Heavy reading in heavy metal
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Chapter 2

The use of computerized tomography (CT) to evaluate hip resurfacing

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ABSTRACT

Computerized tomography (CT) is a cross-sectional imaging technique suitable for measuring the position of hip resurfacing components and to evaluate the periprosthetic bone. Metal artifact reduction methods reduce the streak artifacts caused by the presence of metal components. This chapter reviews the use of CT for the preoperative evaluation of the hip joint and the planning of a hip resurfacing. It further explains the measurement of acetabular component inclination and anteversion and of femoral anteversion. Peri-prosthetic bone and soft tissue lesions can be evaluated and accurately delineated in several planes.
THE SCIENCE OF COMPUTERIZED TOMOGRAPHY (CT)

The term computed axial tomography (CAT), more commonly called computerized tomography (CT), refers to an imaging method using radiographic cross-sectional (axial) tomography created by computer processing. A three-dimensional image of the inside of an object or body is constructed digitally from a large series of two-dimensional x-ray images around an axis of rotation. The images generated are usually in the axial or transverse plane, perpendicular to the long axis of the body or the part of the body being scanned. Modern scanners, however, also allow the reformatting of data in other planes or the construction of three-dimensional (3D) images of the scanned structures (so-called multi-slice CT). CT can be used together with other imaging techniques like single photon emission computed tomography (SPECT) on bone scan and positron emission tomography (PET). The CT imaging of metal devices is complicated by streak artifacts caused by the presence of metal corrupting projection data. As with magnetic resonance imaging, metal artefact reduction (MAR) algorithms have been developed. MAR methods are usually based on the attenuation of x-rays by metal implants partially impeding the projection of data. The ‘missing’ data are either avoided (in iterative reconstruction) or interpolated (in non-iterative, filtered back-projection with data completion; typically, with filling data ‘gaps’ via linear functions). A comparative study of four different algorithms demonstrated superiority of the iterative algorithm producing a considerable improvement of CT imaging in all uses. Recently, new MAR techniques have been developed to achieve more accurate image analysis and better image quality. A wavelet-based multi-resolution analysis method, in which information is extracted from corrupted projection data, was shown to be significantly more accurate for depiction of anatomical structures, especially in the immediate neighbourhood of metal devices like femoral stems. MAR is even more challenging in 3D-CT reconstruction, and further research is under way to improve the accuracy and quality of images in the presence of metal devices.

THE USE OF COMPUTERIZED TOMOGRAPHY (CT) SCANS FOR PRE-OPERATIVE EVALUATION AND PLANNING OF HIP RESURFACING

In order to avoid femoro-acetabular impingement (FAI) following hip resurfacing, several authors have advocated the use of CT scanning for pre-operative evaluation of the femoral head and neck. Cam-type deformities of the femoral heads may complicate a hip resurfacing operation and require accurate pre-operative assessment of the anatomy in order to achieve correct implant positioning. Most hips with pre-operative painful FAI will require a greater correction of the femoral head/neck offset in order to minimize the risk of post-operative impingement leading to symptoms of pain,
increased wear and eventually to implant failure. CT scanning is a superior method compared to conventional x-rays with regard to correct pre-operative assessment of femoral head/neck deformities/abnormalities and the pre-operative measurement of acetabular anteversion (Fig. 1).

The use of navigation and robotics for accurate implant positioning in hip resurfacing is controversial. A number of studies have evaluated the post-operative femoral varus-valgus and combined femoro-acetabular anteversion position using image-free navigation based on measurements carried out with 3D CT scans and the reliability of the navigation software regarding the accuracy of the calculated implant position. Schnurr et al. showed an improved accuracy in varus-valgus angle positioning when using 3D CT measurements compared to biplanar radiographs. However, the software calculation of the acetabular position was often inaccurate needing manual adjustment. The precision achieved with robotics was assessed by Barrett et al. by comparing pre-operative CT-based plans with post-operative CT scans. A definite advantage of this method over visual planning could not be demonstrated. A study by Krüger et al. compared the post-operative result of freehand positioning of the femoral drill guide compared to navigated positioning using CT scan views for the computer-assisted operations. The post-operative position of implants was evaluated on plain radiographs showing no difference between both groups with regard to either femoral component position (p > 0.05) or femoral notching. A trend for a better cup anteversion was observed for the navigated hips, but there was no statistically significant difference. The authors concluded that navigation with hip resurfacing surgery may allow a better visualization but is probably only advantageous with mini-incision surgery (MIS).
THE USE OF COMPUTERIZED TOMOGRAPHY (CT) SCANS TO EVALUATE HIP RESURFACINGS

