SIMULATION OF THUMB CARPOMETACARPAL JOINT SADDLE SHAPE WITH SURFACES OF REVOLUTION FOR OFFSET AXES OF ROTATION

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Fick[2] postulated that the thumb carpometacarpal joint moved about two fixed axes of rotation because of its saddle shape. Hollister et al.[3] located these two axes, a flexion-extension (FE) axis in the trapezium and an abduction-adduction axis in the metacarpal. The axes are not perpendicular to each other or to the bones and do not intersect. The surfaces of revolution for two nonperpendicular, nonintersecting revolutes are skewed tori. The factors for the torus are the distance between the two revolutes, the two angles of offset between them and the distance of the surface from the axes. The interacting surfaces of the joint can be modeled as the surfaces of revolution for two offset revolutes with the dimensions and angles for the joint[3].

Computer aided design (CAD) and computer aided engineering (CAE) analysis were used to design and analyze solid models of the articulating surfaces. A Hewlett Packard Apollo 9000 Series 715/50 workstation, with HP-UX 9.01 UNIX software (Hewlett Packard Van Nuys, Ca) and Structural Dynamics Research Corporation's (SDRC) (Cincinnati, OH) IDEAS Master Series (versions 1.0 through 1.2) CAD and CAE software were used to develop the joint surfaces. The surfaces are nonuniform rational Bezier splines (NURB) surface patches bounded by curves generated from surfaces of revolution or swept surfaces[5,6]. This method uses a circular curve as the sweeping arc for generating the surfaces. The points at the origin of the first and second axis of rotation were inserted and the axes are constructed. A circle whose origin is on the first axis is built. This circle passes through the second axis of rotation at the center of the bone curvature shape for the second axis. A second circle of the appropriate radius for the second axis is created. The circle is oriented so that its axis is aligned with the second axis. The second circle is then swept around the first to generate a torroid. A saddle shaped patch of the torroid surface with the desired range of motion is selected. Conics can be incorporated in the torroidal shape without changing the kinematics. These surface shape variations can improve stability or congruency in different joint positions. A conic with an increasing radius about the trapezial axis from the center of the joint to the volar aspect of the trapezium is incorporated to recreate the saddle angle[3]. Closed section geometries are used during all modeling steps to create solid parts.

Curve analysis, evaluation of congruency and kinematic studies were performed with the solid models. Curve analysis[1] showed similar patterns to those reported for normal bones with circular curves in the middle of the saddle and ellipsoidal curves at the periphery. Congruity of the joint varies with position, the most congruous position being in flexion abduction. The configuration space for the joint shows all three anatomic rotations and displacements for the metacarpal on the trapezium. Finite element modeling and analysis can also be performed with the solids, allowing evaluation of surface stresses in normal and pathological shapes[4].

Mathematical modeling of the thumb CMC joint surfaces is a new promising tool for understanding joint structure and function.

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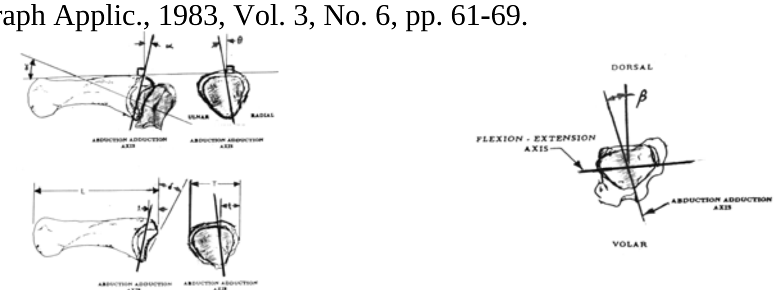

Figure 1 The thumb carpometacarpal joint axes of rotation in the bones. The FE axis is in the trapezium and the AA axis is in the metacarpal. These axes orientations and distances are used to construct the torroids.

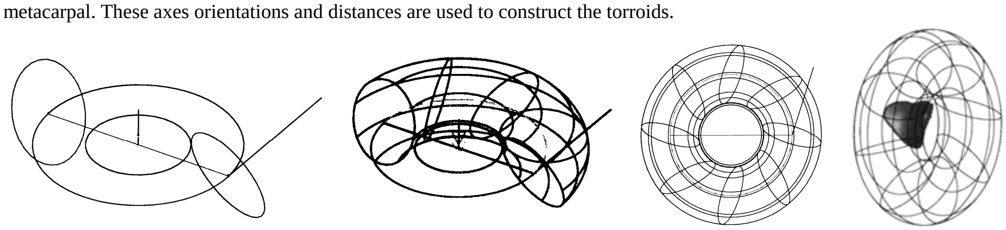

Figure 2 Construction of the torroids begins with establishing the revolutes at the correct offsets and angles relative to each other. A circle of the appropriate size for the joint surface is formed about the second revolute and this offset circle is swept about the first revolute to produce the torroid. The surface patch for the trapezium is shown with the desired orientation and range of FE and AA motions.

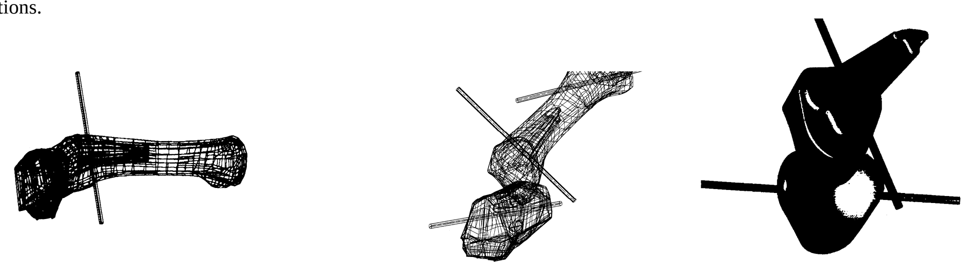

Figure 3 The solids of the surfaces on the bones and their articulation are shown about each axis.

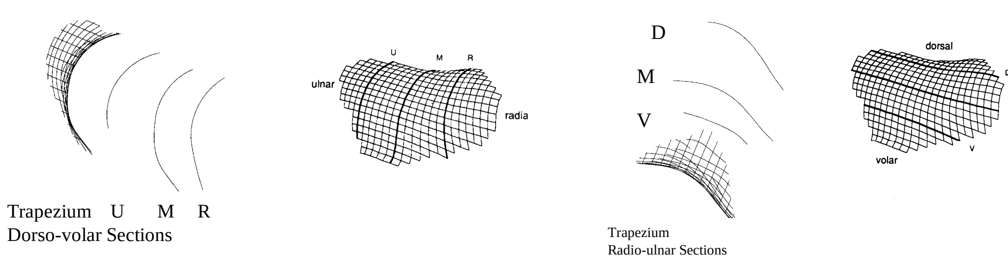

Figure 4 Curvature analysis of the metacarpal and trapezial surfaces after Atesian et al [1]. The centers of the surfaces shapes have circular curves whilst the outer portions are ellipsoidal. This is similar to the pattern seen in human specimens [1].