



Total hip arthroplasty planning

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- Preoperative planning is mandatory to achieve the restoration of a correct and personalized biomechanics of the hip.
- The radiographic review is the first and fundamental step in the planning. Limb or pelvis malpositioning during the review results in mislead planning.
- Correct templating is possible using three different methods: acetate templating on digital X-ray, digital 2D templating on digital X-ray and 3D digital templating on CT scan.
- Time efficiency, costs, reproducibility and accuracy must be considered when comparing different templating methods. Based on these parameters, acetate templating should not be abandoned; digital templating allows a permanent record of planning and can be electronically viewed by different members of surgical team; 3D templating is intrinsically more accurate. There is no evidence in the few recently published studies that 3D templating impacts positively on clinical outcomes except in difficult cases.
- The transverse acetabular ligament (TAL) is a reliable intra-operative soft tissue reference to set cup position.
- Spine–hip relations in osteoarthritic patients undergoing hip joint replacement must be considered.

Keywords: digital templating; kinematic alignment; preoperative planning; spine–hip relation; total hip arthroplasty

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Introduction

The evolution of hip replacements has increased patients' expectations in terms of function and longevity. The main goal of surgery is full restoration of the original bio-mechanical setting of the hip affected by osteoarthritis and represents a key step to achieve a complete functional recovery. A common mistake is to believe that planning and templating are equivalent steps, simply aiming at guessing the size of the acetabular and femoral hip components before surgery. The patient's age, sex,

preoperative diagnosis, mental status, level of activity, medical history and current medical status, expectations from the surgery and life expectancy should be considered in order to choose implant fixation, implant design and surgical approaches. Clinical preoperative examinations must also assess the patient's gait, hip range of motion, ipsilateral knee status, lumbosacral spine and fixed or functional deformities. Both the actual and functional limb-length discrepancies must be established. When there is a difference between the actual and functional limb length, pelvic obliquity may be evaluated by comparing the level of both hemi pelvises with patient standing and sitting.¹

Preoperative planning allows prediction of the optimal implant position and size and potential difficulties before the surgery. In the past the most common approach was the use of acetate on printed radiograph films, despite several problems of reproducibility. New technologies provide innovative techniques that allow a more accurate and consistent surgical planning.

The target of our review is to refresh the historical principles of total hip arthroplasty planning and then to describe whether and how technology may improve templating accuracy and reproducibility.

Planning steps

Preoperative planning is a step-by-step procedure that begins before surgery and requires:

1. X-ray review to assess the quality of the radiograph (femoral rotation, pelvic inclination and symmetry).
2. Identification of anatomical bone landmarks (the medullary canal, the greater and lesser trochanter, the acetabular roof and the teardrop).
3. Optimization of the implant shape, position and size with templating.^{2,3}

X-ray review

While it is quite easy to theoretically define a 'good' antero-posterior pelvic radiograph (well exposed, well oriented,

