Interest of an intraoperative limb-length and offset measurement device in total hip arthroplasty

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Accepted: 21 February 2012

KEYWORDS
Total hip arthroplasty;
Offset;
Limb-length discrepancy;
Surgical planning

Summary

Introduction: Total hip arthroplasty (THA) seeks to restore a stable, mobile and pain-free joint. This requires good implant positioning and peroperative restoration of limb-length and femoral offset.

Hypothesis: A mechanical measurement device (length and offset optimization device [LOOD]) fixed to the pelvis can optimize lower-limb length and offset control during THA performed on a posterolateral approach.

Patients and methods: Two prospective THA series were compared: 32 using the LOOD and 26 without. Patients with more than 5 mm preoperative limb-length discrepancy were excluded. The intraoperative target was to restore individual anatomy. Radiographic analysis was based on pre- and postoperative AP pelvic weight-bearing views in upright posture, feet aligned, with comparison to peroperative LOOD data.

Results: Mean deviation from target length (i.e., pre- to postoperative length differential) was 2.31 mm (range, 0.04–10.6 mm) in patients operated on using the LOOD versus 6.96 mm (0.01–178 mm) without LOOD (P = 0.0013). Mean deviation from target offset was 3.96 (0.45–13.50) mm with LOOD versus 10.16 (0.93–28.81) without (P = 0.0199). There was no significant difference between operative and radiographic measurements of length deviation using LOOD (P = 0.4); those for offset, however, differed significantly (P = 0.02).

Discussion: The LOOD guides control of limb-length and offset during THA on a posterolateral approach. Reliability seems to be better for limb-length than for offset. It is a simple and undemanding means of controlling limb-length and offset during THA.

Level of evidence: III, prospective case-control study.

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Introduction

Controlling lower-limb length in total hip arthroplasty (THA) is difficult and is a frequent cause of patient dissatisfaction and litigation [1–8]. Restoring femoral offset is also essential to a good functional result, maintaining an
effective hip abductor lever-arm to improve implant stability and longevity and quality of gait [9–15]. At the present time, length and offset restoration depends on preoperative planning by tracing [11] and peroperative tests of soft-tissue tension and length (Charnley’s “shuck” test [12], the “dropkick” test and the “leg-to-leg” test); these tests, however, are affected by the surgeon’s experience, the type of anesthesia [16] and other factors which make them somewhat subjective [17].

The present study sought to assess the reliability of a measurement device (length and offset optimization device [LOUD]) implemented during THA to control lower-limb length and femoral offset peroperatively. The working hypothesis was that the LOUD would improve control of lower-limb length and offset.

Patients and method

Patients

A continuous prospective single center study was performed on patients undergoing THA between July 2009 and January 2010. Inclusion criteria were: primary or secondary osteoarthritis of the hip with preoperative limb-length discrepancy (LLD) less than 5 mm on preoperative AP weight-bearing pelvic X-ray, for which primary THA without bone reconstruction was indicated. Two consecutive series were included: for the first 3 months of the study, patients were operated on without LOUD, and for the following 3 months with. Exclusion criteria were: preoperative LLD > 5 mm on AP weight-bearing pelvic X-ray, and history of conservative hip surgery for hip dysplasia. The peroperative target was to restore preoperative limb-length and offset.

Fifty-eight patients were included: 32 operated on with LOUD and 26 without. Age, indication, gender, laterality and body-mass index (BMI) were collected for both groups (Tables 1 and 2).

Surgical technique

The LOUD device (Amplitude, Neyron, France) (Fig. 1) comprises three parts. The fixation nail, with a triangular point to ensure stable bone anchorage and prevent rotation, is graduated every 5 mm to measure offset, and is connected, via an angular protractor guide with locking screw, to a measuring device calibrated every 5 mm which is fixed on the nail. Finally, a probe is fixed on the measuring device by a second screw (Fig. 1).