Evaluation of acetabular cup positioning

CT measurement of the inclination of the acetabular component is performed on an anterior pelvic image (as with plain x-rays) by drawing a line joining the ischial tuberosities and measuring the angle with the line drawn through the lateral and the medial edge of the acetabular rim (Fig. 2). For the measurement of the acetabular anteversion, a transischial line is drawn through the ischial tuberosities on an axial image. The line is then transposed to an axial image of the acetabular cup. A second line is drawn through the anterior and posterior edges of the cup rim. The version angle is the angle formed by the transischial line and the line through the cup (Fig. 3). Malpositioning of the acetabular component has been associated with higher wear and soft tissue reactions to metal debris.\textsuperscript{12,13} Optimal placement of the acetabular component is defined as an inclination of 45° and an anteversion of 20°.\textsuperscript{1} A ‘safe zone’ is defined as a zone of ±10° about the optimum orientation. Components placed outside the ‘safe zone’ are considered to be malpositioned.\textsuperscript{14}

\begin{center}
Fig. 2. \textit{Measurement of acetabular inclination}
\end{center}
Other authors\textsuperscript{15} still use Lewinnek’s safe zone definition\textsuperscript{16} of 30-50° inclination and 5-25° anteversion of the acetabular component to predict impingement and subluxation of hip resurfacing arthroplasties, although Lewinnek’s original diagram was referring to the risk of dislocation of conventional hip arthroplasty with a small diameter head (≤ 28 mm). Adequate measurement of cup position can be performed with EBRA\textsuperscript{1} and should be carried out on x-rays taken in standing position in order to take into account pelvic tilt which influences the orientation of the acetabulum and the forces exerted on the hip articulating surfaces. However, acetabular anteversion is sometimes difficult to assess on plain radiographs and therefore some authors have advocated the use of CT scans.\textsuperscript{15,17,18} Three-dimensional (3D) CT scanning has been suggested as a better method of assessing component positioning compared to axial CT or plain radiographs because the acetabular cup is obscured by the large metal femoral head. Hart et al.\textsuperscript{15} (Imperial College London) use a validated 3D CT reconstruction software and base their measurements on an anatomical frame of reference to neutralize pelvic rotation. In the anterior pelvic plane points are set on the most anterior prominences of both anterior superior iliac spines and the most anterior point of one of the pubic tubercles. The anatomical inclination is measured as the angle to the transverse plane and the anatomical version as the angle to the parasagittal plane. Similarly the acetabular component inclination is measured as the angle to the transverse plane (Fig. 4) and the acetabular component version as the angle to the parasagittal plane (Fig. 5). The authors conclude 3D CT scans are useful for the confirmation of impingement and to identify cup malpositioning. However, as CT scans are currently taken in supine position, they are not the best method to accurately measure the acetabular angles in standing and sitting positions which represent heavier loading conditions and may be more hazardous with regard to subluxation. Lazannec and co-workers\textsuperscript{17,18} confirmed the bias of acetabular position measurements on CT scans.
However, they found a strong correlation \( (r = 0.857) \) between supine (mean 24.2\(^\circ\)) and standing (mean 31.7\(^\circ\)) measurements, whilst the correlation between the measurements in lying and sitting positions were very poor \( (r = 0.484) \) making supine CT measurements less adequate to predict subluxation or dislocation in sitting position.

For the identification of FAI as a cause of pain after hip resurfacing, CT scans are nevertheless the best current imaging method.

**Fig. 4.** 3D-CT image of hip resurfacing. Measurement of the acetabular inclination as the angle to the transverse plane (2D)

**Fig. 5.** 3D-CT image of hip resurfacing. Measurement of the acetabular version as the angle to parasagittal plane (2D)
Evaluation of femoral anteversion in total hip arthroplasty and hip resurfacing

CT scanning can adequately measure femoral anteversion in total hip arthroplasty when the knee is included in the same sequence. A line is drawn parallel to the retrocondylar axis of the knee and then transposed to the hip. A second line is drawn along the taper (neck) of the total hip prosthesis or resurfacing component in order to measure anteversion (Fig. 6(a) and 6(b)). Measuring anteversion of the femoral stem is more relevant in total hip arthroplasty than in hip resurfacing. It can be used to detect malposition of the femoral stem or to do a pre-operative planning before an acetabular revision.

![Fig. 6. Measuring femoral version on CT scan: (a) CT scan of the knee showing 5.7° of exorotation and 4° of anteversion relative to the horizontal plane; (b) transposition of this line to the femoral neck results in 1.7° retroversion (malposition of the stem). Note the anterior pseudotumour (arrows)](image)

Evaluation of periprosthetic bone

The presence and extent of osteolysis may be missed or underestimated on conventional plain radiographs by the overlapping of adjacent bone trabeculae. On a CT scan, lytic lesions are more easily recognized and delineated. The extent of the lesions can be measured in several planes, enabling the surgeon to calculate the volume of the lesion and plan bone grafting in case of a revision. However, MRI has been found to be the best imaging method to detect periacetabular osteolysis with a sensitivity of 95% compared to 75% with CT scans and 52% with plain oblique radiographs. The reduced sensitivity is probably related to artifacts generated by the large metal prosthesis obscuring an adequate evaluation of the medial wall when MAR is not used. However, CT scans generate adequate imaging of the superior, anterior and posterior acetabulum. The evaluation of osteolytic lesions in the acetabulum can be helpful when
planning acetabular bone grafts or evaluating femoral bone stock in femoral revisions (Figs. 7 and 8). As metal debris can adversely affect bone behind the acetabular component without initially producing cystic lesions, the resulting bone defect following removal and debridement of the acetabular bone is often much larger than anticipated on plain x-rays. The extent and dimensions of the osteolytic lesion is better assessed on a CT scan (Fig. 9). In revision cases with bone grafting procedures, the incorporation of the bone graft can also be assessed adequately on a CT scan.

**Fig. 7.** (a) Acetabular bone defect, (b) acetabular defect detail

**Fig. 8.** (a) Anteromedial bone defect and partial deficiency of the posterial acetabular wall. (b) Detail of anteromedial bone defect and deficient acetabular wall
Similarly, the onset and extent of heterotopic ossification is better visualized on CT scan than on plain x-rays. Whether phantom less based bone mineral density (PLBMD) can be reliably used for measuring the acetabular bone density in patients with metal-on-metal total hip arthropasty (MoM THA) or in patients with MoM hip resurfacing arthroplasty (MoM HRA) is still under investigation. Also the influence of a ‘pseudotumour’ on acetabular bone mineral density is being investigated. These post-processing techniques together with metal artefact reduction techniques will help the clinician to estimate the expected bone capacity of the acetabulum in revision surgery. Periprosthetic fractures behind hip resurfacing prosthetic components may not be readily visible on plain x-rays and have a greater chance to be discovered on CT scans, either at the level of the acetabulum (Fig. 10) or the greater trochanter (Fig. 11).
The use of computerized tomography (CT) to evaluate hip resurfacing

23.7 (a) Acetabular bone defect, (b) acetabular defect detail.

23.8 (a) Anteromedial bone defect and partial deficiency of the posterior acetabular wall. (b) Detail of anteromedial bone defect and deficient acetabular wall.

23.9 Extensive acetabular bone defects (arrows).

23.10 Fracture of the acetabulum wall and loosening of the cup.

Fig. 10. Fracture of the acetabulum wall and loosening of the cup.

