



## Limb Length Discrepancy after Total Hip Arthroplasty: A Review of Literature

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### ABSTRACT:

One of the intraoperative challenges in Total hip arthroplasty (THA) is correcting limb length inequality without compromising hip stability. Significant limb length discrepancy after THA is common and is a major cause of patient dissatisfaction and litigation against surgeon. Surgeons performing THA should aim to minimize Limb Length Discrepancy (LLD), and therefore should adopt a reliable method of doing so. Thus a reproducible technique which effectively reduces postoperative LLD without increasing operative time and easy to apply is a need of time. Although various preoperative and intraoperative techniques are described in literature, none is universally applicable and is without limitations. In this article, we present a systematic review of 50 articles on limb length discrepancy after total hip arthroplasty, implications of LLD and several techniques to avoid it. We suggest that every effort should be made to minimise postoperative Limb Length Discrepancy by combined use of preoperative and intraoperative techniques.

**Keywords:** Total hip arthroplasty, Limb Length Discrepancy, Hip replacement, Limb Length Inequality

### INTRODUCTION

Limb length discrepancy (LLD) or limb length inequality after Total hip arthroplasty (THA) is not an uncommon problem after THA and is associated with patient dissatisfaction, poorer outcome after THA and has been a common cause for litigation against orthopaedic surgeons. There is a broad consensus in the literature that any residual LLD of less than 10mm on AP radiographs is clinically acceptable, but there is no agreement over an upper limit that would be considered clearly unacceptable. Although various preoperative and intraoperative methods has been described in literature but still there is a lack of universally accepted, easy to use and reproducible and effective method of minimising LLD after THA. In this article we present a review of LLD, its incidence in general population and after THA, risk factors, its implications and preoperative and intraoperative techniques to reduce LLD after THA.

### Definition of LLD

LLD after THA can be described as true and apparent or structural and functional respectively. The structural or true leg-length inequality is caused by

lengthening of the prosthetic head-neck distance and component malpositioning and is divided into 2 categories. 1) situations in which component positioning directly leads to limb-lengthening, such as when narrow femoral canal or high femoral cut leads to incomplete stem insertion resulting in a stem which sits too proud, or where the acetabular cup has been placed too low. 2) situations in which component positioning indirectly leads to limb-length discrepancy, such as when a retroverted acetabular component results in intraoperative instability and causes the surgeon to improve the soft-tissue restraints by increasing the neck length or the offset of the femoral stem, thus stabilizing the hip but causing limb-length discrepancy.<sup>1</sup>The apparent or functional leg-length inequality (FLLI) describes the amount that is attributable to other factors such as the tightness of the anterolateral soft tissues about the hip (Gluteus medius and minimus, tensor fascia lata, rectus femoris, psoas muscle) and degenerative disease with scoliosis of the lumbar spine, causing obliquity of the pelvis.<sup>2</sup>

### Prevalence of LLD

Prevalence of LLD in general population is 90% and varies from 2.4 mm to 6.8 mm (mean magnitude of discrepancy is 5.2mm). Right leg is anatomically shorter in 53% to 75% of population as compared to left. Gender plays no role in amount of LLD. For most people, anatomic leg-length inequality does not appear to be clinically significant until the magnitude reaches ~ 20 mm. This shows that leg-length inequality is near universal, but the average magnitude is small and not likely to be clinically significant.<sup>3</sup> Range of preoperative LLD in literature is reported to vary from -70mm to +14mm with mean preoperative LLD ranges from -0.5mm to -7.5mm.<sup>4-10</sup>

The incidence of LLD after primary THA has been reported to range from 1 % to 27% and in the literature the LLD is reported to vary from 3 to 70 mm with a mean from 3 to 17 mm. Most often the limb is lengthened rather than shortened after THA and  $\geq 1$  cm LLD is noted in up to 50 % of cases having LLD; of which only 15%–20 % of patients require shoe correction for leg length equalization.<sup>11</sup>

