Three-Dimensional Modeling of Screw Placement at the Tarsometatarsal Joint

INTRODUCTION:
The Lisfranc joint, also referred to as the tarsometatarsal (TMT) joint, was named after Jacques Lisfranc (1790-1847), a French surgeon who described an amputation involving the TMT joint after a sandler fell from a horse with his foot caught in the stirrup (4). Approximately one third of all Lisfranc injuries occur due to low-energy trauma while the rest occur from high-energy forces sustained in industrial accidents, motor vehicle accidents, and falls from a height (4). The Lisfranc ligament is located between the base of the second metatarsal and the medial cuneiform in the mid-foot. Lisfranc injuries occur in 1 per 55,000 cases each year in the United States, accounting for approximately .02% of all fractures but often go undiagnosed due to unfamiliarity with the disorder and use of improper imaging procedures in identifying the problem (3).

Temporary fixation with screws is recommended to injuries that involve disruption of Lisfranc’s ligament and/or fracture of the base of the second metatarsal (3). Soft tissue, nerve, and articular damage may occur secondary to the energy associated with the initial trauma or as complications related to its treatment (1). The conventional approach to fixation of the disruption of the Lisfranc ligament entails placement of the “Lisfranc’s screw” from the medial cuneiform to the base of the second metatarsal (2). Cook et al. has proposed screw orientation from the second metatarsal to the medial cuneiform; however, there have been no three-dimensional studies to date that study various insertion angles using this orientation that minimize damage to the articular and ligamentous structures.

METHODS:
Twenty-four adult preserved cadaver medial cuneiforms and second metatarsals were previously digitized and utilized for this study. Left foot specimens were transformed to right foot orientation tostandardize comparison of screw position and insertion angle. A standardized local x-y-z coordinate frame was oriented so that the surface geometries of multiple specimens could be related to one another (Figure 1). For each specimen, an “optimal” screw path was manually positioned and oriented such that cartilage and ligament would be minimally affected by the inserted screw, and as near as possible to orthogonal angle between screw and bone surfaces. The position and orientation vector of the optimal path were recorded in the defined local 3D coordinate frame. Extremes of dorsal, plantar, posterior, and anterior screw paths were also recorded, constrained by the same criteria as the optimal screw path, but at maximized contact angles.

Figure 1 Orientation of Coordinate System

Ligament attachment areas for each specimen from the medial and plantar aspects of the second metatarsal as well as the lateral aspect of the medial cuneiform were then isolated using an image processing program (ImageJ, NIH). These multiple attachment areas were summed to create a single image from their respective perspectives to show the variation in ligament attachment position from specimen to specimen (Figure 2).

RESULTS:
Insertion angles were calculated from screw placement vectors in the local coordinate system for each specimen. Anterior and posterior angles of the sagittal and coronal planes, respectively, were calculated in the lateral to medial orientation. Table 1 summarizes the angles associated with optimal screw positions as well as an overall summary which includes safe extremes of position.

Table 1 Angle of Insertion

<table>
<thead>
<tr>
<th></th>
<th>Anterior Angle in the Sagittal plane (degrees)</th>
<th>Lateral Angle in the Coronal Plane (degrees)</th>
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<tbody>
<tr>
<td>Optimal</td>
<td>Average</td>
<td>53</td>
</tr>
<tr>
<td></td>
<td>Standard Deviation</td>
<td>3</td>
</tr>
<tr>
<td>Overall</td>
<td>Average</td>
<td>55</td>
</tr>
<tr>
<td></td>
<td>Standard Deviation</td>
<td>9</td>
</tr>
</tbody>
</table>

Figure 2 summarizes the variation in attachment size area, size, and location for all specimens. The colored contours represent each 20th percentile increment, ranging from the 20th percentile in burgundy through the 80th to 100th percentile in yellow for variations in the Lisfranc ligament attachments. In this figure, the relative positions of the 2nd metatarsal and 1st cuneiform are preserved vertically and horizontally, so that the relative positions of the respective attachment sites on each bone may be compared.

DISCUSSION:
The use of screw fixation has been shown to provide good results; however, reasons for a less than optimal result can occur from secondary damage to the articular surfaces, nerves, and soft tissue relating to treatment (1). Radiographs, CT, and MRI have not been shown to precisely identify ligamentous structures (4). While fluoroscopy is commonly used to determine precise screw orientation it does not allow for the surgeon to accurately determine the probability of articular surfaces and soft tissue structures in the path of orientation (4). The introduced approach to modeling 3D screw placement allows us to determine optimal angles of insertion based on the variations seen in the Lisfranc ligament attachments. This ability will offer confidence that damage to soft tissue, nerve, and articular surfaces is minimized during treatment of Lisfranc injuries.

SIGNIFICANCE:
Transarticular screw fixation of Lisfranc injuries have been associated with injury to soft tissues and articular surfaces. Three-dimensional modeling of the Lisfranc joint complex can be used to determine ideal insertion angles of the “Lisfranc’s screw” to minimize soft tissue, nerve, and articular damage.

REFERENCES: