

CUSTOM HIP ARTHROPLASTY

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ABSTRACT

Total hip replacement is a rapidly growing procedure due to pain relief, restoring the range of motion and patient's satisfaction. The primary goal is to restore the individual geometry of the patient's hip joint, to achieve long-term component survival and most importantly – to improve the patient's quality of life.

In past decades this surgery has had several limitations such as patient's age, bone morphology (incl. anatomical deformities), previous surgeries, etc. Recently, with the development of modern implants (cups and stems) these limitations have been eliminated.

Young patients indicated for THA are always a great challenge, because of their functional requirements, life expectancy, anatomical variations (due to congenital or acquired disorders), greater mobility and higher risk of aseptic loosening.

Standard cementless stems have some unsolved issues such as fixed intra/extramedullary dimensions, proximal stress shielding, impingement, etc. They are based on 2D planning and often have a mismatch between the acetabular and the femoral center of rotation.

Custom femoral stems are based on a specific 3D scan of the hip joint, which presents the individual shape of the acetabulum and especially that of the femoral canal. This allows for optimal bone support for the stem, preserving bone substance, excellent bone-stem contact and most importantly - restores the center of rotation.

For the period 2010-2014 we have operated on 16 patients, 8 were with osteoarthritis (OA); 4 - with avascular necrosis (AVN); 2 - with dysplastic hips (DDH) and two - with posttraumatic osteoarthritis. The follow-up is in 6-42 months.

We performed THA with a modified posterior surgical approach with minimal femoral reaming, due to individual femoral rasp with the same size as the customized femoral stem.

During the follow-up period we found no complications. The Harris Hip Score was 97 pts. and 85% of the patients had regular physical exercises for 3 weeks.

Keywords: *osteoarthritis, THA, cementless stems, custom hip, 3D-planning*

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INTRODUCTION

Total hip and total knee arthroplasty are rapidly growing procedures. In the USA, growth expectancy is 600% till the year 2030. The reasons for this are many, but probably the most important one is excellent functional results after appropriate treatment. Nowadays, THA allows restoration of the individual geometry of the patient, minimal wear and long-term fixation of the bone component. For the pa-

tient this means better quality of life – maximizing the range of motion without pain and greater physical activity.

In the recent years, with the development of better components, performing THA in younger patients becomes possible. The challenges in such patients are higher functional requirements and increased life expectancy. These patients often present with anatomical hip deformities due to dysplasia, posttraumatic arthrosis and recent surgical treatment. Younger patients are predisposed to aseptic loosening due to micro movement and incomplete “fit and fill” (3,5,6).

Cementless stems have some disadvantages, particularly when applied in such patients. These stems have fixed extra/intramedullary dimension, which can't be used in certain cases with altered anatomy. There is a high risk of proximal stress shielding, impingement and some disadvantages related to modular neck corrosion, fracture or high level of metal ions.

Primary stem stability is a prerequisite to bone ingrowth and long-term fixation. Stability depends on the filling of the proximal femur and the anatomical position of the stem (fit) (7,8). Primary OA and dysplastic hips are correlated with great anatomical variations of the intramedullary canal and femoral neck (anteversion, offset, femoral neck angle) (6,7).



Fig. 1. Proximal femur deformity (left) and superimposed custom stem (right)

There are great differences in the tridimensional anatomy of the femoral canal, as well as in the extramedullary parameters, between dysplastic hips and primary OA (7,8). The stage of dysplasia is correlated with the difficulties in the restoration of the acetabular center of rotation, which is necessary for the

