Measuring limb length discrepancy using pelvic radiographs: Most appropriate method

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Abstract
Introduction: Leg length inequality following total hip replacement is still common. In order to reduce limb length inequality, surgeons undertake pre-operative measurements, by preoperative templating and use various forms of intraoperative measurements, including computer navigation. We studied to compare and find out which measurement technique for assessing limb length discrepancy using two different pelvic reference has excellent inter-observer variability using standard antero-posterior radiograph.

Material and Methods: 40 patients (40 hips) had their measurement of limb length discrepancy on standard AP radiographs. The measurement was done by two observers one is orthopedic surgeon, and other one is radiologist. Two lines were constructed on each of the radiographs, bisecting the acetabular teardrops, ischial spines. Measurements were taken from these lines to the most conspicuous medial point on the lesser trochanter.

Results: For measuring limb length using teardrop as a pelvic reference and lesser trochanter as femoral reference inter-observer agreement for radiological measurements kappa=0.893 (good agreement) for pre-operative radiographic measurements and kappa=0.813 (good agreement) for post-operative radiographic measurements. By using ischial tuberosity as a pelvic reference and lesser trochanter as femoral reference inter-observer agreement for radiological measurements kappa=0.723 (Substantial agreement) for pre-operative radiographic measurements and kappa=0.752 (Substantial agreement) for post-operative radiographic measurements.

Conclusions: Measurement of limb length on radiographs has excellent interobserver reliability with the use of the inter teardrop as a pelvic landmark was a better with measurements to the lesser trochanter. Interobserver variability testing showed less agreement when the ischial tuberosity was used as a pelvic landmark compared with the teardrop.

Keywords: Leg length, still common, total hip replacement

Introduction
Measurable leg length discrepancy (LLD) after total hip replacement is common [1, 2], and when symptomatic can cause patient dissatisfaction and distress [3, 4]. Patients who have symptomatic LLD may have an unstable hip, sciatic nerve palsy or an abnormal gait which may exacerbate back, and joint pain and may require the use of a shoe raise [5, 6]. To minimize LLD preoperative templating is essential to the orthopaedic surgeon for preoperatively evaluating and planning many aspects of a THA. The advantage of templating include accurate prediction of prosthetic size, subsequent optimization of prosthetic longevity, and decrease intraoperative complications [5].

Preoperative templating helps to achieve appropriate offset and limb length equality, which would lead to better abductor muscle function, less limping, and decreased need for walking aids [7]. Although limb lengthening may be required to provide a stable hip [8], a LLD not only is associated with patient dissatisfaction [9], but also is the most common reason for litigation after THA [10]. LLD after THA has been associated with complications, including sciatic, femoral, and peroneal nerve palsies [11, 12, 13, 14], low back pain [15, 16, 17, 18], abnormal gait [19, 20], and dislocation [21].
It is well-known that preoperative pelvic radiographs are helpful in assessing LLD but also are subject to variation as a result of changes in the position of limbs and pelvis. Different measurement techniques are used to determine the LLD. As a pelvic reference, both ischial tuberosities and the teardrops are used. On the femoral side, the lesser trochanter is used. LLD is defined as the difference of the distance between a femoral and a pelvic landmark on both sides. In the literature, two radiological techniques prevail and are commonly used in clinical practice. The distance between the most inferior point of Ischia and the lesser trochanter is commonly utilised in clinical practice. The distance between the femoral and a pelvic landmark on both sides.

