

TOTAL HIP ARTHROPLASTY PLANNING : LIMITS OF X-RAY AND CONTRIBUTION OF THE CT-SCAN

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SUMMARY

Background: Traditional preoperative planning for total hip arthroplasty relies on two-dimensional radiography, which is prone to inaccuracies due to magnification errors, pelvic tilt, and patient positioning. These limitations often result in suboptimal restoration of limb length and femoral offset, potentially compromising functional outcomes and joint stability.

Objective: This article evaluates the clinical application and technical advantages of three-dimensional CT-based planning software compared to conventional radiographic templating in primary and revision hip arthroplasty.

Key Points: Analysis of 472 arthroplasties performed between 2008 and 2014 demonstrated that CT-based planning provides sub-millimetric precision across six standardized steps, including limb length measurement, Hounsfield bone density evaluation, and Lewinnek plane orientation. While radiographic templating shows less than 50% concordance with implanted component sizes due to variable magnification (110%–120%), CT-based planning achieved 94% to 100% accuracy for acetabular and femoral sizing. Specifically, CT allows for precise quantification of femoral torsion and offset, the latter of which is frequently underestimated by up to 10 mm on standard radiographs. In 3.4% of cases involving complex femoral morphology or post-osteotomy deformities, the software facilitated the design of custom implants. Despite a 15-minute planning duration and an average radiation dose of 6.16 mSv, the method eliminates the need for additional specialized radiographic views and improves the predictability of the surgical reconstruction.

Conclusion: CT-based preoperative planning enhances surgical precision by providing a comprehensive three-dimensional anatomical analysis, effectively reducing errors in limb length and femoral offset. It remains a valuable tool for managing complex hip pathologies and optimizing implant selection.

KEYWORDS

Arthroplasty, Replacement, Hip; Tomography, X-Ray Computed; Surgery, Computer-Assisted; Hip Prosthesis; Radiographic Image Interpretation, Computer-Assisted

INTRODUCTION

Since the time of Maurice Muller in the 1980s, total hip arthroplasty has been planned using the reference standard x-ray method. Image digitisation and CT have since been used to develop high-performance planning software. In a large number of pathologies, CT has outmatched x-ray with its millimetric precision and three-dimensional image display. After seven years using CT-based planning software and comparing it with standard x-ray, I was able to see the shortfalls of conventional x-ray more clearly.

X-ray planning uses a frontal pelvic x-ray, with strict quality criteria: fixed plate-beam distance, standing position, knees in extension and feet in maximum internal rotation. In theory, this produces a frontal view of the hip with magnification identical to that of layers.

The image of the hip is projected onto the x-ray plate. Patient build, abnormal hip position and a tilted pelvis can distort the image projected. Such approximate planning, along with perioperative risks may lead to unequal length, or significant lateralisation, factors contributing to a poor functional result.

METHOD

In an attempt to reduce these imprecisions, I chose to use CT image-based software as of 2008.

Its main advantage is that it is capable of providing sub-millimetric slices, enabling three-dimensional planning using the HIP PLAN software. (6, 7, 10)

The HIP PLAN software was developed by Symbios. Symbios has produced more than 16,000 made-to-measure implants since 1990. The made-to-measure service is what makes the company different from others. The computer specialists developed software which is now available for surgeons. It can be used to plan hip arthroplasty from a scout view of the lower limbs, and sub-millimetric CT acquisition on the pelvis, knees and ankles

CT-based preoperative planning was used for 392 records out of 472 arthroplasties performed from 2008 to 2014. Standard x-ray is still used for elderly patients and for second side surgery. The software makes it possible to use several types of implants, including a 129° self-locking straight stem. I now always use this stem when I can, the 129° angle corresponding to the mean value of a CT database (Fig. 1).



Figure 1.

The 129° straight stem can be used in 85 % of situations. Tilted, high offset stems can be used in almost all of the other cases. 135° stems are now only used on rare occasions. In some cases, planning indicates that a made-to-measure implant would be more appropriate. This concerned 16 records out of 472 implants, representing 3.4 % of implants.

The software involves step by step planning based on 6 successive stages:

Step 1: The frontal and side on scout view can be used to perform length measurements outside and within the joint (Fig. 2).

