HINGED EXTERNAL ELBOW FIXATION: OPTIMAL AXIS ALIGNMENT TO MINIMIZE MOTION RESISTANCE

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Introduction: The literature supports several benefits from the use of hinged elbow external fixation for specific elbow disorders [1]. Problems persist, however, such as limited elbow motion, pin loosening and breakage, pin tract infection, and persistent instability [2]. These may be related to mal-alignment between the fixator hinge axis and the rotation axis of the natural elbow. This study describes how an optimal single hinge axis position can be established for the application of hinged external fixation to the elbow joint. In a cadaveric study of six elbow specimens, we applied a prototype hinged external fixator along a computed best-fit axis and determined the influence of an imposed fixator on normal elbow joint kinematics. Further, by deliberately introducing various amounts of relative mal-alignment between the best-fit elbow joint axis and the actual fixator hinge axis, we quantified the corresponding amounts of additional resistance to joint motion due to a fixator hinge misalignment.

Methods: Six fresh frozen cadaveric upper extremities were amputated through the mid-humeral shaft and disarticulated at the radiocapital joint. The mid-diaphysis of the humerus was secured in a Plexiglas tube, which in turn was rigidly affixed to a customized elbow motion apparatus (Fig. 2). This experimental setup applied flexion or extension moments to the elbow joint in a minimally constraining manner, via a cable that was attached to the mid-diaphysis of the ulna. The resulting cable tension was continuously recorded with a custom load cell (1). A d.c. motor (2) with an integrated rotation encoder generated the force necessary to rotate the elbow through its range of motion (ROM). Counterweights (3) were attached to the musculotendinous insertions via anatomically aligned cables, in order to simulate a constant applied brachialis force $F_{br}$ (10 N) and triceps force $F_{tr}$ (10 N). These muscle forces were simulated to ensure continuous joint compression force between the articular surfaces. An electromagnetic motion tracking system ("Flock of Birds", Model 6DFOB, Ascension Technology Corp., Burlington, VT) was used to record the 3-D-motion of the ulna relative to the humerus. These motion data were used to determine the pathway of instantaneous rotation of the humero-ulnar articulation, which were described in terms of screw displacement axes (SDA). For each specimen, a "best-fit" SDA was defined by averaging all SDA’s obtained over the entire ROM. From the load cell recordings, the moment required to rotate the elbow through its ROM was obtained (1) without the external fixator, (2) with the articulated external fixator aligned along the calculated "best-fit" axis, and (3) with the articulated fixator mounted in one of 16 distinct "off-axis" positions (hinge axis translated 5 or 10 mm anterior/ posterior / proximal / distal, or angulated in 5° or 10° of eversion / inversion / int. rot. / ext. rot.). To condense the large data set, the energy required to rotate the elbow through an 86° ROM (from 23° to 109°) was calculated from the moment vs. angular displacement data. The increase in required energy due to imposing the external fixator hinge at various positions was then determined.

Results: The computed best-fit SDA penetrates the antero-inferior aspect of the capitellum and trochlea, the center of the trochlea, and the center of the projection of the capitellum onto a para-sagittal plane. For a fully extended elbow viewed in the frontal plane, the best-fit SDA formed angles of 86.1± 2.5 and 85.4± 3.8 with the longitudinal axes of the humerus and ulna, respectively. Application of the external fixator to the elbow constrained motion of the elbow joint to be purely a rotation around the single fixed hinge axis of the fixator. The energy needed to rotate the natural elbow (no fixator applied) through an 86° ROM was vanishingly small (<0.02 J). Application of the fixator with its hinge precisely aligned along the computed best-fit axis caused a slight increase in motion resistance, requiring on average an energy increase of 0.15 J (s. d. = 0.14). Any of the 16 distinct hinge off-axis locations resulted in a much larger energy increase, verifying that the computed best-fit location established an optimal hinge position that involved minimal increase in motion resistance (Fig. 2). There was no correlation between the direction of mal-alignment and the energy increase. Hinge off-axis translations of 5 mm required on average 4.0 times the energy of the best-fit hinge position. Off-axis translations of 10 mm resulted on average in 8.2-fold higher (maximum: 10-fold) energy values. This was true for off-axis translations in all four directions. Hinge off-axis orientations of 5° required an average 3.7-fold increase of the motion energy over the best-fit hinge position. Off-axis orientations of 10° averaged a 7.1-fold energy increase, and a maximum of an 8.7-fold increase.

Discussion: Constraining the motion of the elbow joint to be purely rotation around the fixed hinge of an external fixator leads to an increase in energy needed to rotate the joint through its ROM. Using the 3-D motion data, we were able to compute an optimal hinge position, for which this energy increase was minimal. The large additional resistance to motion accompanying a mal-positioned fixator axis suggests the development of untoward intra-articular forces that could pose several problems in the clinical setting. In the acute unstable situation with loss of soft tissue and/or bony restraints, mal-alignment of the fixator hinge would impose abnormal joint kinematics, with resultant incongruent articulation and/or joint instability. In addition, as healing progresses to create a more constrained situation, increased stress would be transferred to the pins and the pin-bone interface. This may account for the clinical problems of pin loosening, pin breakage, and persistent instability.

References:

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