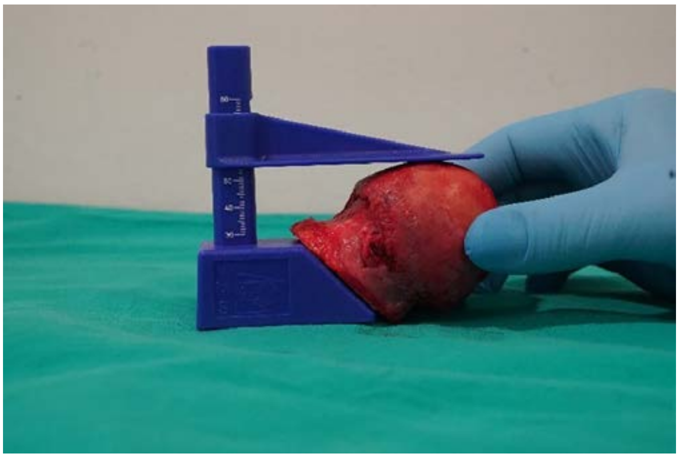

Figure 2. The measurement jig utilised by the Vertical Measurement System™ (VMS) to measure the vertical height of the excised femoral head and neck

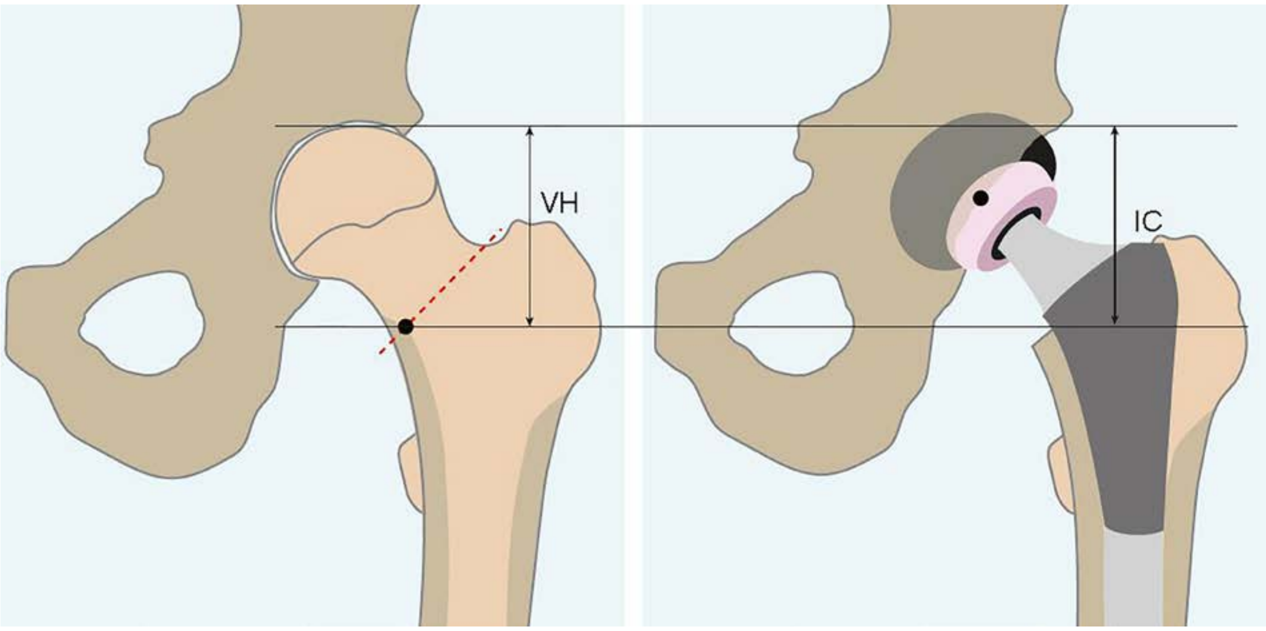

Figure 3. Vertical measurement system: the height of the implanted components (IC) minus the height of the excised bone (VH) determines the leg length correction
(source: verticalmeasurementsystem.com, used with permission)

