BALNEO RESEARCH Balneo and PRM Research Journal
English Edition
e ISSN 2734 - 8458 p ISSN 2734 - 844X ROMANIAN ASSOCIATION OF BALNEOLOGY

Research article

Early rehabilitation after total arthroplasty with custom hip prosthesis – case report

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Citation: Obada B., Iliescu M.G., Iliescu D.M, Caraban B.M., Baz R. - Early rehabilitation after total arthroplasty with custom hip prosthesis – case report
Balneo and PRM Research Journal **2023**, *14(4): 638*

Academic Editor(s):
Constantin Munteanu

Reviewer Officer:
Viorela Bembea

Production Officer:
Camil Filimon

Received: 01.12.2023
Accepted: 04.12.2023
Published: 20.12.2023

Reviewers:
Aura Spinu
Ioana Andone

Abstract: Background: The main aim of this study was to compare conventional radiograph and computer tomograph (CT)-scan measurements of femoral offset. The second aim was the compare the pre- and postoperative values of femoral offsets as well as the variations cre-ated by total hip arthroplasty (THA) replacements using the same protocol of analysis for a patient operated on both hips by the same surgeon using a modified lateral approach. Methods: The CT protocol involves 1mm slices from top of the iliac crest to the isthmus of the femur, 2mm slices from top to the bottom of femoral condyles and top and bottom of the ankle joint. The CT protocol involves 1mm slices from top of the iliac crest to the isth-mus of the femur, 2mm slices from top to the bottom of femoral condyles and top and bot-tom of the ankle joint. The implant came with an operative plan to guide the neck osteot-omy site, and with its own bone compacting or bone removing rasp according to the in-tramedullary cortical or cancellous bony architecture indicated by the 3D-CTplan. Results: In addition to a clinical review and oxford hip scoring, the patient had postoperative radi-ographs and were reviewed regularly at 6 weeks and 6 months. Conclusions: We conclud-ed that this 3D-CT guided custom design femoral stem produces reliable proximal 'fit and fill' and primary stability with restoration of limb length discrepancy with complex prox-imal femoral deformity without the need of a corrective osteotomy.

Keywords: hip arthrosis; custom hip prosthesis; rehabilitation

Introduction

Normal hip biomechanics is the most important goal of total hip arthroplasty (THA) and provides a better functional recovery [1]. Restoration of the limb length equality is another important goal, and must be achieved without compromising the stability and the function of the hip prosthesis [2]. Lower limb length discrepancy is a common source of patient insatisfaction and and a cause of poor biomechanic of the hip. The discrepancy may be anatomical or functional, and a clear understanding of all the factors that lead to length discrepancy is very important for the success of the hip replacement. Femoral component of the prosthesis became recently a target of interest, since cementless stems were introduced. We will discuss the measurement of femoral offset, which is highly controversial, and the impact of offset on function. Anteversion also influences offset and must be strongly considered during femoral stem replacement.

Femoral offset is the perpendicular distance from the center of rotation of the femoral head to the line of action of the abductor muscles.[3-5]

Acetabular offset is the perpendicular distance from the center of rotation of the femoral head to the vertical transteardrop line. Global hip offset is the sum of femoral and acetabular offsets. Excessive anteversion (or external rotation) is associated with a decrease in the femoral offset value measured on an antero-posterior radiograph. Internal rotation of about 20◦ minimizes this error. However, the exact value of femoral anteversion must be known in order to accurately measure femoral offset on the same side. Computed tomography (CT) can be used to measure proximal femoral torsion. [6-8]

In this era of growing expectations regarding both limb function and implant survival, careful consideration of the three-dimensional geometry of the prosthetic hip is crucial. The shift towards biological fixation of femoral implants has changed surgical practices. It mandates attention to both intra-medullary and extra-medullary anatomy. Preservation of lateralization ensures optimal abductor muscle function. The use of tridimensional imaging and CT scan become simpler and more accessible in daily practice. By giving full consideration on the influence of anteversion, these radiological tools will allow surgeons to reliably predict which implants are optimal for remaking the normal three-dimensional anatomy in each individual patient.[9-11]

The main aim of this study was to compare conventional radiograph and CT-scan measurements of femoral offset. The second aim was the compare the pre- and postoperative values of femoral offset as well as the variations created by THA replacement using the same protocol of analysis in a group of patients operated on by the same surgeon by the modified lateral approach of Hardinge.

