Feature

3D-CT: A better map for hip surgery

Professor Alister Hart and colleagues explore the 3D-CT planning software available to surgeons in the context of hip and knee arthroplasties

Introduction

When was the last time you consulted a road atlas? Nowadays we use Global Positioning Systems (GPS) for navigation. Similarly, in orthopaedics, more and more surgeons are using specialised 3D-CT software to plan hip and knee arthroplasties, as the benefits of using such systems are becoming more recognised and CT technologies continue to improve. Some examples of commercially available CT-based 3D planning software include ZedHip (LEXI), mediCAD (HecTec), Hip-Plan (Symbios) and Ortoma Plan.

Although CT itself has been used for planning joint replacements for over 30 years [1], preoperative planning with 3D-CT is a more recent concept in orthopaedics. The surgical planning potential of 3D-CT was first explored for craniofacial surgery in the 1980s after it was found that 3D reconstructions could be generated from CT data [2,3].

Since then, two main surgical applications of 3D-CT in orthopaedics have been described. The first is 3D printing, where 3D-CT models can be used to create physical models that surgeons can hold in their hands and inspect [4,5]. These models may even be used to simulate surgery and for training purposes. The second is dedicated planning software that surgeons can feed patients' CT data into and produce detailed 3D-based surgical plans; these computed plans can then be modified and adjusted by surgeons according to what they deem to be best for the individual patient [6,7]. This article will discuss planning software primarily in the context of hip and knee arthroplasties.

Table 1. Some examples of orthopaedic software with 3D preoperative planning capability

Software	Manufacturer	Modality
ZedHip	LEXI Co.	CT
mediCAD Hip 3D	HecTec	CT
Hip-Plan	Symbios	CT
Corin OPS	Corin Group	Radiograph + CT
Ortoma Plan	Ortoma	CT + MRI
hipEOS	EOS Imaging	Radiograph
MyHip	Medacta	CT
ProMade	Lima	CT

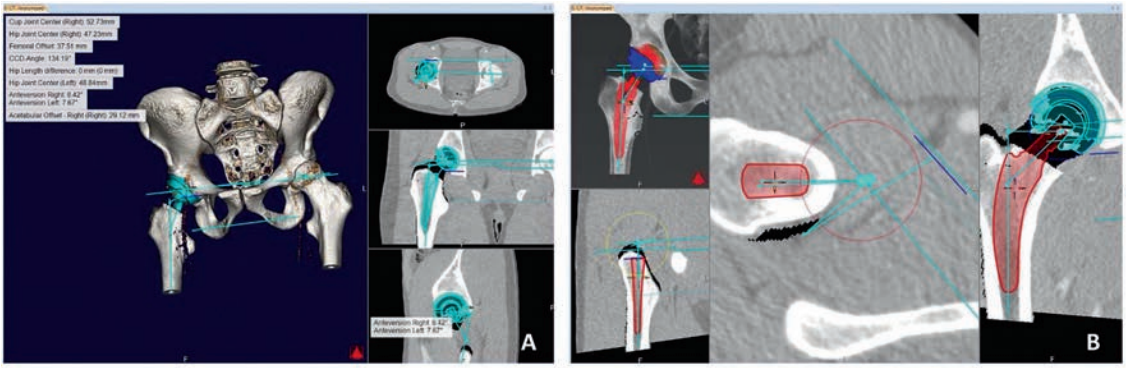


Figure 1 – 3D-CT planning with a dedicated software package (mediCAD©, HecTec GmbH). A) Most if not all THA planning software have 3D reconstruction functionality and allows positioning of the acetabular component on the axial, coronal and sagittal 2D views. B) This is also possible with stem anteversion and position of the femoral head.

Who benefits from 3D-CT planning?

Surgeons

The conventional method of planning hip and knee arthroplasties is plain radiograph templating, which involves superimposing a template film over plain acetate radiographs to infer both the likely size and position of the implant [8,9,10]. With the advent of digital radiography and institution-integrated picture archiving and communications systems (PACS), there have been shifts towards digital templating as a more up-to-date alternative [11]. However, this technique may not be entirely accurate owing to the two-dimensional nature of templating and its uncertainties in representing three-dimensional bony structures [10, 11].

With 3D-CT software, a pelvic model is generated using the 2D slices of the patient's CT scan. Subsequently, depending on the software, the likely component sizes may be computed by the programme, which the surgeon or radiologist can size up or down and reposition within the model to achieve a best fit. This has been shown to reduce intraoperative guesswork when it comes to choosing component sizes for both acetabular and femoral components in total hip arthroplasty [6,12-14]. This is particularly useful for less-experienced orthopaedic surgeons as 3D-CT plans help automate and increase accuracy during the process of implant selection [13, 15]. Most planning software also calculate values such as cup orientation and femoral neck anteversion, allowing surgeons to check whether these plans meet the correct parameters. Overall, there is evidence to suggest that 3D-CT planning enhances surgical precision of joint replacement surgery [16].

As a three-dimensional construct, 3D-CT plans are considered to be a better map of the patient's anatomy and measurements taken are generally more accurate [17]. Being able to visualise pelvic anatomy *ex-vivo* allows surgeons to appreciate the patient's unique anatomy in a way that would not be possible with standard medical imaging, giving them a more concrete idea of what to expect before the operation. This may help surgeons anticipate potential intraoperative complications, such as femoral fracture and leg length inequality [18].

Patients

The main benefit to patients is better intraoperative planning and overall surgical outcome. Although there have not been randomised controlled trials looking at the effectiveness of 3D-CT planning in the long-term, one case-series study showed good clinical outcomes – successful restoration of leg length and hip centre of rotation was reported, with a low rate of complications at a five-year follow-up [18].

An additional benefit of 3D-CT is that it can be a useful tool to explain joint replacement procedures to patients. While this is often done through viewing medical images such as digital radiographs or a CT series, a 3D-CT plan may be more comprehensible to the untrained eye in terms of what the operation entails and how the surgeon intends to execute it.

Industry

From an industry perspective, 3D-CT planning for orthopaedic surgery is attractive as it provides the basis for development of single-use instruments and reduced implant inventory in the theatre stores. The surgical hardware used for joint replacement surgery is usually extensive; this is largely due to surgeons not knowing exactly what implant sizes to use for each individual patient, and hence a broad array of sizes of femoral and acetabular implants are needed on standby.

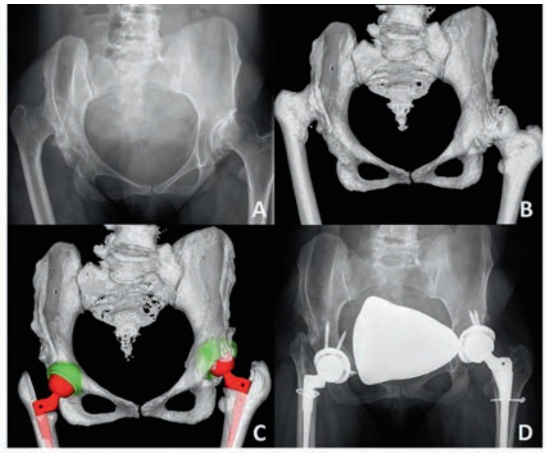


Figure 2 – 3D-CT planning can guide surgical decision-making for complex hip cases. A) AP radiograph of a 46 year old woman with severe bilateral DDH and inability to cope with walking. B) This case was planned with 3D-CT software (Zedhip© LEXI Co.). C) Modular S-ROM stems were chosen to bring the centres of hip rotation to their correct anatomical position, keeping them as symmetrical as possible. D) Post-op AP radiographs showed that the pre-operative plan was achieved, and at 1-year follow up the patient is satisfied with her improved walking ability.

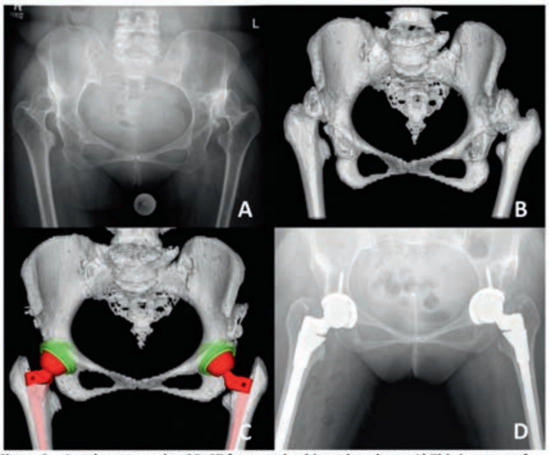


Figure 3 – Another case using 3D-CT for complex hip arthroplasty. A) This is a case of bilateral Crowe Grade IV DDH in a 54 year old woman who was finding walking increasingly difficult. B) A pelvis model was created to gain a better appreciation of her unique anatomy and deformity. C) The components chosen were S-ROM ceramic-on-poly Pinnacle hip replacements. D) The plan was achieved with almost perfect symmetrical reconstruction of hip centre of rotation, horizontal and vertical femoral offsets, and angular orientation of both cups and stems.

