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Review

Three dimensional (3D) modelling and surgical planning in trauma and orthopaedics

*Patrick Eniola Fadero**, *Mahir Shah* [a]

Department of Orthopaedics and Trauma, Croydon University Hospital, 530 London Road, CR7 7YE, UK

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ABSTRACT

Introduction: Three dimensional (3D) modelling facilitates visualization, manipulation, and analysis of image data, the three dimensional format of such image, allows a better appreciation of the geometry, size, and exact relationship between diseased and normal tissue. The role in orthopaedic surgical planning is highlighted.

Discussion: Surgical procedures in **orthopaedics** and trauma rely on imaging, which in addition to making the diagnosis also assist in planning the elected surgical procedure through to a successful execution.

In the area of trauma management, the **use** of 3D modelling eases the execution of fracture operative approach, reduction and appropriate fixation, especially in complex fractures, like in the acetabulum. Post trauma correction of deformities is made easier using 3D modelling in the preoperative surgical planning.

For the purposes of tumour excision, a more acceptable margin of excision can be planned and successfully implemented.

There is an increasing role for computer assisted procedures in arthroplasty, the use of a 3D image for preoperative planning promises to deliver patient specific bone cut in dimensions that will allow less of inappropriate loading thereby promoting longevity of the implant especially in younger patients.

Conclusion: The processes for acquiring **3D** images need to be made simpler and easier to gain more widespread use in orthopaedics and trauma.

Introduction

The processes that are applied in the acquisition of multidimensional image data to facilitate visualization, manipulation, and analysis of the information captured in the image data are described as three dimensional modelling (3D). The sources of digital multidimensional images are, computerized tomography (CT), magnetic resonance imaging (MRI), positron emission tomography (PET), single photon emission computed tomography (SPECT), ultrasound (US), functional

* *Corresponding author*. Tel.: +44 07981738322.
E-mail addresses: patfad2003@yahoo.co.uk (P.E. Fadero), shahmahir1@gmail.com (M. Shah).
[a] Tel.: +44 07717677820.

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MRI (fMRI), magnetic source imaging, and surface light scanning.[1]

Three dimensional modelling operations can be divided into four steps: i) pre-processing, which is about defining the object system, ii) visualization, which permits viewing and comprehending the structure and dynamics of the object system, iii) manipulation, which is an operation for virtually altering the individual objects or the relationships among the objects in the object system as in a virtual surgical operation, and lastly, iv) analysis, which is used to quantify the morphological and/or functional information about the object system.

The most imaging modality used in orthopaedics and trauma is the plain X-ray in which a beam of X-ray is produced by an X-ray generator and is projected towards the body region to be visualized. According to the density and composition of the different areas of the region, a proportion of the X-rays are absorbed by various tissues in the body. The X-rays that pass through are captured behind the body part with a detector (film sensitive to X-ray or a digital detector) which provides a two-dimensional (2D) representation of all of the structures superimposed on each other. Other imaging modalities that are routinely used are, computed tomography (CT) scanning, ultrasound, and magnetic resonant imaging. Computed tomography scanning, utilizes X-ray beams passed into the body and produces a set of data that can be manipulated through a process known as "windowing", to demonstrate various bodily structures based on their ability to block the X-ray beam. Historically, images were generated in the axial or transverse plane perpendicular to the long axis of the body; modern scanners allow this volume to be reformatted in various planes or even as a volumetric 3D representation of structures.

Ultrasound uses a probe containing multiple acoustic transducers which send pulses of sound into the body. Tissues of varying density (acoustic impedance), reflect back to the probe some part of the sound which is detected as an echo. The time taken for the echo to travel back to the probe is used to calculate the depth of the tissue interface causing the echo. The difference between the acoustic impedances, determine the size of the echo, if the pulse hits gases or solids, the density difference is so great that the majority of the acoustic energy is reflected, reducing the perception of deeper structures. The frequencies for medical imaging are generally in the range of 1–18 MHz. The velocity, frequency or wavelength of a wave can be calculated by using the formula $\upsilon = f\lambda$ if the other two values are known, where (υ) is the speed of the wave which is measured in m s^{-1}, frequency (f) is the number of times a particle oscillates per second and is measured in Hz, and the wavelength (λ) is the distance between two compressions or rarefactions and is measured in m. Ultrasound uses high frequency sounds that are higher than the human ear can perceive, higher frequencies of ultrasound produce better resolution however they have short wavelength, are absorbed easily and are not as penetrating. Therefore high frequency ultrasound is used for scanning areas of the body close to the surface and low frequency ultrasound is used for areas that are deeper in the body.

Magnetic resonance imaging (MRI) utilises a powerful magnetic field to align the magnetization of some atomic nuclei in the body, and radiofrequency fields systemically alter the alignment of this magnetization; tissues appear differently as a result of the amount of protons they are able to generate. MRI provides good contrast between the different soft tissues of the body, which makes it especially useful in imaging the brain, muscles, the heart, and cancers compared with other imaging techniques such as computed tomography (CT) or X-ray. Unlike CT scans or traditional X-rays, magnetic resonance imaging does not use ionising radiation.

Surgical procedures tend to have better outcomes if they are preceded by the appropriate planning. It is imperative to visualize the lesion to be treated directly or indirectly to offer appropriate treatment. Surgical procedures in orthopedics and trauma rely on imaging, which in addition to making a diagnosis, helps in planning the elected surgical procedure through to a successful execution.

This review highlights the role of three-dimensional imaging in the pre-operative assessment and planning of surgical interventions in orthopaedics and trauma.

Three dimensional imaging methods that are appropriate for surgical planning in trauma and orthopaedics include computed tomography (CT) scanning especially, for the study of the geometry in articular fractures, this method is also useful in defining the fracture geometry in complex bony anatomy, for example the acetabulum and the calcaneum when surgical treatment is indicated. Magnetic resonance imaging (MRI) scanning has been useful in characterising, determining the boundaries and staging of bone tumours and soft tissue sarcomas. Ultrasound scanning (USS) has been used to determine the nature of lumps and bumps and in determining extent of fluid collection in tissues, tissue plains and the presence and estimation of fluid in deep seated joints such as the hip.

Images can be obtained in two and three dimensions with computed tomography scanning (CT), magnetic resonance imaging (MRI) and ultrasound scanning (USS).

Orthopaedic trauma surgical procedures generally involve close or open reduction and internal fixation of fractures, in which metallic implants are used to stabilize the fractures in the best reduced position achievable, in certain circumstances such as in intra-articular fractures, precise reduction must be attained and rigidly stabilised to limit or prevent the later complication of degenerative disease of the involved joint. In elective orthopaedic surgery, procedures commonly performed include joint replacement (partial or total), the correction of deformities (congenital or acquired), ligament reconstruction e.g., the anterior cruciate ligament (ACL) and the excision of benign or malignant tumours. The surgical treatment of benign tumours are usually limited to simple excision, which is primarily marginal but occasionally includes wide excision, but the treatment of malignant tumours of the bone or soft tissue sarcoma may necessitate wide excision to prevent recurrence with preservation of the limb.

Treatment of fractures

In the area of trauma management, the use of 3D modelling in preoperative surgical planning has been shown to make the procedure easier with satisfactory outcomes especially in complex fractures, such as those in the acetabulum.

Although the functional anatomy of the pelvis and acetabulum is well studied[2–5] and 3D CT has improved imaging, a