Table 1: Different methods used to determine LLDs on an AP pelvic radiograph

| Study Landmark        | Pelvis | Femur |
|-----------------------|--------|--------|
|                       | IT  | BI  | LT  | CH |
| Austin et al. (2003)  | x   | x   |     |    |
| Bono (2004)           |     | x   | x   |    |
| Clark et al. (2006)   |     | x   | x   |    |
| Egli et al. (1998)    |     | x   |     |    |
| Gonzalez Della Valle et al. (2005) | x   | x   |     |    |
| Hoikka et al. (1991)  |     |     |     |    |
| Khanduja et al. (2006) | x   |     |     |    |
| Konyves and Bannister (2005) | x   | x   |     |    |
| Krishnan et al. (2006) |     | x   |     |    |
| Maloney and Keeney (2004) |     |     |     |    |
| Matsuda et al. (2006) |     |     |     |    |
| Mihalko et al. (2001) |     |     |     |    |
| Murphy and Eckert (2007) |     | x   |     |    |
| Parvizi et al. (2003) |     |     |     |    |
| Ranawat and Rodriguez (1997) | x   | x   |     |    |
| Rand and Istrup (1983) |     | x   |     |    |
| Sathappan et al. (2008) | x   |     |     |    |
| Suh et al. (2004)     | x   |     |     |    |
| Unnununtana et al. (2009) |     | x   |     |    |
| Wedemeyer et al. (2008) |     | x   |     |    |
| White and Dougall (2002) |     | x   |     |    |
| Williamson and Reckling (1978) | x   | x   |     |    |
| Woo and Morrey (1982) |     | x   |     |    |
| Woolson et al. (1999) | x   |     |     |    |

IT = interteardrop line; BI = bisschial line; LT = tip of the lesser trochanter; CH = center of the femoral head.

All methods for measuring LLD are subject to error. Error margins can be reduced by using standardised radiograph magnification, accurate and secure patient positioning to reduce pelvic tilt and rotation and taking care over the placement of computer cursors when measuring lengths. This study was undertaken to establish the most appropriate method of measuring limb length discrepancy using pelvic radiographs out of two well known measurement techniques.

Objectives
To assess the which radiographic measurement technique is most appropriate for measuring leg length from a digital pelvic x-ray preoperatively and postoperatively and evaluated their reliability.

Materials and Methods
Source
The study was done on preoperative and postoperative pelvic radiographs obtained from 40 patients who underwent total hip replacement painful arthritis of hip were operated in the Orthopaedic Department of K R HOSPITAL, Mysuru during November 2019 to January 2022 fulfilling the inclusion criteria and exclusion criteria.

Type of study: Prospective study.

Area of study Department of Orthopaedics, K R Hospital Mysore Medical College & Research Institute, Mysore.

Sample size: 40

Duration of study: November 2019 to January 2022.

Inclusion Criteria
1. Patients of age more than 20yrs and of either sex who had clinical feature of painful arthritis of hip.
2. X Ray of the patient’s hip must show well established arthritic changes in the form of joint space reduction with or without subchondral cyst.

Exclusion Criteria
1. Patients unwilling to consent for the study
2. Patients who are medically unfit for major surgery
3. Patients with clinically detectable focus of locally active infection
4. Ipsilateral knee pathology and degenerative condition of knee
5. No evidence for flexion contracture of hip or knee
6. No previous arthroplasty of hip
7. Deformity of the spine

Methods of collection of data
After obtaining valid consent, the complete data was collected from the patients by taking history, detailed clinical examination was done to rule out ipsilateral knee deformity and to rule out contralateral hip involvement and relevant investigations like CRP and ESR was sent to rule out local infection of the hip. All cases with TOTAL HIP Replacement were evaluated for limb length using the proposed criteria. Following consent and surgery.

Methodology
We evaluated all cases undergoing THR for arthritis. Leg length was calculated using digital x-rays by 2 examiners orthopedic surgeon and radiologist (who were blinded) preoperatively and postoperatively. While taking the X-ray, in order to avoid inaccuracies in measuring discrepancy, all the patients were in a standard position (anatomical position), internally rotating the lower limb when necessary and looking for maximum symmetry of the limb posture.

Each examiner measures 80 measurement each for 40 THR cases, considering the two different methods of measuring limb length on pelvic AP radiographs, Radiographs were exchanged via DICOM file.

Leg length was measured by drawing 3 lines at 3 levels (Inter teardrop line, Interischial line, line drawn on most medial point on lesser trochanter)

First method: On digital X-ray a line was drawn at the level of & parallel to inter teardrop area and intersecting the most prominent medial part of lesser trochanter on each side (TD-LT).

