Surgeon Ergonomics During Total Knee Arthroplasty

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INTRODUCTION: Healthcare has many occupational hazards, including radiation, chemical, psychological, and musculoskeletal (MSK) injuries. In arthroplasty, 97% of surgeons report MSK pain and 66% of surgeons report procedural related MSK disorders [1], [2]. Orthopedic surgeons spend the most operating time in demanding torso positions and third most time in demanding neck positions [3], commonly reporting pain in the low back (28%), neck (21%), and shoulders (14%) [1], [2]. Previous studies of surgeon ergonomics have measured the total effort exerted during manual and robotic total knee arthroplasty (TKA), but have not documented the specific demanding positions at each step of the procedure [4], [5]. To address this gap, the goal of this study was to quantify kinematics and kinetics of the lumbar spine, cervical spine and shoulders for 11 distinct surgical steps during TKA as guidance for ergonomic improvement of the procedure.

METHODS: After IRB approval, four orthopedic surgeons (3M/1F: 170.2 cm±6.7 cm, 75.6 kg±5.7 kg) performed TKA on two synthetic lower limbs (Fusetec) in a gait laboratory (8 total surgeries). Participants were screened for shoulder or spine injury in the prior year or pain in the spine or shoulders that caused impaired function. Surgeons were outfitted with reflective markers to capture 3D motion (VICON) alongside ground reaction forces (Figure 1A). A standard surgical table was placed adjacent to the force plates, and the position was adjusted throughout the procedure to ensure surgeons stood on the force plates without compromising their surgical technique. Likewise, table height was adjusted based on the surgeon's preference. The TKA procedure was divided into 11 discrete surgical steps: drill the femoral canal (DFC), place and pin the femoral resection guide (FRG), distal femoral resection (DFR), place and pin the tibial resection guide (TRG), proximal tibial resection (PTR), gap assessment and balancing (GAB), place and pin the 4-in-1 block (41B), anterior/posterior/chamfer cuts (APC), tibial ream and broach (TRB), femoral trial and lug prep (TLG), and implant impaction and reduction (IIR). Surgeons were asked to perform each step to completion in a discrete fashion on right and left knees (Figure 1B). MSK models were scaled for each participant using height, weight, and marker data from a static position (OpenSim) using a full body model previously used in ergonomic studies [6]. Kinematics and kinetics were calculated using the OpenSim workflow for the lumbar spine, cervical spine, and shoulders for each surgical step (Figure 1C). The mass of the saw, drill, and mallet were tracked and included in the joint moment calculations. Demanding joint angles were defined as >20° of lumbar flexion, >10° of lumbar lateral bending and axial rotation, >10° of cervical flexion, lateral bending, and axial rotation, and >45° of shoulder abduction and flexion [3], [4], [7].

RESULTS: During DFC, surgeons averaged 31.1°±16.3° and 35.3°±19.7° of abduction of the left and right shoulder, respectively, and averaged 21.1°±4.6° of cervical flexion during APC. Surgeons spent the greatest amount of time in demanding lumbar lateral bending (36.0s±26.6s), cervical flexion, lateral bending, and axial rotation (89.1s±29.7s, 55.4s±27.8s, & 45.2s±26.2s), and increased time in demanding shoulder positioning during APC. During TRB, surgeons spent 12.7s±14.5s in a demanding lumbar axial rotation position and 24.7s±8.5s & 13.7s±10.4s with demanding right shoulder flexion and abduction. Average joint moments were elevated in the shoulders for surgical steps requiring a saw or drill in conjunction with static abduction and flexion (DFC, DFR, APC, & TRB), whereas peak joint moments were greatest for surgical steps requiring impaction with a mallet (TRB & IIR) (Figure 2).