### Implications of LLD

LLD of 6mm leads to pelvic tilt and scoliosis and LLD of 15 mm causes pelvic torsion. LLD of between 2 and 3 cm is the critical point with regard to the effects on most physiologic parameters there is increased oxygen consumption in patients with LLD of 2-3cm and increased heart rate in patients with LLD of 3-4cm. With a 4-cm limb-length discrepancy, there is a significant increase in plantar flexor activity in the shorter limb. Persons who have developed a LLD later in life are more debilitated by LLD of the same magnitude when compared to persons who have had LLD since childhood.<sup>12</sup> Most patients with minor limb length discrepancy after THA have few symptoms, and most patients with moderate limb-length discrepancy have readily manageable symptoms. However, a minority of patients, mostly those with marked limb-length discrepancy, may have substantial disability as a result of pain or functional impairment. The clinical presentation of problematic LLD can vary and include limp, fatigue, pain, or nerve damage.<sup>13</sup> The characteristic limp resulting from limb-length discrepancy is associated with a decreased stance time on the shorter side, decreased walking velocity, increased cadence, and decreased step length on the shorter side. Compensatory mechanisms during walking include holding the foot in equinus on the shorter side, pelvic drop with leaning of the ipsilateral aspect of the trunk on the shorter side, and flexion of the contralateral knee.

There is an increased risk of developing degenerative arthritis in the longer limb, because it bears more weight and due to lowering the pelvis on the shorter side while walking, the coverage of the femoral head by the acetabulum decreases on the side with the longer limb.<sup>14</sup> Symptoms can occur immediately in the post-operative period or develop at a later date. Although not mutually exclusive, nerve pain and palsy will tend to present earlier than mechanical and gait associated symptoms. Nerve injury is the most serious complication associated with limb length inequality. In a review of 23 THA complicated by peroneal and sciatic nerve palsy, Edwards et al noted an average lengthening of 2.7 cm for peroneal palsy and 4.4 cm for sciatic palsy.<sup>13,15</sup>

### Measurement of LLD

LLD can be quantified clinically and radiologically. Though radiographic measurement is expected to be more accurate than clinical measurement in determining leg length discrepancy<sup>16</sup>. There are two popular methods for clinical measurement of limb length : (a) an 'indirect method' done in standing using lift blocks under the short leg and visually examining the level pelvis, and (b) a 'direct method' done in supine measuring the distance of fixed bony landmarks with a measuring tape. Two commonly used tape measure methods (TMM) include measuring the distance between (a) the anterior superior iliac spine (ASIS) and the lateral malleolus and (b) the ASIS and the medial malleolus. The literature testing the TMM has shown that the malleolus measurement is an inaccurate and imprecise method; with a mean difference in LLD measure of 8.6 mm compared to radiographs, and an intraobserver mean error of 1.1 mm.<sup>12</sup> Two radiological techniques predominate in the literature and are widely used in clinical practice. In the methods described by Williamson and Reckling distance between most inferior point of Ischia and lesser trochanter is measured, whereas in method described by Woolson et al distance between inferior point of acetabular tear drop and lesser trochanter is measured.<sup>17</sup> Neither Woolson's nor Williamson's method takes account of hip flexion or abduction deformity at the time of the x-ray (which tends to reduce the measured LLD) or any causes of LLD which does not involve the hip.<sup>18</sup> Heaver et al<sup>16</sup> reported that inter ischial line was best pelvic landmark for measurement of LLD, whereas Meermans et al<sup>19</sup> reported teardrop line to be better. Meermans et al<sup>19</sup> further reported that centre of femoral head should

