MEASUREMENT OF RELATIVE BONE MOVEMENT IN THE ANTERIOR CRUCIATE LIGAMENT TRANSECTED CAT KNEE USING SONOMICROMETRY

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Introduction: Relative bone movements in the unstable joint alter the joint mechanics (1) and may play an important role in the pathogenesis of osteoarthritis (OA). However, despite an abundance of general mechanical assessments such as kinematics or ground reaction forces, there is virtually no information on the relative movements of bones in animal models of OA for in-vivo, dynamic conditions. The lack of information can be attributed to the lack of adequate techniques available to measure bone movement.

Bone movements have been estimated using superficial skin markers (5), roentgen-stereo analyses (4), video-fluoroscopy (6), implanted bone pins (3) or external frames (2). However, all these methods have inherent limitations. The substantial errors associated with the displacement of superficial skin markers caused by relative skin movement, and the errors associated with digitizing procedures have been well recognized (3). The best possible accuracy of video records has been determined to be 1:1000, which translates into a 1mm error in marker coordinate determination for a frame size of 1m. Roentgen-stereo analyses can only be used for static situation (4). Video-fluoroscopy uses a biplanar x-ray system in combination with high-speed video cameras for the tracking of bone movement (6). The data analyses procedures are off-line and the error in marker coordinate determination is the same as those for other video based systems. Bone pins that are “rigidly” implanted into the target bones (3), or metal plates that are attached as external frames to bones are highly invasive, and consequently, these techniques are not suitable for long-term use. Also, persistent lameness and impaired ground reaction forces have been reported after implantation of bone plates on the hindlimb of dogs (2). In summary, previous techniques used to measure 3D bone movements have limitations with respect to accuracy and long-term use. Thus, new methods are needed for the systematic evaluation of bone movements.

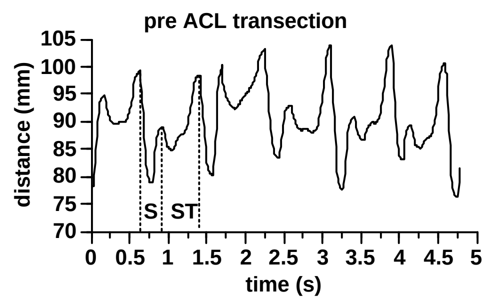
The purpose of this study was to develop a system for measurement of in vivo bone movements that has a high spatial and temporal resolution (and therefore, the potential for high accuracy), and that can be used for long-term, chronic measurements.

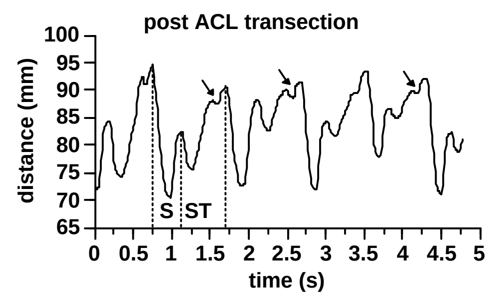
Methods: The approach used in this study was based on pulsed ultrasound that is emitted and received by piezoelectric crystals fixed on the target bones. Movements of the cat tibia relative to the femur were measured for slow walking using four crystals each on the tibia and the femur. The four crystals on the femur were designated as transmitters and the four crystals on the tibia were designated as receivers. Therefore, a total of 16 distance measurements could be made from the transmission time and the ultrasound transmission speed, allowing for the determination of the location and orientation of the tibia relative to the femur at any instant in time.

The placement of the crystals was determined in an in-vitro preparation using a cat tibia and femur, and in an in-situ preparation on an anesthetized animal. The line of transmission between the transmitters and the receivers must not be broken by any bony prominence, and must be within the soft tissue structures of the cat hindlimb for the entire range of motion (i.e. included knee angle of 70° – 150°). In order to optimize crystal arrangements and fixation, crystals were embedded in acrylic cement plates, that were fitted to the shape of the tibia and the femur prior to implantation. The four crystals for the femur were fixed onto a single plate and attached with screws to the femur. The four crystals for the tibia were embedded in two plates that were screwed to the tibia just proximal and distal of the insertion of the semitendinosus muscle. The leads of the crystals were run subcutaneously to a backpack connector mounted on the cat. From there, the leads were connected to the data collection system. The settings for the pulse delay, sensitivity and sampling frequency were adjusted in order to obtain optimal signals through the whole range of motion.

A first data recording session was performed 5 days following implantation of the crystals. Data were collected on line while the cat was walking on a motor driven treadmill at a nominal speed of 0.4m/s and 0.7m/s. Sampling frequencies of 100Hz and 200Hz were used for all recordings. All trials were taped on video. Additional data were collected at day 7, 11, and 15 post surgery. Nineteen days after the crystal implant, the anterior cruciate ligament (ACL) of the left hindlimb was transected. Further data collections was performed 5 and 12 days after ACL transection.

Results: The figure shows a series of consecutive steps in the ACL-intact (upper trace) and the ACL-transected (lower trace) cat. The traces display the straight-line distance between one crystal on the femur and one crystal on the tibia. The cat knee undergoes a flexion-extension cycle during swing (S) and stance (ST) which is associated with a shortening-lengthening of the crystal distance shown in the figure. Following ACL transection, the extension phase in the second half of stance shows a distinct shortening-lengthening trace (see arrows) which is likely associated with some knee instability.





Discussion: The present study describes a new approach for measuring relative in vivo bone movements using pulsed ultrasound. This approach has several distinct advantages over currently used in vivo bone movement analysis systems. First, its temporal resolution is high. Data may be collected at sampling frequencies up to 1000Hz, if required, which exceeds most video-based systems. Second, the spatial resolution of the system is 0.016 mm which is orders of magnitudes better than any video-based system that requires an image width of about 1 m (as would be required here). Third, once implanted, the system is well tolerated by the animal, works for weeks (possibly months), and all data are immediately available for analysis. Cumbersome and time-consuming digitization processes are avoided. In summary, the present approach to in vivo bone movement measurement is accurate and can be used for long-term, chronic assessment of bone kinematics.

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