were mostly Triloc, Summit and C-stem stems with Pinnacle cups (De Puy Synthes, Warsaw, IN, USA), while a small proportion were Accolade stems and Tritanium cups (Stryker, Kalamazoo, MI, USA). After the femoral neck osteotomy, the vertical height (VH) of the excised bone (resection measurement) was measured using the VMS or Vertical Measurement System™ (Peninsula Orthopaedics, Cape Town, South Africa) jig *(Figure 2)*. Acetabular and femoral preparation, trial implantation and reduction were performed, and the hip tested for range of movement (ROM), stability and tension. The resection measurement and implanted component data were then utilised by the available application (VMS), an online calculator with a database of implant sizes and measurements that obviates the need to use multiple charts, to calculate the LLC. The difference between what is resected, i.e. the height of the excised femoral head and neck (VH), and the height of the implanted components (IC) *(Figure 3)* determines the LLC.[14]

At this point, if it was found that the LLC achieved (using the VMS system) did not match what was planned (as per the pre-operative X-ray measurement), intra-operative adjustments were made to further correct the leg length, until the objective was achieved. The surgery was concluded in the normal manner.

Post-operative

Standard rehabilitation protocols were followed, and the patients were followed up at six weeks. Standardised, calibrated X-rays and templating software were again utilised to measure the radiological LLC achieved. This radiological LLC was compared to the intra-operative LLC measurement provided by the VMS.

Statistics

All data analyses were performed using IBM SPSS ver. 25 (Armonk, New York, USA) and G*Power ver. 3.1.9 (open source).[15,16] The distribution of VMS and X-ray measurement data were analysed using the Shapiro-Wilk test for normality. The two sets of measurements were compared using the Mann–Whitney U test for statistical significance. The cut-off for type I error (α) was set at 0.05.

Table I: Baseline characteristics of the study group

Variable	Result
Number of patients	92
Male:female	43 (46%):50 (54%)
Mean age (years)	60.8
Laterality (right/left)	47/46

Results

For this study, 98 patients were enrolled over the period of 19 weeks. Prior to the six-week follow-up, one patient died from an unrelated cause. A further four patients were later excluded from the final analysis due to incomplete data, and one patient failed to return for their six-week follow-up. This left 92 patients who completed the six-week follow-up and whose data was complete for analysis. Baseline characteristics of the study group are listed in *Table I*.

The difference between the means of the VMS measurements and the X-ray measurements was –0.1±3.3 mm *(Figure 4)*. The mean absolute measurement difference between the two sets of values was 2.4±2.2 mm. The difference of each patient's values (VMS and X-ray) was plotted against their mean *(Figure 5)*. The mean difference of all these values was very close to zero, which was ideal, and most measured differences were found to lie within the 95% confidence interval.

When compared to the target LLC decided on pre-operatively, the mean absolute residual LLD post-op was 3.2±3.1 mm. Of the 92 patients, 82% (n=75) had a residual post-operative LLD of ≤5 mm, while 96% patients (n=88) had an LLD of ≤10 mm.

Discussion

The primary goals of THA include pain relief and the restoration of normal hip biomechanics, gait and function. However, restoring or maintaining equal leg lengths is critical for patient satisfaction and return to function. The orthopaedic literature is replete with articles on LLD, the effects thereof, and methods to achieve adequate LLC during THA. Nevertheless, the amount of LLD at which it becomes clinically significant, or that leads to symptoms, is still debated. Generally, an LLD of less than 10 mm is widely accepted.[11] Beard *et al.* found patients had worse Oxford Hip scores at three years if LLD was greater than 10 mm.[17] Our clinical aim was to achieve equal leg lengths since even small discrepancies are associated with functional impairment and pain.[18,19]

In our study, the desired LLC was decided on pre-operatively, using a combination of measuring the LLD on a templating pelvic X-ray and clinical measurement. We then aimed to achieve this LLC intra-operatively, by using the VMS. Intra-operative adjustments were therefore possible (in component sizing and positioning), allowing restoration of leg length to near equal.

When comparing the intra-operative VMS measurements to the six-week post-operative radiographic measurement, there was no statistically significant difference ($p>0.05$) between the two sets of values. The mean absolute difference of 2.4±2.2 mm is very similar to the values quoted in other studies, where an intra-operative method was compared to the post-operative radiograph. Barbier *et al.*[20] utilised a mechanical measurement device (LOOD – length and offset optimisation device) fixed to the pelvis to correct LLD, and the mean deviation from target length was 2.3 mm (range 0.04–10.6 mm). Other studies have reported post-operative radiographic LLD of between 1.8 mm and 3.5 mm.[21,22]

Using intra-operative fluoroscopy is an available option, particularly in the anterior approach where supine positioning is conducive to imaging, as discussed by Austin *et al.*, who compared two different techniques of LLC.[23] Using a radiographic overlay technique, the LLD was 4.8 mm, and their transverse rod method yielded a LLD of 4.4 mm. However, this involved increased surgical time, radiation exposure and increased surgical cost.

More invasive measures have been utilised, which involve fixing a reference device into the pelvis and obtaining measurements to the greater trochanter or other reference point on the femur. The reference can be iliac fixation pins, intra-operative callipers, infracotyloid pins, and fixed suture lengths. In order for these devices to work properly, the operating table must be level with the floor and the position of the hip must be reproduced precisely in all planes before and after reconstruction is performed.[24]

Ranawat *et al.* used a Steinman pin fixed to the ischium in the posterior acetabulum and achieved LLD<6 mm in 87% of their cases.[25] Shiramizu *et al*. compared a series of patients operated on with or without the use of a calliper fixed to the anterior superior iliac crest, and found a mean post-op LLD of 2.1 mm using the calliper versus 8.2 mm without.[26] A plethora of other examples of similar techniques have been reported. However, due to these techniques having their own problems – inconsistent leg positions during measurement, extra skin incisions, additional invasiveness of inserting devices into the pelvis, reference pins or devices loosening during surgery, greater surgical time and greater cost – most of them are not widely used.

More recently Tagomori *et al.* proposed a simpler intra-operative technique of LLC. They utilised a reference mark cut into the posterior acetabular wall with a saw and referenced this off a marking on the greater trochanter. Their measurement error, as calculated by intra-operative measurement versus post-operative CT LLD measurement, was 1.9±1.4 mm.[27]

Modern advancements in arthroplasty include the use of computer-assisted navigation to enhance the accuracy of implant placement. This method of computer-assisted surgery (CAS) uses two different techniques, i.e. imageless and image-based (using CT, MRI or intra-operative fluoroscopy). Imageless systems use a generic simulated model, whereas CT-based systems allow

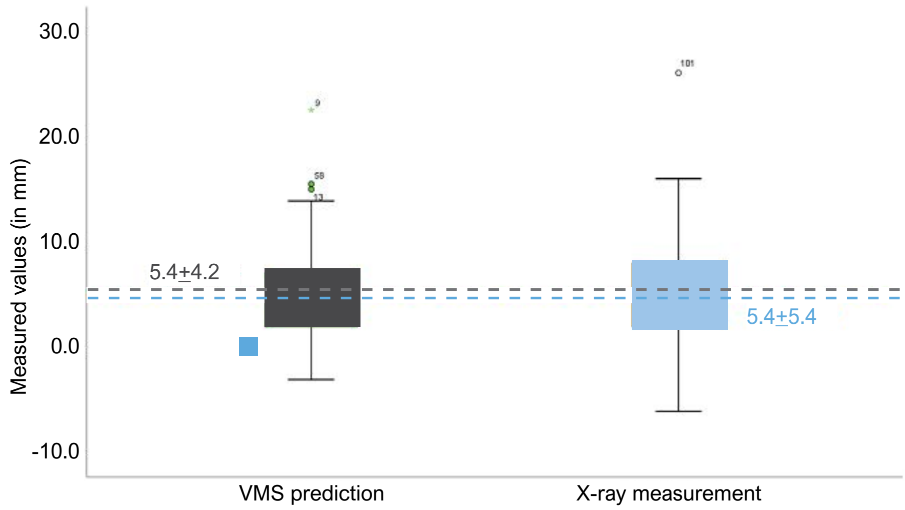

Figure 4. The two data sets are shown: VMS and X-ray measurements. Depicted are their means, standard deviations and ranges. The difference between the two means was –0.1±3.3 mm.