All patients were operated on by a posterolateral approach, in lateral decubitus. Where the LOUD was used, after exposing and sectioning the pelvi-trochanteric muscles, the fixation nail was positioned across the medial gluteal muscle in the iliac wing following the axis of the femur, 3 to 5 cm above the greater trochanter. The LOUD was then assembled and a reference point was marked on the greater trochanter by electrocautery, with the lower limb positioned reproducibly in extension in the axis of the body, foot parallel to the ground (Fig. 2). In case of difficulty in marking, the electrocautery mark could be replaced by a short screw in the greater trochanter. The moveable part of the LOUD was then removed, without disturbing the settings, its height being determined using the graduation on the iliac fixator. The implant was a model with a modular cone reproducing standard or varus necks of various lengths (Amplitude, Neyron, France). Where the LOUD was used, it was repositioned on the iliac fixator nail at the same height as initially, and the lower limb was repositioned in extension in the reference position (Fig. 3). The peroperative target was to reproduce the initial offset and length. Stability tests were systematically made to determine neck type in patients in whom the LOUD was not used and to

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Characteristics of the two study groups.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>With LOUD</td>
</tr>
<tr>
<td>Number of patients</td>
<td>32</td>
</tr>
<tr>
<td>Male/female</td>
<td>13/19</td>
</tr>
<tr>
<td>Mean age (yrs)</td>
<td>70.5 ± 15.5 (range, 47–87)</td>
</tr>
<tr>
<td>Lateralization right/left</td>
<td>19/13</td>
</tr>
<tr>
<td>Body-mass index</td>
<td>24.9 ± 3.8 (range, 17.7–31.1)</td>
</tr>
</tbody>
</table>

LOUD: length and offset optimization device; NS: non-significant.
Table 2  Etiologies of indications for THA in the two groups.

<table>
<thead>
<tr>
<th>Etiologies</th>
<th>With LOOD (n = 32)</th>
<th>Without LOOD (n = 26)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary osteoarthritis</td>
<td>24</td>
<td>17</td>
<td>NS</td>
</tr>
<tr>
<td>Rapidly destructive osteoarthritis</td>
<td>1</td>
<td>1</td>
<td>NS</td>
</tr>
<tr>
<td>Minor dysplasia</td>
<td>3</td>
<td>3</td>
<td>NS</td>
</tr>
<tr>
<td>Aseptic osteonecrosis of the femoral head</td>
<td>4</td>
<td>4</td>
<td>NS</td>
</tr>
<tr>
<td>Inflammatory rheumatism</td>
<td>0</td>
<td>0</td>
<td>NS</td>
</tr>
<tr>
<td>Posttraumatic osteoarthritis</td>
<td>0</td>
<td>1</td>
<td>NS</td>
</tr>
</tbody>
</table>

LOOD: length and offset optimization device; NS: non-significant.

7 control implant stability where the LOOD was used, the priority being to achieve a stable hip.

**Assessment methods**

Data collection comprised:

- in both groups, pre- and postoperative (1 month) radiologic analysis on AP weight-bearing X-ray view with the feet together and parallel, measuring (Fig. 4):
  - the height between the most medial point of the lesser trochanter and the horizontal line between the teardrops, to measure limb length and change in limb length,
  - global offset, defined as the distance between the midpoint of the pelvis (determined by the sacrum-to-pubis line) and the tip of the greater trochanter,
  - diameter of the femoral head and of the cup.

To avoid enlargement bias related to the radiograph scale, the scale for the preoperative radiograph measurements was calculated from the ratio of the inferosuperior diameter of the femoral head, as measured peroperatively by caliper, to the femoral head diameter measured on the radiograph. The scale for the postoperative radiographs was calculated from the ratio of the implanted cup diameter as measured on the postoperative radiograph to the real cup diameter. All differential measurements (both on X-ray and on LOOD) were recorded as absolute values.

**Figure 2** Peroperative view of the LOOD before arthroscopy: the pin fixation was placed through the gluteus medius in the iliac bone, in the axis of the femur, 3 cm above the greater trochanter and the reference point was marked with electrocautery on the greater trochanter with the leg in extension in the axis of the body.

**Figure 3** Peroperative view of the LOOD after completion of THA: the probe is on the great trochanter reference mark. The LOOD enables limb-length and offset restoration to be checked.