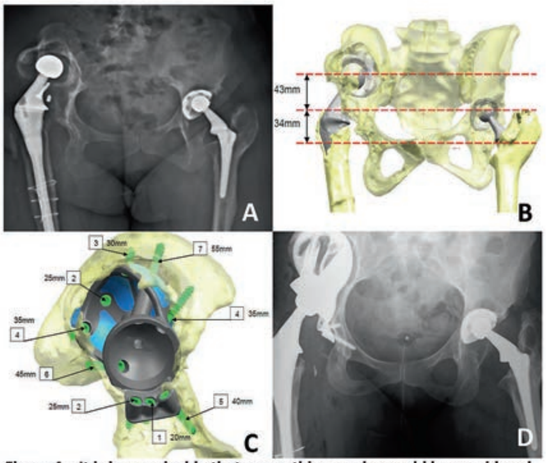
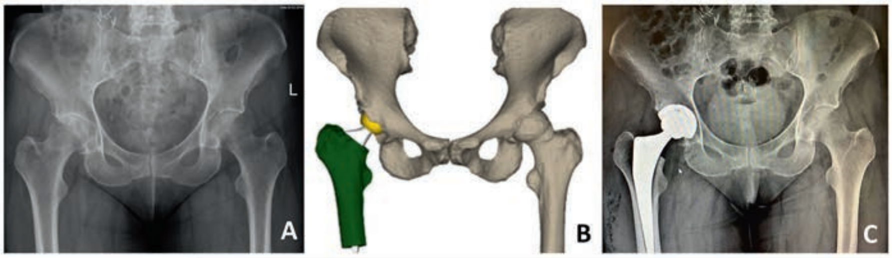


Figure 4 – It is inconceivable that a case this complex could be considered and attempted without 3D-CT planning. A) This patient is a 57-year old woman with a large acetabular defect and significant superior migration of the femoral head. B) By reconstructing the pelvis, we are able to determine how much the head needs to be brought down by to restore the correct centre of rotation (43mm). C) A custom acetabular implant can then be designed to repair the defect. The position, number and lengths of screws to be used to fasten the implant to good quality bone is also determined as part of the preoperative plan. D) A post-operative AP pelvic radiograph showed that the plan has been achieved.

This represents a sizable cost in terms of manufacturing large cases of instruments and implants, which are expensive to sterilise, transport and store.

With 3D-CT, as the implant sizes are better known to the surgeon, the volume of equipment normally made available for joint replacement surgery can be pared down to reflect the true sizes required by the surgeon to fit their patient. This allows for smaller, more compact sets of surgical tools that are easier to assemble and use. Further down the line, this can be made even more convenient for the industry and hospitals alike through developing disposable tools, which may be safer to use and more cost-effective in the long run.



	Post-op Report			
	Radiographic measurements		Offset and leg length	
	Inclination	Version	HFO	VFO
Planned	40°	20°	40mm	53mm
Achieved	38°	20°	35mm	54mm
Difference	**-2°**	**0°**	**-5mm**	**+1mm**

Figure 5 – 3D-CT planning of a standard uncomplicated case involving a manufacturer-specific implant. A) AP radiograph of a 77 year old woman with right side osteoarthritis. B) Her case was contracted and planned by Medacta, which offers 3D-CT planning services using their components. However, components from other manufacturers may be used with commercially-available 3D-CT planning software. C) A postop radiograph shows that the implant appears to be well-positioned. An additional service offered by Medacta is using 3D-CT to check planned versus achieved outcomes.

What are some of the challenges with using 3D-CT planning?

Cost

Most 3D-CT planning systems are licensed software packages that warrant yearly fees to hospital or implant manufacturers to keep them available to the surgeons. Although prices depend largely on negotiations between healthcare service providers and software manufacturers, costs if high can be a prohibitive factor. The cost of the CT scan can appear prohibitive, especially in straightforward primary cases, but in complex and revision surgery a planning CT scan is now considered best practice.

Technical use

Another large barrier to widespread use of 3D-CT planning is the learning curve associated with new technology and systems. Specialised software often involves many complex steps to attain what appears to be a simple function – for instance, 3D pelvic modelling for many planning systems requires specific anatomical points to be selected, and the design of user interfaces can appear daunting to approach at first glance. As such, it may be difficult to convince radiologists and orthopaedic surgeons to invest effort and resources into familiarising themselves with the software, especially if the benefits are not readily apparent. Receiving training from manufacturers is one possible solution, but would be likely to come at an additional monetary cost.

