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CORR Insights

CORR Insights®: Increased Hip Stresses Resulting From a Cam Deformity and Decreased Femoral Neck-Shaft Angle During Level Walking

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Where Are We Now?

Two primary presentations of femoroacetabular impingement (FAI) have been identified: (1) Pincer, defined as acetabular overcoverage, and (2) cam, characterized by an aspherical femoral head and/or reduced femoral head-neck offset. Cam FAI is much more common than isolated pincer FAI, and occurs primarily in men. Cam FAI patients present with more-extensive cartilage damage than pincer FAI, often resulting in complete delamination of cartilage from subchondral bone [5]. Given its high prevalence and sometimes-aggressive clinical presentation resulting in pain and premature arthritis, there is an immediate need to improve the diagnosis and management of cam FAI.

It is generally assumed that the aspherical femoral head of cam FAI patients restricts hip motion, causes aberrant joint translations, induces impingement, and increases stresses at chondral and labral tissue. What is interesting, however, is that cam-type morphology also occurs in patients with asymptomatic hips. Many asymptomatic individuals are athletic (such as collegiate football players [10]), and so their hips have to undergo large ROM in demanding mechanical environments. Yet, cam FAI is not limited to young athletes; 67% of asymptomatic senior athletes had cam FAI, but radiographic findings were not predictive of OA [4]. These studies challenge the notion that morphological features of cam FAI indeed are responsible for OA. At the very least, these studies suggest that the most common radiographic measurements of cam FAI may lack the fidelity to distinguish anatomical features that are truly pathologic.

The study by Ng and colleagues is timely, innovative, and important for several reasons. First, they investigated the femoral neck-shaft angle, which may be more predictive of joint mechanics than common radiographic measurements. Second, they included asymptomatic subjects (with cam

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morphology), symptomatic cam FAI patients, and screened controls, which is a critical step to determine if it is the anatomy that is truly driving symptoms and damage. Third, they incorporated patient-specific loads (like the joint reaction force) and boundary conditions (such as the kinematic position of the hip), and then applied these parameters to anatomically accurate finite element (FE) models. This is important, as hips with cam FAI have unique anatomical features, and likely, distinct kinematics, kinetics, and muscle forces. Given the presence of cartilage delamination in hips with cam FAI [5], it has been put forward that shear stresses, rather than contact stresses, are primarily responsible for damage. By reporting shear stress, Ng and colleagues have ensured that their model predictions are relevant to the study of cam FAI.

Where Do We Need To Go?

Accurate representation of bone, cartilage, and labrum in hip contact models is critical, as bone and cartilage topology influence stress predictions [2]. Hip cartilage is typically only a few pixels thick on CT arthrography or MRI; the labrum is also diminutive, and the boundary between opposing layers of cartilage as well as the chondrolabral border can be difficult to visualize. Given these factors, it is often necessary to employ manual, or at least semi-automatic, segmentation to generate FE model geometry. Unfortunately, this is a laborious process. In our lab, for example, more than 200 hours are required to segment bone, cartilage, and labrum from a single CT arthrography image dataset. As a result, most patient-specific FE modeling studies are inadequately powered to make definitive clinical conclusions. It is for this reason that our primary focus should be on developing ways to improve the efficacy of FE modeling. Advancements in segmentation, including the use of statistical shape modeling, may reduce the time required to segment tissues [6]. While these techniques show promise, we also need to direct efforts to improving the quality of medical images to facilitate automatic thresholding.

Shear stress may be the most-relevant parameter to studying the pathomechanics of cam FAI. However, to my knowledge, hip joint contact models have only been validated by comparing model predictions of cartilage contact stress to measurements of pressure-sensitive film [9]. Unfortunately, designing an experiment to measure cartilage shear stress would be extremely difficult. In the absence of such validation data, investigators should turn to sensitivity studies. Sensitivity studies assess the influence model inputs (such as material properties, boundary conditions, and loading conditions) have on key model outputs (shear stress) [3]. Although sensitivity studies do not directly quantify model accuracy, they provide assurances that errors in estimating the value of a model input will not affect the primary conclusions of the study. In addition to sensitivity studies, analysts should increase the clinical relevance of their findings by correlating areas of altered stress and strain to patient-reported outcomes as well as tissue damage visible at the time of surgery, or on medical images.

Given the aspherical shape of the femoral head, it is likely that the hip with cam FAI does not have a constant center of rotation. This abnormal rotation of the hip joint may ultimately be the mechanism that increases shear stress. As such, incorporation of patient-specific kinematics into FE models of cam FAI patients is likely necessary. Yet, measurement of hip articulation is challenging. Recent work by our group showed that tracking of markers adhered to the skin, which is the most common technique to calculate joint kinematics, can yield substantial errors in the estimation of the hip joint center [8]. Inaccurate estimation of the hip joint center may in-turn adversely affect other biomechanical predictions that serve as input

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to FE models, such as the kinematic position of the joint, and the equivalent joint reaction force applied across the contact interface. Dynamic imaging techniques, such as dual-fluoroscopy, can quantify in-vivo joint kinematics in FAI patients [11]. However, dual-fluoroscopy is time-consuming, expensive, and not widely available. As such, investigators who use traditional motion capture methods should rely on sensitivity studies to determine how inaccuracies in the measurement of hip kinematics influence model predictions.

How Do We Get There?

In an attempt to increase the clinical acceptance of computer models, analysts have spent considerable time making their protocol more patient-specific. It may be of equal value to expend efforts establishing which patient-specific variables are not required for the study of FAI. For example, while incorporation of patient-specific joint reaction to load FE models is innovative, it is unclear if model predictions are actually sensitive to the direction and magnitude of the joint reaction force. To address this question, one could compare predictions from models driven by patient-specific joint reaction forces to those analyzed using hip contact forces measured in-vivo using telemeterized implants [7]. Showing that the difference in predictions between models is minimal would support the use of previously published hip contact forces, thus eliminating the need to model muscles, which is time-consuming. Demonstrating there was a difference, however, would indirectly suggest that muscle and joint reaction forces play an important role in modulating shear stresses. This is an example of how sensitivity studies not only provide data to support the exclusion of parameters, but also yield clinically relevant information.

Development of novel imaging protocols that yield high-quality images would reduce segmentation time, thus increasing sample size. In this regard, a study recently showed that 3T MR arthrography images acquired using a three-dimensional (3-D) dual-echo steady state sequence were segmented into 3-D surfaces representing bone and cartilage with better accuracy than CT arthrography [1]. Importantly, MRIs in this study were segmented automatically without a substantial loss in reconstruction accuracy, which was made possible by using a protocol that ensured bone, cartilage, and injected contrast appeared with distinct voxel intensities.

As a community of clinicians and scientists, we should bear in mind the difficulty associated with patient-specific modeling as we evaluate the merit of computational studies. We must also acknowledge that a model is not reality; there will always be assumptions. Sensitivity studies will provide justification to exclude model inputs that do not influence key outputs, which will save time. Use of quality medical images will facilitate automatic segmentation, which will also save time. However, patient-specific FE models will still be technically challenging. In addition, access to high-quality image data may not be available to all organizations. For these reasons, we should advocate for sharing of image data, models, and expertise. Existing forums, such as SimTK (https://simtk.org/), could be used for this purpose, but it would also be feasible to create an online community dedicated to the study of FAI.

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