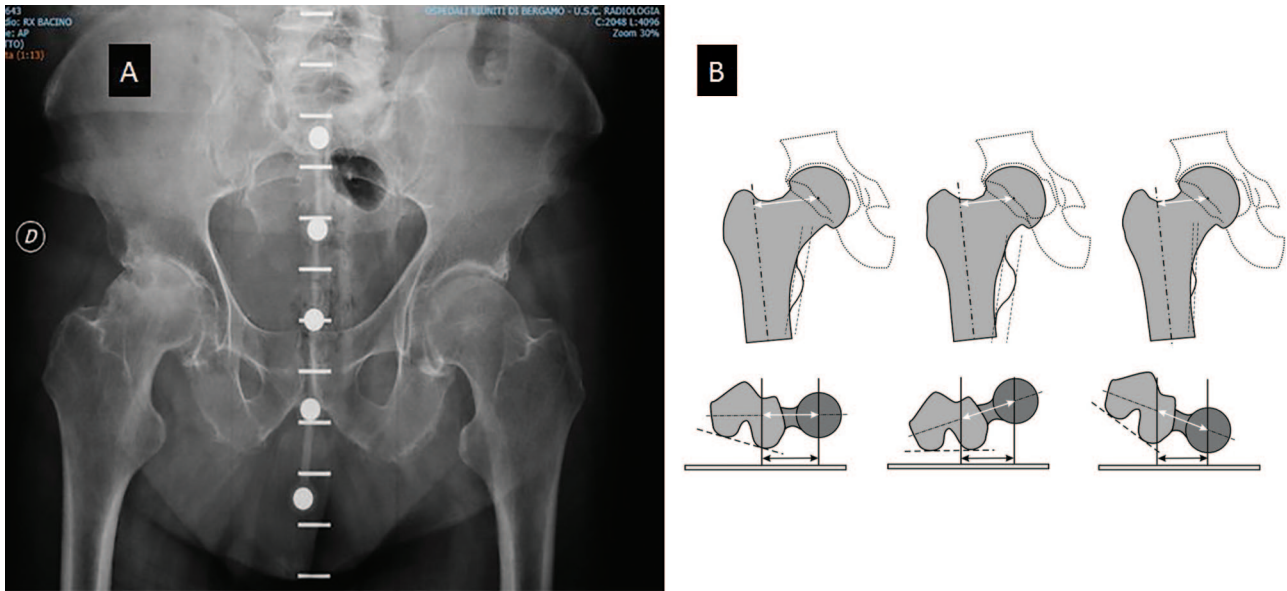


Fig. 1 (a) Example of bad X-ray for planning. Different femur rotation, wrong pelvic position, missing symmetry of foramen obturatum. (b) How the femoral rotation can affect offset evaluation.

high quality, standardized), it appears particularly challenging to obtain such images in clinical practice (Fig. 1).

‘Standard pelvic radiographs’ are generally centred on the sacrum. A low AP pelvic radiograph with the X-ray beam centred on the pubis is preferred for hip templating. As such, the whole proximal third of the femur is visible and is located more or less in the same horizontal plane as the X-ray source, avoiding excessive distortion.

To evaluate functional leg-length discrepancies and pelvic tilt in the frontal and sagittal plane, AP pelvic radiographs should be taken with both iliac spines at the same distance from the film. As such, the symphysis pubis should project on a line through the middle of the sacrum.

The natural pelvic tilt in the sagittal plane can be estimated by the distance between the projection of the sacrococcygeal joint and the upper border of the symphysis. When the pelvis is in neutral inclination the distance between the sacrococcygeal joint and the symphysis is 32 mm (range: 8–50 mm) in women and 47 mm (range: 15–72 mm) in men.² The distance increases when the pelvis is tilted forwards and decreases when the pelvis is tilted backwards. To estimate the length of the femoral neck, both femora should be positioned in 15–20° of internal rotation, corresponding to the natural femoral anteversion. As such, the femoral neck is parallel to the film and projects in its full length. Radiographs taken with more or less internal rotation of the femur may underestimate the femoral neck length and the femoral offset.²

Several variables can influence radiological accuracy and reproducibility: magnification (may be improved by digital radiology), wrong X-ray beam angle, limb or pelvis

malposition (caused by an operator mistake or induced by anatomical alteration (Fig. 2). A wrong X-ray beam angle can change also the postoperative evaluation (Fig. 3).

Determining the magnification of the radiograph is one of the main variable when talking about templating. The surgeon needs to know the magnification of the X-ray he is working on. Assuming that the X-ray tube is at the distance of 1 metre from the table and that the film is 5 cm below the table, magnification will be approximately 20%. Magnification is directly proportional to the distance between pelvis and X-ray film, so increased magnification should be expected in obese patients and less magnification in slim patients. Therefore, it can be useful to have one magnification marker at the level of the great trochanter. A circle with a known diameter can be also used as a marker.^{1–4} In our practice we take X-rays using two markers: a belt with five spheres (with known diameter) lying on the patient’s abdomen and a rectangle with 11 lines (whose length is known) leaning on the table. These devices allow the planning software to calculate the correct magnification, taking into account all variables.

Identification of bone landmarks

In order to have reliable images for our planning and to be able to carry out an X-ray review as discussed above, we need to identify bone landmarks. Landmarks have to be geometrical and morphological references easy to find during surgery (even in cases where the anatomy has been distorted by osteoarthritis); they must be reliable, and they have to be reproducible and consistent to help the surgeon in postoperative evaluation.