**Figure 4** Radiological measures made on the pre- and postoperative 1-month pelvic weight-bearing X-ray views, with feet placed side by side in parallel. A. Distance between the most medial point of the lesser trochanter and the horizontal line between the teardrops, to measure limb-length change. B. Distance between the middle of the pelvis, defined by the sacrum-to-pubis line, and the tip of the greater trochanter, measuring global offset. C. Diameter of the femoral head or acetabular cup.
Statistics

Statistical analysis used the StatPlus™ software package (AnalystSoft, Alexandria, VA, USA). Demographic data were compared between the two groups by non-parametric Mann-Whitney and Kruskal-Wallis tests. Categoric variables (change in length and offset) were expressed as means, ranges and standard deviations and analyzed on Fisher exact tests for inter-group comparison. The significance threshold was set at $P \leq 0.05$.

Results

 Fifty-eight patients were included. The 2 groups were comparable on the study parameters (Table 1). Etologies were likewise comparable, with a majority of primary osteoarthritis (Table 2).

 There were no peroperative complications, and no failures of proximal fixation of the LOOD. Stability tests results never led to a change in neck size or contradicted the LOOD data. There were no cases of femoral stem subsidence on 1-month radiographs.

 Analysis of pre- and postoperative radiographs found a mean length difference of $2.31 \text{ mm (SD, 2.64 mm; range, 0.04–10.60 mm)}$ with LOOD and $6.96 \text{ mm (SD, 4.72 mm; range, 0.01–17.80 mm)}$ without ($P=0.0013$). Mean pre- and postoperative offset difference was $3.96 \text{ mm (SD, 4.79 mm; range, 0.45–13.50 mm)}$ with LOOD and $10.16 \text{ mm (SD, 7.05 mm; range, 0.93–28.81 mm)}$ without ($P=0.0199$) (Table 3).

 Peroperative and radiographic measurements of change in length using the LOOD did not significantly differ: $1.70 \text{ mm (0.04–8.20 mm)}$ versus $2.31 \text{ mm (0.04–10.60 mm)}$ ($P=0.4$). Measured change in offset, on the other hand, was significantly different between the peroperative LOOD and radiographic data (respectively: mean $5.20 \text{ (0.69–20.54)}$ versus $3.96 \text{ (0.45–13.50)}$ ($P=0.02$)) (Table 3).

 Discussion

 The present study sought to assess the efficacy of the LOOD device in terms of improving peroperative control of limb-length and offset during THA. Post-THA limb-length discrepancy (LLD) exceeding 10 mm, raising legal and/or neurological issues, is reported in 16–32% of cases in the literature [1–7,18–24]. Beyond this 10-mm threshold, LLD is felt by the patient [25], thereby affecting functional outcome [24–27]. Usually, patients are bothered by such LLD during the first postoperative months, with symptoms fading off over time; 15%, however, remain symptomatic [28,29] and more than half of these cases require a compensatory insole to improve satisfaction [2,4]. Restoring offset is important to improve hip abductor lever-arm and implant longevity [9–15]. The recent results show that the LOOD can improve peroperative control of both limb-length and offset, and enables quantification of change in limb-length, although not in offset.

 The main study limitation concerns the accuracy of the radiographic measurements, which may be questioned, especially in comparison with computed tomodensitometry (CT) [30]. Kjellberg et al. [30], however, reported radiographic LLD measurements to be reasonably reproducible regarding interobserver reproducibility (kappa = 0.83) as well as intra-observer reproducibility (kappa = 0.90). Differences between X-ray and CT measurement of offset and limb-length can be explained by the influence of pelvic tilt and of lower-limb rotation [31–35]. To ensure reproducible lower-limb rotation in a given patient and to avoid flexion deformity during X-ray, pelvic views were taken with the feet together and parallel and postoperative views were taken only at 1 month to avoid the postoperative functional flexion deformity, which affects pelvic tilt. Other possible solutions could have been: following Jaramaz et al. [36], to associate preoperative CT to postoperative X-ray, so as to correct pelvic positioning; or following Tannast et al. [31], to use an algorithm to correct tilt and rotation. However, both of these procedures transform the change in pelvic positioning into a measurement of pelvic abduction and inclination angles, without directly relating these to the linear measurements. Stephen et al. [37] limit the impact of pelvic tilt by measuring the difference in diameter between the two hips on each X-ray view, considering the tilt-effect between any two images to be comparable in both hips. Measurements from image to image may further be subject to enlargement bias due to change in pelvis position with respect to the plane of the film and the centering of the X-rays [31,38]. To limit this source of bias, the scale for the preoperative radiograph measurements was calculated from the ratio of the inferosuperior diameter of the femoral head, as measured peroperatively by caliper, to the diameter of the femoral head measured on the radiograph. The scale for the postoperative radiographs was calculated from the ratio of the implanted cup diameter, as measured on the postoperative radiograph, to the real cup diameter. Even so, there may be residual error due to X-ray divergence, as the rays are not perpendicular to the cup on AP pelvic views but rather centered on the midline of the pelvis. Only CT [30,39] would enable precise measurement — but at the cost of extra-irradiation. The offset measurements further lost accuracy as we did not use femoral or global offset, as described by Lecerf et al. [9], but included the distance between the teardrop line and the center of the pelvis in this measurement. In all, while still using plain X-ray, we sought to minimize measurement error in this prospective study design. One final limitation concerns the choice of surgical approach, inasmuch as the present findings cannot be extrapolated to surgery using other approaches.