Second method: line was drawn at most inferior point of ischial tuberosity to inter teardrop area and line drawn at most prominent medial part of lesser trochanter on each side (IT-
LT) When performing the X-ray, in order to avoid inaccuracies in measurements of limb length, all the patients were in a standard position (anatomical position), internally rotating both the lower limb when necessary and looking for maximum symmetry of the limb posture and the measurements were taken preoperatively and postoperatively.

Analysis of data
We evaluated 40 cases undergoing THR for painful arthritis of hip at K R Hospital MMCRI for interobserver reliability of limb length measurements using 2 different methods on digital pelvic x-rays by 2 different examiners. IBM SSPS software version 23 is used to analyse statistical data. Pictures depicting x-rays, where measurements were taken on a digital x-ray using a computer software.

Results
For measuring limb length using teardrop as a pelvic reference and lesser trochanter as femoral reference inter-observer agreement for radiological measurements kappa=0.893 (good agreement) for pre-operative radiographic measurements and kappa=0.813 (good agreement) for post-operative radiographic measurements. By using ischial tuberosity as a pelvic reference and lesser trochanter as femoral reference inter-observer agreement for radiological measurements kappa=0.723 (Substantial agreement) for pre-operative radiographic measurements and kappa=0.752 (Substantial agreement) for post-operative radiographic measurements.

Table 1: Interpretation of Cohens Kappa for statistical strength of agreement.

| Kappa    | Level of agreement | % of data reliability |
|----------|--------------------|-----------------------|
| 0 - 0.20 | None               | 0-4%                  |
| 0.21 - 0.39 | Minimal          | 4-15%                |
| 0.40 - 0.59 | Weak             | 15-35%               |
| 0.60 - 0.79 | Moderate         | 35-63%               |
| 0.80 - 0.90 | Strong           | 64-81%               |
| Above 0.90 | Almost Perfect   | 82-100%              |

Discussion
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. 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 involves the hip.

Radiographic measurement has been found to be more accurate compared to clinical measurement. Leitzes et al. used the electronic calliper measurement as a gold standard in their study. In this study, we compared the plain radiographic measurement methods and reliability. There are many described methods of measuring LLD, all of which have their advantages and disadvantages. Clinical measurement between two bony prominences and block measurement to clinically level the pelvis are examples of simple techniques. Studies have shown that block measurement is more accurate than tape measurement of true and apparent leg length. Terry et al. have shown that radiographic measurement is more accurate than clinical measurement in determining leg length discrepancy, however, this does involve exposure to radiation. There is much debate as to whether CT scanograms or full length radiographs are more reliable. Scanograms with radio-opaque rulers give more accurate LLD measurement but can miss angular deformities of the femur or tibia and fixed flexion deformities. Long leg radiographs can be done in a number of ways (orthoroentgenograms, teleoroentgengrams,) depending on the equipment and skills available. CT scanograms are comparable with radiographs but the dose of radiation received by the patient may be less if adequate images are gained on the first scan.

CT Scanogram and MRI has very high intrabrowser and interobserver reliability in various studies. Both modalities are not available in tertiary centres and bear a financial burden to the patients. Hence pelvic radiograph was chosen as the method in our study.

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Meermans et al. evaluated LLD measurement preoperatively when templating for THA. The authors found that LLD measurement by using the interteardrop line correlated with LLD measurement by full-leg radiographs better than using the bi-ischial line. The teardrop points have been found to be reliable and constant landmarks of the pelvis, due to the vertical and rotational stability of these points in association with different pelvis positions.

Heaver et al. reported that inter ischial line was best pelvic landmark for measurement of LLD, whereas Meermans et al. reported teardrop line to be better. Meermans et al. went on to say that the femoral reference point should be the centre of the femoral head rather than the lesser trochanter.

