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# A Simple Method Using a PACS to Minimize Leg Length Discrepancy in Primary THA A Method to Minimize Leg Length Discrepancy

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ABSTRACT

We determined whether a PACS-based method (head-lesser trochanter distance [HLD]) better equalized leg length discrepancy (LLD) after primary THA than a conventional method. We retrospectively reviewed 312 patients (379 hips) with osteonecrosis or primary osteoarthritis who underwent primary cementless THA: 198 patients (240 hips) underwent THA using the HLD method, while the conventional group consisted of 114 patients (139 hips) in whom we measured with the method of McGee and Scott. We then compared the LLDs in the two groups. We observed no difference in the mean postoperative LLD. A higher percentage of patients in the HLD group had an LLD less than 6 mm: 81% vs 68% hips, respectively. HLD method decreases the possibility of an LLD over 6 mm after THA.



Substantial leg length discrepancy (LLD) after THA can be associated with complications, including sciatic, femoral, and peroneal nerve palsies [1,2], lower back pain [3,4], abnormal gait [5,6], and dislocation [7]. In addition, patient dissatisfaction with the LLD has been the most common reason for litigation after THA [1]. LLD has been perceived in between 6% and 32% of patients, and was perceived when shortening exceeds 10 mm and lengthening 6 mm [8]. Even for highly skilled surgeons it is challenging to obtain equal leg length during surgery.

A variety of methods have been described for minimizing LLD, including preoperative templating [9–11] and intraoperative techniques, such as the shuck test [12], comparing the dimensions of the resected bone with the dimensions replaced by the prosthesis [10,13], use of mechanical jigs and measuring calipers [14–16], and use of reference pins driven into the pelvis [17–19]. None of these studies discussed the accuracy of the measurement technique or reported the correlation between the predicted and actual lengths.

The use of a picture archiving communication system (PACS) has led some institutions to abandon conventional plain film radiography. Fowler et al reported that the mean measured values were very accurate (within 0.1 mm for a known distance of 3.2 mm) when using PACS measuring tools, the standard deviation of measurements (0.5 mm) could affect the interpretation of data [20]. Because a 1-mm difference in measuring the leg-length discrepancy is unlikely to be clinically significant, we reasoned that a PACS could be used to measure LLD [20].

We examined (1) whether the head-lesser trochanter distance (HLD) method reduced LLD after primary THA, based on the postoperative LLD and (2) whether the distribution of the LLD was comparable with the results of preoperative templating and use of the conventional method of McGee and Scott [18].

## Patients and Methods

We retrospectively reviewed 363 patients (438 hips) who underwent primary THA between March 2002 and March 2009. Of these, we excluded 39 patients (44 hips) for one of the following reasons: previous trochanteric osteotomy (14 patients, 14 hips), previous pelvic osteotomy (12 patients, 16 hips), severely dysplastic hips with a simultaneous shortening osteotomy of the femur (eight patients, eight hips), and prior septic arthritis (five patients, five hips). Of the remaining 324 patients (394 hips), 12 patients (15 hips) did not have the appropriate radiographs for analysis (no AP pelvis radiograph at index arthroplasty). This left 312 patients (379 hips) who had a minimum 2-year followup (mean, 67 months; range, 27–108 months) and radiographs available for review at both the index THA and latest clinical followup. These were divided into two groups based on which procedures were used preoperatively and intraoperatively to equalize the leg length during THA. In the THAs performed between March 2002 and September 2007 (114 patients, 139 hips), the leg length was equalized using preoperative templating and intraoperative distance measurement with a u-shaped reference pin, as described by McGee and Scott [18] (conventional group). Our study

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was a comparative cohort study with patients undergoing the McGee and Scott method serving as a control group.

In the THAs performed between October 2007 and March 2009 (198 patients, 240 hips), the leg length was equalized using the PACS (HLD). All of the data used for this study were retrieved from our institution's database; we did not see or contact patients specifically for this study. We received institutional review board approval for the study.

A power analysis (alpha = 0.05; n = 312; differences, 5 mm; SD, 5.42) was performed to determine whether the sample size was appropriate for the analysis (Student's t-test) of the LLD of each group, resulting in a *P* value of 1.0.