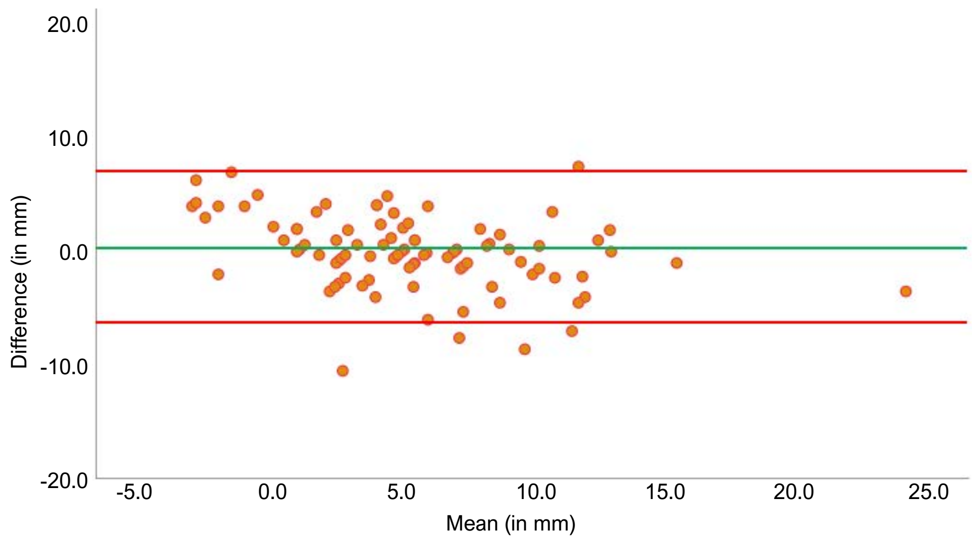

Figure 5. Bland-Altman plot showing each patient's values. The difference between the VMS and X-ray measurements are plotted against their mean. The green line is the mean difference between the values, namely X-ray vs VMS (very close to zero here, which is ideal). The red lines are the upper and lower limits of the 95% confidence interval of the measured differences.

visualisation of a patient-specific model.[12] CAS systems require the registration of landmarks on the pelvis and femur. This requires placement of a reference frame on the pelvis, commonly involving placement of Steinman pins or similar into the iliac crest, and other landmarks on the pubis sometimes requiring mini incisions to accurately locate them. Femur landmarks are registered using a dynamic sensor array, which the surgeon controls. This intra-operative method can lead to complications during surgery, including failure to calibrate the CAS station and fracture of the iliac crest, greater trochanter and distal femur when inserting the pins for the sensor arrays.

In a study by Brown *et al.,* where CAS was compared to conventional freehand technique, no difference was found in component positioning, leg length and Harris Hip Scores (HHS) in their series. They reported an increased operative time of 18 minutes in the CAS group, increased blood loss (69 ml), and a higher cost of surgery, with no additional benefit over freehand THA.[28] In contrast, Ellapparajda *et al.* used navigation in a series of 152 THAs, and produced very good results, with 96% of THAs restoring the leg length to within 6 mm of the contralateral side. They also reported minimal extra surgical time or surgical cost required in the navigated THAs.[29] Similarly, Renkawitz *et al.* compared the intra-operative values provided by the CAS system they used to the post-operative LLC measured on radiographs, and found a high degree of correlation between the two measurement methods, and recommended CAS as a good intra-operative tool.[30]

According to Rajpaul and Rasool, CAS enables the surgeon to more accurately and reproducibly correct leg length, with fewer outliers and no major complications. However, the improved accuracy does not translate into better outcome scores, and the technique is associated with complications including fractures, pin-site infections and pain.[12] Longer-term studies are required to assess the effect of CAS on implant longevity and revision rates.

All the methods discussed here have their drawbacks. Some intra-operative tools are invasive, cumbersome or expensive; many are not user-friendly or accurate enough; more modern tools have steep learning curves, are very costly to acquire and have potential complications with their use. A simple, accurate and reliable method that is easy to use, and that gives live feedback or results, allowing intra-operative adjustments to be made in order to accurately achieve the desired LLC, would be the panacea of LLC in THA.