be taken as femoral reference point instead of lesser trochanter. Tipton et al reported that LLD measured by taking distance between inter teardrop line and centre of femoral head was closest to true LLD. The measurements used to predict LLD from an AP radiograph of the pelvis underestimates LLD and are not comparable to the evaluated LLD as measured from a full-length radiograph. Thus taking only pelvic radiograph to assess LLD would not be adequate.<sup>20</sup> Kersic et al<sup>21</sup> in a series of 119 primary THA reported that preoperative clinical LLD was on an average 5-8 mm more than radiographic LLD whereas postoperative clinical and , radiological LLD differed only by 1-2mm. Similarly, Plaas et al<sup>4</sup> stated that clinical and radiological measurement correlates poorly ( $\omega=0.36$  pre- and  $\omega=0.186$  postoperatively). Sayed-noor et al<sup>22</sup>, in their series of THA involving 139 patients reported that clinical method of measurement of LLD was not a reliable method to find out preoperative LLD. However they further reported a better correlation between clinical and radiological measurement when taken postoperatively. This was probably on account of correction of any preoperative deformity existing at hip joint. Gogia et al<sup>23</sup> performed clinical leg length measurement and scanogram in 30 healthy subjects and reported that clinical LLD measurement (ASIS-medial malleolus) and a radiological measurement had excellent correlation (ICC=0.99). They also stated that flexion deformity of knee and hip could alter the results and palpation of ASIS can be difficult in obese patients. Beattie et al<sup>24</sup> also supported these findings in their study. However their observation of good correlation between clinical and radiological measurement was probably on account of the fact that, in their study there was no deformity at the hip joint as all the subjects were healthy. Patient perception of LLD and presence of actual LLD do not correlate well. One large-scale postal audit survey found the prevalence of patient-perceived LLD after THR to be 30%. In this study of THR outcomes of 1114 patients , at 5 to 8 years post-op follow-up, 329 patients (30%) perceived an LLD following total hip replacement, while radiographic analysis of this sub group of patients indicated that only 36% of these patients had actual LLD of  $\geq 5$ mm.<sup>25</sup> Konyves and Bannister In their study they reported that 56 of their patients (62%) had limb lengthening by a mean of 9mm and it was perceived by 24 patients after three months and by 18 after 12 months. They observed that patients who had lengthening were significantly more likely to detect LLD than those with shortening.

Multiple studies have shown that satisfaction and dissatisfaction after THA is multi-factorial. There is, however, disagreement about significance of radiologically evident LLD in comfort, satisfaction and functional outcome of THA. Konyves and Banister reported that Oxford Hip Score of patients who perceived lengthening was significantly worse than patients who considered their operated leg to be of equal length or short but, there was no association between the centre of rotation, surgeon based Harris hip score, patient based general health questionnaire and postoperative LLD.<sup>26</sup> White et al in a study concluded that radiological lengthening (35 mm) or shortening (21 mm) during THR does not correlate with function, comfort or satisfaction six months after operation.<sup>27</sup>

There is a lack of agreement in the literature about what constitutes a significant LLD either pre or post operatively. Asymptomatic leg length inequality of 2cm or more is relatively common even in the general population who have not undergone hip replacement arthroplasty<sup>3,12</sup> and it is well recognised that both lengthening and shortening of this magnitude can occur with hip replacement arthroplasty. Due to absence of a globally accepted LLD measurement protocol there are differences in both definitions and reported normative values. After reviewing the literature it appears that postoperative LLD of about 10mm or less is likely to be acceptable, but there is little agreement about a limit of LLD that would be considered definitively unacceptable.

### **Approach to Minimizing Symptomatic LLD**

Although LLD after THA altogether cannot be eliminated, the problem can be minimized. To prevent postoperative limb length discrepancy and its attendant problems, its important to understand the various components of leg length assessment related to THA, including identification of patients at risk, preoperative planning, intraoperative measurements and postoperative management.

