Computer assisted tumour surgery – An insight

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ABSTRACT

Success in the management of bone sarcomas entails being able to achieve wide margins, which helps decrease the risk of local recurrence and provide an improvement in overall survival. The role of computer-assisted surgery has been investigated across various areas of orthopaedics, including joint replacement, cruciate ligament reconstruction, and pedicle screw placements which has led to increased interest in computer assisted tumour surgery (CATS). CATS can be used in a wide array of tumour surgeries, however its role in pelvic and sacral tumours is unparalleled. Its importance lies in being able to provide radiological information to guide the surgeon at the time of surgery i.e. the distance from the tumour to the resection margin can be determined precisely based on preoperative planning and intra-operative image guidance. This minimises unnecessary bone resection, aiming to achieve good oncological and functional results which can be challenging in pelvic surgery. Most published articles on CATS have concentrated on the surgical aspects of navigation surgery.

Although advanced imaging techniques such as magnetic resonance imaging (MRI) and computed tomography (CT) scans can provide anatomic detail about the primary tumour, the successful transfer of that information from a viewing screen to the intraoperative field can be difficult. The role of the radiologist lies in being able to provide appropriate imaging (CT, MRI) to facilitate surgical planning.

This article aims at providing the radiologist a surgical insight on CATS and to facilitate optimal imaging in a patient tentatively being planned for CATS.

1. Introduction

Bone sarcomas represent a group of rare heterogeneous tumours, which collectively account for approximately 1% of all malignancies and may cause a diagnostic challenge to clinicians in view of their rarity leading to a potential delayed diagnosis. Management of bone sarcomas essentially involves surgery and/or the use of adjuvant therapy in the form of chemotherapy or radiotherapy or both. Success in the management of sarcomas entails being able to achieve negative excision margins as described by Enneking et al.^{1,2,11} Wide margins in non-metastatic cases decreases the risk of local recurrence which helps in improving overall survival.¹¹

The role of computer-assisted surgery has been investigated and its use instigated across various areas of orthopaedics, including joint replacement, cruciate ligament reconstruction, and pedicle screw placement.³ This has led to the use of computer assisted surgery in the resection of tumours described as computer assisted tumour surgery (CATS). CATS can be used in a wide array of tumour surgeries, however its role in pelvic and sacral tumours is unparalleled.^{4,5} Its importance lies in being able to provide radiological information to guide the surgeon

at the time of operation i.e. the distance from the tumour to the resection margin can be determined precisely based on preoperative planning and intra-operative image guidance.^{6–8} This can show tumour involving superior minimising tumour involving superior unnecessary resection, aim at preserving maximum function and achieve good oncological and functional results in the pelvic surgery.⁹

With increasing demand for patient safety and treatment related outcomes, CATS has incorporated itself in modern orthopaedic oncologic surgery for providing adequate surgical margins with optimal/improved oncological outcomes. CATS can be used for resection of benign and malignant tumours of an extremity, pelvis or axial skeleton. It is most useful in areas where achieving surgical margins without significant morbidity is technically challenging i.e. pelvic and sacral tumours. Pelvic surgery may require multiplanar osteotomies often requiring reconstruction with biological/non-biological implants to reconstruct the pelvic void and joint preserving intercalary resections.^{9,10}

The aim of this article is to highlight the importance of imaging for CATS and details what surgeons expect from radiologists when planning a case for CATS and discuss future developments in CATS.

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Fig. 1. Pre-operative Imaging (MRI & CT pelvis for a Chondrosarcoma of the left superior pubic ramus, anterior column acetabulum).

a to c – Coronal T1 and STIR sequence and CT coronal showing tumour involving superior, inferior pubic ramus and also involving the anterior column of left hip d to f – Axial T2 Fat suppressed and CT axial sequences showing the lobulated appearance of the tumour in the superior pubic ramus.

2. Key requirements in CATS

Preoperative planning with fusion images of the patient's tumour is a critical factor of surgical success along with intraoperative navigation as surgical accuracy in predicting margins is purely dependent on the surgical planning done preoperatively in coordination with the radiologists. Magnetic resonance imaging (MRI) and computerized tomography scans (CT) are essential prerequisites to perform a successful CATS.¹² MRI imaging helps in identifying the location of tumour, its relationship to neurovascular structures and helps in assessing ideal margins for tumour resection. The recommended MRI sequences for orthopaedic oncology surgeons to plan a case for navigation assisted surgery include coronal T1, sagittal T2, axial T2 fat suppressed (FS) sequences and short T1 inversion recovery sequence (STIR) which provide the necessary information regarding tumour characteristics i.e. extent of the tumor, to facilitate differentiation of tumour from osseous oedema and to evaluate the relationship of the tumour to an adjacent

Table 2

Indications for CATS.

