Diagnosis of Femoroacetabular Impingement Using the Equidistant Method – More Accurate Than Previous Hip Joint Simulation Methods

Introduction:
Accurate assessment of the complex three-dimensional pathomorphology and detection of the exact zones of impingement is crucial for diagnosis and planning of joint preserving surgery in patients with femoroacetabular impingement (FAI). Currently, most examiners rely on assessment of classic radiologic parameters on imaging studies such as plain x-rays, computed tomography or MRI scans. Sufficient comprehension from these diagnostic tools is even more aggravated, since FAI is a dynamic entity, happening during hip joint range of motion.

Several attempts to simulate joint function and define impingement areas in these patients three-dimensionally have been presented. While some of these studies had never been properly validated [1], others despite methodological validation had to deal with up to 5 degrees of inaccuracy, which might be unacceptable for detection of subtle pathomorphologies [2]. A mutual problem among these studies was the definition of a rigidly fixed center of rotation for motion calculation and impingement detections. A consequence was the occurrence of intraarticular impingement artifacts. We present an impingement detection application based on the Equidistant Method and compared it to three other methods. We propose that this approach will be more accurate in detecting impingement zones than previously presented interference detection applications.

Methods:
Four different hip joint simulation methods, being used for collision detection around the hip joint were implemented to detect FAI: a Simple method, a Constrained method, a Translated method and our newly developed Equidistant method. The Constrained method utilizes a fixed center and collects any kind of impingement between femur and acetabulum. In contrast, the Equidistant method simply ignores intraarticular impingement, while also rotating around a fixed center. It only collects impingent within a 5mm perimeter around the acetabular rim. The Translated and the Equidistant method, both compute a translation vector in addition to rotation. However, while the Translated method calculates this vector only in case of occurring impingement, the Equidistant method continuously maintains a constant joint space by superposing approximated best fitting acetabular and femoral spheres. Five sawbone pelvises and 10 sawbone femurs (Synbone AG, Switzerland) were used. The head-neck junction of each femur and the acetabular rim of each pelvis were remodeled with epoxy to simulate different pathomorphologies. This allowed for 50 different hip joints to be assessed. Feltpads simulated acetabular cartilage. Using a tracked hand-held laser scanner (Steinbichler Optotechnik GmbH, Germany), three-dimensional models of these sawbones were generated. Specimens were then affixed to a table-based screw clamp. Each femur and pelvis was equipped with a dynamic reference base (DRB). In order to match the 3D-models to their “anatomy”, we performed a restricted surface matching. The anterior pelvic plane (APP) was set up. After registration, hip motions were performed. The pelvic and the femoral DRB were tracked by a NDI Optotrak Camera (Northern Digital Incorporation, Ontario, Canada). A navigation application based on the MARVIN medical research application framework[3] recorded the motions. As soon as the examiner visualized impingement between the head-neck junction and the acetabular rim anteriorly and posteriorly, the exact location was digitized with a tracked pointer. The recorded DRB transformations were converted into motion paths and then applied to the four hip joint simulation methods. Then interference detection was performed in order to determine possible impingement areas. Rotational and angular measurements were performed and compared among the methods with statistical analysis.

Results:
The univariate ANOVA tests for each dependent variable showed a significant variation between the hip joint simulation methods. In more detail, the posthoc analysis showed that the Equidistant Method needed significantly less additional virtual femoral rotation to provoke a collision between acetabulum and femur compared to the other methods (p < 0.001). Furthermore, the distance between the virtual femoral head and the manually digitized impingement point was significantly smaller for the Equidistant Method (p < 0.001). The computed acetabular impingement area was smallest for the Equidistant Method, including the smallest standard deviation. However, there was only statistical significance in comparison to the Simple Method, which was also significantly inferior to the translated and Constrained Method.

Regarding false positive occurrence of intraarticular impingement, the Equidistant Method showed the highest sensitivity rate (89.8%). Regarding the specificity the Translated Method shows the highest rate (82.4%).

Discussion:
The results confirmed the hypothesis that the Equidistant Method would be the most accurate and reliable hip joint simulation for detection of location and extent of FAI. Regarding the linear simulation error, this was demonstrated by measuring the distance between the digitized impingement point and the femoral head. Regarding the angular simulation error, the Equidistant Method needed significantly less additional femoral rotation to provoke impingement at exactly the digitized point, compared to all other methods. Furthermore, it becomes apparent, that the Translated Method approaches the results of the equidistant method closely. We assume this is a consequence of the similar behavior of both methods: a dynamic center of rotation is employed and once impingement is detected, an additional femoral translation vector is computed. Thus this method resembles the pathophysiologic motion paths, which occur once head and neck collide, more closely.

Possible sources of error might exist in model generation, segmentation faults and during the restricted matching process. Finally, it has to be emphasized, that this study was performed with plastic sawbones. The simulation and diagnosis is based on assessment of the bony anatomy. Soft tissue influence on range of motion is neglected. However, as an advantage the use of plastic bones and concomitant modification of the acetabuli and the femoral head-junctions allowed for creation of a wide pattern of morphologies ranging from dysplasia-like hips to extreme mixed-type impingement. In addition, the absence of any periarticular soft tissue allowed for exact visualization and digitization of the provoked femoroacetabular impingement. Despite existent, the above-mentioned limitations impair all applied simulation methods likewise, without favoring one method.

Concluding, we present an accurate and robust application for collision detection. This method has the potential to build the foundation for a reliable set of diagnostic and therapeutic planning tools for assessment of FAI.

References: