A new Improved Tracking Technique for assessment of high Resolution Dynamic Radiography Skeletal kinematics

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ABSTRACT: Previous attempts to track skeletal kinematics from sequences of images acquired using biplane dynamic radiography report challenges in automating the tracking technique due to image resolution issues, occlusion from segments appearing synchronously due to small field of view and computational load. This translates into many hours of manual work to export the kinematics. The proposed new tracking method tackles the above problems and reduces the time to export kinematics from several hours to less than 3 minutes.

METHODS: Ten subjects (Males, age: 32±4 years) with ACL reconstructed knee and healthy contra-lateral knee were selected from an ongoing study of ACL reconstruction (approved by our institutional IRB). After obtaining informed consent, 1.6mm tantalum markers were implanted in the distal femurs and proximal tibia of each joint (3 per bone) at the time of ACL reconstruction surgery. In-vivo 3D knee kinematics was acquired 3 years after ACL reconstruction during one-legged forward hopping (sub-maximal, hop distance 50% of lower limb length) using a new high-speed (both at 250 and 480 frames/s) and high-resolution (with both 576x576 and 1152x1152 pixel) dynamic radiography instrumentation (DRSA) [1](Fig. 1). Performance of the Biplane Radiographic system was assessed using a customized calibration object (cube). Static precision (a function of system noise) was assessed with the test object positioned stationary in the center of the field of view. Dynamic errors were assessed by suspending the cube from a stiff elastic band and then dropping them (increased rotational motion), allowing them to twist and bounce throughout the field of view. A range of tests was performed using different combinations of acquisition rates, resolution, exposure i.e. 125-1000 images acquired at 250-400 frames/s with exposure (shutter) times ranging from 500-3000 μs. X-ray system protocols ranged from 40 to 90 kVp, 40 to 120 mA, 1 s with low (576x576) and high resolution (1152x1152) trials. In the trials with the patients 3D coordinates of implanted markers were determined for single-legged hopping trials using the DRSA method.

RESULTS: The effect of resolution, brightness and exposure is shown in Fig. 2a,b for the high resolution experiment. It should be noted here that not only does kVp control the contrast of the X-ray, it also affects the density in two ways. As kVp is the energy of the stream of electrons, if increased it results in a higher part penetration. Increasing kVp also causes more radiation to be produced, which includes scattered radiation, which increases the density (“blackness”) on the image. It seems that in most cases that there is an optimum in the exposure (kVp) and brightness (mA) combination. Increasing the exposure up to a certain point optimizes the gray level signature for the markers in the cubes moving at high speed in the calibration space. To distinguish between the two cameras we call them “red” and “green”. The “green” camera is the camera with enhanced sensitivity and its lens can reach aperture of one (1). The lens on the “red” camera is set so that it cannot produce better aperture than 2 for comparison. It was obvious that increasing kVp and mA results in increase of gray level value for the low-resolution images.

DISCUSSION: The DRSA method was tested with moving objects and in-vivo with embedded bone markers on patients moving at very high speeds. It was demonstrated that accuracy in tracking skeletal kinematics is much higher than conventional motion analysis techniques (one order of magnitude) and it can be performed at much lower exposure, almost at the level of fluoroscopy without data loss from blurring effects due to motion. Dynamic errors were greatly reduced with increasing image resolution. The interplay between brightness, contrast, exposure and resolution for the 1.6 mm tantalum bone markers was characterized for the new DRSA system with a variety of protocols.