DISCUSSION: DFC, APC, and TRB required surgeons to sustain demanding positions with increased sustained and peak demand in the cervical spine, lumbar spine, and shoulders. Surgeons experienced elevated abduction and flexion angles of both shoulders to align the drill with the femoral canal during DFC. APC required extensive time in demanding joint positions for multiple joints in various degrees of freedom, and caused increased sustained loading in both shoulders. Surgeons had elevated right shoulder flexion and abduction angles during TRB, corresponding to sustained unfavorable positioning of the right shoulder and relatively high sustained joint moments, due to positioning during reaming, and elevated peak joint moments, due to impaction. Additionally, TRB caused unfavorable bending and rotation of the lumbar spine, along with increased joint moments, which is related to high compression and shear force in the lumbar spine [8]. Traditional surgical table design requires surgeons to stand laterally to the patient which may cause excessive shoulder flexion and abduction and asymmetrical spine postures throughout the procedure to access the surgical field. The small sample size and variability in surgical techniques lead to high standard deviations across subjects and limited the ability to determine statistical significance differences.

SIGNIFICANCE/CLINICAL RELEVANCE: Quantifying MSK demand of discrete surgical steps during TKA provides guidance into surgical tasks that increase risk for arthroplasty surgeons and guides further improvements of surgical instruments and processes.

REFERENCES: 1. Alqahtani et al. *J Arthroplasty* 2016; 2. McQuivey et al. *J Arthroplasty* 2021; 3. Meltzer et al. *JAMA Surgery* 2020; 4. Haffar et al. *J Arthroplasty* 2022; 5. Scholl et al. *J Knee Surgery* 2021; 6. Bruno et al. *J Biomech Eng* 2015; 7. Delleman et al. *Ergonomics* 2007; 8. Kim et al. *Ergonomics* 2017

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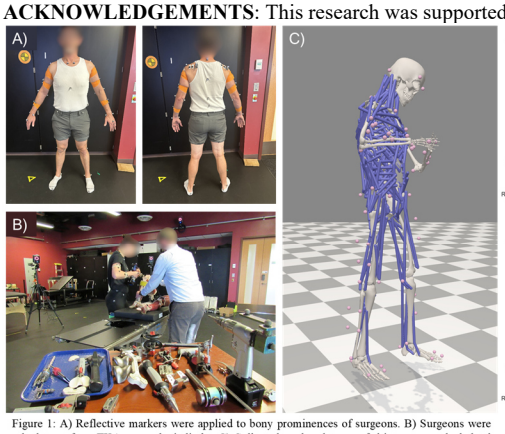

Figure 1: A) Reflective markers were applied to bony prominences of surgeons. B) Surgeons were asked to perform TKA on synthetic limbs. C) Collected marker data was fed into a musculoskeletal model for kinematic and kinetic data output.

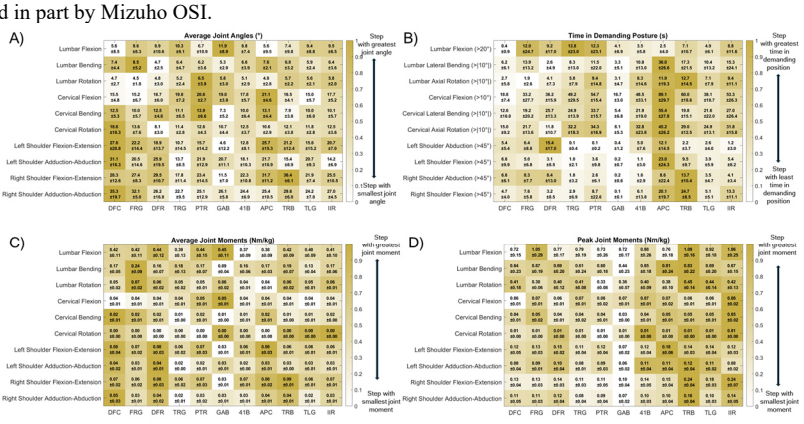

Figure 2: Average joint angles (A), time in demanding positions (B), average joint moments (C), and peak joint moments (D) for each step of TKA. Dark colors indicate highest joint demands normalized across all steps.