Tipton et al. reported that LLD estimated on AP radiograph of
the pelvis are not comparable to LLD calculated on full length radiographs of limb and hence taking only pelvic radiograph to assess LLD is not adequate. Tipton et al. reported that LLD calculated on AP radiograph of the pelvis are not comparable to LLD calculated on full length radiographs of limb and hence taking only pelvic radiograph to assess LLD is not adequate[61]. He reports a intraobserver agreement, when the interteardrop line was used produced values of 0.66 for tear drop to LT and 0.62 for tear drop to centre of femoral head. The interobserver agreement was strong for the bi-ischial line, 0.69 and 0.78 for bi-ischial to LT and bi-ischial to centre of femoral head, respectively [61].

Keršič et al. in their study of 119 primary THA patients reported a LLD of 5-8 mm between preoperative clinical and radiological LLD but, this difference decreased to 1-2 mm postoperatively [62]. Sayednoor et al. also supported these findings in their study [65].

In a study by Martin Kjellberg et al. [64], computed tomographic scanogram (CT-Scan) was used to evaluate its accuracy by comparing it with LLD measurement on radiograph. They found excellent interobserver reliability (mean ICC 0.83) and intraobserver reproducibility (ICC 0.90 and 0.88) of the LLD measurements on plain radiographs. There was a moderate to excellent agreement, but with wide variation of measurements among the four observers, when plain radiographic measurement was compared with CT-scanogram (ICC 0.58, 0.60, 0.71, and 0.82).

There is no universal agreement for taking reference points to accurately measure limb lengths. Various authors have pointed out that the measurements from plain radiographs are susceptible to error, due to variations in positioning of the pelvis relative to the plane of the film and the divergence of the X-ray beams. The abduction/adduction deformities of the femur with respect to the pelvis also cause substantial error in the measurement of the length and offset changes. A radiograph cannot detect angular deformities of the lower limb and may underestimate the LLD in patients with discrepancies in foot height [65, 66]. These points should be improved in order to achieve more accurate measurements.

The rotation of the lesser trochanter and the position of the tip can vary according to the rotation of the leg when taking the radiographs. In order to minimize this variation, the legs were kept with a symmetrical internal rotation by the same radiology assistant to make measurements as standardized as possible. The radiographs were accepted for inclusion when obturator foramen, lesser trochanter, and knee and ankle joint all appeared symmetrical bilaterally.

This study is limited in that the leg length discrepancy is only measured across the hip joint. This does not account for any discrepancy arising from the femoral shaft, knee, tibia or ankle and subsequent imaging must be directed by thorough history taking and clinical examination., limb length was evaluated based on the plain pelvic radiographs instead of the CT scans, which have been used in other studies to eliminate the variables of pelvic tilt that exists while taking radiographs [68, 69]. Measurements and calculations from plain X-rays are susceptible to error, due to variations in positioning of the pelvis relative to the plane of the film and the divergence of the X-ray beams [67]. Our study comprises of small study group.

**Conclusion**

In our study, Measurement of limb length on radiographs has excellent interobserver reliability with the use of the interteardrop as a pelvic landmark was a better with measurements to the lesser trochanter. Interobserver variability testing showed less agreement when the ischial tuberosity was used as a pelvic landmark compared with the teardrop. The accuracy of this method is limited when compared with CT-scanogram.

Clinicians should be aware of this limitation when using the radiographic method in their clinical practice.