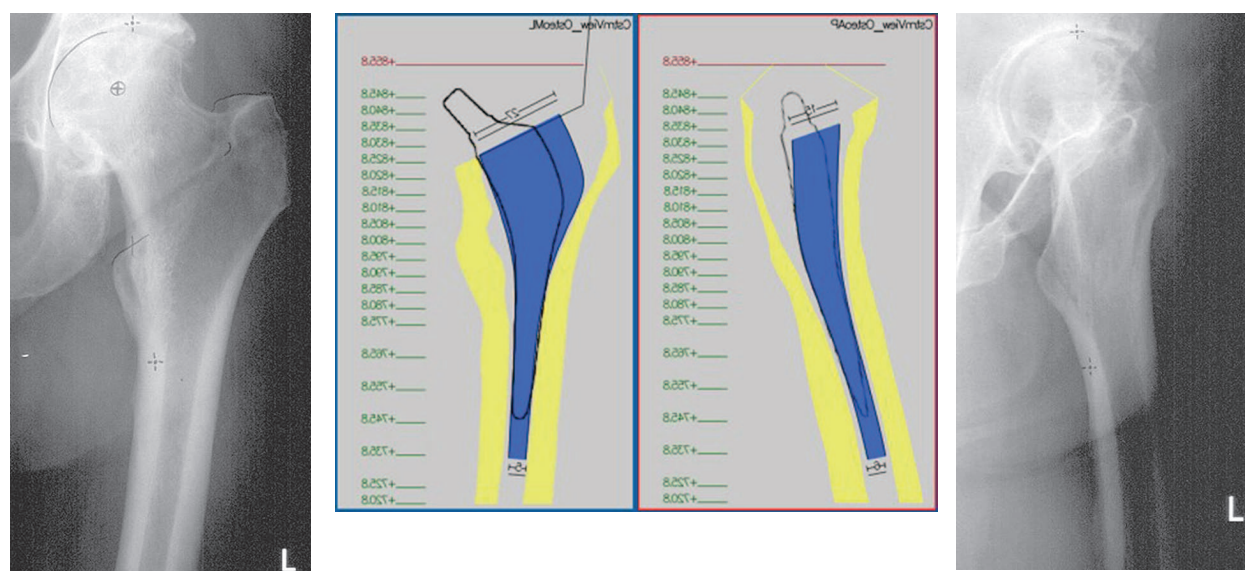


Fig. 2. Increased canal flare index

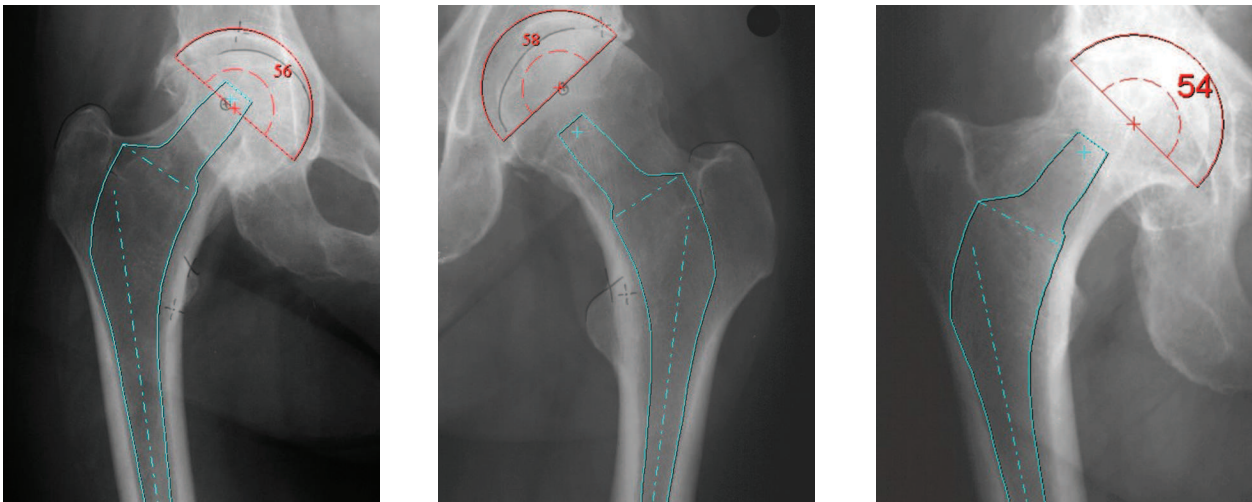


Fig. 3. Standard cementless stem (left picture) in a good intramedullary position and optimal reconstruction of the center of rotation (COR); admisible intramedullary position (in the middle), but indicated for longer valgus neck; good intramedullary position (right picture), but indicated for longer varus neck

correct joint kinematics and the lever of the abductor musculature (10,11).

Difficulties in the points of intramedullary variations are: femur deformities (Fig. 1), increased canal flare index (Fig. 2), lateral curvature, and femur helitortion.

The extramedullary variations are in the acetabular/femoral offset, the femoral neck length and anteversion, and the femoral neck angle (FNA). All these parameters define the lever of the abductor musculature.