Software requirements

As software, the vast majority of 3D-CT planning systems are programmed to run on the Windows operating system. While this normally does not pose a problem due to the ubiquity of Windows, it is still worth considering potential difficulties faced by medical institutions or professionals who prefer other computer operating systems, in which case even less 3D-CT planning software would be available.

Furthermore, there may be compatibility issues with regard to an institution's CT scanning protocols and those required by some planning software. Often, CT acquisition parameters such as the collimation and type of bone reconstruction kernel must follow specific presets in order to produce scans that can be used with the software. Hence, existing imaging and scanning protocols would need to be reviewed prior to distribution of 3D-CT planning systems throughout an institution.

Radiation

As is generally the case with all medical imaging, there is the concern of increased radiation exposure for patients undergoing CT investigation for 3D planning. Best medical practice dictates that patient radiation exposure should be kept as low as reasonably possible [19], and hence there is a need for CT scanning protocols that both fulfil the requirements set out by planning software and restrict radiation dose to a minimum.

Current and future innovations

In this section we will discuss the innovations that are vital to successful 3D-CT planning and their likely improvements in the near future.

Hospitals

The use of 3D-CT planning may now be considered a feasible option in contemporary orthopaedic practice where it may not have been possible a decade ago. This is largely due to better and more widely available CT scanners that can capture bony geometry at a higher spatial resolution and reduced noise, producing scans of sufficient quality to perform 3D reconstructions with. Modern scanners are also able to image patients much more quickly than before, reducing patient discomfort and radiation exposure [20]. Future improvements to CT scanners will no doubt further increase the viability of employing 3D-CT planning on a large scale than what currently exists.

Radiographers

Recent advances in low-dose CT technology tailored for the specific purpose of planning orthopaedic surgery have made justifying the radiation burden to the patient and surgeon considerably easier. The new imaging protocols include imaging the hip, knee and ankle regions at a comparatively lower effective radiation dose without a significant trade-off in image quality [21,22,23]. These protocols have seen a four-fold reduction in radiation equivalent to one year of background radiation, and have been enhanced further by the introduction of orthopaedic metal artefact reduction (MARS) sequences on many modern CT scanners, allowing suppression of noise produced by pre-existing metal implants [24,25]. This is especially important when planning revision surgery with 3D-CT, as the presence of excessive metal artefact will render 3D reconstruction impossible.

Radiographers in many orthopaedic units are now trained to operate CT scanners with both low-dose protocols and MARS sequences, which has partly set the groundwork for wider rollout of 3D-CT planning. The next possible steps include surgeon-specific CT protocols that radiographers can input into CT scanners and interchange with ease, and optimising 3D-CT planning software for compatibility with low-dose scanning parameters in mind.

Consultant radiologists and orthopaedic surgeons

Radiologists often work closely with orthopaedic surgeons to provide necessary medical images for preoperative planning. An extended partnership would ideally see radiologists who are able to use 3D-CT planning software to help orthopaedic surgeons plan cases on request, especially busy surgeons who may not be familiar with the software. To streamline this process, radiologists should be trained in the use of planning software, and there should be an institute-approved standard operating procedure detailing the steps for handling cases, from receipt of CT data to delivery of the surgical plan.

Ergonomics should be a key consideration in the future design of planning software; the learning curve for new technology is often steep and it is more likely that medical professionals will embrace and become accustomed to using the planning software if it is as user-friendly as possible – this may be accomplished through minimalistic user interfaces with clear labels as well as integrated video tutorials on the software's available functions. In an ideal scenario, all 3D-CT planning software would be intuitive enough that even surgeons with little to no technical experience with the software would still be able to generate a basic plan.

Conclusion

3D-CT planning is the first rung on the ladder to better implant surgery, opening up a world of benefits to surgeons, patients, industry and hospitals. The benefits include quicker and more accurate surgery, better functional outcomes for patients and a push towards the development of an optimal inventory of implants and tools for joint replacement surgeries. It is a modern approach to the conventional planning process, which has been very much akin to navigating roads with a paper map. With the most sophisticated and current technologies available to us, 3D-CT is a promising field in which many more developments can be expected.

● All cases discussed in this article and others can be found on *www.complexhipsurgery.com*

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