- Image guided biopsies
- Curettage of benign aggressive bone tumours involving the pelvis eg: Giant cell tumour of bone, Chondroblastoma.
- Radiofrequency ablation for osteoid osteoma.
- Primary bone sarcomas and metastatic carcinomas involving the ilium, periacetabulum, pubic ramus, ischium and partial sacrum either independently or as a combination of segments as described by Enneking and Dunham.
- Soft tissue sarcomas invading the iliac bone or above-mentioned bones.
- Primary Bone sarcomas or metastatic carcinomas involving the sacrum.

joint and important neurovascular structures.¹³ CT helps in delineating 3-dimensional bony anatomy and identifies bony landmarks (also termed as fiducial/reference points) during preoperative planning which aids in navigation to guide the orientation of osteotomies intraoperatively with adequate margins.¹² The two-dimensional (2D)/three-dimensional (3D) fused images of CT and MRI enable a detailed delineation of tumour margins, allowing precise definition of the plane of intended bone resection as described by Wong et al. They reported good results in a patient with a periacetabular resection and reconstruction with a custom-made pelvic prosthesis using CATS, which incorporated both the planes of intended resection and the location of the pelvic prosthesis at the navigation planning stage.¹⁴ (Figs. 1 and 2).

Early research in CATS was lacking until Cartiaux et al. described an experimental study in 2008. Four experienced tumour surgeons were asked to operate on simulated plastic pelvic models under ideal working situations with complete visualization and access to the bone surfaces. The probability of an experienced surgeon obtaining a 10-mm surgical margin with a 5-mm tolerance above or below was only 52% (95% CI 37–67) in addition, the degree of host-graft contact for reconstruction was found to be poor. This group went on to demonstrate in another experimental study that cutting accuracy was significantly better with computer navigational guidance. In a simulated bone model, the error of navigated saw bone cutting was only 2.8 mm, whereas that of the non-navigated group was 5.2 mm.⁸ The use of CATS in orthopaedic oncology has increased especially in areas such as the pelvis and sacrum where the risk of obtaining inadequate margins is higher.^{9,12} The unique complexity of the anatomy of the pelvis, including a complex shape of the bone, close proximity to vital organs (and large neurovascular structures) and the frequent presence of purely interosseous tumour extension not visible at surgery led to a high rate of macroscopic or microscopic contamination at surgery. With the advent of CATS, assessment of margins is more precise with a CATS technique reducing intralesional resection from 29 to 8.7% in a series of

Table 1

Field of view chart for different anatomic locations.

Anatomy	FOV/Coverage Chart
Pelvis	Include entire pelvis, 50 mm above crest, 50mm below lesser trochanter, minimum FOV to cover area of interest/pathology/coil
Hip	Include affected hip, crest to 50 mm below lesser trochanter, lateral skin line to 50 mm across the pubic symphysis, minimum FOV to cover area of interest/pathology

Fig. 2. Intraoperative Navigation Planning Images in a pelvic chondrosarcoma.

Fig 2 a to e – Fused navigation images with tumour and planned osteotomies in axial, sagittal and coronal sequences. (Yellow – Highlighted tumour, Red Disc – Osteotomy planned through anterior column of hip joint, Blue disc – Osteotomy planned through superior pubis ramus, Pink disc – Osteotomy planned through inferior pubic ramus. Fig 2f. Post operative Radiograph shows planned navigation resections sparing the native hip joint.

31 patients with pelvic or sacral malignant tumours undergoing resection.⁹ Recent studies have now shown an improvement in disease free survival in patients where computer navigation has been used compared to those undertaken with a traditional approach.^{15,16}

Two commercially available navigation systems (Stryker and Brain lab) can enable CATS especially for tumours surgery. The other navigations systems are StealthStation (Medtronic, USA) and NavigationPanel Unit (Storz, Germany).