We found that the VMS method enabled us to achieve a reliable intra-operative LLC, and this correlated well to the post-operative six-week X-ray. The accuracy of the method is in keeping with that of other methods, with a mean absolute measurement difference of 2.4 mm. This is a reliable and trustworthy method, indicating that the LLC calculated by VMS is very close to what one will actually achieve. The residual LLD measured on X-ray was 3.2±3.1 mm, which is well below what most patients would notice, and is similar to the results achieved by other authors.[12,20-23,25-30]

Nevertheless, we analysed why the results could not be even better. In determining the desired LLC, we used a combination of X-ray determination of LLD, as per the Woolson method,[8] and clinical measurement of LLD. This introduces an element of human error, which could skew the effectiveness of whatever method is used to correct LLD. Clinical measurement of LLD at the medial malleolus is open to a margin of error and inter-observer variation.[31] Furthermore, the Woolson method relies on measuring the difference of two lines drawn between a reference pelvic line and the vertex of each lesser trochanter (LT), to calculate the LLD. Determining the lowest point of the acetabular teardrop on X-ray to draw the pelvic reference line is often a bit difficult, with only moderate inter-observer correlation.[31] In addition, there is inter-observer difference in determining exactly where the vertex, or most medial point, of the LT is. This is due to the differing shape of the LT among individuals, and some LTs having a long vertex (in the vertical plane), making the determination of the point to measure to quite inconsistent. A further variable which would influence the final outcome is the determination of the exact measurement of the height of bone excised (VH). The measurement jig is designed to measure the height from a reference point on the inner cortex of the calcar, which the surgeon needs to pay careful attention to when placing the head and neck on the jig, to avoid any errors.[14]

In this study, our technique was not compared to a control group, in which no measurement protocol was used, and where the surgeon used more traditional methods of estimating LLC, such as comparison to the other leg by feeling the heels and knees. Further studies would be required in this regard.

Conclusion

In this study, we found that the VMS method offers the surgeon a reliable, accurate, simple and inexpensive method of quantifying LLC intra-operatively, where adjustments can be made to fine-tune the outcome. Provided that the surgeon pays careful attention while templating and with intra-operative measurements, the VMS can accurately predict the post-operative radiographic LLC.

Ethics statement

Prior to commencement of the study, ethical approval was obtained from the following ethical review boards: University of Cape Town, Faculty of Health Sciences, Human Research Ethics Committee, HREC REF: 117/2019; Institutional Review Board (IRB) Number: IRB00001938. Informed written consent was obtained from all patients prior to being included in the study.

The authors declare that this submission is in accordance with the principles laid down by the Responsible Research Publication Position Statements as developed at the 2nd World Conference on Research Integrity in Singapore, 2010. All procedures were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008.

Declaration

The authors declare authorship of this article and that they have followed sound scientific research practice. This research is original and does not transgress plagiarism policies.

Author contributions

ZM contributed to the conceptualisation, study design and data collection, performed surgeries and prepared the manuscript.

MBN contributed to conceptualisation and design, performed surgeries, supervised the study and reviewed the manuscript.

RD contributed to data and statistical analysis, as well preparation of graphs and manuscript review.

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References

1. Rasanen P, Paavoilanen P, Sintonen H, *et al*. Effectiveness of hip and knee replacement surgery in terms of quality-adjusted life years and costs. *Acta Orthop*. 2007;**78**(1):108-15.
2. Turula KB, Friberg O, Lindholm TS, Tallroth K, Vankka E. Leg length inequality after total hip arthroplasty. *Clin Orthop Relat Res*. 1986;**202**:163.
3. Williamson JA, Reckling FW. Limb length discrepancy and related problems following total hip joint replacement. *Clin Orthop Relat Res.* 1978;**134**:135.
4. Joint Commission on Accreditation of Healthcare Organisations: Ambulatory care sentinel event statistics – 24 June 2003.
5. Clark CR, Huddleston HD, Schoch EP, 3rd, Thomas BJ. Leg-length discrepancy after total hip arthroplasty. *J Am Acad Orthop Surg*. 2006;**14**(1):38-45.