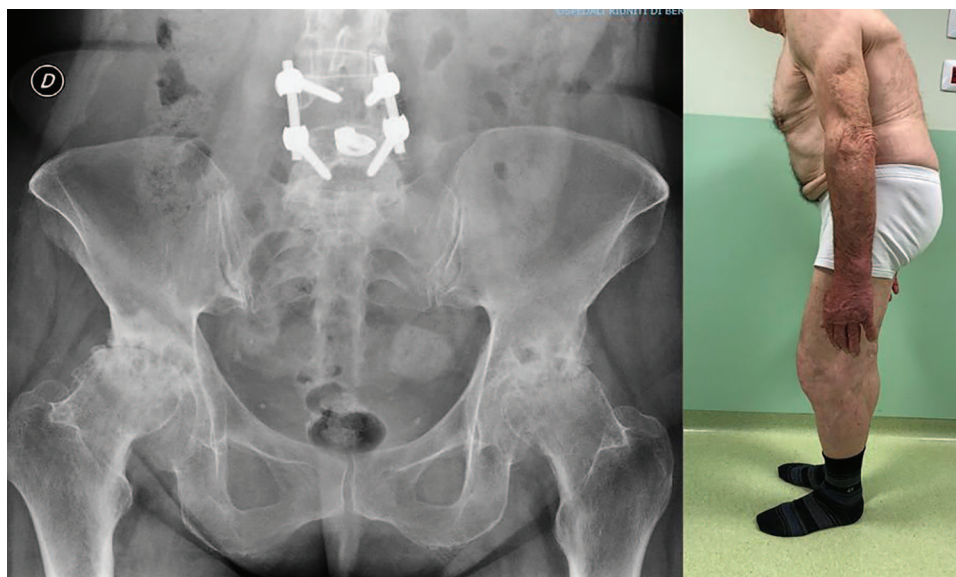


Fig. 2 Example of incorrect X-ray image due to pelvic tilt following a lumbar arthrodesis.

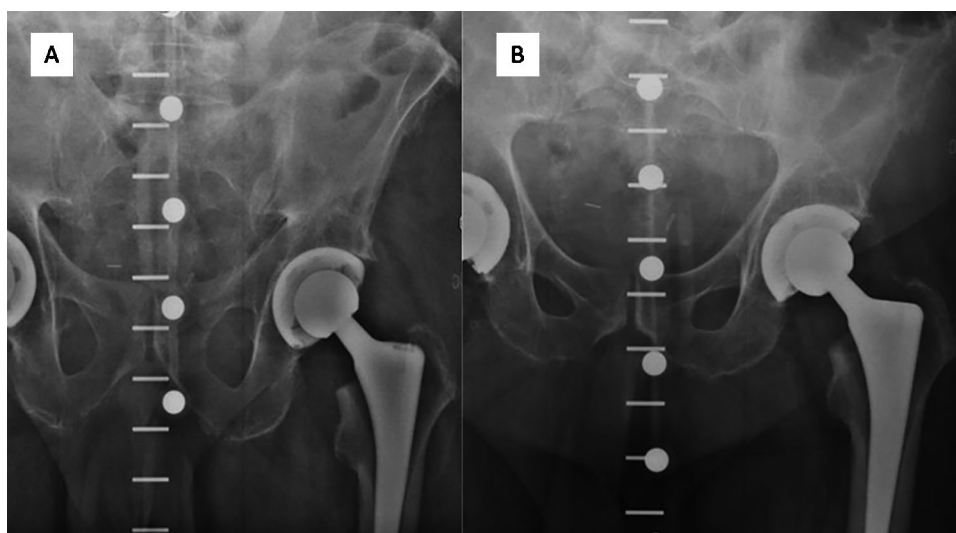


Fig. 3 Same implant and patient, different X-ray angle leading to different evaluation of cup orientation. (a) incorrect beam angle: cup too vertical and anteverted position. (b) Correct beam angle: correct acetabular orientation.