**Master Chart**

| S. No | AGE (years) | SEX | Diagnosis | SIDE | Tear Drop-LT | Ischial Tuberosity –LT |
|-------|-------------|-----|-----------|------|--------------|------------------------|
|       |             |     |           |      | Examinor-1(TD-LT) | Examinor-2(TD-LT) | Examinor-1(IT-LT) | Examinor-2(IT-LT) |
|       |             |     |           |      | Pre-Op | Post-op | Pre-Op | Post-op | Pre-Op | Post-op | Pre-Op | Post-op |
| 1     | 32          | M   | AVN       | R    | 4.2    | 5.2     | 4.2    | 5.2     | -0.9   | -0.1   | -0.9   | -0.1   |
| 2     | 51          | M   | OA        | R    | 3.2    | 4.6     | 3.2    | 4.5     | -0.7   | 0.2    | -0.6   | 0.2    |
| 3     | 28          | F   | AVN       | L    | 3.9    | 4.2     | 3.9    | 4.2     | -1.1   | -0.2   | -1     | -0.2   |
| 4     | 56          | M   | OA        | R    | 3.8    | 5       | 3.8    | 5       | -0.8   | -0.1   | -0.7   | -0.1   |
| 5     | 27          | F   | AVN       | L    | 3.3    | 4.5     | 3.3    | 4.5     | -0.9   | -0.3   | -0.9   | -0.3   |
| 6     | 56          | M   | OA        | R    | 4.5    | 4.9     | 4.5    | 4.8     | -0.8   | 0.1    | -0.8   | 0.1    |
| 7     | 62          | M   | OA        | L    | 3.6    | 4.2     | 3.6    | 4.2     | -1.3   | 0.3    | -1.2   | 0.4    |
| 8     | 59          | F   | OA        | L    | 4.1    | 4.6     | 4.1    | 4.6     | -1     | -0.2   | -1     | -0.2   |
| 9     | 61          | M   | OA        | R    | 5      | 7       | 5.1    | 7       | -1.5   | -0.5   | -1.5   | -0.5   |
| 10    | 35          | M   | AVN       | L    | 3.9    | 4.2     | 3.9    | 4.1     | -0.3   | 0.7    | -0.3   | 0.7    |
| 11    | 52          | M   | OA        | R    | 3.8    | 5       | 3.8    | 5       | -0.9   | 0.2    | -0.9   | 0.2    |
| 12    | 49          | F   | OA        | R    | 4.3    | 5.4     | 4.3    | 5.4     | -0.6   | -0.1   | -0.6   | -0.1   |
| 13    | 61          | M   | OA        | L    | 2.4    | 3.5     | 2.4    | 3.5     | -1.2   | -0.2   | -1.2   | -0.2   |
| 14    | 26          | M   | AVN       | R    | 3.7    | 3.9     | 3.8    | 3.9     | -1.3   | -0.5   | -1.3   | -0.5   |
| 15    | 36          | F   | AVN       | L    | 3.1    | 4.1     | 3.1    | 4       | -0.2   | 0.4    | -0.2   | 0.4    |
| 16    | 39          | M   | OA        | L    | 2.9    | 4.4     | 2.9    | 4.4     | -0.7   | 0.5    | -0.7   | 0.5    |
| 17    | 45          | M   | OA        | L    | 3.7    | 4.3     | 3.7    | 4.4     | -0.8   | -0.1   | -0.8   | -0.1   |
| 18    | 41          | F   | OA        | L    | 3.2    | 3.4     | 3.2    | 3.4     | -0.2   | 0.6    | -0.2   | 0.6    |
| 19    | 32          | M   | OA        | R    | 4      | 6       | 4      | 6       | -0.8   | 0.3    | -0.9   | 0.4    |
| 20    | 31          | F   | AVN       | L    | 1.8    | 3.1     | 1.8    | 3.1     | -0.9   | 0.2    | -0.9   | 0.3    |
| 21    | 52          | M   | OA        | R    | 4.2    | 3.9     | 4.2    | 3.9     | -0.6   | 0.4    | -0.6   | 0.4    |
| 22    | 33          | M   | AVN       | L    | 5.2    | 6.1     | 5.2    | 6.2     | -0.9   | 0.2    | -0.9   | 0.2    |
| 23    | 28          | M   | AVN       | R    | 3.8    | 4.2     | 3.8    | 4.2     | -1.7   | -0.8   | -1.8   | -0.9   |
| 24    | 32          | M   | AVN       | L    | 3.3    | 3.6     | 3.3    | 3.6     | -1.1   | -0.1   | -1     | -0.1   |
References