 We chose to use an implant with a modular cone so as to give the surgeon a range of possibilities in following the LOOD measurements [9]. Peroperative testing was, however, always associated to the LOOD, to ensure implant stability. Following the LOOD data never led to instability, and it was never necessary to change the neck in order to prioritize stability over restoration of limb-length and offset, abandoning the LOOD input.

 The primary study objective was to show that the LOOD device improved per- and postoperative control of limb-length and offset. Control of both parameters was found to be significantly better in the LOOD group. Other studies have reported on similar methods [8,18–20,23,40–49]. Most seem effective, but concern only limb-length control and not offset. McGee and Scott [50] described a simple
Table 3  Comparison of change in limb-length and offset between pre- and postoperative radiographs in the two groups (with LODD = 32, without LODD = 26). For the LODD group, comparison between peroperative and radiographic measurements.

<table>
<thead>
<tr>
<th></th>
<th>Mean (range) (mm)</th>
<th>Standard deviation</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Comparative analysis of pre- and postoperative radiographs</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Change in lower-limb length*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Series operated on using LODD</td>
<td>2.91 (0.04–10.60)</td>
<td>2.64</td>
<td>0.0013</td>
</tr>
<tr>
<td>Series operated on without LODD</td>
<td>6.96 (0.01–17.80)</td>
<td>4.72</td>
<td></td>
</tr>
<tr>
<td>Change in offset*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Series operated on using LODD</td>
<td>3.96 (0.45–13.50)</td>
<td>4.79</td>
<td>0.0199</td>
</tr>
<tr>
<td>Series operated on without LODD</td>
<td>10.16 (0.93–28.81)</td>
<td>7.05</td>
<td></td>
</tr>
<tr>
<td><strong>Comparison of change in limb-length and offset as measured peroperatively by LODD and on pre- and postoperative radiographs in the LODD group (n = 32)</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Change in lower-limb length</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Change as measured by LODD</td>
<td>1.70 (0.04–8.20)</td>
<td>1.63</td>
<td>0.4 (NS)</td>
</tr>
<tr>
<td>Change as measured on X-raya</td>
<td>2.31 (0.04–10.60)</td>
<td>2.64</td>
<td></td>
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<tr>
<td>Change in offset</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Change as measured by LODD</td>
<td>5.20 (0.69–20.54)</td>
<td>4.35</td>
<td>0.02</td>
</tr>
<tr>
<td>Change as measured on X-rayb</td>
<td>3.96 (0.45–13.50)</td>
<td>4.79</td>
<td></td>
</tr>
</tbody>
</table>

LOOD: length and offset optimization device; NS: non-significant.