### **Identification of Patients Most At Risk**

There are several identifiable factors that increase the risk of a patient suffering a symptomatic LLD (Table 1). Atypical anatomy, such as excessive femoral bowing, narrow femoral canal or poor bone stock can cause difficulties in obtaining proper alignment or insertion of the components. This can be further complicated when using an uncemented femoral stem or in the obese patients.<sup>18</sup>The short varus neck of femur makes the abductor muscles

sensitive to stretching thus resulting in a tilted hemipelvis with the operated side lower (functional LLD).<sup>2</sup> Short stature patients tend to have a narrower pelvis, which produces a greater amount of pelvic tilt for any given LLD.<sup>18</sup>

In the patients with pre-existing gluteal shortening, there is apparent lengthening because leg tend to lie in an abducted and externally rotated position. Postoperative lengthening in these patients will further increase their pelvic tilt or, if the required compensation is too great, will have to pivot on the shorter leg to place the longer leg on the ground. Patients with pre-existing but asymptomatic LLD may be less likely to tolerate any increase in their leg length inequality and can experience worse morbidity than would be associated with a similar LLD in other patients.<sup>18</sup>

### Methods for Minimising LLD

The methods for minimising LLD can be divided into four main categories<sup>28</sup>:

In literature various types of techniques have been used to minimise postoperative LLD which can be broadly divided in four broad categories. 1) Based on the preoperative templating to define the correct neck cut, the correct neck length of the femoral component and correct depth of femoral component insertion. 2) Based on the usage of a standard pelvic reference point and of a femoral reference point, and measurement of the distance of these two points as the limb length changes intraoperatively. 3) Based on intraoperative clinical tests such as the shuck test, the drop kick test, and the leg-to-leg comparison 4) Based on navigation system's measurements.<sup>21</sup> In addition, some other techniques have been described, such as measuring the gap between the tenotomy limb edges of the abductor musculotendinous insertion on the greater trochanter or evaluating the level of the center of the head in relation to the tip of the greater trochanter with the aid of a plate in a femoral head slot<sup>29</sup>. A technique which uses intraoperative ultrasound to measure LLD is also described in literature.<sup>30</sup> Postoperative limb lengthening is more common than shortening. In various studies postoperative lengthening After THA varied from 48 – 62% whereas shortening have been seen in 10-32% of cases.<sup>4,26,28</sup> If the operated limb is short patients may not complain because they have been physiologically and psychologically accustomed to this condition. A more common problem after THA, however, is lengthening of operated limb<sup>31</sup>. However extent of

lengthening is of utmost importance for it to be clinically significant.

### Preoperative Techniques

Most of the preoperative techniques are based on overlay templating and determining accurate position and size of implants.<sup>6,17,32-37</sup> The use of templates is the first step in obtaining acceptable clinical results with regard to limb length. However, such use should be combined with a reliable intraoperative method to obtain optimal length.<sup>13</sup> Hofmann et al evaluated the template technique and reported that in 50% of cases they had to change the plan during surgery.<sup>38</sup> Magnification in radiographs and errors in measurement makes it extremely difficult to predict implant size accurately<sup>26,37</sup> leading to incorrect prediction of size of implants in around 40% of cases, making it unreliable method.<sup>37</sup> Halai et al, were able to reduce mean postoperative to 1.3mm (range 0.2-9.3mm) by Exeter technique and templating and concluded that Exeter technique was reproducible and was helpful in reducing incidence of leg-length discrepancy after THA.<sup>39</sup> Woolson et al were able to achieve desired level of neck osteotomy within 6mm in 86% of patients and within 10 mm in 97% of patients.<sup>17</sup> Template technique depends on intraoperative reproduction of centre of rotation of hip and femoral stem length which may not be as accurate. Further it does not takes account of soft tissue tension across hip joint and hence may lead to instability around hip. Woolson et al<sup>17</sup> reported that ninety-seven percent of the patients had a postoperative leg-length discrepancy that was less than 10 mm (with a range of -20 to +20 mm) but twenty-two of their 351 patients (5%) sustained a postoperative dislocation of one hip during follow up, possibly on account of poor soft tissue tension.<sup>17</sup> Valle et al in a retrospective study evaluated the utility of a preoperative planning with template technique and reported that acetabular component size was predicted exactly in 83%; the femoral component size was predicted exactly in 78% and the average limb-length discrepancy was 1.71 mm (range -6 to +20 mm).<sup>32</sup> Preoperative measurement of limb length inequality, preoperative planning with radiographic templates and intraoperative corrections with measurements of limb lengths before and after the insertion of trial components using limb length callipers can reduce the incidence and magnitude of the problem of limb length discrepancy.