At the femoral side the medullary canal, and the lesser and the greater trochanter can be considered good landmarks. During anterolateral or posterior approach, these structures can be easily identified and also with new less invasive approaches the greater and lesser trochanter can be reached during surgery. Also, the most distal part of the junction between the superior aspect of the femoral neck and the greater trochanter is easily identifiable even with the most minimal approach.²

The teardrop is a radiographic landmark created by the superposition of the most distal part of the medial wall of the acetabulum and the tip of the anterior and posterior point of the acetabulum. The acetabular roof and the

‘teardrop’ are considered reliable radiographic landmarks for pelvic side. However, the teardrop is not always easy to identify during surgery.

Even if bone landmarks are well known by all orthopaedic surgeons there are different definitions and measurements in the preoperative planning, preoperative placement and postoperative evaluation.

The choice of reference frame and the definition for acetabular cup orientation angles can have a significant effect on the target orientation for the acetabular cup. Recommendations for the target orientation should always explicitly state which reference frame and angle definition is being used. The average recommendation of

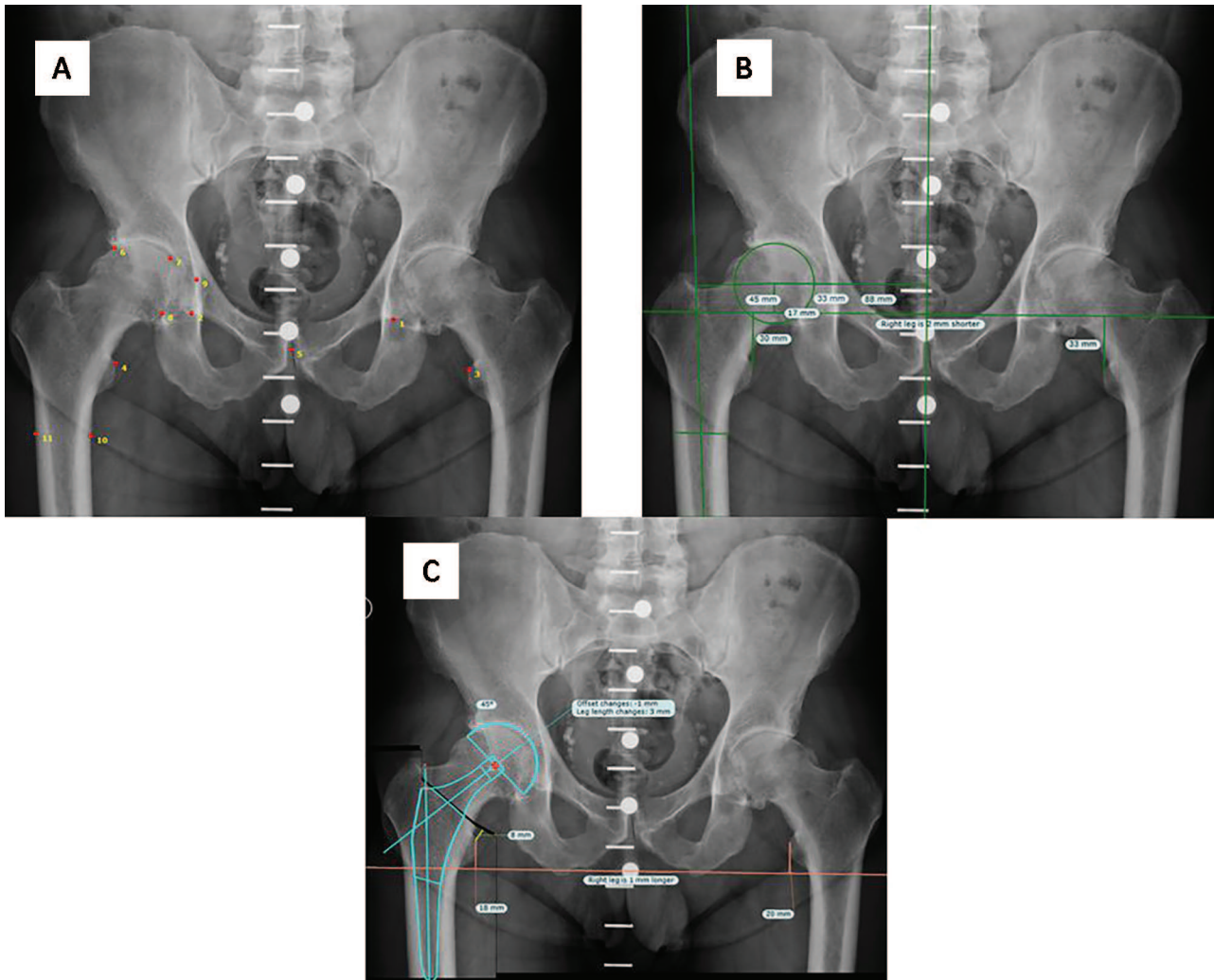


Fig. 4 (a) Digital bone landmark identification: 1–2 teardrop, 3–4 tip of lesser trochanter, 5 centre of pubic-symphysis, 6–8 top, fovea and bottom of femoral head, 9 acetabular posterior wall, 10–11 external femoral cortex. (b) Geometrical software output: horizontal and vertical. (c) Final templating: implant, size, shape and position.

the studies assessed here is 41° inclination and 16° anteversion in radiographic angles or 39° inclination and 21° anteversion in operative angles, both expressed in the pelvic reference frame.⁵

Another key point is the identification of the correct centre of rotation of the hip, this allows the restoration of the hip offset and the possibility for the surgeon to obtain the patient's physiological biomechanics.

Digital planning on digital X-ray should give surgeons the possibility to obtain more reliable measurements and to make them repeatable and visible to all members of the surgical team (Fig. 4).

Templating

As mentioned above, the templating target is not only about guessing the size of the acetabular and femoral hip