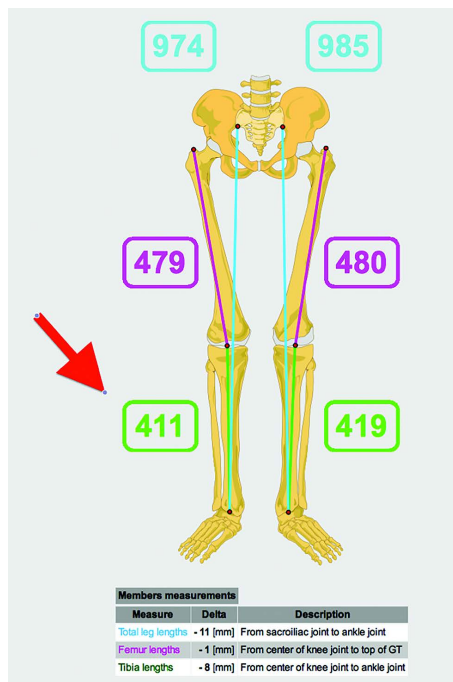


Figure 2 : 8 mm tibial length difference.

Step 2: Bone density is accurately measured (Hounsfield density value) on the CT-scan and can detect osteoporosis or dense femurs.

Step 3: The position of the pelvis uses the Lewinnek plan (reference plane based on the anterior superior iliac spines and the pubic symphysis). It is calculated automatically by the software. It can be used to quantify acetabular inclination and anteversion (Fig. 3).

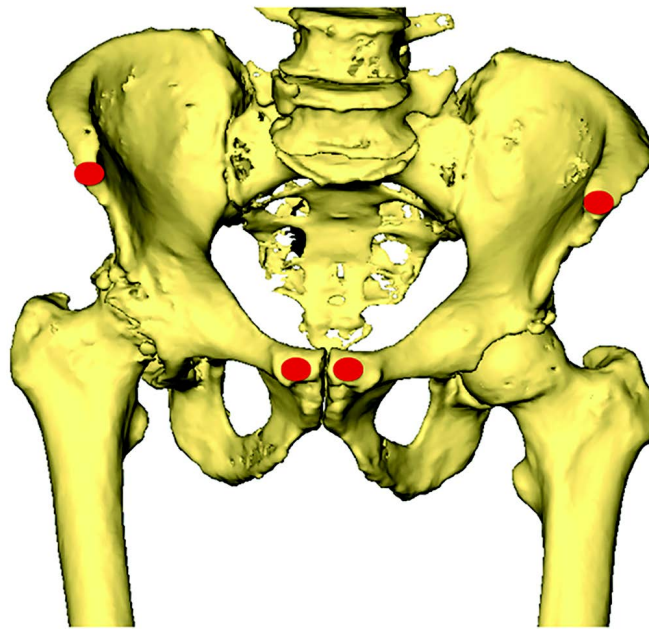


Figure 3 : Lewinnek plane.

Step 4: acetabular planning: 3D acquisition is used to measure the native acetabulum and to select the position of the acetabulum (Fig. 4).

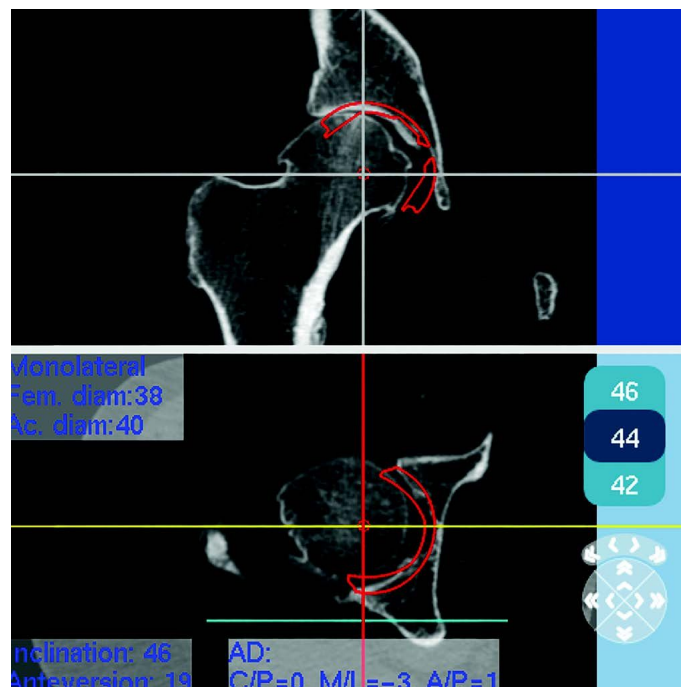


Figure 4 : Size 44 acetabular implant planning.