* Change as measured on X-ray = absolute difference in distance between teardrops and lesser trochanter on pre- vs. postoperative views.

a Change as measured on X-ray = absolute difference in distance between center of pelvis and greater trochanter on pre- vs. postoperative views.

and widely used method [45,46] using a wire placed in the ilium and stretched toward the greater trochanter. Wollson et al. [23] used a caliper fixed on the iliac wing, which ensured less than 6 mm LLD in 89% of their patients. Ranawat et al. [18] used a Steinman nail positioned in the ischium at the inferior part of the posterior horn of the acetabulum, obtaining less than 6 mm LLD in 87% of cases. Using a similar device, Konyves and Bannister [51] reported a mean 9-mm LLD, and Matsuda et al. [44] 2 mm (versus 4 mm without the ancillary). Bose [20] used a metal pin in the iliac wing with a level to position the limb horizontally, achieving a mean LLD of 3.4 mm according to the caliper, versus 8.8 mm without the caliper. Jasty et al. [19], using a caliper fixed to the summit of the iliac wing, reported only 13% postoperative LLD exceeding 5 mm. Takigami et al. [43], using a caliper fixed 2 to 3 cm above the acetabulum, reported a mean postoperative LLD of 4.2 mm (range, 0–13 mm). In 2003, Shiramizu et al. [41] compared a series of patients operated on with or without use of an L-shaped caliper fixed on the anterosuperior iliac crest with the long arm parallel to the limb: mean postoperative LLD was 2.1 ± 1.5 mm using the caliper, versus 8.2 ± 3.8 mm without (P = 0.0001). Other authors [25,40,42,47,49] likewise reported benefit with similar devices for controlling limb-length but none, except for Kutz [52] and Renkawitz et al. [53], assessed restoration of offset. Renkawitz et al. [53] developed a reference system glued to the operative drape, and reported good correlation between pre- and postoperative measurements for limb-length (r = 0.92; P < 0.0001) and offset (r = 0.97; P < 0.001). Kutz [52], using the original superior approach described by Murphy et al. [54] with endofemoral preparation of the femur ahead of neck sectioning, reported significantly improved control of limb-length (P = 0.0004) but not of offset (P = 0.17).

The second objective of the present study was to determine whether the LODD could quantify change in length and offset due to surgery. Results indicated good quantification of postoperative change in the former but not the latter: there was no significant difference between peroperative LODD and pre/postoperative X-ray measurement of length change, whereas the difference was significant for offset. Ranawat et al. [18] reported good correlation (r = 0.82) for LLD as measured by caliper and on X-ray. Likewise, Shiramizu et al. [41] reported a significant correlation (P < 0.0001) between per- and postoperative measurements in their caliper group. Using the technique described by Kurtz [52], peroperative and radiographic measurements showed good correlation for limb-length (mean difference -0.1 mm; r = 0.89) but less so for offset (mean difference -0.4 mm; r = 0.57). Thus, the LODD measurer seems to be reliable; its accuracy depends on adherence to certain technical imperatives. Firstly, limb position during the various peroperative measurements must be reproducible. Sarin et al. [21] demonstrated that a slight difference in limb position induced considerable difference in measurement: a deviation of 5° in abduction/adduction led to 8 mm apparent difference in limb-length. Following the literature, we set the reference position as the hip in extension in the axis of the body. Wixson and MacDonald [38] designed a navigation technique for keeping the limb in the same position during surgery. The second imperative is stable peroperative pelvis fixation, as a change in femur positioning relative to the pelvis induces...
error in limb-length and offset measurement [18]. Ranawat and Rodriguez [12] showed that pelvic tilt caused an apparent limb-length discrepancy. Di Gioia et al. [55], studying pelvic movement during THA in lateral decubitus, reported 23° (from −15.9 to 7.0°) rotation in abduction/adduction, 16° (from −8.1 to 7.5 mm) in flexion/extension and 40° (from −19.5 to 20.1°) in version. There is thus a risk of error using an ancillary fixed to the pelvis, and the further the fixation screws or nails are situated from the center of rotation of the hip, the greater the error is likely to be [18]. The distance between this iliac reference point and the center of rotation of the hip therefore needs to be kept to a minimum, as is the case with the LOOD device. It is also necessary to reduce this distance in order to reduce bias in peroperative measurement: Shiramizu et al. [41] showed that, if the measuring device and the femoral reference point were not in the same axis, parallel to the femur, data collection would be biased by lack of parallax. Unlike the LOOD ancillary, most measuring devices reported in the literature use the anterosuperior iliac crest as reference, although it is remote from the center of rotation of the hip and not in the axis of the femur. Ranawat et al. [18] positioned their pin in the posterior infra-acetabular groove to be closer to the center of rotation.

Conclusion

The LOOD device is a useful means of improving control of limb-length and offset during THA on a posterolateral approach.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

References


