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Effect of Applied Load and Glenoid Morphology on the Stability of Patient-Specific Guide in Shoulder Arthroplasty: A Finite Element Analysis

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Introduction and Background

Accurate positioning of the glenoid component is essential for long-term success in shoulder arthroplasty. Patient-specific instrumentation (PSI) has been developed to improve surgical precision by conforming to each patient's unique scapular anatomy. However, intraoperative handling - especially the direction and magnitude of applied load during PSI application - can affect its stability, potentially compromising the final implant positioning. This study investigated how loading conditions and glenoid surface curvature influence the mechanical stability of patient-specific guides and subsequent glenoid component positioning accuracy.

Material and Method

A total of three FE models (Model A: 45N, Model B: 90N, Model C: 135N applied to small peg) were developed. Additional 45N or 135N shear loads were applied to the large peg at 10° or 20° off-axis in four directions (superior, inferior, medial, lateral). The scapula was modeled as rigid; glenoid and PSI as deformable. Mechanical responses such as translational deviation, twist angle, and lift-off angle were evaluated to identify glenoid component positioning accuracy across models and glenoid morphologies.

Results

Higher forces applied to the small peg significantly increased patient-specific guide displacement, resulting in greater deviation, twist, and lift-off angles. Model C (135 N) exhibited the largest positional errors among all models. Glenoids with a flatter, asymmetric curvature profile (Type 1) demonstrated significantly greater positional deviation compared with more uniformly curved glenoids across all loading conditions (deviation: 1.4 ± 0.02 mm, twist angle: $1.2 \pm 0.12^\circ$, and lift-off angle: $0.7 \pm 0.06^\circ$). Statistical analysis confirmed that loading magnitude, loading direction, and glenoid morphology were all significant contributors to positioning error. Positional instability increased markedly when applied force exceeded 90 N, suggesting a threshold for mechanical instability.

Conclusions

Controlled force application is essential to minimize glenoid malposition in shoulder arthroplasty. Loads >90 N and flatter, asymmetric glenoids increase positioning error and should be considered when refining surgical technique and guide design.