components prior to surgery. Shape, size and position must be considered together to optimize the implant. Shape and size of the implant must be chosen to achieve the best match with the patient's bone shape and to have the best implant position on all planes to reproduce the original biomechanics of the hip. Integration of all these three concepts to total hip arthroplasty (THA) is mandatory in order to achieve the correct implant for patients and respect the combined version of femur and acetabulum. This can decrease the wear to the components of the THA.

Innovation in THA templating

Where do we need to go? How do we get there?

There are three different possibilities for templating: acetate on digital images, 2D templating on digital images,

digital 3D templating. Opinions differ, and the optimal approach remains debated, but the most used method is digital templating on digital X-ray examination. Actually, there is an envelope of software and technology; in the beginning these tools seemed to point to 3D planning as an optimal answer to follow technology development and the increasing functional patients request. 3D planning is the only technique that allows examination in axial view.

Acetate vs. digital templating

Acetate templating on digital images is still often used. Time efficiency and low costs (two parameters used for evaluation of planning methods) make acetate on digital still an interesting approach and several authors (like Pedretta et al.) consider this method more accurate than computer-based templating.⁶ The potential explanation is that good surgical experience and long practice with acetate gives good results and some training time is necessary to learn every aspect of new software in order to obtain the best accuracy that it can offer.

Acetate templating on analogue hardcopy is the oldest way to perform preoperative planning. Even if it has been a cornerstone of developing basic concepts about templating it is now outdated; it adds magnification problems due to old X-ray film to proceed surgery for implant placement.⁷

Shaarani et al noticed that with digital templating on digital images, reproducibility and accuracy are guaranteed and there is larger correspondence between planned and actual size.⁸ Furthermore, multiple implant systems are available for templating on the same software. Surgeons can anticipate potential issues and also recognize an intraoperative mistake when a large discrepancy exists between a trial component and the templated size.⁸ A permanent record of planning is created and can be electronically viewed by different members of the surgical team, and it can be used for postoperative evaluation or for future surgeries on the same patient. Digital on digital has got what authors call a stronger consistency.

