Reliability of Intraoperative Assessment of Kinematics Using Robotic-Assisted TKA

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INTRODUCTION: CT-based robotic-arm assisted total knee arthroplasty (RATKA) enables surgeons to create personalized 3D surgical plans and adjust implant positioning intraoperatively based on ligament laxity. Stability and kinematic assessments may offer enhanced insights into knee laxity across multiple planes, extending beyond the single-plane evaluation provided by coronal gap balancing. The repeatability and reproducibility of these intraoperative RATKA methods remain underexplored. This study evaluated the inter- and intra-rater reliability of intraoperative knee kinematic (dynamic), sagittal and transverse stability assessments in a cadaveric setting with three experienced surgeons.

METHODS: Five fresh-frozen cadaver knees from three specimens (ages 43, 59, and 72; BMI: 12.8-30.87 lbs./in²; 2 males, 1 female) were prepared for cruciate-retaining RATKA. Surgeons applied manual anterior-posterior (AP) and internal-external (IE) stress at 10°, 45°, and 90° of flexion. Medial AP (MAP) and lateral AP (LAP) translations, along with IE rotation were measured (Figure 1a). Dynamic assessments involved exercising the knee through a full range of motion, from deep flexion (>120°) to near extension (<10°), to calculate the medial-pivot ratio (MPR) and average medial contact position (AMCP) expressed as a percentage of tibial length. Pivot classification was defined: lateral:medial ratio ≥1.5 indicated a medial pivot; <0.66 indicated a lateral pivot; and 0.66-1.5 indicated symmetrical rollback. Each surgeon performed the assessments sequentially, rotating between specimens until all three repetitions were completed. This process was conducted for both the intact knees and again after final component implantation. Interclass correlation coefficients (ICC) using a two-way random-effects model were calculated to determine the intra-observer and inter-observer reliability. Reliability and mean variance of assessments were compared for the two surgeons using a leg holder and all three surgeons using a manual support method. Reliability thresholds were defined as poor (<0.4), good (0.4-0.75), and excellent (>0.75) (Fleiss 1981).

RESULTS: Intra-observer and inter-observer reliability was generally good to excellent across measures (Table 1). For intact knees at 10°, 45°, and 90°, inter-rater reliability (for all surgeons) for MAP ranged from good (0.52) to excellent (0.84), LAP was good (0.44-0.57), and IE rotation reliability was good (0.48-0.62). With components, MAP, LAP, and IE rotation showed good inter-rater reliability (for all surgeons). Dynamic assessments showed excellent reliability (0.84-0.93) for AMCP in intact and component conditions, and good to excellent reliability (0.53-0.8) for MPR with components. Intra-rater reliability was high, with ICC values above 0.90 (excellent) for most measures. The leg holder generally improved inter-rater reliability for MAP, LAP, and IE assessments, shown by the reduced variation in assessment values. Mean variance for MAP and LAP ranged from 0.85 to 2.25 mm for all surgeons and 0.71 to 1.77 mm for two surgeons using the leg holder. The mean variance also reduced for IE rotation ranged from 2.70° to 6.11° for all surgeons and 2.32° to 4.58° for two surgeons using the leg holder.

DICUSSION: Knee stability and dynamic assessments exhibited generally good to excellent reliability, although future studies would observe a larger cohort. The leg holder generally improved inter-rater reliability, while intra-rater reliability remained consistently high. Variation in assessments reduced for MAP, LAP and IE rotation with the leg holder having ranges within 2 mm and 5°. The strong reliability of AMCP during dynamic assessment suggests its potential utility in evaluating knee function and guiding surgical planning. These findings highlight the importance of stability and kinematic measures, and support the reliability of these assessments, particularly when performed by the same observer and with leg support.

SIGNIFICANCE/CLINICAL RELEVANCE: Intraoperative assessments of knee stability and dynamics using robotic-arm assisted techniques were shown to be reliable and reproducible, especially when aided by a leg holder and performed by the same surgeon. The demonstrated excellent reliability of the average medial contact position supports integration of such assessments into surgical planning.

REFERENCES: Fleiss, J. L. (1981). Statistical Methods for Rates and Proportions (2nd ed.). New York: John Wiley & Sons.

Table 1: Inter- and Intra-Rater Reliability and Accuracy of Knee Kinematic and Stability Assessments

Measure	10 degrees						45 degrees						90 degrees						Dynamic			
	Intact			Components			Intact			Components			Intact			Components			Intact		Components	
	MAP (mm)	LAP (mm)	IE (deg)	MAP (mm)	LAP (mm)	IE (deg)	MAP (mm)	LAP (mm)	IE (deg)	MAP (mm)	LAP (mm)	IE (deg)	MAP (mm)	LAP (mm)	IE (deg)	MAP (mm)	LAP (mm)	IE (deg)	MPR	AMCP	MPR	AMCP
Inter-ICC, All	0.55	0.53	0.61	0.7	0.58	0.47	0.84	0.57	0.62	0.66	0.8	0.68	0.52	0.44	0.48	0.65	0.71	0.54	NaN	0.84	0.57	0.93
Inter-ICC, Holder	0.36	0.43	0.79	0.84	0.43	0.62	0.91	0.51	0.85	0.9	0.79	0.91	0.48	0.52	0.61	0.85	0.96	0.94	NaN	0.79	0.60	0.91
Intra-ICC, All	0.88	0.83	0.91	0.95	0.91	0.95	0.95	0.87	0.95	0.96	0.98	0.98	0.77	0.92	0.9	0.96	0.98	0.97	NaN	0.99	0.73	0.99
Intra-ICC, Holder	0.77	0.74	0.88	0.94	0.85	0.94	0.92	0.76	0.95	0.98	0.97	0.98	0.69	0.92	0.89	0.96	0.99	0.97	NaN	0.98	0.80	0.99
Variance, All	1.57	1.34	3.23	0.85	0.9	2.7	0.91	1.31	4.11	1.33	1.2	4.24	0.85	1.79	4.7	1.36	2.25	6.11	0.43	2.30	0.32	0.96
Variance, Holder	1.36	1.38	2.98	0.75	1.06	2.32	0.76	1.31	3.66	1.13	1.07	3.18	0.71	1.57	3.79	1.12	1.77	4.58	0.51	2.58	0.34	1.06

*Overall = values for all three surgeons (two using the leg holder and one using manual support); **Holder = values for two surgeons using a leg holder. MAP (mm): Medial Anterior-Posterior Translation (measured in millimeters); LAP (mm): Lateral Anterior-Posterior Translation (measured in millimeters); IE (deg): Internal-External Rotation (measured in degrees); AMCP: Average Medial Contact Position (as a percentage of the tibial length). NaN = Result is undefined because the ratings were identical or lacked enough variation to compute an ICC score.
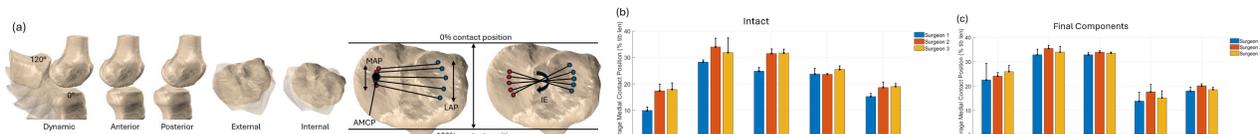

Figure 1: (a) Method for knee stability and dynamic assessments, (b) AMCP for Intact components, and (c) AMCP for Final Components.

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