23.3.4 Evaluation of periprosthetic soft tissue

CT can also detect and delineate solid or cystic masses adjacent to a hip resurfacing arthroplasty, both on axial and coronal images reformatted for reduction of metal artifacts. Masses can be measured and aspirations or biopsies can be performed under CT guidance. However, MRI remains the gold standard for the identification and detailed description of soft tissue abnormalities (Hayter et al., 2011). In one recent study, CT was used to screen for soft tissue masses surrounding a large femoral head metal-on-metal prosthesis and MRI was used to confirm the diagnosis (Bosker et al., 2011). No additional information was gained when using MRI. Furthermore, in symptomatic cases where no soft tissue mass was detected using CT, MRI did not detect additional soft tissue masses (Bosker et al., 2011).

The diagnosis of a soft tissue reaction to metal debris or so-called pseudotumour can initially be challenging, but in a non-infectious patient with a MoM HRA, screening in experienced hands by means of ultrasound is possible (see Chapter 22), although there is a greater inter-observer variability with this modality and follow-up can be more difficult. CT scanning, with or without metal artifact reduction algorithms, is also capable of establishing the diagnosis with good inter-observer agreement. Making use of window-level adjustment, such as a bone window on both axial and coronal reconstructions, enhances the accuracy and detection possibilities. MRI is useful because it is the most sensitive method to describe tissue abnormalities (Hayter et al., 2011), but metal artifacts can make it hard to investigate the relation of the soft tissue lesion with the prosthesis. Moreover, a metal artifact sequence suppression (MARS) is not always available on standard MR systems in all hospitals. Furthermore, MRI scanning is more time-consuming than CT, which is an issue with large cohorts that need to be screened. Nevertheless, MRI has the unique capacity to confidently distinguish solid from cystic components due to its superior soft tissue contrast capacity. However, in our experience, MR imaging has no higher sensitivity in comparison to CT in diagnosing pseudotumours and therefore is of no additional value to CT in the clinical setting of MoM THA or MoM HRA (Bosker et al., 2011).

A reliable MR grading system for the severity of soft tissue changes associated with metal-on-metal hip replacement has been developed (Anderson et al., 2011). This grading system describes the range of presentation from normal post-operative appearance through fluid-filled cavities and periprosthetic masses less and greater than 5 cm, up to severe disease where masses can extend through deep fascia, cause tendon avulsions and fracture. Analogous to this MRI grading, a practical CT grading system is under development (Bosker et al., 2011). It consists of a grading system I–V that describes post-operative CT findings in MoM THA or MoM HRA with or without soft tissue reactions (Table 23.1). Type I represents normal post-operative changes of the capsule of the operated hip joint which consists of thickening of the capsule up to 4–6 mm (Fig. 23.12). Type II consists of a thickened capsule >6 mm with or without bulging but not beyond the neck of the prosthesis and without eccentric enlargement of the capsule.

Fig. 11. Fracture of the greater trochanter with callus formation and fracture of the pubic arch on the right side.
**Evaluation of periprosthetic soft tissue**

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Table 1. CT grading system I-V for post-operative CT findings in MoM THA or MoM HRA with or without soft tissue reactions

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>Type I</td>
<td>Normal thickening of the hip capsule up to 4-6 mm</td>
</tr>
<tr>
<td>Type II</td>
<td>Thickened capsule &gt;6 mm with or without bulging but not beyond the neck of the prosthesis</td>
</tr>
<tr>
<td>Type III</td>
<td>Bulging capsule both anteriorly and posteriorly</td>
</tr>
<tr>
<td>Type IV</td>
<td>Eccentric bulging or enlargement of the capsule</td>
</tr>
<tr>
<td>Type V</td>
<td>Bursitis mimicker, mostly located postero-laterally with extensive filling of the bursa subtrochanterica, or anteriorly with filling of the bursa iliopectinea</td>
</tr>
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</table>