One paper about 100 consecutive THAs performed by the same surgeon shows us the predictive value of digital templating: 98% of the stems were templated within one size; 98% of the cups were templated to within 4 mm and 62% of head lengths were accurately templated. The mean lower limb-length discrepancy was +0.05 mm (*SD* 5.1 mm) postoperatively.⁸ Other papers confirm the utility of digital templating about implant size prediction: cups size was within +/- one size in 81% and the stem size was within +/- one size in 94% of digital templating.² However other authors describe even better results with analogue planning.⁶

In our opinion these two different points of view demonstrate that digital templating is an accurate instrument,

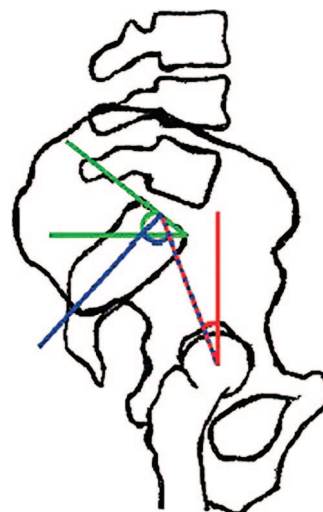


Fig. 5 Spino-pelvic parameters: red pelvic tilt, green sacral slope, blue pelvic incidence.

but that the surgeon's experience still has a key role. Whatever templating method the surgeon decides to use, the process of matching radiological images to the surgeon's mental database (built up through surgical experience) has a great influence on templating effectiveness and accuracy.

2D vs. 3D templating

A step forward in achieving 'consistency' can be taken by using 3D templating. This should give surgeons more references about bone landmarks (before and during surgery). 3D templating is based on CT data, works on both the axial a sagittal planes and is intrinsically more accurate.

Studies by Wako et al, Viceconti et al and Osmani et al have demonstrated that CT-based 3D templating showed excellent reliability for component size and alignment in THA.⁹⁻¹¹ Furthermore, studies have shown the advantages of 3D computer-based preoperative planning over the traditional template planning (especially when deformed anatomies are involved) independently from the surgeon experience.¹⁰⁻¹² This software enables the surgeon to simulate the prosthetic components into their proper positions in the 3D space of the CT data. Reference points are taken on the femur and on the pelvis.⁸ Preoperative planning with this method was consistent between surgeons, independently from their degree of expertise.⁹

Only one paper discussed a robotic-assisted procedure performed by a single surgeon using a minimally invasive posterior approach in the lateral position using rigid pelvic fixation.¹¹ The reproducibility of the preoperative planning is another strength of this method. 3D templating can be followed by traditional surgery or intraoperative navigation guidance. There are few reports about robotic

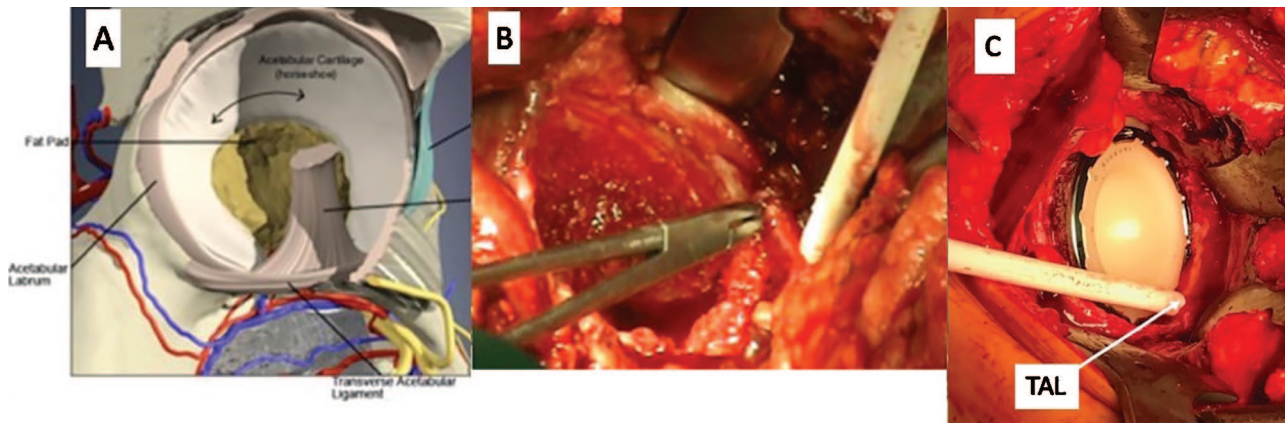


Fig. 6 The transverse acetabular ligament (TAL) (a) anatomical description; (b) intraoperative picture showing cup cradled by TAL, and (c) parallel to TAL.