### Intraoperative Techniques

To date there are around 20 intraoperative techniques are described in literature and all are based on intraoperative measurement of distance between 2 reference points. Most of the techniques use one pelvic and one femoral reference points. While femoral reference point is usually GT in all the techniques, pelvic reference point may be pins inserted in Ilium, callipers, Judd pins, or a suture fixed in pelvis and varies in each technique. These techniques however have not been reliable because they are dependent upon accurate femur repositioning. Sarin et al reported that a 5 and 10 degrees of adduction/abduction intra-operatively can cause as much as 8mm and 17mm error in leg length measurement respectively. However effect on LLD due to incorrect flexion/extension repositioning is much less pronounced. Malrotation of the pelvis with respect to the femur (or operating room table) can also occur and contribute to leg length inequality and incorrect femoral offset restoration. Techniques using pins or jigs that are fixed at some distance away from the bone surface exaggerate the effect of rotational error because the measurements are made away from the rotational centre of the joint hence distance between the femur reference point and the joint centre should be minimised so that the deleterious effect of malrotation can be reduced.<sup>40</sup> Ng et al in their review of literature on LLD after THA described about the importance of acetabular and femoral positioning and their effects on LLD. They stated that though external and internal reference marks may be used to guide acetabular implant positioning, fixed internal anatomical landmarks such as the transverse acetabular ligament, acetabular sulcus on the ischium, and the superior aspect of the acetabulum were less dependent on patient positioning and better indicators of implant positioning as compared to external reference points. They stated that eccentric inferior reaming of the acetabulum and placement of the cup below the planned level of the teardrop can increase the leg length. They also advised to take caution while deciding about the level of femoral osteotomy, as achieving the correct angle and level of the femoral osteotomy is important for seating the femoral implant accurately and avoiding leg length inequality. A high femoral neck cut may lead to more visible space in the medial calcar and the stem may appear undersized and changing to a larger stem to fill this void may lead to inadvertent lengthening of the limb. Similarly if the femoral osteotomy is too low, the femoral stem may not seat

within the metaphysis and appear too large and changing to a smaller stem size to improve seating may lead to shortening of the limb. Lengthening the femoral neck alone will lead to increased femoral offset and limb length.<sup>41</sup> These findings were also supported by Kayani et al in their review of literature on LLD after THA.<sup>42</sup>

Konyves and Bannister in a study of 90 patients undergoing primary total hip arthroplasty sought to identify whether the acetabular or femoral component was principally responsible for LLD after THA and appropriate placement of the femoral component could significantly reduce postoperative LLD.<sup>26</sup> Combined use of templating to predict the necessary length correction and plan femoral neck osteotomy level and the intraoperative use of a simple pelvic reference pin with accurate-positioning of the leg during measurements will provide the surgeon with a practical method for measuring leg length during THA.<sup>6</sup> Although techniques which use large Steinmann pin have been described in literature, they have been criticized as unreliable as they are recommended to be removed and replaced during the surgery in between the measurements.<sup>11</sup> Mcgee and Scott inserted a Steinmann pin into the pelvis 1.5 to 2 cm superior to the acetabulum and bent it into a U and made a mark at the point where the free end of the U contacts the greater trochanter and restoring the mark to the tip of the pin restored the preoperative length.<sup>43</sup> Although sample size was 200 but they failed to substantiate their claim with any radiological or clinical data regarding LLD in their patients.<sup>11</sup> Naito et al used Steinman pin and adjustable calliper to achieve intraoperative limb length correction. Bose and Shiramizu et al described similar techniques with similar results.<sup>18,19,45</sup> Jasty et al<sup>10</sup> in a series of 85 consecutive patients used sliding limb length calliper over pelvic reference wire to measure distance between pelvic reference point and femoral reference point and reported that 14 of 85 patients (16%) had limb length inequality after surgery and out of these 6 patients needed a shoe raise. In this series of 85 THAs, 80 cases were still longer postoperatively. The study has several limitations as it is retrospective, measurements being made by the operating surgeon, who was not blinded, and scanograms were used only pre operatively. Ranawat et al inserted vertical Steinman pin at the infracotyloid groove of the acetabulum and another mark over greater trochanter was made with electrocautry. Leg was kept in 20 degree of flexion and internal rotation. They said that the points of