Generally, the femoral offset was measured on AP radiographs (2D image) without considering anteversion and external rotation, leading to measurement errors thereof. These differences in the measurements can be found in up to 40 percent of cases (6,16). According to Asayama et al. (1) clinical manifestation of the abductor weakness presents when the femoral offset decreases more than 12% (5mm) and clinically manifests as decreased over 28%.

The standard stems are very well adapted intramedullary, but sometimes there is a mismatch between the center of rotation of the stem and the center of rotation of the femoral head of the patient (Fig. 3). Very often the femoral stems, designed for optimal proximal filling don't fit optimally in the metaphysical zone (12).

Apart from the intramedullary canal, the abnormal femoral anatomy is demonstrated also in the

extramedullary parameters of the proximal femur (9).

When the position of the stem (the “fit and fill”) is not optimal and the center of rotation is not restored, the most important indications for a successful hip replacement are not performed (1,2). Such cases are indicated for customized hip prosthesis.

MATERIALS AND METHODS

From 2010 till 2014, 16 patients were operated on in the Department of Orthopedics and Traumatology, 14 men and 2 women, 8 of them suffering from osteoarthritis, 4 - from avascular necrosis of the femoral head, two had dysplasia of the hip and two had post-traumatic osteoarthritis. The average age was 54 (20 – 69), and the average weight was 86.5kg (BMI – 32.4). The postoperative follow-up period was between 6 and 42 months.

We took into account several factors during the patient selection:

- ◆ The Noble index;
- ◆ Conventional 2D planning (MediCAD) (Fig. 4);
- ◆ 3D CT planning (Symbios protocol) (Fig. 5);

The CT protocol is based on 5mm cuts from the acetabulum to the greater trochanter, and 10mm cuts from the lesser trochanter to the femoral isthmus. This allows precise intramedullary reconstruction of the femur. The anteversion is calculated with horizontal cuts on the level of the 2nd metatarsal, femoral condyles and 10mm above the lesser trochanter.

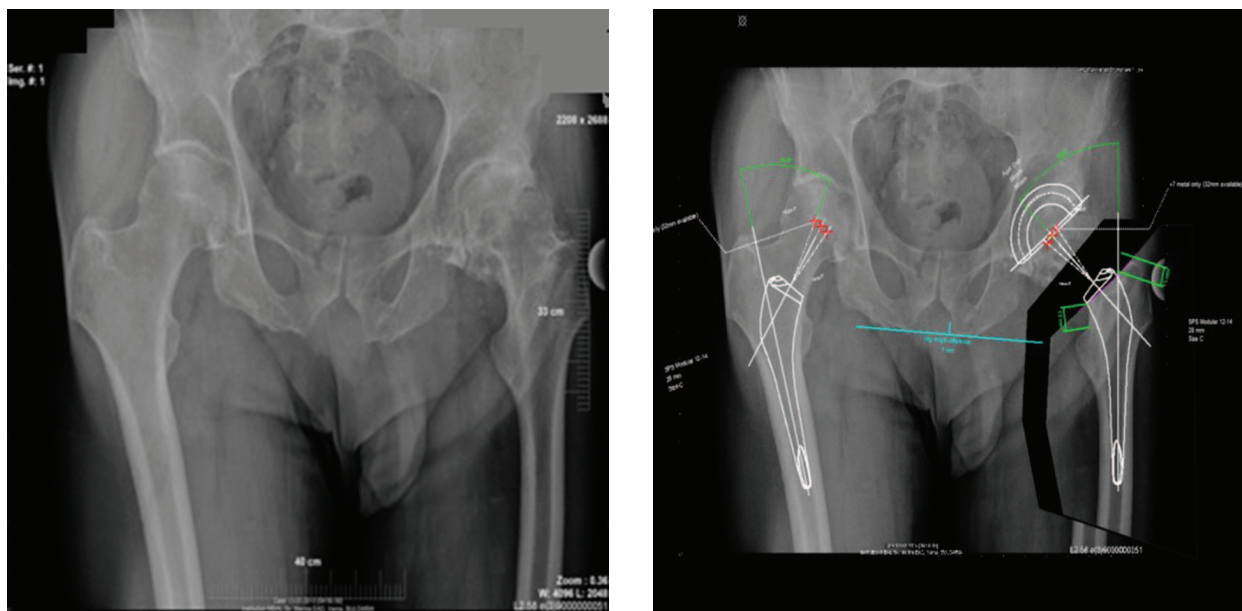


Fig. 4. Conventional 2 D planning (MediCAD)

AP acetabular dimension is formed with additional cuts. This protocol makes possible the calculation of the femoral neck angle (FNA) and the femoral anteversion (Fig. 5) (4).