guided surgery for acetabular component positioning.¹³ The effect of CT-based navigation on the accuracy of the implant has been studied as well.¹⁴

There is general agreement about good reliability of 3D planning and superior accuracy of computer-guided surgery, but there is no evidence that perfect match between planned and actual implant (size and position) has any positive effect on clinical outcome. Our opinion is that advantages of 3D can be shown clearly when treating more complicated cases, as Kuroda et al demonstrated in their study about three consecutive cases for conversion of arthrodesis hips to total hip replacements.¹⁵

Spine–hip relationship

To restore biomechanical setting of the hip, targets may vary between patients. Optimal acetabular cup orientation may have some adjustment after the examination of spine–pelvic relations.^{5,16} The concept of spine–hip relations defines the interaction between the lumbo–pelvic complex and the hip joint. The main spino–pelvic parameters important to know are: sacral slope, pelvic tilt and pelvic incidence. Pelvic incidence is a morphological parameter (constant for an individual), sacral slope and pelvic tilt are morphological parameters (value varies with body position) (Fig. 5). They are fundamental to define the spino–pelvic relations.

Patients with hip osteoarthritis or with previous lumbar fusion often have an abnormal spine–hip relation. A preoperative screening of this kind of patient is mandatory to refine THA planning.

Definition of the individual’s spine–hip relationship can be carried out using the EOS® imaging system or with conventional lumbo–pelvic lateral radiographs. This information allows the surgeon to realize the ‘Kinematic alignment technique’. As Rivièrè et al say^{17–18} ‘this technique aims at restoring the native combined femoral acetabular

anteversion and the hip’s centre rotation occasionally adjusting the cup position and design based on the assessment of the individual spine modification’. The transverse acetabular ligament (TAL) is the reference to adjust the cup position.^{19–20}

The TAL straddles the inferior limit of the bony acetabulum. It is a strong, load-bearing structure and, in the normal hip, in association with the labrum, provides part of the load-bearing surface for the femoral head. In order to identify TAL, a 360° view of the acetabulum should be obtained whatever surgical approach is used. A teardrop retractor should be placed inferiorly.

Beverland hypothesized that the TAL defines anatomical version for the acetabulum; the key to using it as a reference is good intraoperative exposure. This reference is independent from patient positioning and the cup version can be individualized for the patient.¹⁹ According Beverland et al optimal joint centre restoration and cup anteversion are obtained when the implanted cup is cradled and parallel to TAL (Fig. 6).²⁰ This refined implant positioning is clinically relevant to decrease risk of dislocation,²¹ edge loading and wearing.²²

Conclusions

Preoperative templating is fundamental for the THA implant and it can be a guide before and during surgery. Besides improving accuracy and reproducibility during THA, preoperative planning forces the surgeon to think in three dimensions, a necessary condition to perform THA surgery. In this way, the surgeon is forced to match his mental database (coming from surgical experience) to radiological images. Digital templating on 2D and 3D X-ray images is going to have a significant improvement in the near future. Technology can be a friend if we accept and promote cultural contamination amongst different

professional competence. Orthopaedic surgeons have to lead the development of templating software, collaborating with engineers to answer the question ‘Where do we need to go? How do we get there?’ And so, planning becomes a powerful educating tool and method of self-evaluation.

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ICMJE CONFLICT OF INTEREST STATEMENT

CC reports being a consultant for Depuy Synthes, outside the submitted work. The other authors declare no conflict of interest relevant to this work.

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REFERENCES

- Della Valle AG, Padgett DE, Salvati EA.** Preoperative planning for primary total hip arthroplasty. *J Am Acad Orthop Surg* 2005;13:455–462.
- Scheerlinck T.** Primary hip arthroplasty templating on standard radiographs: a stepwise approach. *Acta Orthop Belg* 2010;76:432–442.
- Knight JL, Atwater RD.** Preoperative planning for total hip arthroplasty: quantitating its utility and precision. *J Arthroplasty* 1992;7:403–409.
- Conn KS, Clarke MT, Hallett JP.** A simple guide to determine the magnification of radiographs and to improve the accuracy of preoperative templating. *J Bone Joint Surg Br* 2002;84:269–272.
- Yoon YS, Hodgson AJ, Tonetti J, Masri BA, Duncan CP.** Resolving inconsistencies in defining the target orientation for the acetabular cup angles in total hip arthroplasty. *Clin Biomech (Bristol, Avon)* 2008;23:253–259.