reference in this method are close to centre of rotation of hip hence variations in measurements resulting from limb positions are less likely to occur. In their report postoperative LLD ranged from -7 mm to +9 mm (mean 2.62 mm). Difficulty in accurate positioning of the pin due to large osteophytes at the posterior lip of acetabulum was cited as main limitation of this technique.<sup>47</sup> Desai et al inserted Judd pin into the ilium just superior to the acetabulum, to provide a stable pelvic reference point and tied a suture to this pin. They tied a knot in the suture and a reference mark made with diathermy on the greater trochanter at the level of the knot, which was then used as a guide to either lengthen or maintain the same length based on preoperative templating/planning.<sup>44</sup> Mihalko et al in their case report used a method in which a large unicortical fragment screw was placed above the superior rim of the acetabulum. They placed screwdriver in the hex-headed screw; and the distance was measured from the shaft of the screwdriver to a mark made with the cautery at the vastus tubercle on the lateral aspect of the greater trochanter. After the implantation of the prosthetic trial components, a check was made to ensure the appropriate limb length.<sup>45</sup> Intraoperative techniques which use Steinman pin and adjustable calliper to achieve intraoperative limb length describe a cumbersome and expensive device to be used as an adjunct in routine THA. Also there is a need for a larger or a separate incision to accommodate these devices for their pelvic reference.<sup>5,46,47</sup> Need to remove and reposit the Steinman pin and calliper device is an additional source of error. Loosening of the Steinmann pins, screw or Judd pin which is placed into the ilium or the supra-acetabular bone to provide a proximal reference point is another disadvantage. Loosening of pin in ilium makes it an unstable point of reference. To overcome this disadvantage, Woolson et al, used a specially designed calliper device with 3 triangular pins but it is invasive and requires separate incision. Although they used this method in more than 200 patients and claimed this technique to be effective, they failed to substantiate their claim with clinical, radiological data and statistical evidence.<sup>17</sup> Barbier et al in a series of 58 THA evaluated the efficacy of 'length and offset optimization device' [LOOD] to optimize limb length and offset control. They reported mean LLD of 2.31 mm (0.04 to 10.6mm) in patients operated on using the LOOD versus 6.96 mm without LOOD.<sup>48</sup> Fossae ovalis oriented acetabular centralized technology in

THA can significantly correct abnormal hip center of rotation, thus reduce the relative and absolute limb-length inequality and improve the life quality of the patients.<sup>49</sup> Clave et al used -assisted orthopedic surgery (CAOS) and were able to achieve desired leg length and offset within  $\pm 5$  mm in 83.3% and 88% of cases, respectively and only twenty-two of 321 patients required a heel wedge. Major limitation of this technique is non availability of CAOS at all the centres and requirement of a costly setup which increase cost of surgery. A technique using a skin suture below the iliac crest is described in literature. However different tension on the suture may result in different measurements, especially in old patients.<sup>7</sup> Lakshmanan et al marked points of reference within the femur to negate the variations in measurements with different limb positions during surgery. Difficulty to assess the prominent tubercle on the greater trochanter and in cases with deformed head or proximal femur was main disadvantage which makes this technique unreliable.<sup>50</sup>