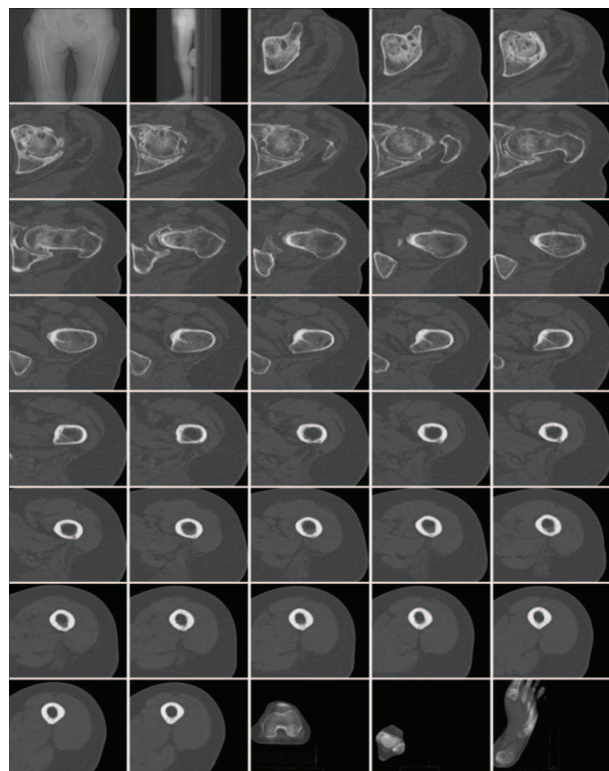


Fig. 5. CT protocol for 3D planning of the individual femoral stem

Custom stem design is based on the preoperative X-ray images and the CT protocol of each patient. 3D reconstruction of the femoral canal is necessary to avoid overreaming of the spongy bone, which results in cortical contact of the stem. The metaphyseal spongy bone is impacted, before stem implantation, with custom rasp designed as the stem. This CT protocol makes possible the correction of extramedullary parameters – offset and neck anteversion (9).

Preoperatively, we use actual size planning (1:1), available in the surgery room - the so-called “Face-Osteo” plan (Fig. 6). It shows bone resection parameters needed for precise stem implantation (values are projected over an X-ray image) and CT level calibration.

The following distances were measured:

1. (A) - from the lesser trochanter, the level of the osteotomy on the medial neck;
2. (B) - from the lesser trochanter to the medial top of the femoral neck;
3. (C) - from the lateral stem curve to the greater trochanter;
4. (D) - from the femoral axis to the top of the femoral head;
5. (F) - from the lateral stem curve to the top of the femoral head

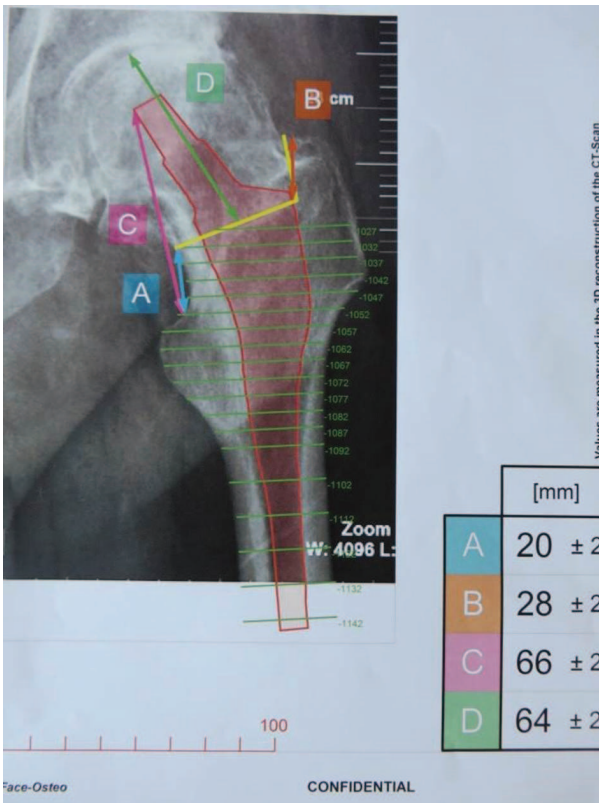


Fig. 6. „Face-Osteo“ planning

Additional measurements:

6. (E) - from the calcar resection to the top of the femoral head
7. (G) - the size of the femoral neck.

