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# Anatomical Mapping of the External Obturator Footprint: A Study In Cadavers with Implications for Direct Anterior THA

**Georges Vles MD, PhD, Anthony van Eemeren MD, Orcun Taylan MSc, Lennart Scheys PhD, Stijn Ghijselings MD**

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## Abstract

*Background* The external obturator footprint in the trochanteric fossa has been suggested as a potential landmark for stem depth in direct anterior THA. Its upper border can be visualized during surgical exposure of the femur. A recent study reported that the height of the tendon has little variability (6.4 ± 1.4 mm) as measured on CT scans and that the trochanteric fossa is consistently visible on conventional pelvic radiographs. However, it is unclear where exactly the footprint of this tendon should be templated during preoperative planning so that it can be useful intraoperatively.

*Questions/purposes* In this study, we sought: (1) to provide instructions on exactly where to template the external obturator footprint on a preoperative planning radiograph, and (2) to confirm the small variability in height of the external obturator footprint found on CT scans in a cadaver study.

*Methods* Two-dimensional (2-D) and three-dimensional (3-D) imaging was used to map the anatomy of the external obturator footprint. This dual approach was chosen because of their complementarity; conventional 2-D radiographs translate to clinical practice but 3-D navigation-based digitalization combined with CT allows for a better understanding of the cortical lines that comprise the outline of the trochanteric fossa. In 12 (four males, mean age 80 years, range 69 to 88) formalin-treated cadaveric lower extremities including the pelvis, the external obturator tendon was dissected, and the top and bottom end of its footprint marked with two small needles, and calibrated radiographs were taken. For another five (three males, mean age 75.7 years, range 61 to 91) fresh-frozen cadaveric lower extremities, including femoral reflective marker frames, CT scans were obtained and the exact location of the external obturator footprint was recorded using 3-D navigation-based digitalization. Qualitative analysis of both imaging modalities was used to develop instructions on where the external obturator footprint should be templated on a preoperative planning radiograph. Quantitative analysis of the dimensions of the external obturator footprint was performed.

*Results* The lowest point of the external obturator footprint was consistently found (± 1 mm) at the intersection of

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Investigation was performed at Institute for Orthopaedic Research and Training, Vesalius Instituut, Leuven, Belgium.

G. Vles, A. van Eemeren, S. Ghijselings, Department of Orthopaedics – Hip Unit, Gasthuisberg, University Hospitals Leuven, Belgium

O. Taylan, L. Scheys, Institute of Orthopaedic Research and Training, Gasthuisberg, University Hospitals Leuven/Catholic University of Leuven, Leuven, Belgium

G. Vles ✉, Department of Orthopaedics – Hip unit, Gasthuisberg, University Hospitals Leuven, Herestraat 49, 3000 Leuven, Belgium , Email: Georges.Vles@uzleuven.be

the vertical line comprised of the lateral wall of the trochanteric fossa and the oblique line formed by the intertrochanteric crest and therefore allows templating of this structure on the preoperative planning radiograph. The median (range) height of the footprint measured 6.4 mm and demonstrated small variability (4.7 to 7.6).
*Conclusions* We suggest templating a 6.4-mm circle with its bottom on the intersection described above.
*Clinical Relevance* The distance between the templated shoulder of the stem and the top of the circle can be used intraoperatively for guidance. Discrepancy should lead to re-evaluation of stem depth and leg length. Future work will investigate the usability, validity, and reliability of the proposed methodology in daily clinical practice.

## Introduction

Leg length discrepancy after THA is a common source of patient dissatisfaction and litigation [3]. Despite the plethora of intraoperative tests and technological advances made through navigation and robotics, no method is currently universally accepted [2, 6–8, 13, 21]. Most surgeons, therefore, rely on a combination of preoperative templating, intraoperative landmarks, and an overall feel for leg length [10, 18]. The benefit of using the direct anterior approach is that the patient can be positioned supine, which allows checking for leg length discrepancy by palpation of the malleoli, as originally suggested by Sir John Charnley and also by means of intraoperative fluoroscopy [8]. The main downside of this approach is the lack of conventional landmarks that are both visible on the preoperative planning radiograph as well as during surgical exposure of the femur because the greater trochanter is covered by lateral capsule and the lesser trochanter can be difficult to palpate.