Essential features when it comes to imaging protocols for hip and pelvic surgery involve making sure there is no tilt in the gantry with no oblique angle of locator/survey lines. The scan should cover the entire region of interest. The patient should be positioned supine with head or feet first depending on the location of the tumour. All scan images should have the same series ID with field of view chart depending on the location of the tumour, i.e. for pelvic surgeries, it should include the entire pelvis from skin to skin extending 50 mm above the iliac crest to 50 mm below the lesser trochanter (Table 1). The best pixel size for the

precise planning of navigation is 512 x 512 which is often difficult to obtain owing to increasing scan times per patient but a minimum of 256 x 256. CT scan slice width is 1–2mm at best with the maximum permissible to 3 mm slice thickness (contiguous with no gaps or overlapping permitted between images). The slice thickness for MRI scans is similar to CT scans however maximal slice thickness acceptable is 6mm with no gaps, no overlapping. T1 or T2 axial images are in 2D single echo only. Another feature to be considered for navigation in sacral tumours would be obtaining MRI sequences in dedicated sacral planes for precise identification of the neural foramina and corresponding lumbosacral nerve roots, being able to differentiate planes between rectum, bladder and prostate which are essential when planning for an en bloc sacral resection and lower third rectal tumours invading into the sacrum (Figs. 2 and 3).

The navigation software allows the fusion of CT and MRI scans even if they have had been performed in different planes as they have an option of direct and indirect correlation available on the computer.

Fig. 3. Navigation assisted Sacral Chordoma resection.

Fig. 3 (a to c) – Sagittal, coronal & axial images showing a lesion in the sacrum (S3 to coccyx) with a presacral mass(d & e) – Navigation planned osteotomies (Yellow – Tumour highlighted, Purple line – planned level for osteotomy)(f & g) – Intraoperative navigation guided resection completed.

Following imaging, the data should be stored in uncompressed DICOM format on CD, DVD, Network, Optical disk or USB thumb drive excluding scout films on archive. Any form of DICOM images can be used for planning navigation in orthopaedic oncology especially in rare cases i.e. Positron Emission Tomography – Computed Tomography (PET-CT), Computed Tomography (CT) angiography & functional MRI scans. These imaging modalities are particularly useful in obtaining detailed information about major neurovascular structures, its relationship to tumour and often obtaining tumour characteristics. Plans for custom made implants designed by engineers can also be imported as a standard triangle language (STL) file to be positioned in vitro as per pre-operative resection planning, this further helps orthopaedic oncology surgeons intraoperatively to confirm that the planned resection margin is still free from tumour as per the latest imaging scans sometimes altering the surgical plan. In general, optimum image quality is achieved by keeping slice thickness, gap and FOV to a minimum but its mandatory to cover the entire area or pathology of interest along with an area of normal tissue as it helps in deciding surgical margins. The only difference when it comes to spinal imaging is to ensure the scan direction is from inferior to superior direction and to ensure that we scan one vertebra above and one below the vertebrae of interest.¹⁷

CATS with arm-assisted robotic surgery is in development and hopefully would be available in the near future.

3. Conclusion

Most Published articles on navigation have documented advantages and disadvantages of using computer navigation targeting orthopaedic oncologists, however no articles have highlighted the requirements surgeons need from an ideal imaging perspective for a successful CATS. This article intends to share some light on the minimal imaging required for obtaining navigation protocol scans (CT/MRI) thereby targeting radiologists who are often unaware on the requirements needed for navigation protocol scans which are an essential requirement for a successful navigation guided tumour surgery as ideal imaging leads to adequate preoperative planning and subsequently decreased morbidity.

Clinical Cases where navigation helped in resection and reconstruction:

Case 1: Fig. 4

Case 2: Fig. 5

Case 3: Fig. 6

Fig. 4. (Coronal T1 (a) and Axial T2(b and c) images showing tumour(arrow) involving the iliac blade, extending into the sacroiliac joint. (d, e, f, h) – CT coronal reformats of the pelvis (de), 3d reformats (f), STIR coronal (g), axial CT(h) showing the permeative appearance of the tumour(arrow) invading into the iliac blade and its proximity to the sacroiliac joint.

Post operative AP radiograph (i) post type I internal hemipelvectomy & defect reconstruction using a fibula autograft and screws.

Fig. 5. Coronal T1(a), STIR coronal (b), STIR axial (c and d) showing tumour-chondrosarcoma (arrow) involving the ilium, acetabulum, superior pubic ramus and sacroiliac joint Preoperative

(e) and post-operative(f) AP radiographs post a type I + II + III internal hemipelvectomy and reconstruction with a proximal femoral implant.

Fig. 6. Axial T1 (a), STIR axial (b) and STIR coronal (c) showing a chondrosarcoma (arrow) involving superior and inferior pubic ramus and soft tissue component displacing the bladder.

(d) – Post operative AP radiographs following a type 3 internal hemipelvectomy.

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Declaration of competing interest

No conflicts of interest.

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