Fig. 12. Type I normal capsule on the left (right side of the image). Note: Transverse CT scan (and MRI) images look at the body from distally (feet) to proximally (head). Consequently, the right side of the body is on the left side of the image and vice versa

Fig. 13. Type II thickened capsule on the right (left side of the image)
Fig. 14. Type III bulging capsule anterior and posterior on the right

Fig. 15. Type IV eccentric extension inferomedially bilaterally

Fig. 16. Type V bursitis mimicker anterior and posterolaterally on the right
Type III consists of a bulging capsule both anteriorly and posteriorly (Fig. 14). Type IV represents eccentric bulging or enlargement of the capsule (Fig. 15). This is often seen inferomedially to the prosthetic head. Type V is reserved for the so-called bursitis mimicker, often located postero-laterally with extensive filling of the bursa subtrochanterica, or anteriorly with filling of the bursa iliopextinea, which can extend quite impressively into the abdominal compartment (Fig. 16). Although there are several other bursae in the hip joint, these two seem the most frequently involved and clinically relevant. In all CT grades (I-V), a thickened capsule is noted. Additionally, the soft tissue reaction further progresses from Type I to IV or V. Simultaneous to the progression of the disease, lesions tend to show more liquified content, although synovial hyperplasia is often present. There is actually considerable variation in the morphology of a ‘pseudotumour’ as described by Fang et al.\textsuperscript{22}

If screening is carried out by an experienced team, pre-operative tissue sampling is not necessary because the characteristic appearance of morphological changes on CT scans in MoM HRA patients is diagnostic.\textsuperscript{20} In our opinion, if one feels a pre-operative biopsy is necessary, ultrasound-guided biopsies are less cumbersome and technically easier than CT-guided biopsies. After revision, the excised tissue can be examined microbiologically and histologically in order to look for signs of aseptic lymphocyte dominated vasculitis associated lesion (ALVAL) or infection.

**CASE STUDIES FROM THE ISALA CLINIC, ZWOLLE, THE NETHERLANDS**

**Case 1**
A 59-year-old female experienced a painless swelling in her right inguinal region for 4 months (Fig. 17(a)). Three years ago, she underwent bilateral metal-on-metal hip arthroplasty with large-size femoral heads (Fig. 17(b)) and experienced an unremarkable post-operative course. Additional CT scan (Fig. 17(c)) and MRI revealed a soft tissue mass of approximately 50 cm$^2$. Histological tests demonstrated extensive necrosis with granuloma-like collections of lymphocytes and viable macrophages with metal particles. Serum cobalt and chromium levels were raised (9.4 and 8.0 µg/L). Clinical presentation and CT/MRI findings suggested the presence of a soft tissue reaction to metal debris which was confirmed upon revision. The hip was revised using extensive bone impaction grafting on the acetabular side and a polyethylene cup.
Case 2

Six years after a MoM large femoral head THA, this 65-year-old patient presented with groin pain and clicking sensations (Fig. 18). Symptoms were progressive and had started 1 year after the operation. Her cobalt levels were 17.9 µg/l, chromium levels were 14.6 µg/l. CT scanning revealed a large anterior pseudotumour which involved the psoas muscle. The stem was found to be malpositioned, therefore the revision arthroplasty included revision of the femoral component.
CONCLUSIONS

CT is a very accurate and reliable method for the pre-operative evaluation of femoral head and neck deformities, for the diagnosis of femoro-acetabular impingement either pre-operatively or post-resurfacing and for diagnosing post-operative soft tissue reactions. However, MRI is a better method than CT to distinguish solid from cystic components. CT scans are a better method than plain x-rays to detect and delineate osteolytic lesions but are probably not as sensitive as MRI, although this is currently still under investigation. Regarding the evaluation of component positioning, since current CT scans are taken in supine position, measurements of the inclination and version of the acetabular component do not take into account the pelvic tilt and cannot be simply extrapolated to the standing position or compared to measurements on standing radiographs. When the ipsilateral knee is included, adequate measurement of femoral anteversion relative to the retrocondylar axis of the knee can be performed.
REFERENCES