Step 5: femur position: the software measures the posterior bicondylar line then defines a femur from the front and side on (Fig. 5). The greater trochanter, the digital fossa and the lesser trochanter landmarks can thus be specified. All of these measures are used to define the femoral torsion and offset.

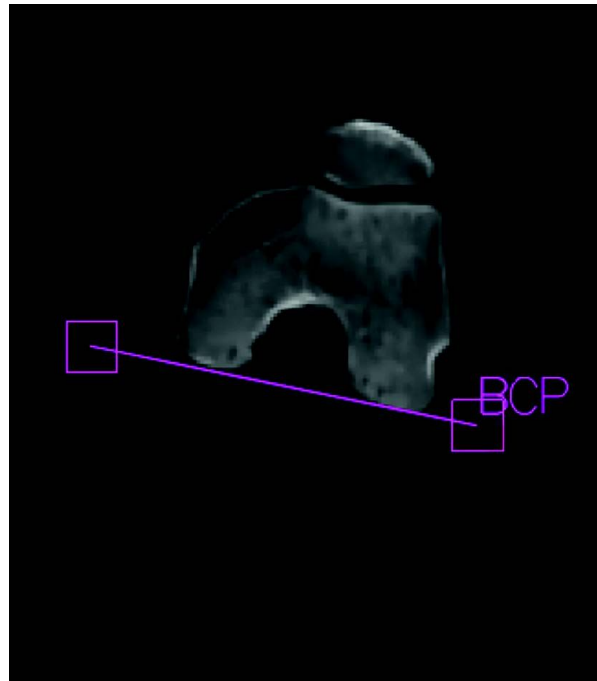


Figure 5 : Bicondylar line measurement.

Step 6: femoral stem planning: we can position a stem, choose the size, evaluate bone stress, measure bone resection (that we can compare during surgery using the callipers) and choose the ball (Fig. 6 and 7). The software calculates lengthening and offset depending on the implants selected.

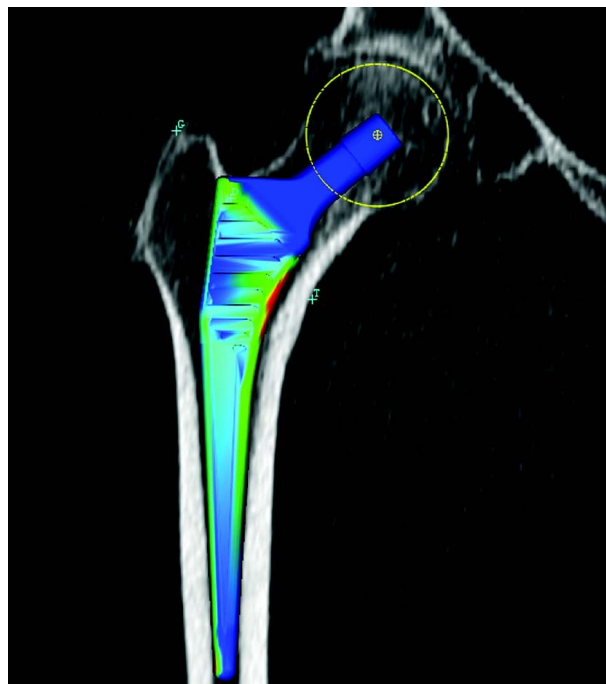


Figure 6 : Choice of femoral stem and bone stress measurement.