Recently, Rüdiger et al. [17] suggested the footprint of the external obturator tendon in the trochanteric fossa as a useful landmark [1, 14]. The authors were the first to describe the dimensions of the external obturator footprint based on 200 CT scans that they correlated to conventional radiographs. They concluded that the trochanteric fossa is consistently visible on a pelvic radiograph, can be grooved or flat-shaped, and that there is small variability in height (6.4 ± 1.4 mm) of the inserting tendon itself. Most direct anterior approach THA surgeons will agree that the upper border of the external obturator tendon can be seen during broaching of the femoral canal with little to no additional dissection required (Fig. 1). This suggests the potential for use of the external obturator footprint as a landmark for stem depth. However, it remains uncertain where the footprint of this tendon should be templated during preoperative planning so that it can be useful intraoperatively. Also, CT is not usually the imaging modality of choice when analyzing soft tissue structures and so the small

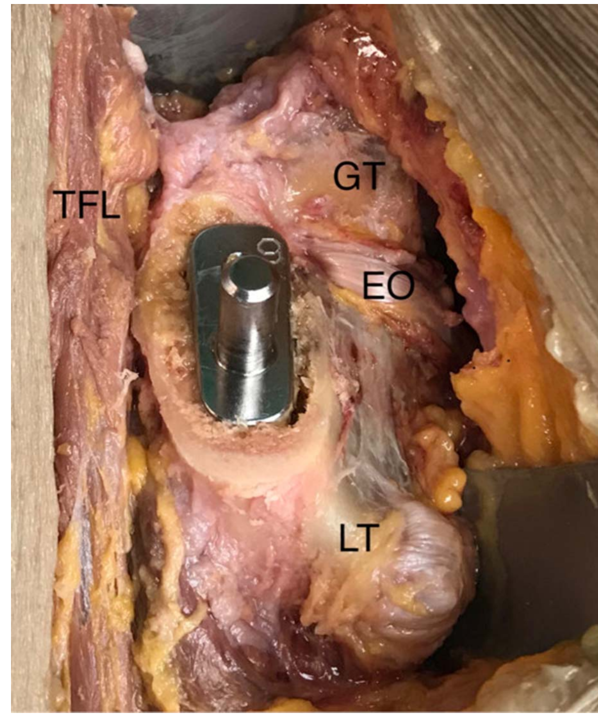


**Fig. 1** Intraoperative photograph of a broach that has been inserted into the femoral canal of a cadaveric specimen via a direct anterior approach. The landmarks have been exposed more than normal; TFL = tensor fascia latae; GT = greater trochanter; LT = lesser trochanter; EO = external obturator.

dimensional variability of the external obturator tendon requires further validation in cadaveric specimens.

We therefore performed an anatomical mapping study that sought (1) to provide instructions on exactly where to template the external obturator footprint on a preoperative planning radiograph, and (2) to confirm the small variability in height of the external obturator footprint found on CT scans in a cadaver study.

## Materials and Methods

### Study Design and Setting

This study used two-dimensional (2-D) and three-dimensional (3-D) imaging to map the anatomy of the external obturator footprint in cadavers. We chose this dual approach because 2-D and 3-D imaging are complementary. Conventional 2-D radiographs translate to clinical practice, but 3-D navigation-based digitalization combined with CT allows for a better understanding of the cortical lines that comprise the outline of the trochanteric fossa and allow precise measuring of the dimensions of the external obturator footprint. Both approaches are needed to develop instructions on where to template the external obturator footprint during preoperative planning. The study arms were approved by the ethical review board (University Hospitals Leuven & Catholic University of Leuven - faculty of medicine) and subsequently registered at the Belgian National Council for Bioethics (NH019 2020-02-02; NH019 2020-03-01).

### Study Cadavers

We considered only cadavers that did not meet the exclusion criterium of previous hip surgery for this study. For the 2-D mapping, we used 12 lower extremities (seven left, including the pelvis) from four male and four female (mean [range] age 80 years [69 to 88]) fully intact formalin-treated cadavers were used. No effect of formalin-treatment on the tendon-insertion site was expected [19].

For the 3-D mapping, we used five lower extremities (three left), disarticulated from the hip joints of three male and one female (mean age 75.7 years, range 61-91 years) fresh-frozen cadavers. These specimens were thawed at room temperature 24 hours before analysis.

### Description of Experiment

For the 2-D mapping, the cadaveric specimens were positioned prone, the external obturator tendon was dissected via a posterior approach, and the bottom and top end of its insertion into the trochanteric fossa were marked with two small needles (Fig. 2A). After a 36-mm calibration marker was placed close to the area of interest, an AP radiograph (Siemens, Cios-Select, Erlangen, Germany) was taken with the leg in 10° of internal rotation to correct for natural femoral anteversion (Fig. 2B) [5, 9]. The DICOM images were uploaded to TraumaCad (Brainlab, 2020, Munich, Germany) for analysis.

For the 3-D mapping, we obtained 0.6-mm slice thickness CT scans (Siemens Somatom Definition Flash, Erlangen, Germany) that included four retroreflective markers mounted onto marker frames and inserted via bicortical bone pins into each femur. Two authors (SG, GV) used a calibrated optical motion capture system with integration of six infrared cameras (100 Hz, MX40, Vicon, Oxford, UK) to digitize the external obturator footprint using a tracking wand while simultaneously tracking the femur-mounted reflective markers. After completing CT-based digitization of each femur and determining the relative position of the reflective markers (Mimics 21.0, Materialise, Leuven, Belgium), we used custom-developed software (Python, v. 3.8.2, Python Software Foundation, Beaverton, OR, USA) to register each recorded external obturator footprint on its respective femurs. Next, we used image processing software (MevisLab 2.8.2, MeVis Medical Solution, AG, Bremen, Germany) to generate digitally reconstructed radiographs (10° of femoral

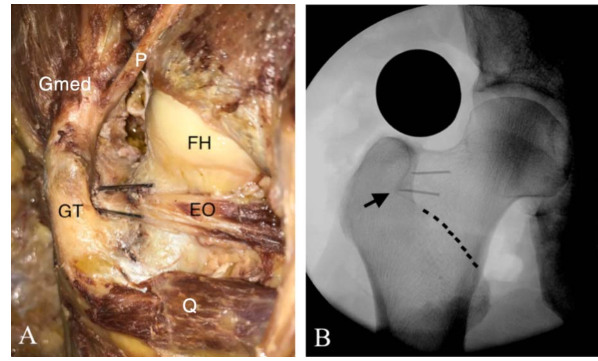


**Fig. 2 A-B** (**A**) A posterior photograph of a cadaveric specimen in which the external obturator footprint has been dissected out and the top and bottom end have been marked with two small needles. (**B**) A radiograph of that same specimen showing the bottom needle at the intersection (arrow) of the line formed by the vertical wall of the trochanteric fossa and a more oblique line formed by the intertrochanteric crest (dotted line). A 36-mm marker was used for calibration; Gmed = gluteus medius; P = piriformis; FH = femoral head; GT = greater trochanter; EO = external obturator; Q = quadratus femoris.

anteversion, tibia perpendicular to the floor) by means of averaged intensity projection (AIP) [15]. The x-y-z coordinates of the external obturator footprint as recorded by the tracking wand were transposed over these AIP images using custom Matlab code (Mathworks R2018b, MA, USA).

### Variables and Outcome Measures

Our primary study outcome was a qualitative assessment of where the external obturator inserts into the trochanteric fossa. The first and senior authors (GV, SG) analyzed the location of the bottom of the footprint in relation to the trochanteric fossa on the conventional radiographs, the 3-D CT models, and the AIP images. Interrater reliability was assessed.

Our secondary study outcome was a quantitative assessment of the dimensions of the external obturator tendon. Two authors (GV, OT) measured the height of the external obturator tendon and the distance from the bottom of the footprint to the tip of the greater trochanter for both the conventional radiographs (TraumaCad) and the 3-D CT based mapping studies (Mimics 21.0, Materialise, Leuven, Belgium) [20]. For the latter, they measured the AP width of the footprint and its distance to the anatomical axis of the femur as well. Again, interrater reliability was assessed.

### Statistical Analysis

All data were entered into the Statistical Package for the Social Sciences (Version 25.0, SPSS, IBM Corp, Armonk,

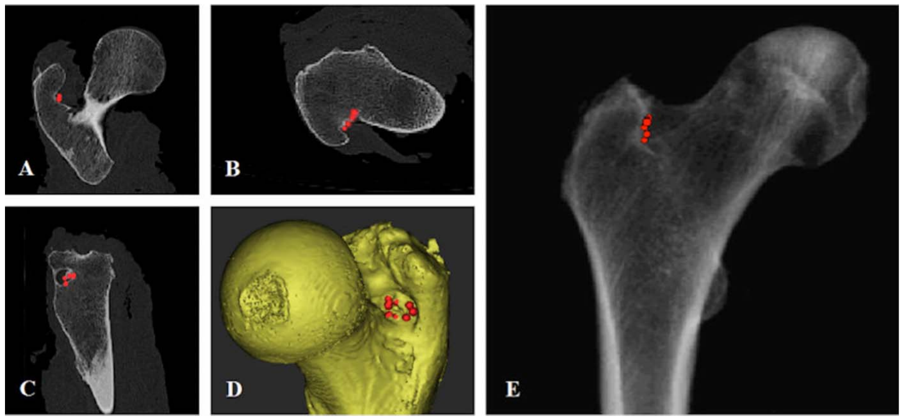


**Fig. 3 A-E** (**A**) A coronal CT slice showing the most distal wand point on the intersection of the vertical wall of the trochanteric fossa and the oblique intertrochanteric crest. (**B**) Axial and (**C**) sagittal CT slices showing the circular tendon inserting into the groove-shaped trochanteric fossa. (**D**) A 3-D CT model of a proximal femur showing the recorded wand points indicating the external obturator footprint in the trochanteric fossa. (**E**) Averaged intensity projection (AIP) image showing what a conventional radiograph of this femur would look like. Red marks in each image are the locations of the wand points.

NY, USA). Median and range of the dimensions of the external obturator were calculated using descriptive statistics. The mean and SD of the height was also calculated for comparison with the results reported by Rüdiger et al. [17]. Comparisons were conducted using independent t tests (equal variances assumed). The level of significance was set at $p < 0.05$.

## Results

### Instructions on Where to Template the External Obturator Footprint on a Preoperative Planning Radiograph

Analyses of conventional radiographs (Fig. 2B), 3-D CT-based mapping studies (Fig. 3A-D), and AIP images (Fig. 3E) showed that the bottom of the external obturator footprint can consistently be found (± 1 mm) at the intersection of the vertical line comprised of the lateral wall of the trochanteric fossa and the oblique line formed by the intertrochanteric crest and therefore allows templating of this structure on the preoperative planning radiograph.

### The Variability in Height of the External Obturator Footprint in Cadavers

The median (range) height of the external obturator footprint was found to be 6.2 mm (4.7 to 7.6) on the conventional radiographs and 6.7 mm (6.3 to 7.2) on the 3-D CT-based mapping studies and these results do not differ from each other ($p = 0.20$) (Table 1).

### Other Relevant Findings

The median (range) distance of the bottom of the footprint to the tip of the greater trochanter was 23.1 mm (21.2 to 27.8) on the conventional radiographs and 21.7 mm (20.4 to 25.6) on the 3-D CT-based mapping studies. The latter imaging modality also showed the external obturator footprint to have a median (range) AP width of 7.1 mm (4.4 to 9.1) and that it was located 3.2 mm (-4.0 to 7.2) from the anatomical axis of the femur.

## Discussion

We believe that the most important tool when trying to prevent a clinically important leg length discrepancy is the availability of a landmark that is visible on both the preoperative planning radiograph and during surgical exposure of the femur. The potential of the external obturator footprint as such a landmark has been suggested [17]; however, it remained uncertain where this structure should be templated during preoperative planning so that it can be useful intraoperatively. Also, its small variability in height, which is of vital importance, is solely based on CT scan assessment [17]. In this anatomical mapping study, we found that the bottom of the external obturator footprint was consistent in relation to the trochanteric fossa, and we were able to confirm its small height variability in 17 cadaveric specimens. Clinicians using the direct anterior approach can use these findings for preoperative planning and intraoperative guidance on stem depth.

**Table 1.** Overview of the results of the anatomical mapping studies

| Parameter | 2-D Mapping (n = 12) | 3-D Mapping (n = 5) | 2-D and 3-D Mapping (n = 17) |
|---|---|---|---|
| Median height in mm (range) | 6 (5 to 8) | 7 (6 to 7) | 6 (5 to 8) |
| Median width in mm (range) | | 7 (4 to 9) | |
| Median distance to tip of greater trochanter in mm (range) | 23 (21 to 28) | 22 (20 to 26) | 23 (20 to 28) |
| Median distance to anatomical axis in mm (range) | | 3 (-4 to 7)[a] | |

[a]A positive value indicates that the tendon is located medially to the anatomical axis; 2-D = two-dimensional; 3-D = three-dimensional.

## Limitations

This study has several limitations. First, a small number of cadaveric specimens (n = 17) was used; however, the natural variability of the external obturator tendon was extensively described previously in 200 patients and was found to be small [17]. Second, anatomical mapping of the external obturator footprint using a tracking wand is investigator-dependent; however, intra- and interrater reliability in our study was excellent. Third, using the external obturator footprint as a radiographic landmark and measure its distance to the shoulder of implant assumes perfect correction for radiographic magnification. In our study we minimized magnification error by using a 36-mm calibatrion marker very close to and at the same depth as the location of interest (Fig. 2B). Finally, the proposed landmark only allows the surgeon to check leg length restoration on the femoral side. Several authors have pointed out that inaccurate reaming on the acetabular side can influence overall leg length as well [4, 11, 12]. Nevertheless, errors are most likely to occur on the femoral side.

## Instructions on Where to Template the External Obturator Footprint on a Preoperative Planning Radiograph

We suggest templating a 6.4-mm circle with its bottom on the intersection of the vertical line comprised of the lateral wall of the trochanteric fossa and the oblique line formed by the intertrochanteric crest (Fig. 4). The distance between the templated shoulder of the femoral stem and the upper border of the external obturator footprint can be used intraoperatively (Fig. 1). Given that the top of the footprint is located close to the shoulder of the femoral implant in most instances, intraoperative measurement of this distance is expected to be more accurate than with landmarks located further away, such as, the greater and lesser trochanters.

We believe the external obturator footprint should always be used in combination with other landmarks and an overall feel for leg length. In theory, one could use a 6.4-mm projection for a patient who actually has a 7.8-mm tendon, erroneously template it 1 mm below the previously described intersection instead of 1 mm above and have an intraoperative measuring inaccuracy of 1 mm to 2 mm. The summation of these errors approaches the limit of 5 mm in leg length discrepancy that results in unphysiological gait parameters [16]. Future studies should investigate the usability, validity and reliability of the proposed methodology in daily clinical practice. Is the trochanteric fossa indeed visible on all preoperative planning radiographs, even for the inexperienced templater? Is the upper border of the

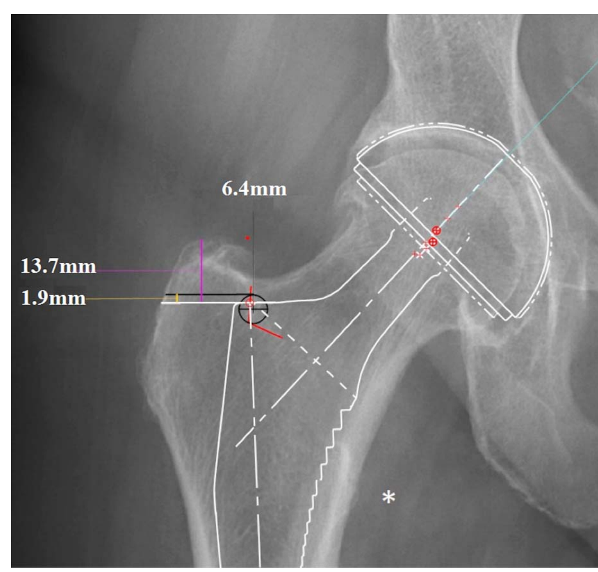


**Fig. 4** Preoperative templating radiograph (TraumaCad) on which the presumed location of the external obturator footprint has been projected by means of a 6.4-mm black circle. The intersecting lines of the vertical wall of the trochanteric fossa and the oblique intertrochanteric crest have been marked red. For this specific patient, the goal would be to get the shoulder of the stem 2 mm below the upper border of the external obturator tendon. The lesser trochanter would be a difficult to use landmark as it is barely visible (*). Calcifications make it difficult to delineate the true tip of the greater trochanter.

external obturator indeed always visible during preparation of the femoral canal, even in hips with valgus morphology or after extensive femoral releases? What are the results on leg length and stability when following this landmark meticulously?

### The Dimensional Variability of the External Obturator Footprint In Cadavers

The mean height of the 17 cadaveric specimens analyzed with 2-D and 3-D imaging in this study (6.3 mm; SD 0.7) did not differ ($p = 0.77$) from the measures reported by Rüdiger et al. [17].

Other dimensional characteristics of the external obturator footprint, such as width, distance to the anatomical axis, and distance to the tip of the greater trochanter showed considerable variability and are therefore not useful in clinical practice. Of note, the distance from the bottom of the footprint to the tip of the greater trochanter found in our specimens was greater than the distance found by Rüdiger et al. [17]. This could be due to differences in morphology of the populations studied or due to difficulties identifying the true tip of the greater trochanter.

## Conclusions

This cadaver study provides additional insights into the location of the external obturator footprint on conventional preoperative planning radiographs. Not only does the external obturator footprint have small variability in height, but also its bottom is consistently located on the intersection of the radiographic lines comprised of the vertical wall of the trochanteric fossa and the oblique intertrochanteric crest. These results support the potential use of this landmark in direct anterior approach THA. Future research should focus on the usability, validity, and reliability of this proposed methodology in daily clinical practice.



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