EVALUATION OF JOINT FUNCTION USING KINEMATIC MAGNETIC RESONANCE IMAGING: RESEARCH AND CLINICAL APPLICATIONS

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INTRODUCTION

While traditional kinematic analyses form the cornerstone of the biomechanical assessment of joint function, interpretation of such data is limited with respect to identifying the internal factors contributing to abnormal joint motion. Kinematic magnetic resonance imaging (KMRI) provides a means by which the intricacies of joint function can be evaluated for both diagnostic and research purposes. KMRI techniques were developed in recognition of the fact that pathologic conditions that affect joint function are position-dependent and/or associated with stressed or loaded conditions. We have used KMRI to evaluate 1) patellofemoral joint kinematics during non-weightbearing and weightbearing conditions and 2) motion of the spine in response to manually applied forces (i.e. joint mobilization). The methods used to obtain these data are described below.

METHODS

Instrumentation
Dynamic imaging of the patellofemoral joint and spine has been performed using a vertically opened (56 cm opening) MR system (0.5 T, Signa SP) developed for interventional MR procedures (General Electric Medical Systems, Milwaukee, WI, USA). This system is equipped with pulse sequence programming and real-time interactive MR imaging capabilities. The vertically-opened design of this MR system permits subjects to be imaged during both weightbearing (standing) and non-weightbearing (seated) conditions. In addition, the opening allows the examiner access to the subject during spine imaging.

Patellofemoral Joint Imaging
Axial images of the patellofemoral joint have been obtained in persons with lateral patellar subluxation using a flexible transmit-receive surface coil and a fast spoiled gradient recalled acquisition in the steady state (spoiled GRASS) pulse sequence. MR images were obtained at a rate of 1 image per 0.75 sec using the following parameters: repetition time (TR), 10.3 msec; echo time (TE), 2.7 msec; flip angle, 40°; field of view, 35 cm x 18 cm; matrix size, 256 x 128; number of excitations: 2. Images of the PFJ were obtained as subjects extended their knee from 45° to 0° during non-weightbearing (5% body weight resistance) and weightbearing (unilateral squat) conditions. Measurements of patellofemoral joint relationships (medial/lateral patellar displacement and patellar tilt) as well as femur and patella rotations relative to an external reference system (i.e. the image field of view) were obtained at 3° increments during knee extension.
Spine Imaging
Sagittal plane imaging of the spine (N=20) has been performed using a flexible receive-only surface coil and the following imaging parameters: TR 200ms; TE 18 ms; matrix: 256 x 256; FOV: 28 x 21 cm; and a 7 mm section thickness with an interslice spacing of 1 mm. Posterior-anterior (PA) forces were applied at each subject’s vertebra starting at L5 and moving to L1. The manual force was aimed at reaching the end range of vertebral motion. The intervertebral angle, defined as the angle formed by lines delineating adjacent vertebral endplates, was measured. Segmental motion was defined as the difference between the intervertebral angles as measured from the resting and the end-range images. An increase in intervertebral angle between those positions was indicative of segmental extension. The superior vertebra was used to define the target segment.

RESULTS AND DISCUSSION
Patellofemoral Joint Imaging
During non-weightbearing knee extension, lateral patellar displacement was more pronounced than during the weightbearing condition between 30° and 12° of knee extension, with statistical significance being reached at 27°, 24°, and 21°. No differences in lateral patellar tilt were observed between conditions (p=0.065). During the weightbearing condition, internal femoral rotation was significantly greater than during the non-weightbearing condition as the knee extended from 18° to 0°. During the non-weightbearing condition, the amount of lateral patellar rotation was significantly greater than during the weightbearing condition throughout the range of motion tested. These results of this investigation suggest that the patellofemoral joint kinematics during non-weightbearing can be characterized as the patella rotating on the femur, while the patellofemoral joint kinematics during the weightbearing condition could be characterized as the femur rotating underneath the patella.

Spine Imaging
The results of this study revealed a consistent pattern of lumbar spine motion during the PA force application. Specifically, motion at the targeted and adjacent segments always was directed towards extension. A theoretical explanation for this pattern of segmental motion can be proposed based on the morphology of the lumbar spine. For example, when a PA force is applied to the spinous processes of L3, the facet of the tested (L3) vertebra approximates the facet joint of the adjacent caudal (L4) vertebra and imposes motion to it. It is conceivable that this approximation would result in the L3 facet “pushing” on its L4 counterpart (bone on bone contact), causing a bending moment rotating L4 away from L3. The facet of L3 moves away from the facet of L2 causing tension in the joint capsule, which in turn also results in a bending moment of L2 on L3 into extension, but of lesser magnitude. The findings suggest that a PA force at one spinous process causes motion at the target vertebra and the neighboring vertebrae. Secondly, we propose a mechanism by which a PA force applied to a spinous process propagates motion caudally and cranially.

SUMMARY/CONCLUSIONS
KMRI techniques can be used to test hypotheses related to normal and abnormal joint function. Information obtained from KMRI may prove to be useful in better understanding the causes of various orthopaedic disorders, thereby assisting clinicians in establishing more effective treatment options.