1. Clark CR, Huddlestone HD, Schoch EP, Thomas BJ. Leg length discrepancy after total hip arthroplasty. J Am Acad Orthop Surg. 2006;14(1):38-45.
2. Maloney WJ, Keeney JA. Leg length discrepancy after total hip arthroplasty. J Arthroplasty. 2004;19(4 Suppl 1):108-10.
3. Bhave A, Marker DR, Seyler TM, Ulrich SD, Plate JF, Mont MA. Functional problems and treatment solutions after total hip arthroplasty. J Arthroplasty. 2007;22(6 Suppl 2):116-24.
4. O’Brien S, Kermoah G, Fitzpatrick C, Hill J, Beverland D. Perception of imposed leg length inequality in normal subjects. Hip Int. 2010;20(4):505-11.
5. Murphy SB, Ecker TM. Evaluation of a new leg length measurement algorithm in hip arthroplasty. Clin Orthop Relat Res. 2007;463:85-9.
6. Bose WJ. Accurate limb-length equalization during total hip arthroplasty. Orthopedics. 2000;23:433-6.
7. Bourne RB, Rorabeck CH. Soft tissue balancing: the hip.

J Arthroplasty. 2002;17(4 Suppl 1):17-22.
8. Austin MS, Hozack WJ, Sharkey PF, Rothman RH. Stability and leg length equality in total hip arthroplasty. J Arthroplasty. 2003;18(3 Suppl 1):88-90.
9. Ranawat CS. The pants too short, the leg too long! Orthopedics. 1999;22:845-846.
10. Hofmann AA, Skrzynski MC. Leg-length inequality and nerve palsy in total hip arthroplasty: a lawyer awaits! Orthopedics. 2000;23:943-944.
11. Mihalko WM, Phillips MJ, Krackow KA. Acute sciatic and femoral neuritis following total hip arthroplasty: a case report. J Bone Joint Surg Am. 2001;83:589-592.
12. Nercessian OA, Piccoluga F, Efekhar NS. Postoperative sciatic and femoral nerve palsy with reference to leg lengthening and medialization/lateralization of the hip joint following total hip arthroplasty. Clin Orthop Relat Res. 1994;304:165-171.
13. Stone RG, Weeks LE, Hajdu M, Stinchfield FE. Evaluation of sciatic nerve compromise during total hip arthroplasty. J Bone Joint Surg Am. 2001;83:907-915.
14. Weber ER, Daube JR, Coventry MB. Peripheral neuropathies associated with total hip arthroplasty. J Bone Joint Surg Am. 1976;58:66-69.
15. Abraham WD, Dimon JD 3rd. Leg length discrepancy in total hip arthroplasty. Orthop Clin North Am. 1992;23:201-209.
16. Cummings G, Scholz JP, Barnes K. The effect of imposed leg length difference on pelvic bone symmetry. Spine (Phila Pa 1976). 1993;18:368-373.
17. Friberg O. Clinical symptoms and biomechanics of lumbar spine and hip joint in leg length inequality. Spine (Phila Pa 1976). 1983;8:643-651.
18. Giles LG, Taylor JR. Low-back pain associated with leg length inequality. Spine (Phila Pa 1976). 1981;6:510-521.
19. 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;83:907-915.
20. Lai KA, Lin CJ, Jou IM, Su FC. Gait analysis after total hip arthroplasty. Spine (Phila Pa 1976). 2001;26:510-521.
21. McWilliams AB, Grainger AJ, O’Connor PJ, Redmond AC, Stewart TD, Stone MH. A review of symptomatic leg length inequality following total hip arthroplasty. Hip Int. 2013;23(1):6-14.
method of leg-length equalization for patients undergoing primary total hip replacement. J Arthroplasty. 1999;14(2):159-64.

24. Austin MS, Hozack WJ, Sharkey PF, Rothman RH. Stability and leg length equality in total hip arthroplasty. J Arthroplasty. 2003;18(3 suppl 1):88-90.

25. Bono JV. Digital templating in total hip arthroplasty. J Bone Joint Surg Am. 2004;86(suppl 2):118-122.

26. Clark CR, Huddleston HD, Schoo EP 3rd, Thomas BJ. Leg length discrepancy after total hip arthroplasty. J Am Acad Orthop Surg. 2006;14:38-45.

27. Eggli S, Pisan M, Müller ME. The value of preoperative planning for total hip arthroplasty. J Bone Joint Surg Br. 1998;80:382-390.