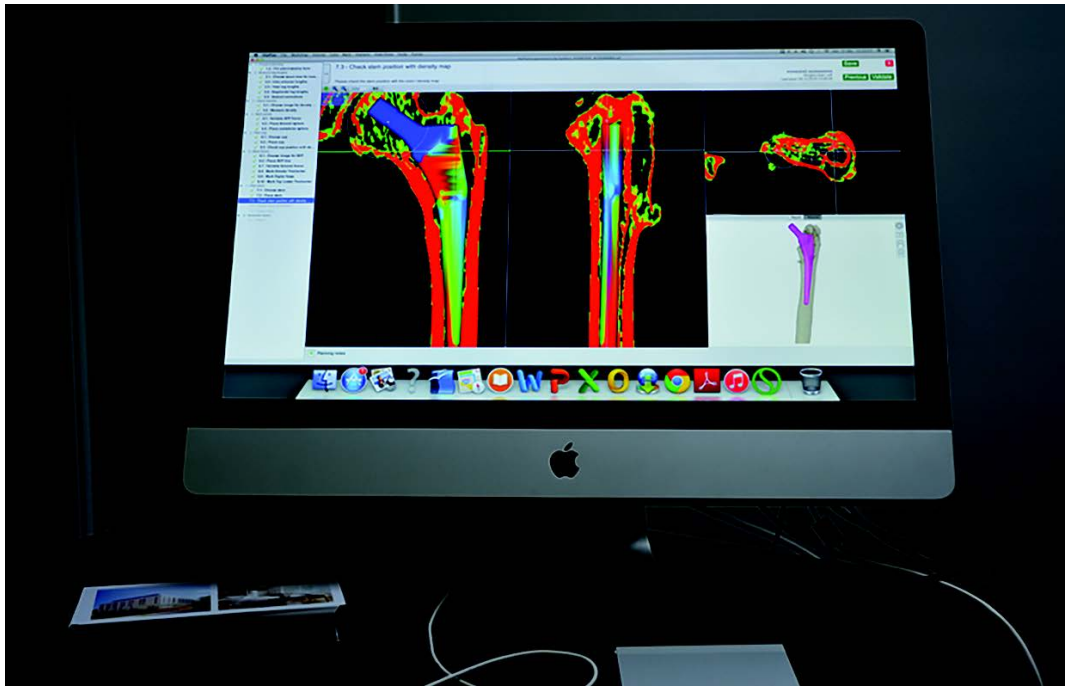


Figure 7 : Planning on Mac or PC

Ideally, to be able to use the HIP PLAN software well (Mac or PC), two days' training is necessary. Arthroplasty planning takes 15 minutes. An engineer supervises when planning for the first few times.

We can check implant position on a CT-scan after the surgery, and overlay it on the initial plan.

We can also use it for revision hip arthroplasty.

DISCUSSION

Total hip arthroplasty planning methods vary. They range from no planning to planning using layers, or software developed on the basis of digitised x-rays or CT-scans. It is of course possible to perform total hip arthroplasty without planning (by comparing what is removed to what is implanted). We can also consider that subcentimetre length errors or implant medialisation do not really have consequences. Such possibilities will not be discussed. Wanting the best possible plan will help achieve the best fit possible for the anatomy of both the hip and also the knee and spine.

Arthroplasty planning involves a number of steps, which are always the same.

- Evaluation of the length to be restored
- Choice and position of the acetabulum
- Choice and position of the stem

The CT-scan will provide better results than the standard x-ray at all stages of the planning.

1/ Intra- and extra-articular length

A frontal pelvic x-ray is generally used to achieve equal length. The most reliable technique is to use the line going through the ischiums (12), then to evaluate the position of the lesser trochanters with respect to the ischiatic line.

This is easy to measure on an even pelvis but is more uncertain on a tilted pelvis, and inaccurate according to the study by HEAVER (12).

Also, it does not evaluate extra-articular length asymmetry. Unevenness is however common.

Patients are sometimes aware of it (history of fracture, etc.) but most often are not.

Hip arthroplasty aims to correct the intra-articular sector but it is useful to also be aware of extra-articular abnormalities. It is not uncommon to find the leg on the side affected by osteoarthritis of the hip to be up to one centimetre longer

The slightest prosthetic lengthening is likely to be very badly tolerated by the patient. We can do a hip-knee-ankle film, but this increases irradiation, or we can use an additional EOS.

The CT-scan scout view can be used to measure lower limb joint, segment and total length without additional irradiation and to determine the corrections to be made for the implant to the nearest millimetre.

2/ Acetabulum

X-ray is little reliable for acetabular planning. In numerous studies, the agreement rate between the planned acetabulum and the implanted acetabulum is often lower than 50 %.

One explanation for this imprecision is the magnification error in standard x-ray. Magnification on standard images is 115 % on average, a value more often used for layers. Magnification varies according to patient build.

It is nearer 110 % in thin subjects and 120 % in obese patients. Digitisation initially aggravated the magnification problems. Digitisation produced pelvic x-rays on which magnification was variable, and could not be used for planning. In 2008, a report by the HAS, French national authority for health (based on the two million pelvic x-rays performed in France) asked radiologists to take images at 115 % to reduce the quantity of pelvic x-rays. Currently, we use commercial planning software based on digitised images (TRAUMACAD, ORTHOVIEW, etc.) or even software available on Osirix or on the cloud (14). Despite the software, concordance between the implants placed and the x-ray planning is often lower than 50 % (16). Conn used a coin, of which the diameter was known, to quantify x-ray magnification, and other authors used test balls integrated in software supposed to improve the accuracy of the actual magnification. However, Franken compared four calibration methods and saw that using average magnification of 121 % was more reliable than using test balls (17).

Currently there is no difference in accuracy between using layer planning or software planning from standard x-rays. Caution should even be exercised when using automated calibration (18).

In my experience (prospective study on 100 consecutive records) the accuracy of acetabulum size CT planning is remarkable, with an agreement rate between the planned acetabulum and the implanted acetabulum of 94 % and 100 % to the nearest size. This type of planning meant I was able to place smaller implants and to use cementless acetabular components only. Acetabular implants in women are almost exclusively size 46 and 48. Dispersion is higher in men, with an average acetabular component size of 52. The CT-scan also makes it possible to evaluate the condition of the anterior wall and to determine whether the acetabulum is likely to overrun in contact with the psoas. Seeing the bone acetabulum on the CT-scan makes placement in situ and adjustment of inclination and anteversion easier. With this system I don't believe an image intensifier or navigation is necessary.

3/ Stem

Concordance between the size of the stem planned on a layer and the size of the stem implanted is sometimes lower than 50 % using standard x-rays. This is also due to several factors: x-ray magnification error, femur in external rotation which reduces the diameter of the duct and under evaluates the offset.

Under evaluation of the offset is the main disadvantage of standard x-ray (Fig. 8). Under evaluation can reach 1 cm with x-ray planning. The risk is thus doubled: risk of prosthetic medialisation and risk of prosthetic instability. The instability observed during surgery may mislead the surgeon who will proceed with lengthening, either by using a larger sized stem or a longer ball. Offset quantification has been discussed in several publications: Medialisation carries the risk of instability and excessive lateralisation and pain. Boddu described an index for the lesser trochanter to predict under evaluation. Merle recommended taking a frontal hip x-ray in addition to the pelvic x-ray (13).

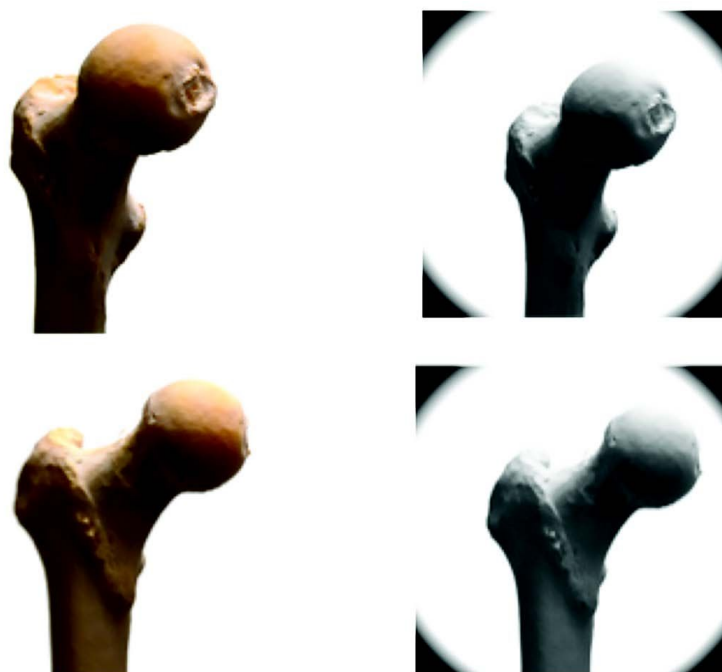


Figure 8 : Visualising the lesser trochanter is tantamount to not being able to use the x-ray for planning.

The CT-scan regularly shows that a hip which seems to be a short neck coxa valga is in fact a long neck coxa vara (Fig. 9 a and b).

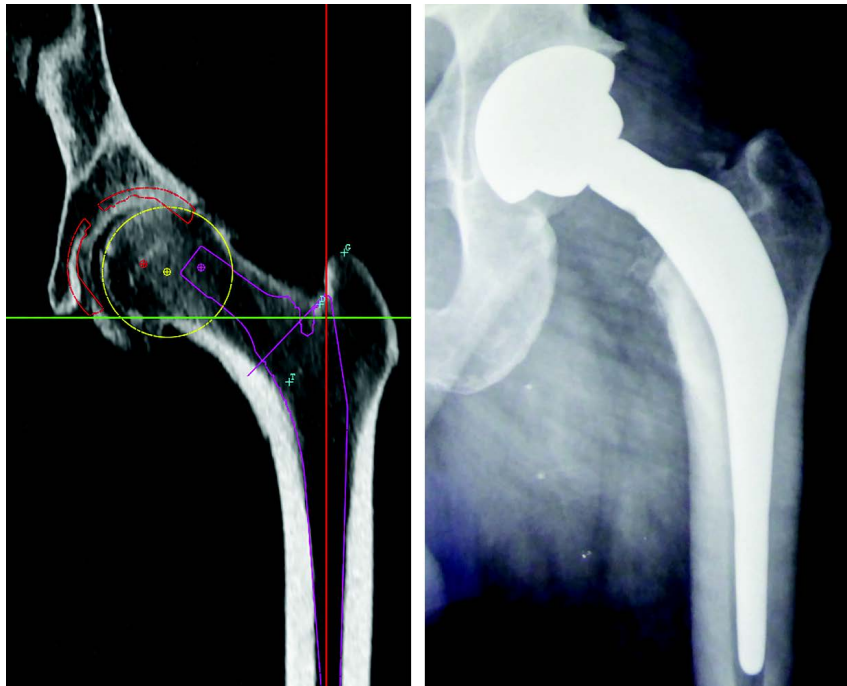


Figure 9 a et b : 61 mm offset measurement and selection of a made-to-measure stem.

Concordance between planned and implanted stems is higher than 90 % with the CT-scan (100 % for Edi Sariali with an anatomical stem, 100 % pour Hassani (19) and 92 % in a personal prospective series of 100 records with straight stem).

4/ Difficult cases

CT planning can be used to select made-to-measure arthroplasty indications. These indications derive from three main situations: small femurs (essentially dysplastic), femurs poorly adapted to standard implants (high offset with narrow intramedullary duct) and post-osteotomy femurs which often combine, to varying degrees, malunion, torsion disorder and unequal length. In my experience, 16 records out of 480 implants (3.4 %) required a made-to-measure arthroplasty. These records, which are difficult to analyse on standard x-rays, are easier to manager with the software (Fig 10 a and b).

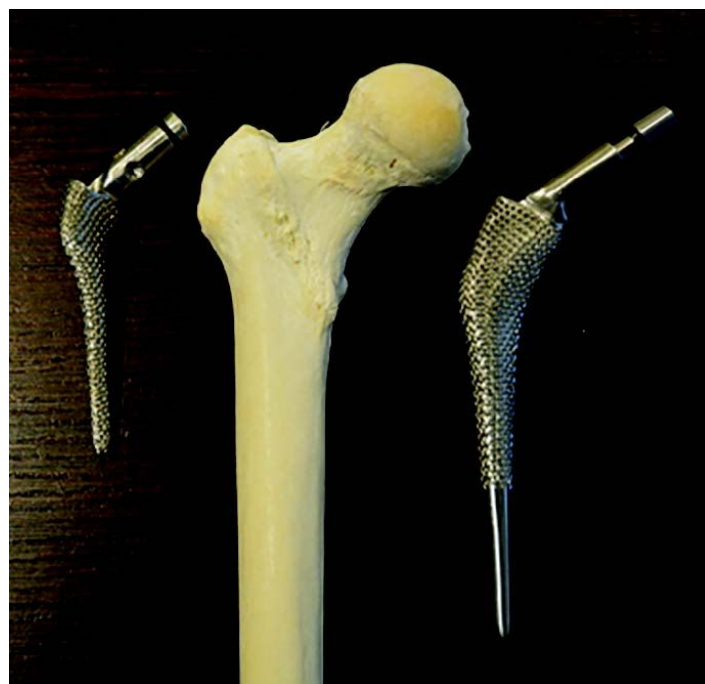




Figure 10 a et b : Made-to-measure stem rasps.

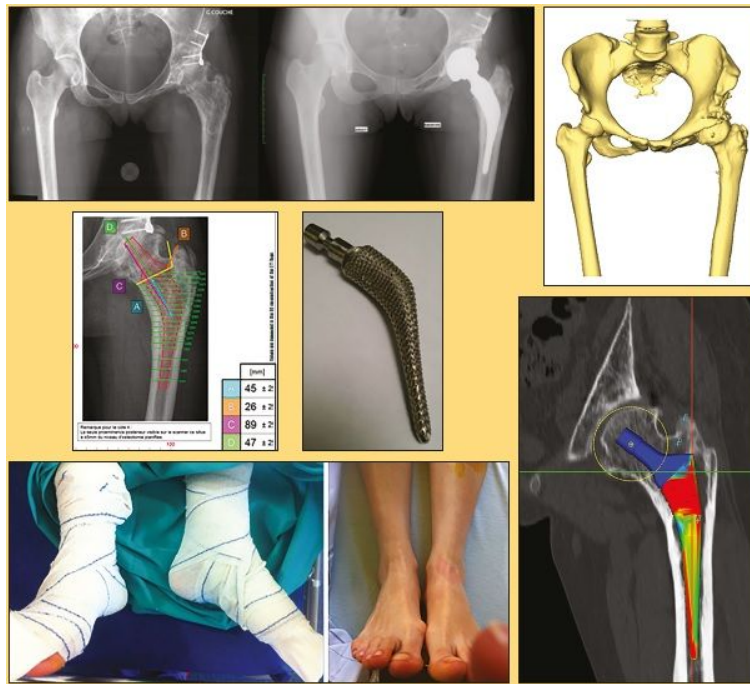
Made-to-measure arthroplasty can be reduced to 0 %. It is almost always possible to place a standard or dysplastic implant, regardless of the situation encountered. This often requires compromise on the length, offset or anteversion. Conversely, made-to-measure arthroplasty has sometimes brought systematic prejudice. This is reported by the initial designers (1, 2, 3) using the made-to-measure implant by SYMBIOS in patients under the age of fifty. It is not currently a solution that can be used on a wide scale.

Where there is an indication for made-to-measure arthroplasty, the CT-scan is sent to the engineers, who will propose a made-to-measure implant. When you know how to use the software, you can discuss their proposal with the engineers, and approve or adjust it (often only by a few millimetres).

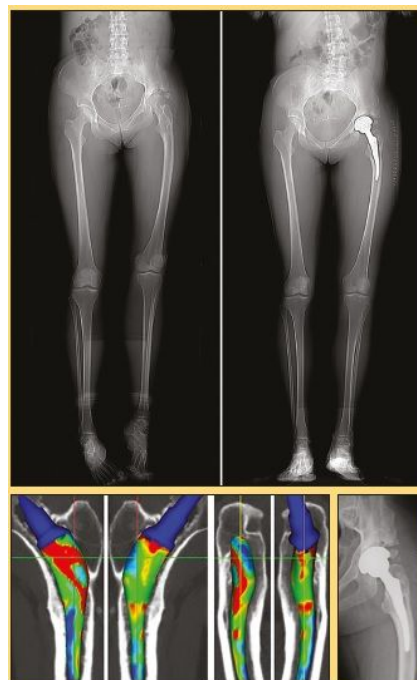
CT planning has two disadvantages however. It takes around fifteen minutes. The extra work is required before surgery, unlike navigation which currently makes surgery more complex and takes longer to perform. I now undertake planning with the patient.

The second disadvantage lies in patient irradiation. This represents around 5mSV (6.16 mSV) per examination. However, once the CT-scan has been done, additional x-rays are not required (hip-knee-ankle film, frontal hip image, etc.) and the examination can be used again if made-to-measure arthroplasty is indicated. Irradiation is however low in the light of the improved position of the implant that is meant to last more than twenty years for many patients.

The EOS can be weighed against the CT-scan on certain points. It is little irradiating, it enables calibrated magnification at 100 %, includes a hip-knee-ankle film and can be used to study the position of the pelvis in the standing position. EOS images can be exported into software such as TRAUMACAD, but for the time being there is no EOS system software equivalent to HIP PLAN for the CT-scan.



CASE N°1 :



CASE N°2 :

CONCLUSION

Using standard x-ray to plan hip arthroplasties exposes the surgeon to the risk of length and offset errors that can be reduced at the cost of additional radiological examinations. This means permanently adapting planning to the techniques acquired in the course of our experience.

CT-based planning software can be used before surgery to control all the important aspects of implant placement step by step. This increases accuracy, furthers understanding of the patient's anatomy and enables monitoring of the most difficult cases.

It is in the best interests of young surgeons to acquire such a device.

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