Another important component is CT reconstruction of the bone density in the metaphyseal-diaphyseal area with the stem in situ (Fig. 7) which allows:

- ◆ Color contrast assessment of the density of the cancellous bone (black, green, yellow and red);
- ◆ Visualization of the areas where bone mass removal is necessary for the correct stroke of the stem;
- ◆ Control of the correct position of the stem at the level of the osteotomy (medio-lateral and antero-posterior);

The next stage of preoperative planning is to determine the anteversion of the stem. Fig. 8 shows the angular geometry of the femoral stem, the knee, and the foot, and we can see:

- ◆ Gait angle

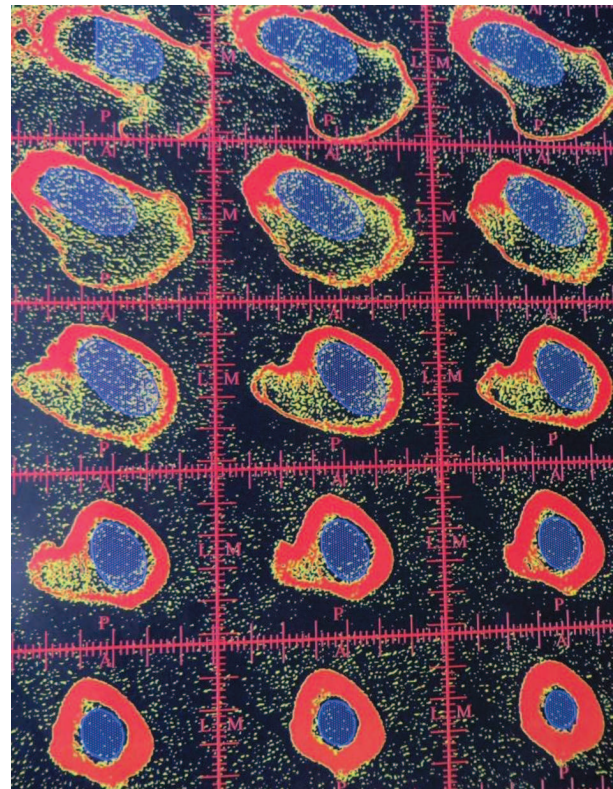


Fig. 7. CT reconstruction of the bone density

- ◆ helitortion of the stem
- ◆ extramedullar angle need for correction, which shows the final anteversion according to the bi-condylar line (PBCP).

The standard targeted anteversion is 15°, if there are no additional instructions from the surgeon.

Other additional plannings which we use are those for cup position, femur position before and after prosthesis reposition.

“Cup planning” is based again on CT reconstruction in axial, sagittal and coronal plan over the cup center of rotation (Fig. 9). It allows the calculation of the level of acetabular reaming for optimal cup position (coverage, version, lateralisation) and preserving enough bone substance.

While planning for our patients we received the following data:

- ◆ anteversion angle of the femur (A): average - 15.4° (10°-20°);
- ◆ helitortion(H): average - 17° (2°-39°);
- ◆ delta (Δ) angle (A - H): from -19° to +18°;
- ◆ acetabular inclination: average - 52° (49°- 57°);