28. Gonzalez Della Valle A, Slullitel G, Piccaluga F, Salvati EA. The precision and usefulness of preoperative planning for cemented and hybrid total hip arthroplasty. J Arthroplasty. 2005;20:51-58.

29. Hoikka V, Santavirta S, Eskola A, Paavilainen T, Wirta J, Lindholm TS. Methodology for restoring functional leg length in revision total hip arthroplasty. J Arthroplasty. 1991;6:189-193.

30. Khanduja V, Tek V, Scott G. The effect of a neck-retaining femoral implant on leg-length inequality following total hip arthroplasty: a radiological study. J Bone Joint Surg Br. 2006;88:712-715.

31. Konyves A, Bannister GC. The importance of leg length discrepancy after total hip arthroplasty. J Bone Joint Surg Br. 2005; 87:155-157.

32. Krishnan SP, Carrington RW, Mohiyaddin S, Garlick N. Common misconceptions of normal hip joint relations on pelvic radiographs. J Arthroplasty. 2006;21:409-412.

33. Maloney WJ, Keeney JA. Leg length discrepancy after total hip arthroplasty. J Arthroplasty. 2004;19(4 suppl 1):108-110.

34. Matsuda K, Nakamura S, Matsushita T. A simple method to minimize limb-length *discrepancy after hip arthroplasty. Acta Orthop. 2006;77:375-379.

35. Mihalko WM, Phillips MJ, Krakow KA. Acute sciatic and femoral neuritis following total hip arthroplasty: a case report. J Bone Joint Surg Am. 2001;83:589-592.

36. Murphy SB, Ecker TM. Evaluation of a new leg length measurement algorithm in hip arthroplasty. Clin Orthop Relat Res. 2007;463:85-89.

37. *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;85:2310-2317.

38. Ranawat CS, Rodriguez JA. Functional leg-length inequality following total hip arthroplasty. J Arthroplasty. 1997;12:359-364.

39. Rand JA, Ilstrup DM. Comparison of Charnley and T-28 total hip arthroplasty. Clin Orthop Relat Res. 1983;180:201-205.

40. Sathappan SS, Ginat D, Patel V, Walsh M, Jaffe WL, Di Cesare PE. Effect of anesthesia type on limb length discrepancy after total hip arthroplasty. J Arthroplasty. 2008;23:203-209.

41. Suh KT, Cheon SJ, Kim DW. Comparison of preoperative templating with postoperative assessment in cementless total hip arthroplasty. Acta Orthop Scand. 2004;75:40-44.

42. Unnanuntana A, Wagner D, Goodman SB. The accuracy of preoperative templating in cementless total hip arthroplasty. J Arthroplasty. 2009;24:180-186

43. Wedemeyer C, Quitmann H, Xu J, Heep H, von Knoch M, Saxler G. Digital templating in total hip arthroplasty with the Mayo stem. Arch Orthop Trauma Surg. 2008;128:1023-1029.

44. White TO, Dougall TW. Arthroplasty of the hip: leg length is not important. J Bone Joint Surg Br. 2002;84:335-338.

45. Williamson JA, Reckling FW. Limb length discrepancy and related problems following total hip joint replacement. Clin Orthop Relat Res. 1978;134:135-138.

46. Woo RY, Morrey BF. Dislocations after total hip arthroplasty.J Bone Joint Surg Am. 1982;64:1295-1306.

47. Woolson ST, Hartford JM, Sawyer A. Results of a method of leg-length equalization for patients undergoing primary total hip replacement

48. Clarke GR. *Unequal leg length: an accurate method of detection and some clinical results. Rheumatol Phys Med. 1972;11:385-90.

49. Cleveland RH, Kushner DC, Ogden MC, Herman TE, Kermond W, Correia JA. Determination of leg length discrepancy. A comparison of weight-bearing and supine imaging. Invest Radiol. 1998;23(4):301-4.

50. Lampe HH, Swierstra BA, Diepstraten FM. Measurement of limb length inequality. Comparison of clinical methods with orthoradiography in 190 children. Acta Orthop Scand. 1996;67(3):242-4.

