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ORIGINAL ARTICLE

Hip-Sparing Equalization Procedures for Leg-Length Discrepancy After Total Hip Arthroplasty: A Retrospective Case Series

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Abstract *Background:* Leg-length discrepancy (LLD) after primary THA is not uncommon. Little is known, however, about the role of hip-sparing procedures for equalization of LLD after THA. *Questions/Purposes:* The aim of this study is to report our experiences with these techniques in patients presenting at one institution over a 10-year period. *Methods:* We retrospectively reviewed records at one institution to find patients who had sought surgical treatment for LLD after THA between January 2007 and August 2017. Patients who had LLD related to conditions other than the THA, such as bone loss or traumatic defects, were excluded. We recorded the time after THA, laterality, and LLD. Assessment of LLD was performed using clinical and radiographic examinations. Patient demographics and true LLD were recorded, as were prior conservative treatment, equalization procedure performed, final leg length after equalization surgery, time to healing, and complications. *Results:* After exclusion of patients with LLD related to other causes, eight patients in whom conservative treatment had failed and who had undergone hip-sparing leg-length equalization surgery were included in the study. The average age was 44.6 years (range, 18 to 66 years). Seven of the patients were female. The preoperative mean LLD was 3.1 cm (range 1.5 to 7 cm). In those who were long after THA, ipsilateral (THA-side) shortening of femur with a retrograde intramedullary nail (IMN; $n = 1$) or with a plate ($n = 1$) was performed. In those who were short after THA, ipsilateral femur lengthening with retrograde Precice nails ($n = 2$), ipsilateral tibial lengthening with Precice nails ($n = 2$), or contralateral femur shortening with a retrograde IMN ($n = 2$) was performed. The average time to full consolidation or union was 6.6 months (range, 2 to 19 months). Two patients had delayed union. All patients but one were satisfied with final results. *Conclusion:* We believe that hip-sparing equalization procedures can be part of the treatment algorithm of LLD after THA. These advancements in the field are promising and might expand the indications of lengthening and equalization procedures to include LLD after THA.

Keywords total hip arthroplasty · leg length discrepancy · hip replacement

Level of Evidence: Level IV: Retrospective Case Series

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Introduction

Leg length symmetry after primary THA can be challenging, and leg-length discrepancy (LLD) is not uncommon. Studies have found that 30 to 43% of patients perceive LLD after primary THA [12, 25]. Moreover, it is well recognized that LLD after THA is a major source of back pain, gait disorders, and patient dissatisfaction and increases the risk of revision surgery (it also increases surgeons' risk of malpractice suits) [16, 19, 26].

Most of the literature on LLD after THA has focused on prevention, risk factors, and conservative treatments, but little is known about available surgical options for the condition. Currently, the primary surgical option is revision arthroplasty. Although revision THA can correct LLD, the risks of post-operative hip instability caused by compromised soft tissue tension and bone loss associated with the revision make for unpredictable outcomes.

Over the past decade, there have been significant advancements in the area of limb lengthening and reconstruction [9]. These have the potential to expand the list of indications for limb-equalization procedures (for both lengthening or shortening) to include LLD after THA. Until now, limb-lengthening techniques in adults have been limited to the use of external-fixation devices [20]. Although these devices have proved successful, newer methods, involving internal lengthening with intramedullary nails, have reduced the complication rates associated with the treatment of LLD, such as infections and stiffness in adjacent joints [14]. Furthermore, the use of motorized lengthening nails in patients with existing artificial joints eliminates the possibility of pin-site infection and lowers the risk of peri-prosthetic joint infection (PJI).

Our aim in this study is to provide a comprehensive description of our experiences with using hip-sparing equalization procedures to treat LLD after THA.

Materials and Methods

After receiving institutional review board approval, we retrospectively reviewed the medical and radiographic records of all patients who visited our office seeking a surgical treatment for LLD after THA from January 2007 to August 2017. Patients who had LLD related to conditions other than the THA, such as bone loss or traumatic defects, were excluded, and eight patients were eligible for and included in this study. All patients underwent surgical limb-length equalization procedures. Four of these patients had hip dysplasia before THA. The other four had primary osteoarthritis of the hip before THA. The average age was 44.6 years (range, 18 to 66 years). Seven of the eight patients were female.