2. Results

We used a program of this type called ''Hip Plan'' (Symbios^{TM}) to calculate and compare variations in pre- and postoperative femoral offset for one patient who underwent THA. The purpose of obtaining preoperative femoral offset was to be able to plan for and choose a combination of hip replacement components that would restore this offset. We also associated leg length measurement into the preoperative planning protocol (Figure 1-6).

The CT-scan examination was performed with a multi-row detector spiral device Siemens^{TM}, with the patient in the supine position with the legs fully extended and the knees straight. CT-scan included contiguous 2mm slices of the pelvis between the iliac crests and the femoral isthmus, which corresponds to the narrowest section of the femoral diaphysis as well as frontal and profile telemetric images of the legs

Image processing and reconstructions were performed with the ''Hip Plan'' (Symbios^{TM}) software, which was developed for 3D preoperative planning. ''Hip Plan'' is a software package to process and analyse 3D images. It is based on a software package that was initially developed to conceive and plan custom total hip replacements in cases of significant femoral dysplasia by Flecher et al. Three windows with coronal, sagittal and axial views, which are perpendicular at one point are seen simultaneously, providing 3D images. Thus, a reference point is naturally obtained where each slice defines one of the three planes. Navigation in this three dimensional space is obtained by moving this point (called the 3D cursor). The user can zoom in or reorient the 3D image in relation to this point (translation and rotation). This type of navigation makes it possible to compensate for poor positioning of the patient during image acquisition by making it possible to locate and mark the patient's anatomical references.[12-15]

Two planes were systematically acquired: first the anterior pelvic plane as defined by the anterosuperior iliac spines and the anterior pubic tubercles, which is a plane that provides patient characteristics, and the craniopodal plane as suggested by Murray [16], which is a reference plane similar to a frontal plane radiograph.

Pre- and postoperative results could be compared and the affects of implantation could be analysed because anatomical references were precisely determined with this method. The high osteotomy level plays a critical role in stem stability and must be therefore respected. It was also important to work on the posterior wall entry point in order to insert the stem. We limited the lengthening because the leg difference come from the contralateral surgery.

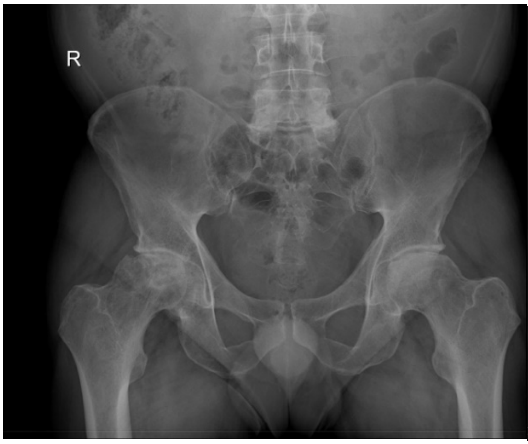
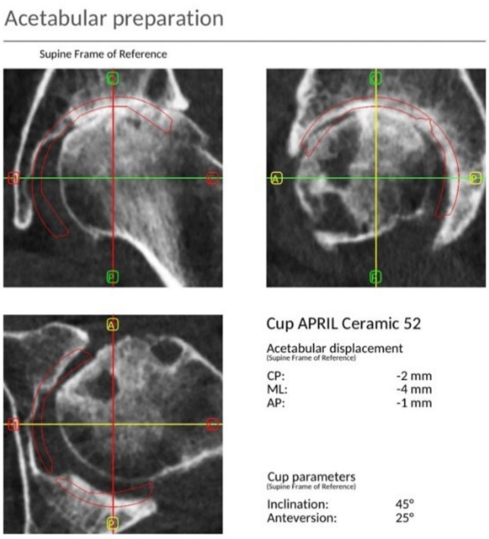


Figure 2 Bilateral hip arthrosis, more advanced right side

Figure 1 Total hip prosthesis right side.



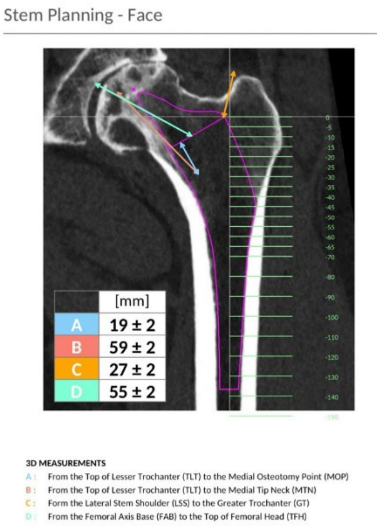


Figure 3. Preoperative planning – acetabular preparation on CT scan, reaming position

Figure 4. Preoperative planning – femoral preparation on CT scan, femoral osteotomy

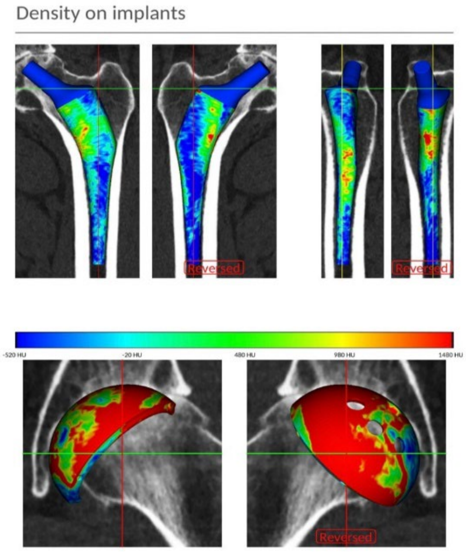


Figure 5. Preoperative planning – proposed position of the custom hip prothesis

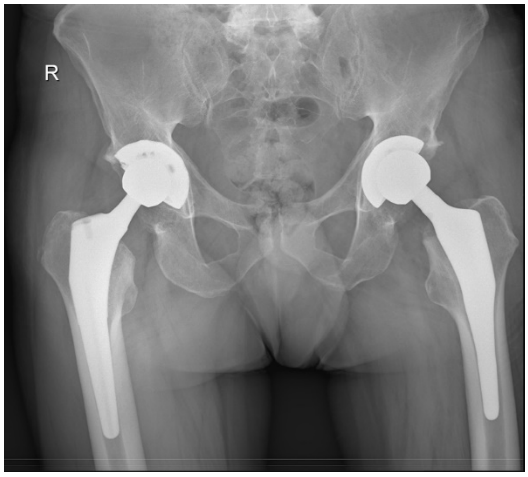


Figure 6. Final radiological aspect of the left total hip arthroplasty with customized prothesis

3. Discussion

Calculating femoral offset with frontal plane radiographic studies is limited by the precision of the radiographic technique, which is dependent upon many variables: 1) first, the patient's position, the position of the X-ray tube the distance between the tube and the plate, which determines the enlargement coefficient; 2) the image must be obtained along the femoral axis while an osteoarthritic neck is often fixed in external rotation. With computed tomodensitometry (CT-scan) other planes of reference can be visualised such as the axial plane, which can be used to measure anteversion according to Suh et al. and Olivecrona et al. With computer assisted 3D CT-scan reconstruction, measurements can be obtained by maximizing the view of the femoral cervical axis [17-19].

With 3D CT-scan reconstruction, the spatial characteristics of the patient's anatomy can be evaluated on one hand, and angles or lengths can be measured on the other, because the characteristics of the CT-scan workspace are well defined. Certain characteristics useful for surgery (measurement of angles, or evaluation of distances) can be obtained with implant simulation programs thanks to the standardized DICOM format. Computer assisted planning was found to be effective for simulations for Noble et al. and virtual planning for Seel et al. Sari Ali et al. have shown that these tools are effective for evaluating oper- ated and contralateral leg length with frontal telemetry, and can effectively be used to choose the center of hip rotation, confirm articular range of motion and identify impingement [20-23].

Therapeutical indications of the custom hip prosthesis are: primary or secondary hip arthrosis, femoral head necrosis or fracture, femoral neck fracture, inflammatory arthritis, congenital dysplasia, extreme coxa valga/varra, posttraumatic sequelae, hip prothesis revision. Contraindications: sepsis, muscular or neurological disorders, low quality of the bone, allergy.

Custom-made hip replacements – the latest orthopaedic technology is a leap forward for hip replacement patients. It is true that most patients can be served perfectly well by the standard hip replacement prostheses currently in use. However, there is data available from large banks of CT scans of hips [24], which show clearly that there is actually great variation between individuals with respect to:

- the width and internal dimensions of the bones,
- the valgus / varus angle of the hip,
- the anteversion / retroversion angle of the hip, and

- the offset distance of the femoral head.

