Dynamic CT Kinematic Analysis in Femoroacetabular Impingement: A Proof-of-Concept

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Summary

Femoroacetabular impingement (FAI) is a condition causing joint pain and restricted movement due to abnormal bone morphology that leads to impingement. Keyhole surgery is a common treatment, but there are no precise guidelines on the amount of bone to remove. This study utilised 4D dynamic CT imaging to analyse hip kinematics to explore its potential use in pre-surgical planning. Dynamic CT scans were conducted during pre-operative assessments with patients' hips moved to replicate the flexion adduction internal rotation (FADIR) test. Landmark position derived from 3D bone modelling and image registration was used to create local, bone-embedded reference frames. Cardan angles and Finite Helical Axis (FHA) parameters were calculated to evaluate femoral motion relative to the pelvis. Results demonstrated the potential of 4DCT to provide detailed kinematic insights. This approach could improve motion simulation models and enable precise identification of impingement areas, optimising surgical outcomes for FAI patients.

Introduction

Femoroacetabular impingement (FAI) is a well-recognized condition that often leads to joint pain and movement impairment. It is characterised by an abnormal bone morphology that causes one bone to impinge on the other. One potential solution is to surgically remove the abnormal portion of the bone using keyhole surgery to restore normal joint movement. Unfortunately, there is no precise guideline for how much bone should be removed during the operation to optimise post-operative motion. Acquiring joint scans during movement is essential to develop reliable tools that can guide orthopaedic surgeons before surgery. A modern approach to analysing joint movement involves the use of dynamic CT imaging. This research project aims to use dynamic CT technology to process motion data from patients with FAI and analyse the kinematics in terms of rotation and Finite Helical Axis (FHA).

Methods

A 4D dynamic CT scan was performed on one hip as part of routine pre-operative assessment. The hip was passively moved during the acquisition to simulate the flexion adduction internal-rotation (FADIR) test. A radiographer experienced in hip imaging guided the hip to the extent permitted by passive range of motion, or until symptoms were provoked [1]. Image acquisition was conducted using a Toshiba Aquilion One CT scanner and a total of 14 time frames were acquired. Semiautomatic segmentation of the femur and pelvis was employed to register all movement steps to the fixed image (hip in full extension). The output of the registration process was a series of transformation matrices, which were subsequently used to propagate bony landmarks at each time point. These landmarks served to create local, bone-embedded reference frames with the centre located at the midpoint between the right and left Antero-Inferior Iliac Spines and at the centre of the femoral head for the pelvis and femur respectively. Orientation of the reference frames follows ISB guidelines. The motion of the femur relative to the pelvis was calculated, and Cardan angles were extracted using the XYZ composition sequence. The relative transformation matrix was also used to compute the Finite Helical Axis (FHA) parameters for each time point.

Results and Discussion

Figure 1 shows the rotations around the three axes for one patient, depicting 68.1° of flexion, 7.8° of internal rotation, and 14.0° of adduction. However. the magnitudes of the different components are dependent on the definition of the reference frame and the rotation sequence.

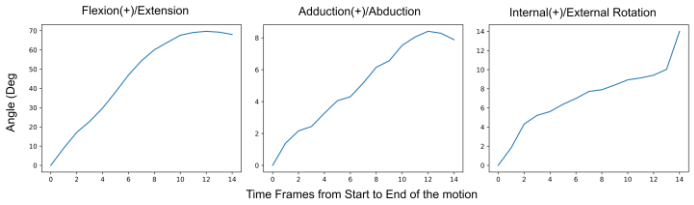

Figure 1: Rotation angles of the Hip joint

FHA showed an overall rotation angle of 73.7° with a progressive change in orientation (Figure 2).

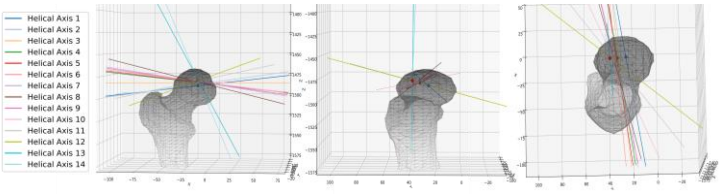

Figure 2: FHI from different view angles.

Kinematic analysis showed restricted hip range of motion, with hip flexion not reaching 90° of flexion and limited adduction and internal rotation. Such analysis can help identify contact points, abnormal motion patterns between femur and pelvis, and behaviour of the axis of rotation.

Conclusions

This proof-of-concept analysis outlines the steps required to analyse the kinematics of FAI patients using 4DCT images. Advanced motion analysis can be integrated into motion simulation models and, alongside 3D bone modelling, can help identify impingement areas and estimate the optimal amount of bone to be removed during surgery.

References

[1] Fernquest et al. (2017). *Bone Joint J.*, 99(4): 41-48