We recorded the time after THA, laterality, and LLD. Prior conservative treatments, type of length-equalization surgery, final leg length after surgery, time to healing, and complications were recorded. Assessment of LLD was performed using both clinical and radiologic evaluations as has been described previously [8]. The LLD measurement signifies the overall contributions from true LLD (shortening or lengthening resulting from THA) and apparent LLD (resulting from muscle contracture), as well as any LLD that was present before THA.

To assess LLD, the patient was asked to be standing without any aids. Blocks of various heights were then placed under the short lower extremity until the patient felt comfortable and the legs were of equal length with no pelvic tilt. For quantitative radiologic assessment of LLD, we obtained digital anteroposterior (AP) 51-in standing hip-to-ankle films with an appropriately sized block under the short extremity; the patient stood with the feet shoulder width apart, the knee joints extended, and the patellae facing forward.

All radiographs were imported into an electronic patient communication system and corrected for magnification error using software calibration with a metal sphere, 25 mm in diameter, placed on all images. To determine the extent of LLD, we measured the distance between the superior aspect of each hip to a horizontal line marked across the pelvis (Fig. 1). The horizontal pelvic line can be determined from the iliac crests, the sacroiliac joints, or the ischial tuberosities. In each patient, we determined which of these three horizontal pelvic lines was most representative on the basis of the pelvic shape, visibility on X-ray, and reconciliation with the physical examination. The difference was subtracted from the wooden block height if the ipsilateral (THA-side) iliac crest was higher (in other words, the leg was longer) than the one on the contralateral side. The wooden block height was added if the ipsilateral iliac crest was lower (the leg was shorter) than one on the contralateral side. That difference was the value used in equalizing the limbs. Two observers, the senior author and a joint-arthroplasty and limb-lengthening fellowship-trained surgeon, performed the analyses. If there was a discrepancy in values or between the two observers, they discussed it to reach agreement on a final measurement.

In patients who underwent surgical lengthening, we used the Precice® intramedullary lengthening nail. The Precice nail is a magnet-operated, telescopic internal lengthening device (NuVasive Specialized Orthopedics®, Aliso Viejo, CA, USA) [4, 7, 11]. The nail contains a magnet that is connected to a gear box internally. Elongation of the nail occurs through communication between the internal magnet and two revolving magnets within an external remote control unit. The external unit can be used to adjust the distraction rate. The nail we used had a maximum lengthening capacity of 80 mm. The unit was programmed to achieve 1 mm of lengthening per day (splits to 0.25 mm four times a day [tibia] or 0.33 mm three times a day [femur]) until the desired length was achieved. The split rate of 1 mm was modified as necessary on the basis of the radiographic evidence of bone growth during bimonthly follow-up appointments.

The surgical technique we used for tibial lengthening was as follows: patients were positioned supine on a radiolucent table with the image intensifier located on the contralateral side. The sites where the tibial and fibular osteotomy were to be performed were marked on the skin under fluoroscopic guidance. A transverse osteotomy was then performed using a 2-cm incision at the junction of the middle and distal thirds of the fibula, followed by prophylactic percutaneous anterior compartment fasciotomy using a separate 2-cm proximal incision. Multiple holes were then drilled percutaneously at the tibial osteotomy site using a 4.8-mm bit. The holes helped to vent the canal during reaming to help reduce the possibility of fat embolism. Next, the knee was maximally flexed and nail entry was achieved through a transpatellar approach with biplanar fluoroscopic guidance. Flexible reamers were used to enlarge the canal in 0.5-mm increments. The canal was reamed to achieve a diameter that was 2 mm larger than the nail diameter. In addition, one Steinmann pin (2.4 mm in diameter) was inserted in the proximal tibia (posterior to the nail path) and another was placed in the distal tibia (both pins were placed from medial to lateral). The Steinmann pins were placed parallel to one another and functioned as rotational markers to ensure that the tibial rotation profile remained unchanged after the tibial osteotomy. The knee was then brought to full extension, and a low-energy tibial osteotomy was completed with sharp osteotomes under fluoroscopic guidance. The knee was manually held in reduced position and then maximally flexed.

The Precice nail was assembled and then inserted and locked proximally and distally. Before inserting the distal locking screws, the rotational markers were checked to confirm the correct rotational profile. One syndesmotic screw was placed proximally and one was placed distally to prevent strain across the tibiofibular joint during the lengthening procedure. In our practice, we generally perform a gastrocnemius–soleus complex recession if the desired tibial lengthening is more than 2 cm to prevent ankle contracture. A blocking screw is inserted adjacent to the nail to prevent deformity if the canal diameter is larger than the nail at the osteotomy level.

The surgical technique used with the Precice femur retrograde lengthening nail has been thoroughly described [6]. The process of lengthening began on the fifth post-operative day in the femur and seventh post-operative day in the tibia. All patients were provided with the external magnet remote control for home use to perform the lengthening according to the daily distraction schedule. All patients were placed on a regimen of partial weight bearing until bone consolidation was achieved. Post-operative physical therapy was initiated during the hospital stay and lasted until the end of the distraction period. Physical therapy was focused on range-of-motion exercises and strengthening in the hip, knee, and ankle. Patients were followed both clinically and radiographically every 2 weeks to monitor bone formation during the active distraction phase. They were then seen once a month until complete bone consolidation was obtained.

At their final follow-up visit, patients were asked whether they would be willing to undergo surgical lengthening again. For our purposes, this served as our best measure of patient satisfaction with the surgery.

Results

Basic demographic and clinical information, including results of surgery, are shown in Table 1, and the hip-sparing equalization procedures used are summarized in Table 2. In two patients, the extremity on which THA had been performed was longer; in six patients, it was shorter. Presurgery symptoms related to LLD and pelvic tilt included abnormal gait in all patients and back pain in two (patient numbers 6 and 7 in Table 1). Attempts at conservative management (including the use of shoe lifts and physical therapy) had failed, but no patients appeared to have any intrinsic problems with the position or stability of the hip implant.

The mean time of presentation at the clinic after THA was 2 years (range, 6 months to 3 years). In the six patients with a shorter THA-side leg, physical therapy included hip flexor and abductor stretching for at least 3 months. In the two with a longer leg, physical therapy was focused on adductor stretching and abductor strengthening. All patients experienced some relief of symptoms with a shoe lift, but they did not wish to use a permanent shoe lift and wanted a surgical solution.

The mean pre-operative LLD was 3.1 cm (range, 1.5 to 7 cm), and the mean time to bone consolidation or union was 6.6 months (range, 2 to 19 months). The mean post-lengthening LLD was 2.6 mm (range, 0 to 7 mm). All patients were walking independently without the need for a shoe lift at the final follow-up visit. The mean recorded follow-up period was 33.8 months (range, 18 to 66 months). Figure 1 illustrates the case of a patient who underwent an equalization procedure with a motorized lengthening nail. Figure 2 shows the final result in a patient who underwent an equalization procedure with a plate technique.

Union was delayed in two of the eight patients. Seven of the eight patients answered "yes" to the question "Would you undergo this limb-equalization procedure again?" The patient who was not satisfied with the equalization procedure had delayed union at the shortening osteotomy site and underwent two additional procedures (exchange nailing at 4 months after surgery and compression nailing technique at 17 months after surgery). The patient had clinical and radiologically confirmed union at 19 months of follow-up.

Discussion

Little research has focused on hip-sparing equalization surgery to correct LLD after THA. Most of the available literature has focused on preventing LLD after THA [1, 5, 21], and little is known about the surgical management of this condition. This is likely because the available surgical options have been limited to revision arthroplasty or contralateral THA (when indicated). In this paper, we report our experience with these procedures, focusing on patients' clinical data, residual LDD, time to healing, and complications. Conservative management had failed in all eight patients, and all desired surgical intervention. Various equalization procedures were performed (Table 2). The average time to bone consolidation or union was 6.6 months, and the residual LLD after surgery was 2.6 mm. The reported complications were delayed union in two patients, a risk that needs to be discussed with patients. No patient had a PJI during follow-up. Seven of the eight patients reported being satisfied with the equalization procedures. These results are encouraging, and we believe that hip-sparing equalization procedures can be added to treatment algorithms for LLD after THA.

The primary limitation of this study is our small sample size. LLD after THA is, for the most part, managed conservatively, and only rarely do patients seek surgical management. It is possible that these hip-sparing equalization procedures are not widely known among arthroplasty surgeons and that, as a consequence, patients may not be offered corrective surgical treatment. An additional limitation is that the study lacks an objective assessment of functional outcomes. These were not administrated as part of the

Table 1 Patients' basic demographics, clinical characteristics, treatment, and results

Patient no.	Age in years, sex	Side of THA	LLD	Equalization procedure	Time to union or full consolidation	Complications	Residual LLD	Follow-up period
1[a]	18, F	Left	25 mm short	Ipsilateral (THA-side) lengthening of the femur with a retrograde Precice nail	5 months	None	3 mm short	36 months
2	49, F	Right	21 mm short	Contralateral femur shortening with a retrograde nail	11 months	Delayed union but was successfully treated with exchange nailing	7 mm short	18 months
3	66, F	Right	15 mm long	Ipsilateral femur shortening with a retrograde nail	2 months	None	0	2 years
4	57, M	Right	15 mm long	Ipsilateral femur shortening with a plate	2 months	None	3 mm short	5 years
5[a]	49, F	Left	29 mm short	Ipsilateral tibial lengthening with a Precice nail	5 months	None	3 mm short	5 years and 6 months
6[a]	41, F	Left	65 mm short	Ipsilateral tibial lengthening with a Precice nail	5 months	None	5 mm short	
7[a]	21, F	Left	70 mm short	Staged ipsilateral femur lengthening with retrograde Precice nails (4 cm, then 3 cm)	4 months to full consolidation (4 cm lengthening) and 3½ months to full to full consolidation (3 cm lengthening)	None	0 mm	24 months
8	56, F	Right	15 mm short	Contralateral shortening of the femur with IMN	19 months	Delayed union with consequent exchange nailing at 4 months after surgery and compression nailing at 17 months. United at 19 months after initial surgery	0 mm	19 months

THA total hip arthroplasty, *LLD* leg-length discrepancy, *IMN* intramedullary nail
[a] Patient had hip dysplasia before THA

Table 2 Summary of hip-sparing equalization procedures ($N = 8$)

Type of LLD	Procedures used
Two patients were long in the ipsilateral (THA-side) extremity after THA	Ipsilateral shortening of femur with retrograde IMN ($n = 1$) Ipsilateral femur shortening with plate ($n = 1$)
Six patients were short in the ipsilateral extremity after THA (four had pre-existing hip dysplasia)	Ipsilateral femur lengthening with retrograde Precice motorized nails ($n = 2$), ipsilateral tibial lengthening with Precice nails ($n = 2$) Contralateral femur shortening with retrograde IMN ($n = 2$)

LLD leg-length discrepancy, *THA* total hip arthroplasty, *IMN* intramedullary nail

original treatment course, and the retrospective nature of the study makes such assessment impossible. Patients' reported willingness to undergo the procedure again, were it necessary, serves as a surrogate patient-reported outcome, and we acknowledge that the absence of validated pre- and post-surgery outcome scores limits the generalizability of our results. Finally, details regarding LLD that was present before THA were not available because seven of them underwent THA elsewhere. Such details could have added to our understanding of LLD after THA in this population.

LLD can occur after THA, despite extensive pre-operative planning and optimization of surgical techniques to equalize leg length [2, 17]. In some intra-operative circumstances, lengthening the extremity is difficult to avoid and results from the need to optimize soft tissue tension to prevent hip instability. Similarly, shortening of the extremity during THA may occur as a result of attempts to avoid stretching the sciatic nerve in those with known risk factors, such as hip dysplasia [3, 16]. After a postal audit survey of 1535 patients, Wylde et al. found that 30% of patients perceived LLD after THA [25]. Those who perceived LLD had significantly poorer midterm outcomes. Other researchers have found that LLD after THA is a major source of back pain, gait disorders, patient dissatisfaction, and malpractice lawsuits in the USA [16, 26]. Although revision arthroplasty is helpful for correcting the limb length when malposition of components is the primary source of lengthening or shortening [15], the potential bone loss and soft tissue compromise associated with revision techniques make outcomes difficult to predict. The use of external-fixation lengthening devices around implanted artificial joints can result in pin-site infection and PJI, and most surgeons do not consider this a viable hip-sparing option.

There is a lack of consensus on threshold for LLD that indicates a need for surgical correction. This lack of consensus is likely attributable to variety in the clinical and radiologic tools used for LLD assessment. In general, LLD of less than 1 cm can be treated with a shoe lift. According to some researchers, surgical options are generally reserved for those patients with LLD of more than 2 cm to prevent compensatory pelvic obliquity [22, 24]. Interestingly, in our report, three patients had LLD of less than 2 cm but a least 15 mm; conservative management had failed in all three, and all had sought out surgical correction. This highlights the negative effects even minimal LLD can have in patients after THA. In a recent study by Mavcic et al., it was found that each additional 5 mm of clinically measured LLD after THA increases risk of self-reported LLD by 38% [13]. In our practice, the LLD is calculated using a combination of radiologic and clinical assessments. We believe that the clinical assessment and use of wooden blocks are essential to optimize the accuracy of the digital radiographic measurement. Using the blocks reduces the likelihood of compensatory knee flexion (in the long leg) or pelvic tilt during standing when long hip-to-ankle radiographs are being obtained. To help determine whether the long THR side is tight, evaluation for hip flexion and abduction contracture using Thomas and Ober tests is helpful. It has been reported that using pelvic radiograph measurements alone to estimate LLD does not correlate with patients' subjective perception of LLD [23]. Furthermore, Mavcic et al. found clinical measurement of LLD after THA to be a better predictor of self-perceived post-operative LLD than pelvic radiographic measurement [13]. We support these results because patients with hip arthritis perceive not only a loss of height caused by proximal migration of the hip and cartilage wear, but they also perceive LLD related to muscle contractures (apparent LLD) or pre-existing LLD. Therefore, pelvic measurement of LLD before or after THA may underestimate the overall LLD. In some patients with primary hip osteoarthritis, pre-existing LLD, including LLD that has been present since childhood [18], may be missed if only pelvic radiographs are used to estimate LLD before THA.

A decision to shorten the ipsilateral extremity after THA should be made with caution because there is, in theory, a chance that hip instability could develop. However, using the hip-sparing techniques described here, it can be performed safely without compromising the soft tissue tension around the hip joint. We performed two ipsilateral shortening procedures distal to the THA implants, and the patients experienced no instability. Another approach to treating this type of LLD is to lengthen the contralateral extremity. Thakral et al. [22] reported on two patients who underwent lengthening of the contralateral extremity to equalize leg length after THA. The authors used a motorized lengthening nail and reported no complications at final follow-up.

In our report, the motorized lengthening nail (Precice) was used in four patients to equalize leg length. All of these patients had been short in the ipsilateral leg after THA secondary to dysplasia of the hip and underwent lengthening of the extremity with no reported complications after surgery. It is likely that the THA alone could not address the LLD in those patients because of concerns about

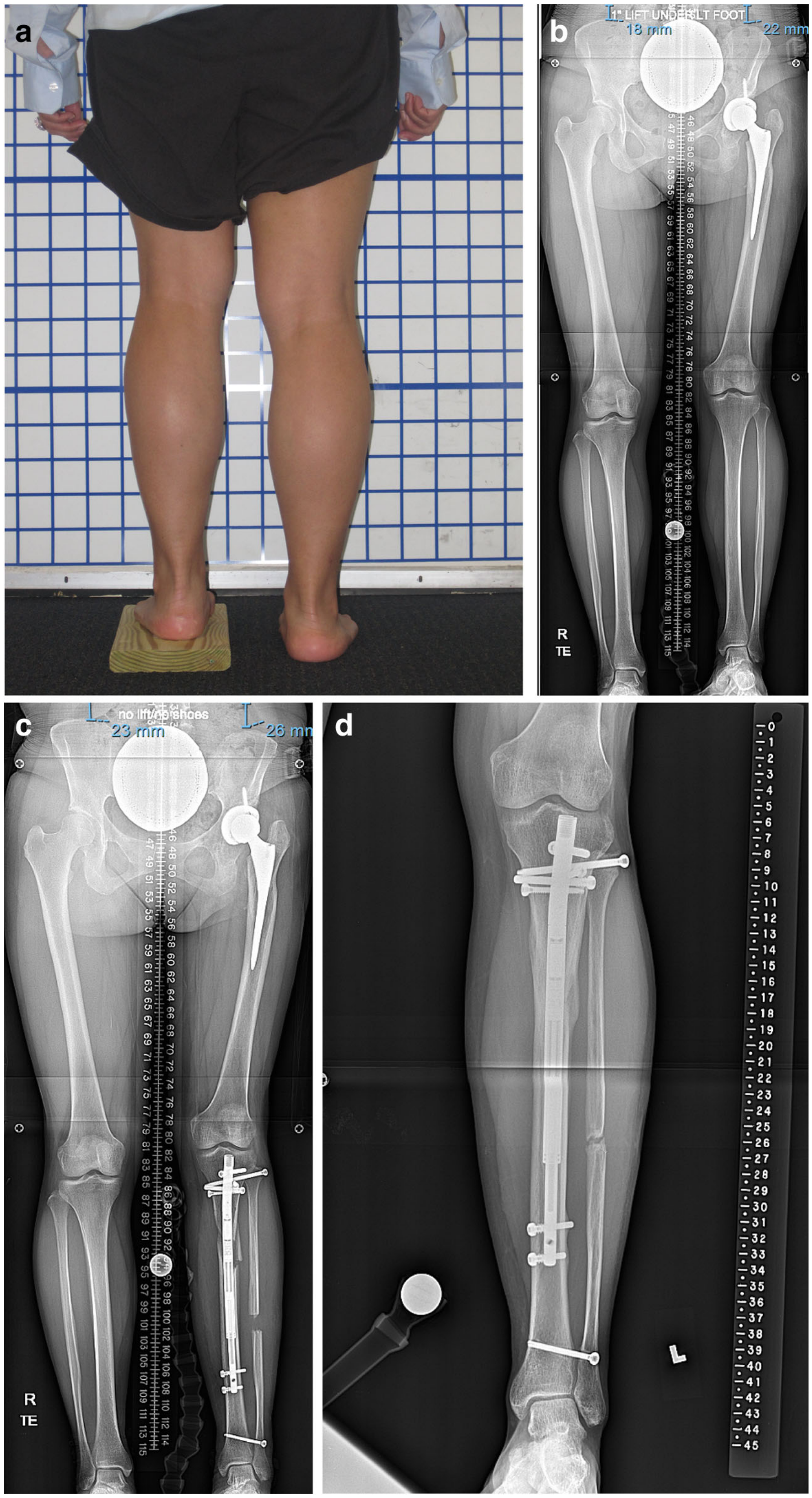

Fig. 1. **a** Clinical photo at the initial presentation. The wooden block lift was used under the left foot to clinically equalize the pelvis. The height of the illustrated block was 25 mm. **b** Long film anteroposterior (AP) radiograph at initial presentation with a wooden block of 25 mm height placed under the left foot at the time of the radiograph. We measured the distance between the superior horizontal aspects of the digital film and a horizontal line of the pelvis. The difference between the two sides in mm was 4 mm (22 mm–18 mm). This 4 mm was added to the wooden block height since the ipsilateral iliac crest (left side) is lower (shorter) than the contralateral one. LLD is, therefore, estimated as 29 mm. **c** Long film AP radiograph after left tibial lengthening with a Precice motorized internal lengthening nail. Residual LLD is estimated as 3 mm. **d** Left tibial AP radiograph after full consolidation

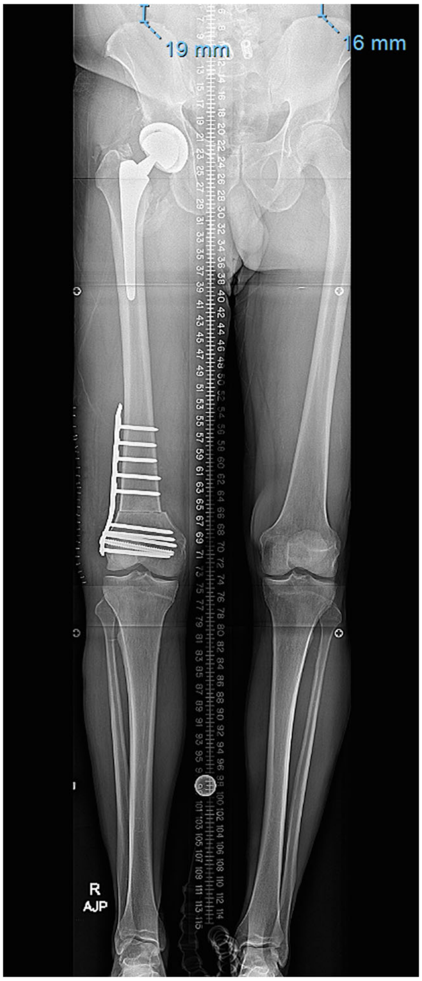

Fig. 2. Long film anteroposterior radiographs for a patient who underwent ipsilateral shortening of the femur with a plate. Residual LLD is estimated to be 3 mm

overlengthening the soft tissue and the risk of nerve injury. Arthroplasty surgeons rarely lengthen the limb more than 3 cm, primarily in an effort to avoid a sciatic nerve injury [3]. The hip-sparing techniques with internal lengthening implants function as second-stage reconstruction after THA in patients with significant LLD before THA. This process was recently reported in a multicenter study by Harkin et al. [10], who described three cases of hip dysplasia in patients who underwent a two-stage reconstruction: THA followed by ipsilateral lengthening with a retrograde femoral Precice lengthening nail. All three patients reported independent ambulation without assistive devices and had excellent bone and functional outcomes without complications. We believe that this two-stage reconstruction protocol should be considered and discussed with patients with shortening greater than 3 cm before THA.

In patients who are not candidates for contralateral THA or in whom the extent of LLD is beyond correction with contralateral THA alone, our current approach is to shorten the long ipsilateral side if the patient feels tight on that side. We perform Ober, Ely, and Thomas tests to help confirm the tightness. By shortening the femur distal to the implant, tension is decreased in muscles that cross both hip and knee, including the iliotibial band, rectus femoris, and sartorius. Shortening is achieved using a static retrograde nail or plate. We lengthen the contralateral femur with an antegrade internal lengthening nail, if the patient does not feel tight on the THA-side and had negative results on Ober, Ely, and Thomas tests. If the THA-side is short, we lengthen the femur distal to the THA implant with a retrograde internal lengthening nail. Elderly patients who are not felt to be candidates for lengthening can also be treated with contralateral-femur shortening. In two cases in our study, we lengthened the ipsilateral tibia and shortened the contralateral femur because the ideal size retrograde motorized lengthening nail was not available at the time. (The manufacturer now offers additional nail sizes.) Figure 3 is a flow chart describing the approach to surgical treatment used for the patients in this study.

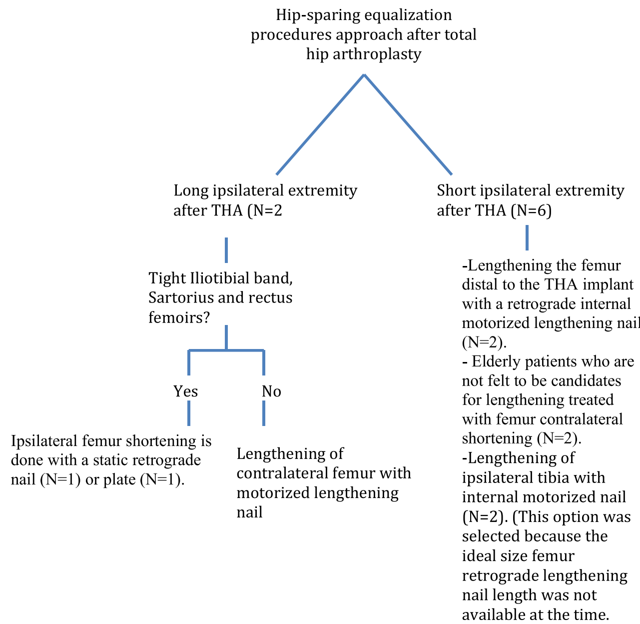

Fig. 3. Flow chart to illustrate our current approach to hip-sparing equalization procedures after total hip arthroplasty

In conclusion, we believe that hip-sparing equalization procedures can be part of the treatment algorithm in LLD after THA. According to the experiences reported in this study, these advances in the area of limb lengthening are promising and may expand the indications for lengthening and equalization procedures to include LLD after THA.

Compliance with Ethical Standards

Conflict of Interest: Asim M. Makhdom, MD, MSc, FRCSC, declares that he has no conflicts of interest. Austin T. Fragomen, MD, reports receiving consulting fees from Synthesis, NuVasive Specialized Orthopedics, and Smith and Nephew. S. Robert Rozbruch, MD, reports receiving royalties from NuVasive Specialized Orthopedics and Stryker and consulting fees from Smith and Nephew.

Human/Animal Rights: All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2013.

Informed Consent: Informed consent was waived from all patients for being included in this study.

Required Author Forms Disclosure forms provided by the authors are available with the online version of this article.

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