The femoral offset is the distance from the centre of the femoral head to a line running down the anatomical long axis of the femur. Most importantly, recent research has shown that each of these variables can alter independently of each other. This means that surgically implanting a bigger prosthesis to correct for one large variable may actually overcompensate for one of the others, or vice versa [25,26].

Decrease in the offset in the hip joint significantly weakens the abductor muscles of the hip. Research has shown that a decrease hip abductor muscle strength by anything more than just 12% causes functional problems such as early fatigue and limping. Further research has also shown that implanting a hip where the femoral stem angle plus the cup angle cumulatively fall outside of the "safe range" of 40 – 60 degrees leads to a 7- times greater risk of post-operative dislocation of the hip replacement [13,14,27].

Attempts to appropriately correct all of the different variables in hip geometry with standard hip replacements can potentially lead to surgeons inserting the hip prosthesis in a position that is good for the hip joint itself, but which unfortunately leads to either shortening or lengthening of the overall leg length. Leg length discrepancies in the region of just 1cm are noticeable to patients, and leg length inequality can cause a variety of problems, including limping and low back pain. Small leg length discrepancies can be corrected for by patients using heel raise inserts inside their shoes. However, leg length differences of more than 1cm normally require a built-up shoe on the short side, which can be very restrictive in terms of footwear.

One the main difficulties lies with the fact that simple X-rays are notoriously bad at measuring true hip dimensions and geometry, and they can often be misleading.

Fortunately, the latest technology that has been specially developed allows for extremely accurate 3-dimensional mapping and measurement of the hip joint using rapid CT-scanning, with a radiation dose not significantly different from a simple plain X-ray. The data from the scan is interpreted by software that allows 3-dimensional reconstruction of a patient's bones and hip joints on a computer. This then allows measurements of relevant distances, dimensions and angles to determine exactly what offset, neck angles and neck lengths are required to anatomically reconstruct the patient's hip joint. Recent research has shown that 3-D imaging software allows unprecedented degrees of accuracy in hip replacement surgery [28].

Thus, true anatomic reconstruction of all the different joint variables can be achieved in the large majority of patients, without having to compromise on loss of offset and without creating leg length discrepancies. There is, however, a small number of patients in who even the new generation of modular implants does not have the sufficient range of shapes and sizes to adequately restore appropriate anatomy. Clinical experience has demonstrated that somewhere in the region of 5% of patients may fall into this category. For such patients as this, a new generation of custom-made hip prostheses are now available, which are designed specifically for the size and shape of an individual's anatomy, allowing for relatively easy reconstruction even in patients with significant deformity of the hip and the proximal femur.

With this method of 3D CT-scan reconstruction, images can be recentered along predefined planes and femoral off- set can be precisely determined by placing the frame on the femoral metaphyseal axis and the femoral diaphyseal axis. We found a significant difference between radiographic and CT-scan methods. CT-scan reconstruction put in evidence how diferent is the hip anathomy from patient to patient and that is the main reason why a custom-made hip prothesis brings segnificant improvment for faster recovery and a better hip biomechanic in comparison with classical primary total hip replacement.

During THA implantation, restoring soft tissue balance is essential for hip stability. There are several choices if the surgeon feels that stability is insufficient: increase neck length or reduce the neck angle of the femoral compo- nent or both. Each of these possibilities simultaneously affects leg length and soft tissue tension, which affects off- set. As Charles et al. have emphasized, increasing neck length causes leg lengthening and increases femoral off- set, while reducing neck-diaphyseal femur angle increases offset more than it increases leg length. To restore off- set in a diseased hips from various causes, this variable must be evaluated preoperatively, and the length of the leg in relation to the contralateral leg must be deter- mined. As Ranawat et al. have suggested, offset can be evaluated during surgery before dislocation and cutting of the femoral neck. It can also be confirmed after implan- tation of the replacement components during evaluation of hip stability by different manoeuvres, as suggested by Jasty et al [29,30].