We compared the two groups with respect to age, BMI, and the preoperative Harris hip score (HHS) [21] using a student t-test and gender and diagnosis using chi-square test (Table 1). There were no differences in age, gender, or diagnosis characteristics between the HLD and conventional groups.

For all surgeries, we made a preoperative plan and performed templating on standardized plain radiographs on a PACS. The radiographs consisted of an AP view of the pelvis centered over the pubic symphysis, with the contralateral nonarthritic hips in 10º to 15° of internal rotation, and lateral views of both hips. We presumed that if the actual distance from the center of the femoral head to the superior end of the lesser trochanter (the HLD) were about the same for both hips, the leg length after THA would be equal. The prevalence of anatomic inequality was found to be 90%, the mean magnitude of anatomic inequality was 5.2 mm (SD 4.1) [22]. We selected 200 people, who do not complain of leg length discrepancy and LLD was less than 5 mm measured by slit scanogram. The difference was calculated between HLD of both hips. Two investigators (YWL, YJC) independently evaluated the results to assess the interobserver variation and reliability. The average difference was 1.01 mm (SD, 0.89) with a range of 0 mm to 4.2 mm. The ICC for interobserver reliability was 0.897.

Consequently, the HLD of the opposite hip was measured on a PACS preoperatively, and the HLD was equalized by selecting a suitable modular head during surgery (HLD method). Using these plain radiographs, we measured the HLD and determined the implant combination. We recorded the data on the PACS and viewed it on a monitor in the operating theater. We used a magnification marker for all preoperative and postoperative radiographs in the HLD group (Fig. 1). In case of bilateral hips, all surgeries were performed staged. At the first stage, we underwent THA according to pre-operative templating, and at the second stage THA, we measured the preoperative HLD of the opposite hip, assuming that the opposite hip referred normal. In the conventional group, a 20% oversized transparent acetate sheet was used on the radiograph with a fixed focus film distance of 1150 mm, producing a mean magnification of 120%.

The same surgeon (YSK) performed all surgeries through a modified posterolateral approach. The surgical procedures were generally the same in both groups: patients were placed in the lateral decubitus position, and a posterolateral approach was used in all cases. The difference between the procedures was the method used to select the modular head. In the conventional group, the surgeon inserted a u-shaped pin in the anterior superior iliac spine before making the incision and checked the location of the end of the pin on the lateral thigh. After broaching the femur, the surgeon positioned the femoral component determined in the preoperative templating, and selected the modular head based on the checkpoint and tip of the u-shaped pin, as described by McGee and Scott [18]. In the HLD group, the surgeon first inserted a trial modular head with a 7-mm long neck, and then used a ruler to measure the distance between the center of the trial head and the superior edge of the lesser trochanter (Fig. 2). Based on the preoperative HLD of the contralateral hip, the surgeon selected the modular head that gave the distance nearest to the planned neck length. For both groups, after the final modular head was inserted, the hip was reduced. Finally, the surgeon inserted a drain and closed the wound. Thirty-seven patients underwent bilateral THA in the HLD group. Regardless of whether a simultaneous or staged THA was performed, one hip served as the contralateral side to obtain the intraoperative HLD. On the first operation, we underwent THA according to pre-operative templating, and measuring and recording the HLD during operation. And then, at the second operation, modular head was selected according to the previously measured HLD.

To validate the accuracy on PACS measuring method, we first measured the acetabular cup diameter (A) and 10-cm magnification bar (B) using PACS measurement tools. The acetabular cup diameters using PACS (C) were calculated (C = A*100/B). The difference was calculated between C and the real diameter recorded in chart. Two investigators (YWL, YJC) independently evaluated the results to assess the interobserver variation and reliability. One investigator in each group repeated the measurements 2 weeks later to assess the intraobserver variability in the corresponding technique. The average difference was 0.88 mm (SD, 0.69) with a range of 0 mm to 2.8 mm. The ICCs for interobserver reliability intraobserver reliability were 0.855, and 0.965, respectively.

We assessed the LLD 6 months postoperatively using the method described by Ranawat et al [19]. On an AP radiograph of the pelvis, we drew a horizontal reference line through the inferior aspect of the teardrops (the perpendicular distance between the reference line and lesser trochanter; Fig. 3). Two investigators (YWL, YJC) independently evaluated the results with each method to assess the interobserver variation and reliability within each technique. One investigator in each group repeated the measurements 4 weeks later to assess the intraobserver variability in the corresponding technique. They assessed the intermethod variation and reliability of the LLD using all of the measurements made within each technique. The investigators who made the measurements were familiar with digital assessment. As the neck shaft angle and offset of the Bencox (Corentec, Seoul, Korea) and Corail (DePuy Orthopaedics, Inc, Warsaw, IN, USA) stems were the same, there was no variance depending on the type of stem. We evaluated the HHS [21] for pain and function preoperatively and 2 years postoperatively. The average difference of LLD between the observers was 0.97 mm (SD, 0.54) with a range of 0 mm to 1.8 mm. The ICCs for interobserver reliability intraobserver reliability were 0.822, and 0.913, respectively.

We compared the means of all numeric variables (age, BMI, HHS, and LLD) of the two groups using Student's t-test. The gender distribution and dislocation rate among groups were examined using the chi-square test. We subdivided the LLD into two groups (LLD less than 6 mm and LLD greater than 6 mm) and compared them using the Mann–Whitney u-test. We performed statistical analyses using SPSS (Version 11.5; SPSS, Chicago, IL, USA).

**Table 1**
Patient Data.

| Variable | HLD Group | Conventional Group | *P*-Value |
|---|---|---|---|
| Number of patients (hips) | 198 (240) | 114 (139) | |
| Mean age (years) | 51.4 ± 14.2 | 52.5 ± 14.4 | 0.579 |
| Gender (male/female) | 124/74 | 67/47 | 0.956 |
| Mean BMI (kg/m$^2$) | 24.2 ± 8.1 | 23.9 ± 7.9 | 0.648 |
| Diagnosis (AN/OA) | 179/61 | 96/43 | 0.374 |
| Mean Harris hip score (range) | 47.2 (17–78) | 46.8 (14–76) | 0.784 |
| Mean followup period (months) (range) | 36.2 (27–48) | 79.6 (47–108) | |
| Prosthesis (number of hips) | Bencox (240) | Corail stem with Duraloc cup (139) | |

HLD = head-lesser trochanter distance ; AN = avascular necrosis; OA = primary osteoarthritis; Bencox total hip system (Corentec, Seoul, Korea); Corail hip system (DePuy Orthopaedics, Inc., WarsawIN, USA); Duraloc acetabular cup system (DePuy).


**Fig. 1.** (A–F) These images show the procedure for preoperative templating of the HLD. (A) The 10-cm magnification bar. (B) We checked and altered the location of the magnification bar in the lateral femur view to place the same level between femur and magnification bar. (C) The bar must be located in the medullary canal for an accurate magnification rate. (D) The radiographs consisted of an anteroposterior view of the pelvis centered over the pubic symphysis, with the contralateral nonarthritic hips in 10º to 15° of internal rotation, and lateral views of both hips. (E) We adjust the film scale with the magnification marker with 10-cm, and (F) record the data on implant composition and HLD on the PACS and display it on the monitor system in the operating theater.

**Fig. 2.** This photograph shows the intraoperative measurement of the HLD. The arrow indicates the center line of the trial head. The free end of the ruler is located at the superior end of the lesser trochanter.