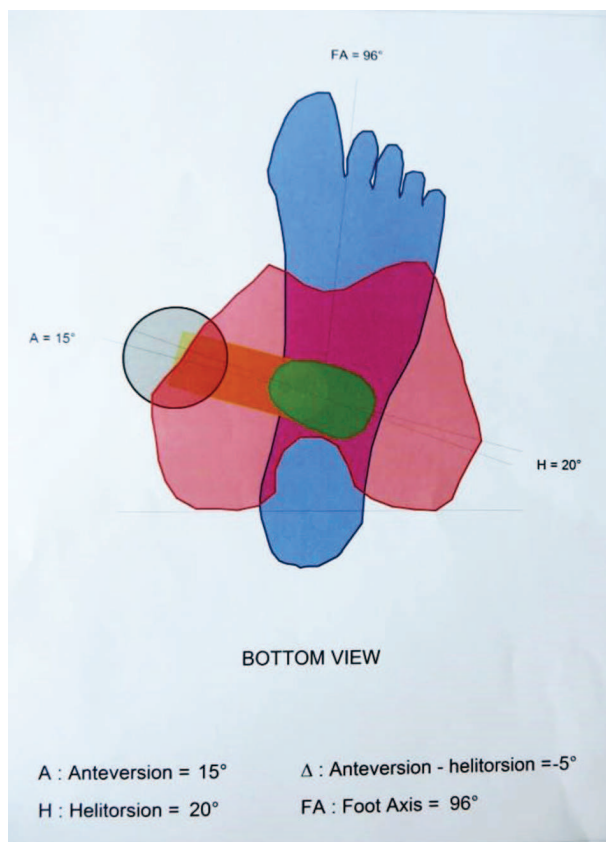


Fig. 8. Adjustment planning of the stem corresponding to the lower limb anatomy

- ◆ acetabular anteversion: average - 18° (12°-24°).

Planned cup inclination was 45° and 20° anteversion. Bone resections were calculated as follows:

- ◆ (A) – 17mm (11mm-21mm)
- ◆ (B) – 37mm (20mm-67mm)
- ◆ (C) – 38mm (27mm-67mm)
- ◆ (D) – 52mm (45mm-64mm)
- ◆ (F) – 66mm (available only in 3 patients)

We performed the standard posterior surgical approach with preserving m. piriformis. The metaphyseal spongy bone was impacted with a smooth impactor, excluding 4 patients who needed tooth (aggressive) rasp (Fig. 10). We implanted titanium HA cups Hillock/MaxiMom (Symbios, Yverdon, Switzerland) and crosslinked polyethylene insert/MOM. The customized stem is with 2/3 hydroxyapatite coverage (HA) (Symbios, Yverdon, Switzerland) and variable femoral heads: ceramic – 28.32 mm Alumina and 36 mm Delta; 32.36 mm Cr Co, MaxiMom (Fig. 6, 7).

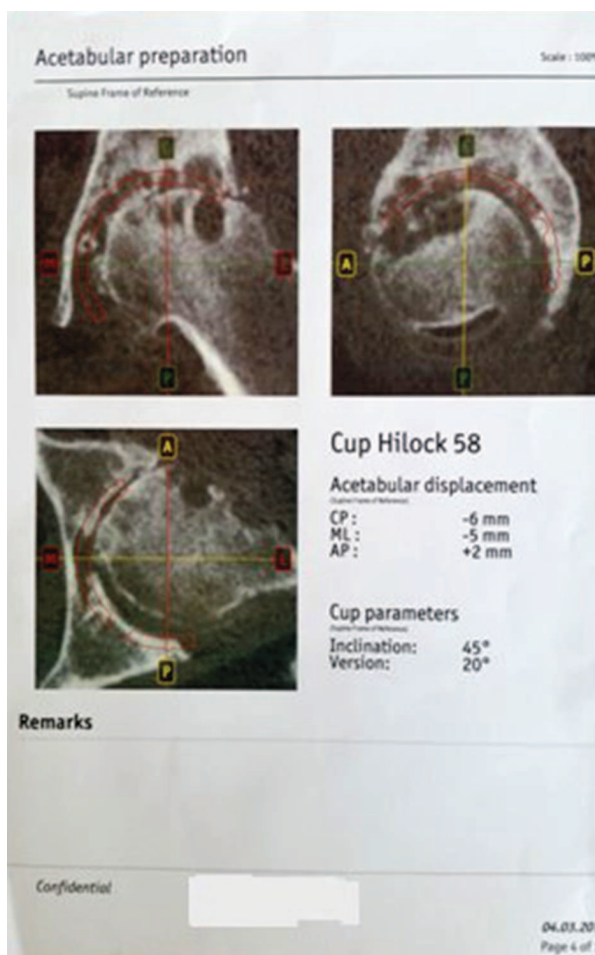


Fig. 9. Cup planning

The postoperative rehabilitation protocol includes immediate partial weight bearing in the first 3 weeks, depending on the patient's tolerance. Standard antithrombotic treatment with low-molecular heparin is performed for 35-40 days.