51. Terry MA, Winell JJ, Green DW, Schneider R, Peterson M, Marx RG, et al. Measurement variance in limb length discrepancy: clinical and radiographic assessment of interobserver and intraobserver variability. J Pediatr Orthop. 2005;25(2):197-201.

52. Haber M, Barnhart PX, Song J, Gruden J. Observer variability: a new approach in evaluating interobserver agreement. J Data Sci. 2005;3:69-83.

53. Terry MA, Winell JJ, Green DW. Measurement variance in limb length discrepancy: clinical and radiographic assessment of interobserver and intraobserver variability. J Pediatr Orthop. 2005;25(2):197-201.

54. Lampe HI, Swierstra BA, Diepstraten AF. Measurement of limb length inequality. Comparison of clinical methods with orthoradiography in 190 children. Acta Orthop Scand. 1996;67(3):242-4.

55. Sabharwal S, Zhao C, Meekon J, Melaghari T, Blacksin M, Wenekor C. Reliability analysis for radiographic measurement of limb length discrepancy: full-length standing anteroposterior radiograph versus scanogram. J Pediatr Orthop. 2007;27(1):46-50.

56. Horsfield D, Jones SN. Assessment of inequality in length of the lower limb. Radiography. 1986;52(605):223-7.

57. Huurman WW, Jacobsen FS, Anderson JC, Chu WK. Limb length discrepancy measured with computerized axial tomographic equipment. J Bone Joint Surg Am. 1987;69:699-705.

58. McWilliams AB, Grainger AJ, O’Connor PJ, Redmond AC, Stewart TD, Stone MH. A review of symptomatic leg length inequality following total hip arthroplasty. Hip Int. 2013;23(1):6-14.

59. 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.

60. Geert Meermans, Ahmad Malik, Johan Witt, Fares Haddad: Clinical Orthopaedics and Related Research®.
61. Tipton SC, Sutherland JK, Schwarzkopf R. The Assessment of Limb Length Discrepancy Before Total Hip Arthroplasty. J Arthroplasty. 2016;31(4):888-92.

62. Keršič M, Dolinar D, Antolič V, Mavčič B. The Impact of Leg Length Discrepancy on Clinical Outcome of Total Hip Arthroplasty: Comparison of Four Measurement Methods. J Arthroplasty. 2014;29(1):137-41.

63. Sayed-Noor AS, Hugo A, Sjödén GO, Wretenberg P. Leg length discrepancy in total hip arthroplasty: comparison of two methods of measurement. Int Orthop. 2009;33(5):1189-93.

64. Kjellberg M1, Al-Amiry B, Englund E, Sjödén GO, Sayed-Noor AS. Measurement of leg length discrepancy after total hip arthroplasty. The reliability of a plain radiographic method compared to CT-scanogram. Skeletal Radiol. 2012 Feb;41(2):187-91.

65. Machen MS, Stevens PM. Should full-length standing anteroposterior radiographs replace the scanogram for measurement of limb length discrepancy? J Pediatr Orthop B. 2005;14:30-37.

66. Sabharwal S, Zhao C, McKeon JJ, McClements E, Edgar M, Behrens F. Computed radiographic measurement of limb-length discrepancy. Full-length standing anteroposterior radiograph compared with scanogram. J Bone Joint Surg Am. 2006;88:2243-2251.

67. Murphy SB, Ecker TM. Evaluation of a new leg length measurement algorithm in hip arthroplasty. Clin Orthop Relat Res. 2007;463:85-89. [PubMed]

68. Haaker RG, Tiedjen K, Ottersbach A, Rubenthaler F, Stockheim M, Stiehl JB. Et al. Comparison of conventional versus computer-navigated acetabular component insertion. J Arthroplasty. 2007;22(2):151-159. [PubMed]

69. Kalteis T, Handel M, Bathis H, Perlick L, Tingart M, Grifka J et al. Imageless navigation for insertion of the acetabular component in total hip arthroplasty: is it as accurate as CT-based navigation? J Bone Joint Surg Br. 2006; 88(2):163-167. [PubMed]