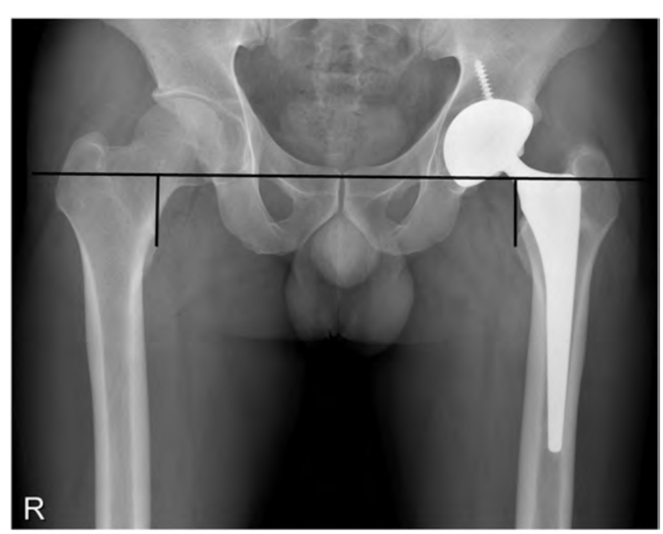


**Fig. 3.** This radiograph shows the postoperative measurement of limb-length discrepancy.

## Results

We observed no difference ($P = 0.182$) in the mean postoperative LLD in the HLD group and in the conventional group: 1.5 ± 4.2 mm (range, 0–11 mm) and 5.4 ± 6.9 mm (range, 0–19 mm), respectively. A higher percentage ($P = 0.038$) of patients in the HLD group had an LLD less than 6 mm after surgery than in the conventional group: 160 of 198 (81%) hips vs 77 of 114 (68%) hips, respectively (Table 2). The mean HHS after THA improved from 47.2 to 93.3 in the HLD group and from 46.8 to 91.8 in the conventional group (Fig. 4). One patient had an LLD greater than 10 mm in the HLD group resulting from an acetabular cup position located above the anatomical position. The mean LLD of the 42 hips for which we referred to the contralateral side to obtain the intraoperative HLD was 1.9 ± 2.4 mm (range, 0–7 mm).

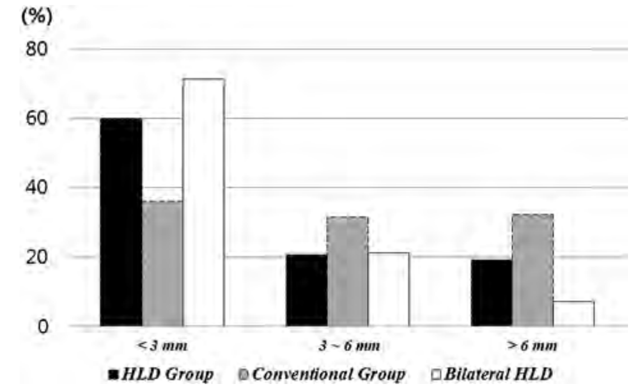


**Fig. 4.** This graph shows the distribution of the LLD in the HLD, conventional, and bilateral HLD groups.

## Discussion

Digital radiography and a PACS system make it possible to accurately measure small anatomic distances and thereby enhance the accuracy of surgical procedures. We presumed that if the actual distance from the center of the femoral head to the superior end of the lesser trochanter (the head-lesser trochanter distance or HLD) were about the same for both hips, the leg length after THA would be equal. We found that a higher percentage of patients in the HLD group had an LLD of less than 6 mm when compared to leg length in patients in which the conventional method of McGee and Scott was used. However, even with the apparent greater accuracy of the HLD method, there were no differences between HHS in the two groups. The HLD proved to be accurate when matching leg lengths in patients undergoing bilateral hip arthroplasty.

There were several limitations to our study. First, because the HLD method does not account for acetabular positioning, when the acetabular cup was not positioned anatomically, the leg length was not equalized. Konyves and Bannister [23] have shown that 98% of true post-operative LLD was related to the position of the femoral component. In cases of patients with a severe acetabular deformity, the conventional method and the HLD method should be combined to correct the fault of the HLD method. Second, improper positioning of the magnification maker can result in errors when correcting for magnification on the pre-operative radiographs. To overcome this problem, we always checked the lateral hip radiograph to confirm that the magnification marker was at the same level as the femur (Fig. 1C). Third, a centerline was marked on the trial modular heads for the Bencox system (Fig. 2), but not for the other hip systems used; therefore, it was possible to make an error during surgery if the other system was used. Fourth, the HLD does not account for femoral offset. Failure to correctly reproduce this parameter can result in instability of the joint. Fifth, the greatest source of error may be use of a ruler at surgery to measure the HLD. We attempted to decrease this error by repeating the measurement several times during surgery.