- Petretta R, Strelzow J, Ohly NE, Misur P, Masri BA.** Acetate templating on digital images is more accurate than computer-based templating for total hip arthroplasty. *Clin Orthop Relat Res* 2015;473:3752–3759.
- Stigler SK, Müller FJ, Pfau S, Zellner M, Füchtmeier B.** Digital templating in total hip arthroplasty: additional anteroposterior hip view increases the accuracy. *World J Orthop* 2017;8:30–35.
- Shaarani SR, McHugh G, Collins DA.** Accuracy of digital preoperative templating in 100 consecutive uncemented total hip arthroplasties: a single surgeon series. *J Arthroplasty* 2013;28:331–337.
- Wako Y, Nakamura J, Miura M, Kawarai Y, Sugano M, Nawata K.** Interobserver and intraobserver reliability of three-dimensional preoperative planning software in total hip arthroplasty. *J Arthroplasty* 2018;33:601–607.
- Viceconti M, Lattanzi R, Antonietti B, et al.** CT-based surgical planning software improves the accuracy of total hip replacement preoperative planning. *Med Eng Phys* 2003;25:371–377.
- Osmani FA, Thakkar S, Ramme A, Elbuluk A, Wojack P, Vigdorich JM.** Variance in predicted cup size by 2-dimensional vs 3-dimensional computerized tomography-based templating in primary total hip arthroplasty. *Arthroplast Today* 2017;3:289–293.
- Kuroda K, Kabata T, Maeda T, et al.** The value of computed tomography based navigation in revision total hip arthroplasty. *Int Orthop* 2014;38:711–716.
- Kanawade V, Dorr LD, Banks SA, Zhang Z, Wan Z.** Precision of robotic guided instrumentation for acetabular component positioning. *J Arthroplasty* 2015;30:392–397.
- Nakahara I, Kyo T, Kuroda Y, Miki H.** Effect of improved navigation performance on the accuracy of implant placement in total hip arthroplasty with a CT-based navigation system. *J Artif Organs* 2018;21:340–347.
- Kuroda Y, Akiyama H, Nankaku M, So K, Goto K, Matsuda S.** A report on three consecutive cases using computer tomography 3D preoperative planning for conversion of arthrodesed hips to total hip replacements. *HSS J* 2015;11:76–83.
- Snijders TE, Willemsen K, van Gaalen SM, Castelein RM, Weinans H, de Gast A.** Lack of consensus on optimal acetabular cup orientation because of variation in assessment methods in total hip arthroplasty: a systematic review. *Hip Int* 2019;29:41–50.
- Rivière C, Lazic S, Villet L, Wiart Y, Muirhead Allwood S, Cobb J.** Kinematic alignment technique for total hip and knee arthroplasty: the personalized implant positioning surgery. *EFORT Open Rev* 2018;3:98–105.
- Rivière C, Lazic S, Dagneaux L, Van Der Straeten C, Cobb J, Muirhead-Allwood S.** Spine–hip relations in patients with hip osteoarthritis. *EFORT Open Rev* 2018;3:39–44.
- Beverland D.** The transverse acetabular ligament optimizing version. *Orthopedics* 2010;33(9):631.
- Beverland DE, O'Neill CKJ, Rutherford M, Molloy D, Hill JC.** Placement of the acetabular component. *Bone Joint J* 2016;98-B:37–43.
- An VVG, Phan K, Sivakumar BS, Mobbs RJ, Bruce WJ.** Prior lumbar spinal fusion is associated with an increased risk of dislocation and revision in total hip arthroplasty: a meta-analysis. *J Arthroplasty* 2018;33:297–300.
- Teeter MG, Goyal P, Yuan X, Howard JL, Lanting BA.** Change in acetabular cup orientation from supine to standing position and its effect on wear of highly crosslinked polyethylene. *J Arthroplasty* 2018;33:263–267.