Fig. 10. Customized rasp (aggressive) used for impaction of spongy bone in the metaphyseal area. The custom stem has the same size and form

All patients had a smooth postoperative period. We found no late complications. The average Harris-Hips Score (HHS) was 97 (50-100) (Table 1). In 85% of the patients, we had regular physical exercises with full ROM on the last follow-up visit. There were no pain or ROM limitations.

Table 1. Preoperative and postoperative HHS

Harris Hip Score	Preoperative	Postoperative
General	41.9 (25-88)	97 (50-100)
Pain	18.2 (10-44)	42.6 (20-44)
Walking	9 (2-11)	31.7 (9-33)
Activity	7.6 (2-14)	13.5 (6-14)
Deformity	4.3 (0-4)	4 (3-4)
ROM	2.8 (0-5)	4.8 (2-5)



mise between the intramedullary anatomy and the bone density. An X-ray analysis of the femoral canal is insufficient, because it does not show these two parameters. The high accuracy of the 3D planning has been proved by Sugano et al. (11), who showed the inaccuracy of the X-ray analysis, when combining femoral anteversion with fixed external rotation over 15°. Such cases are recommended for 3D CT planning. 2D planning of the proximal stem fit to medial endosteal line is inaccurate, with sensitivity of 41% and specificity of 23%. In 3D planning, the sensitivity is 93% and the specificity - 86%.

The customized hip arthroplasty concept is from the 80s and the early results are worse than those with conventional stems. With the improvement of the diagnostic and manufacturing protocols,

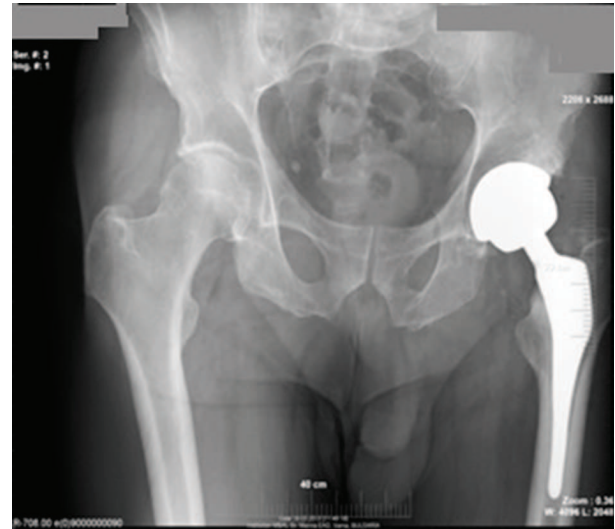


Fig. 11. Post-operative custom hip arthroplasty

DISCUSSION

THA is a challenge, when performed on young patients and those with anatomical deformities due to OA, dysplasia or surgical procedures (2). These cases present with an increased life expectancy, functional demand, ROM and implant longevity. Anatomical studies show that optimal prosthesis fit and fill in the metaphyseal zone and extramedullary adaptation is sometimes hard to achieve with conventional cementless stems (10,14).

Stability of the cementless stems is secured with optimal fit and femoral canal preparation, but reaming stops when cortical bone resistance is reached. Due to that, the final stem size is therefore a compro-

mean implant survival in the first decade is 100% in patients under 65 years with a substantial reduction of the clinical symptoms. Custom stem usage reduces the risk of early aseptic loosening, proximal stress shielding and femoral osteolysis (7,9,15).

We believe that the greatest advantage of the customized stems is the 3D preoperative planning, responsible for stem manufacturing. It reproduces independently the extra- and intramedullary parameters, especially the cases with altered anatomy. Improved function, due to restored kinematics, component survival (optimal fit and fill) are keystones for a successful customized hip arthroplasty.

CONCLUSION

The custom stem has advantages especially when used in younger patients with anatomical alterations and high functional requirements. It achieves anatomical reconstruction and avoids intraoperative complications. These stems are a prerequisite for normal kinematics, low rate of bone restructuring and osteolysis, increased survival and low wear. They restore quickly, provide a high quality of life and physical activity.

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