Even with highly skilled surgeons, equal leg length cannot be guaranteed after THA. A reliable intraoperative method should be used to obtain the optimal length. McGee and Scott [18] used a method in which a Steinmann pin was driven in 2 cm superior to the acetabulum and bent into a "u" shape; a mark was made at the point where the free end of the "u" contacted the greater trochanter [18]. The pin was swiveled out of the operative field and returned during measurements. In our study, the mean postoperative LLD was 5.4 mm (range, 0–19 mm). Bose [14], Jasty et al [24], and Shiramizu et al [16] used a variety of measuring calipers, resulting in a mean postoperative LLD between 2.1 and 5.4 mm. Woolson [13] determined the amount of femoral bone needing resection to equalize leg length in preoperative planning, and chose the modular femoral head before surgery. In that study the mean LLD was 2.9 mm before surgery and 1 mm after surgery. Gonzalez et al [25] and Matsuda et al [26] reported a method of measuring the actual HLD preoperatively and reproducing it in the operative field with a modular neck system, resulting in a mean postoperative LLD between 1.71 and 2 mm. However, the radiographs used for the preoperative templating did not consistently give an exact magnification ratio. In our study, the mean postoperative LLD was 1.5 mm in the HLD group (Table 3).

Gonzalez et al [25] reported that the postoperative LLD was within 5 mm in 90 of 103 (87%) hips. Although the measurement method was similar to ours, cemented femoral components were used for all cases in their study. Matsuda et al [26] reported that the postoperative

**Table 2**
Postoperative Data.

| Parameter | HLD Group | Conventional Group | Bilateral HLD Group |
|---|---|---|---|
| Mean LLD, mm[a] | 1.5 ± 4.2 | 5.4 ± 6.9 | 1.9 ± 2.4 |
| <3 mm[b] | 119 (60.0) | 41 (36.0) | 30 (71.4) |
| 3–6 mm[b] | 41 (20.7) | 36 (31.6) | 9 (21.4) |
| >6 mm[b] | 38 (19.3) | 37 (32.4) | 3 (7.2) |
| Harris hip score[c] | 93.3 (65–100) | 91.8 (58–100) | 95.1 (84–100) |

[a] Mean ± standard deviation.
[b] Number of hips (%).
[c] Mean (range).

**Table 3**
Literature Review.

| Study | Mean LLD | Methods |
|---|---|---|
| Woolson [13] | 1 mm | Comparing the dimensions of the resected bone with the dimensions replaced by the prosthesis |
| Bose [14] | 3.4 mm | Use of measuring calipers (The Acculength hip gauge device) |
| Jasty et al [15] | 5.4 mm | use of mechanical jigs and measuring calipers |
| Ranawat al. [19] | 7.4 mm | A vertical Steinmann pin at the infracotyloid groove of the acetabulum. |
| Shiramizu et al [16] | 2.1 mm | Use of measuring L-shaped caliper |
| McGee and Scott [18] | 5.4 mm[a] | A Steinmann pin was driven in 2 cm superior to the acetabulum and bent into a "u" shape; a mark was made at the point where the free end of the "u" contacted the greater trochanter |
| Matsuda et al [26] | 2 mm | Measuring the actual HLD preoperatively and reproducing it in the operative field with a modular neck system. |
| Gonzalez et al [25] | 1.71 mm | Measuring between the proximal edge of the lesser trochanter and the center of rotation of the femoral head |
| Lim et al [current study] | 1.5 mm | Measuring head to lesser trochanter length using PACS, and reproducing it in the operative field with a modular neck system. |

LLD = leg length discrepancy.
[a] Result of current study.

LLD was less than 5 mm for 40 of 45 (89%) hips. We also observed a difference in postoperative LLD less than 6 mm in the HLD group and in the conventional group: 160 of 198 (81%) hips and 77 of 114 (68%) hips, respectively. Other studies and our study suggested that the HLD method had an advantage in reducing the possibility of severe LLD after THA.

The HLD method had several advantages compared with other intraoperative measurement methods. Both the preoperative measurement and intraoperative procedure were simple and easy. There was no need to prepare additional devices or perform manipulations, and no need for additional invasive procedures; we only need a ruler. This method was not affected by an unexpected femoral stem size or positioning, which sometimes occurs in cementless implant fixation. In addition, when the contralateral hip was operated on using this method, the previous intraoperative HLD could be verified and applied. Nevertheless, the method had some limitations. Theoretically, errors arising from the position of the acetabular component could not be overcome. If the acetabular component was placed above the true acetabulum, and this was not recognized, the leg would be shortened. Our series involved one case of dysplastic hip surgery with this error. In terms of equipment, the trial modular heads used in this method needed to be ready-made with a circumferential equatorial line marked through the center of the head. It was important that the end of the ruler on the lesser trochanter was placed accurately in a constant location. Although we found the distance measured from the superior edge of the lesser trochanter was precise and reproducible, some patients had a less prominent lesser trochanter or one that was difficult to expose because of femoral retroversion.