As compared to general anaesthesia, patients operated under spinal anaesthesia have higher LLD possibly due to increased soft tissue laxity after spinal anaesthesia which affects tests dependent on soft tissue tension unreliable and makes them erroneous. Thus while performing total hip arthroplasty under spinal anaesthesia, the surgeon should not rely on the shuck test to assess hip stability but should test range of motion for stability.<sup>31</sup> Mastuda et al introduced a simple method to select an appropriate modular head during surgery so that LLD can be minimised. They calculated the ideal distance between the centre of the modular head and lesser trochanter on a preoperative AP radiograph. During surgery, they measured the actual distance between the centre of trial heads and the lesser trochanter with a ruler, and selected the head in which the measured distance was closest to this distance. Mean postoperative LLD was <5mm in patients operated with this technique. This technique can be used for non cemented THA only. Main disadvantage of this method as admitted by the authors was the difficulty in evaluation of acetabular component position, which is a key step in the technique. Similar technique was described by Gonzalez et al using cemented components but the same limitations applied to this study as well.<sup>14,51</sup> Affatato et al examined the validity of determining leg length differences using an ultrasound system. They measured the distance between three points, in millimetres, and the difference between preoperative

and postoperative measurements represented change in the leg length. hazards), The method is non-invasive (ultrasound is not limited by radiation, easy, quick to use, and can be used for standard clinical screening. Studies are still in progress to resolve difficulties concerning the device sterilisation and the positioning of the entire set-up in a surgical unit.<sup>30</sup>

**Conclusion**

Limb length inequality following Total hip replacement is fairly common, though magnitude of inequality is variable a LLD of more than 10 mm is usually unacceptable and hence every effort should be made to minimise it. A comprehensive analysis of risk factors, preoperative extent of LLD, and combined use of preoperative and intraoperative techniques may help to select appropriate implants and to adjust final leg lengths and minimise postoperative LLD.

**Table 1: Mean and range of postoperative LLD in various studies in literature**

Study	Method used to reduce LLD	Postoperative LLD (mean in mm)	Postoperative LLD (range in mm)
Plaas et al <sup>32</sup>	Preoperative Template technique and intraoperative measurement from cone of femur to lesser trochanter	0.2	-28 to +20mm
Konyves and Bannister <sup>11</sup>	No technique specified	-6.5	-40 to +22
Maloney and Keeney <sup>60</sup>	Preoperative templating and intraoperative clinical palpation of knees and feet	-1.0	-12 to +7
Papadopoulos et al <sup>21</sup>	Single suture applied on lateral pelvis and intraoperative measurement by suture thread	1.58	-8 to +7mm
Desai et al <sup>48</sup>	Application of Judd pin	+0.46	-12 to +8
Hoffman et al <sup>43</sup>	Preoperative templating and intraoperative x ray	+0.46	-12 to +8
Barbier et al <sup>23</sup>	Intraoperative LOOD device	2.31	0.04 to 6.96
Ranawat et al <sup>47</sup>	Steinman pin at infracotyloid groove and caliper device	2.62	-7 to +9
Naito et al <sup>45</sup>	Steinman pin and caliper device	0.5	0 to 2mm
Shiramizu et al <sup>18</sup>	L shaped caliper device	2.1	---
Lakshmanan et al <sup>49</sup>	Intraoperative length measurement by taking 2 reference points on femur	-0.06	-9 to +16
Halai et al <sup>16</sup>	Preoperative templating and intraoperative marking of femoral rasp	+1.3	0.2 to 9.3
Valle et al <sup>44</sup>	Preoperative templating	2.8	-6 to +10
Woolson et al <sup>20</sup>	Preoperative template technique	<10 mm	-20 to +20
Jasty et al <sup>46</sup>	Use of Jigs and calipers	5.4	-0.5 to +40

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