Numerous authors consider lateralization with increased offset (at least 4 mm) to be the best method to restore soft tissue tension by moderately lengthening the operated limb. Maloney and Keeney feel that maintain- ing preoperative leg length in the operated limb or avoiding postoperative lengthening of the operated leg is an impor- tant factor and results are not improved by radiographic preoperative planning for Konyves and Banister. The length of both legs should be determined preoperatively and confirmed during surgery. Maloney and Keeney emphasize the poor postoperative tolerance of postoperative leg lengthening and the importance of pre- operatively identifying length inequalities. Although the leg to be operated on is usually shorter, the opposite also fre- quently occurs and this should be included in preoperative planning. Konyves and Banister estimate that lengthen- ing occurs in 20% of legs with osteoarthritic hips requiring surgery, and found that 60% of legs had lengthened after THA. With the type of preoperative planning used in our study, leg length can be systematically defined, making identification of individual differences and determination of the surgical strategy easier [31-33].

When the local hip anatomy permit, primary total hip replacement with classical implants is enough to achieve best biomechanic with rapide full recovery of the joint. But there are anathomical situations which can not lead to these goals and the choice of a custom-made hip implant will bring the desired reconstruction of the hip.

4. Materials and Methods

We have evaluated a 48 years old patient which was diagnosed with bilateral hip arthrosis, more advanced on the right side and the initial surgical indication was of total hip arthroplasty on the right side with uncemented Zimmer Biomet prosthesis. We used Zimmer Trilogy acetabular system, 32mm liner Longevity crosslinked polyethylene with 32mm CoCr head, Taperloc porous coated stem. 6 months after the surgery, the operated lower limb was found prolonged with 2 cm, the walk was limping and the left hip presented advanced coxarthrosis with severe pain and functional impotence. The surgical decision was to perform left total hip arthroplasty with a Symbios custom hip prosthesis. We started the hip CT protocol to evaluate the local anatomy of the lower leg.

The CT protocol involves 1mm slices from top of the iliac crest to the isthmus of the femur, 2mm slices from top to the bottom of femoral condyles and top and bottom of the ankle joint. The intra and extra medullary parameters were assessed in 3D planes. The deformity was assessed to determine whether an 'Off the shelf implant' will achieve metaphyseal 'fit & fill' and stability without needing a corrective osteotomy. If the deformity was deemed unsuitable for an 'off the shelf' implant then a custom femoral stem was designed to achieve metaphyseal 'fit and fill', primary stability and to correct the extra medullary parameters. The metaphyseal intramedullary volume was assessed using Hip Plan Software^{TM}. This volume was used to design the metaphyseal part of the stem. The fit was assessed by the software algorithm simulation to demonstrate stability.

The resultant custom implant was made of Ti Alloy and had proximal hydroxy apatite coating. The diaphyseal part of the implant was smooth, uncoated and is designed not take part in load transfer or osteointegration. The implant came with an operative plan to guide the neck osteotomy site, and with its own bone compacting or bone removing rasp according to the intramedullary cortical or cancellous bony architecture indicated by the 3D-CTplan.

The procedure were performed by a specialist trained Arthroplasty surgeons using the modified lateral approach of Hardinge to the hip with the patient in the supine position. The Uncemented custom Ti-alloy stem with proximal hydroxyapatite (HA) coating (Symbios, Yverdon-Les-Bains, Switzerland) was used in all patients. Postoperative rehabilitation protocol included immediate full weight bearing with elbow crutches and active range of movement and muscle strengthening exercises.

In addition to a clinical review and oxford hip scoring, the patient had postoperative radiographs and were reviewed regularly at 6 weeks and 6 months. Postoperative leg length discrepancy (LLD) was assessed radiologically by measuring the distance from the acetabular tear drop to the lesser trochanter and from the antero-superior iliac crest to the tip of the tibial malleolus.

5. Conclusions

We concluded that this 3D-CT guided custom design femoral stem produces reliable proximal 'fit and fill' and primary stability with restoration of limb length discrepancy with complex proximal femoral deformity without the need of a corrective osteotomy. It also achieves good metaphyseal osteointegration in the short term. The method applied for this patient create functional improvements and increase the quality of life, with fast return to previous activities and early rehabilitation.

Author Contributions: Conceptualization B.O. and R.B; resources and visualization, MGI.; writing—original draft preparation, B.O. and D.M.I.; writing—review and editing, B.M.C, and R.B.; supervision, M.G.I. and B.O. All authors have read and agreed to the published version of the manuscript. *All the authors had equal contribution*.

Funding: This research received no external funding.
Institutional Review Board Statement: Not applicable.
Informed Consent Statement: Written informed consent has been obtained from the patient to publish this paper.
Data Availability Statement: Not applicable.
Conflicts of Interest: The authors declare no conflict of interest.

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