6. Ranawat CS, Rodriguez JA. Functional leg-length inequality following total hip arthroplasty. *J Arthroplast*. 1997;**12**:359-64
7. Maloney WJ, Keeney JA. Leg length discrepancy after total hip arthroplasty. *J Arthroplast*. 2004;**19**:108-10.
8. Woolson ST. Leg length equalization during total hip replacement. *Orthopedics*. 1990;**13**(1):17-21.
9. Meermans G, Malik A, Witt J, Haddad F. Preoperative radiographic assessment of limb-length discrepancy in total hip arthroplasty. *Clin Orthop Relat Res*. 2011;**469**(6):1677-82.
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**:159-64.
11. Ng VY, Kean JR, Glassman AH. Limb-length discrepancy after hip arthroplasty. *J Bone Joint Surg Am*. 2013;**95**(15):1426-36.
12. Rajpaul J, Rasool MN. Leg length correction in computer assisted primary total hip arthroplasty: A collective review of the literature. *J Orthop*. 2018;**15**:442-46.
13. Manzotti A, Cerveri P, De Momi E, *et al*. Does computer-assisted surgery benefit leg length restoration in total hip replacement? Navigation versus conventional freehand. *Int Orthop*. 2011;**35**(1):19-24.
14. No authors listed. Vertical Measurement System. Available from: https://www.verticalmeasurementsystem.com/assets/docs/Scientific_Evidence.pdf (date last accessed 07 November 2019).
15. Faul F, Erdfelder E, Lang A, Buchner A. G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behav Res Methods.* 2007;**39**(2):175-91. https://doi.org/10.3758/bf03193146.
16. Faul F, Erdfelder E, Buchner A, Lang A. Statistical power analyses using G*Power 3.1: Tests for correlation and regression analyses. *Behav Res Methods*. 2009;**41**(4):1149-60. https://doi.org/10.3758/brm.41.4.1149.
17. Beard D, Palan J, Andrew J, Nolan J, Murray D. Incidence and effect of leg length discrepancy following total hip arthroplasty. *Physiotherapy*. 2008;**94**(2):91-96.
18. Gurney B, Mermier C, Robergs R, Gibson A, Rivero D. Effects of limb-length discrepancy on gait economy and lower-extremity muscle activity in older adults. *J Bone Joint Surg Am*. 2001;**83**-A(6):907-15.
19. 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**-A(12):2310-17.
20. Barbier O, Ollat D, Versier G. Interest of an intraoperative limb-length and offset measurement device in total hip arthroplasty. *Orthop & Trauma*. 2012;**98**:398-404.
21. Sayed-Noor AS, Hugo A, Sjödén GO, Wretenburg P. Leg length discrepancy in total hip arthroplasty: comparison of two methods of measurement. *Int Orthop*. 2009;**33**(5):1189-93.
22. Ogawa K, Kabata T, Maeda T, *et al*. Accurate leg length measurement in total hip arthroplasty: a comparison of computer navigation and a simple manual measurement device. *Clin Orthop Surg*. 2014;**6**(2):153.
23. Austin DC, Dempsey BE, Kunkel ST, *et al*. A comparison of radiographic leg-length and offset discrepancies between two intraoperative measurement techniques in anterior total hip arthroplasty. *Arthropl Today*. 2019;**5**:181-86.
24. Desai A, Dramis A, Board TN. Leg length discrepancy after total hip arthroplasty: a review of literature. *Curr Rev Musculoskelet Med*. 2013;**6**:336-41.
25. Ranawat CS, Rao RR, Rodriguez JA, Bherde BS. Correction of limb-length inequality during total hip arthroplasty. *J Arthroplasty*. 2001;**16**:715-20.
26. Shiramizu K, Naito M, Shitama T, *et al*. L-shaped caliper for limb length measurement during total hip arthroplasty. *J Bone Joint Surg (Br)*. 2004;**86**:966-99.
27. Tagomori H, Kaku N, Tabata T, *et al*. A new and simple intraoperative method for correction of leg-length discrepancy in total hip arthroplasty. *J Orthop*. 2019;**16**:405-408.
28. Brown ML, Reed JD, Drinkwater CJ. Imageless computer-assisted versus conventional total hip arthroplasty: one surgeon’s initial experience. *J Arthroplasty*. 2014;**29**(5):1015-20.
29. Ellapparadja P, Mahajan V, Deakin AH, Deep K. Reproduction of hip offset and leg length in navigated total hip arthroplasty: how accurate are we? *J Arthroplasty*. 2015;**30**(6):1002-1007.
30. Renkawitz T, Sendtner E, Schuster T, *et al*. Femoral pinless length and offset measurements during computer-assisted, minimally invasive total hip arthroplasty. *J Arthroplasty*. 2014;**29**(5):1021-25.
31. Moonda Z, Nortje MN. An assessment of the accuracy of measurement of leg length discrepancy and inter-observer reliability, using a digital PACS X-ray system and templating software. [abstract]. SAOA Congress, 2019.