In conclusion, the HLD method resulted in a small proportion of patients having an LLD over 6 mm after THA. The HLD method was a readily applicable, reproducible method for minimizing the occurrence of LLD.

## References


1. Hofmann AA, Skrzynski MC. Leg-length inequality and nerve palsy in total hip arthroplasty: a lawyer awaits! Orthopedics 2000;23:943.
2. 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.
3. Abraham WD, Dimon 3rd JH. Leg length discrepancy in total hip arthroplasty. Orthop Clin North Am 1992;23:201.
4. Giles LG, Taylor JR. Low-back pain associated with leg length inequality. Spine 1981;6:510.
5. Gurney B, Mermier C, Robergs R, et al. Effects of limb-length discrepancy on gait economy and lower-extremity muscle activity in older adults. J Bone Joint Surg Am 2001;83:907.
6. Edeen J, Sharkey PF, Alexander AH. Clinical significance of leg length inequality after total hip arthroplasty. Am J Orthop 1995;24:347.
7. Woo RY, Morrey BF. Dislocations after total hip arthroplasty. J Bone Joint Surg Am 1982;64:1295.
8. Sarangi PP, Bannister GC. Leg length discrepancy after total hip replacement. Hip 1997;7:121.
9. Carter LW, Stovall DO, Young TR. Determination of accuracy of preoperative templating of noncemented femoral prostheses. J Arthroplasty 1995;10:507.
10. Eggli S, Pisan M, Muller ME. The value of preoperative planning for total hip arthroplasty. J Bone Joint Surg Br 1998;80:382.
11. Unnanuntana A, Wagner D, Goodman SB. The accuracy of preoperative templating in cementless total hip arthroplasty. J Arthroplasty 2009;24:180.
12. Charnley J. Total prosthetic replacement of the hip. Reconstr Surg Traumatol 1969;11:9.
13. Woolson ST. Leg length equalization during total hip replacement. Orthopedics 1990;13:17.
14. Bose WJ. Accurate limb-length equalization during total hip arthroplasty. Orthopedics 2000;23:433.
15. Jasty M, Webster W, Harris W. Management of limb length inequality during total hip replacement. Clin Orthop Relat Res 1996;333:165.
16. 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.
17. Huddleston HD. An accurate method for measuring leg length and hip offset in hip arthroplasty. Orthopedics 1997;20:331.
18. McGee JMJ, Scott JHS. A simple method of obtaining equal leg length in total hip arthroplasty. Clin Orthop Relat Res 1985;194:269.
19. Cs Ranawat, Rao RR, Rodiguez JA, et al. Correction of limb-length inequality during total hip arthroplasty. J Arthroplasty 2001;16:715.
20. Fowler J, Ilyas A. The accuracy of digital radiography in orthopaedic applications. Clin Orthop Relat Res 2011;469:1781.
21. Harris WH. Traumatic arthritis of the hip after dislocation and acetabular fractures: treatment by mold arthroplasty: an end result study using a new method of result evaluation. J Bone Joint Surg Am 1969;51:737.
22. Knutson GA. Anatomic and functional leg-length inequality: a review and recommendation for clinical decision-making. Part I, anatomic leg-length inequality: prevalence, magnitude, effects and clinical significance. Chiropr Osteopat 2005;20:13.
23. Konyves A, Bannister GC. The importance of leg length discrepancy after total hip arthroplasty. J Bone Joint Surg Br 2005;87:155.
24. Cole RJ, Bindra RR, Evanoff BA, et al. Radiographic evaluation of osseous displacement following intra-articular fractures of the distal radius: reliability of plain radiography versus computed tomography. J Hand Surg Am 1997;22:792.
25. Gonzalez Della Valle A, Slullitel G, Piccaluga F, et al. The precision and usefulness of preoperative planning for cemented and hybrid primary total hip arthroplasty. J Arthroplasty 2005;20:51.
26. Matsuda K, Nakamura S, Matsushita T. A simple method to minimize limb-length discrepancy after hip arthroplasty. Acta Orthop 2006;77:375.