Comparison of Static and Continuous Knee Laxity Testing in Cadaveric Knees using a 6-DOF Robotic System

Gabe Colbrunn[1,2], Aiden Magoolaghan[1,3], Elizabeth Pace[4], Tara Nagle[4]
[1]Andrews Research and Education Foundation, Gulf Breeze, FL, [2]Kent State University, Kent, OH, [3]Ohio Northern University, Ada, OH, [4]Cleveland Clinic, Cleveland, OH
gabe.colbrunn@andrewsref.org

Disclosures: Gabe Colbrunn (N), Aiden Magoolaghan (N), Elizabeth Pace (N), Tara Nagle (simVITRO)

INTRODUCTION: Two methods for biomechanically testing joint laxity in cadaveric knees with 6-degree-of-freedom (DOF) robotic simulators include static testing, where target loads are applied and held at discrete flexion angles[1], and continuous testing, where target loads are applied while the joint undergoes a continuous flexion motion [2]. Static testing is more commonly used due to the limitations of older technology. However, static knee laxity testing can become time-consuming when measuring a variety of loading conditions and will ultimately limit the flexion angles that can be assessed. An alternative continuous knee laxity testing method has been used by researchers in elbow testing [2] and has shown to be more time efficient. This continuous method is hypothesized to lead to similar kinematic results as static laxity testing for the flexion angles considered in knee testing.

METHODS: Nine fresh-frozen cadaveric knees (5 male, 4 female) were tested on a 6 DOF simVITRO® robotic testing system to examine native knee laxity. Knees underwent six (6) static and continuous laxity tests, including 10 Nm varus/valgus (VV) torques, 5 Nm external/internal rotation (IRER) torques, and 100 N anterior/posterior (AP) forces. Static tests were performed at 0°, 30°, 60°, and 90° flexion. Continuous tests were performed while flexing from 0→90° continuously and repeated while extending from 90→0°. Test orders of static and continuous testing were balanced across specimens. Paired t-tests were used to compare kinematic results of the testing methods at 0°, 30°, 60°, and 90° flexion.

In accordance with institutional policy, institutional review board approval was not required for this cadaveric biomechanical study. The research institution is approved to receive cadaveric specimens for research and training purposes.

RESULTS: Table 1 displays kinematic laxity values across all tests. Static and continuous 0→90° testing were largely similar, with differences observed at 60° for anterior laxity ($p = 0.001$), 0° for valgus laxity ($p = 0.029$), and 30° for posterior laxity ($p = 0.016$). Comparisons between static and continuous 90→0° testing showed broader differences: varus, valgus, and external-rotation laxity differed at all flexion angles ($p < 0.05$); internal-rotation laxity differed at 0° and 30° ($p < 0.05$); and posterior laxity differed at 30° ($p = 0.016$). No differences were detected between Static and continuous 90→0° for anterior laxity. RMS values to show force tracking accuracy are summarized in Table 2.

DISCUSSION: Static testing produced similar results to the continuous 0→90° path but differed more from the 90→0° path across several degrees of freedom. These findings suggest that knee laxity testing with a 0→90° flexion path may provide a reasonable alternative to static testing and that reported laxities may depend on the direction of the flexion path. Protocol direction should therefore be standardized and explicitly reported in studies. Future work will quantify the kinematic repeatability of continuous testing and evaluate static vs continuous testing across different surgical conditions to determine when continuous testing is appropriate. Limitations of the study include only testing on uninjured knees, even though laxity testing is commonly used for injured and surgically repaired knees. Continuous testing also results in a different, often higher RMS error when comparing the desired vs actual force. The acceptability of this error may depend on the clinical question of the study.

SIGNIFICANCE/CLINICAL RELEVANCE: Continuous laxity testing allows for the collection of kinematic data across all flexion angles, which has historically been neglected or interpolated with static laxity testing. It may also provide a more efficient alternative for knee laxity testing while still giving reliable results. This adaptation will allow for studies performed in orthopedic research to collect more data in an efficient manner.

REFERENCES: [1]Holthof SR et. al, *Knee surgery, sports traumatology, arthroscopy: official journal of the ESSKA*, 2025, [2] Rogers TH et. al, *Journal of shoulder and elbow surgery*. 2022

IMAGES AND TABLES:

Flexion	Static	Continuous 0→90	Continuous 90→0	P Static vs C0→90	P Static vs C90→0	P C0→90 vs C90→0
Varus Rotation (°)						
0	3.72 ± 1.56	3.77 ± 1.42	3.99 ± 1.51	0.502	0.004	<0.001
30	5.27 ± 1.89	5.38 ± 1.74	5.55 ± 1.83	0.130	<0.001	0.003
60	5.92 ± 2.21	5.89 ± 2.06	6.19 ± 2.11	0.742	0.006	<0.001
90	8.00 ± 2.42	8.12 ± 2.30	8.28 ± 2.32	0.247	0.010	<0.001
Valgus Rotation (°)						
0	2.29 ± 0.88	2.44 ± 1.00	2.53 ± 1.02	0.029	0.007	0.004
30	5.06 ± 1.54	5.12 ± 1.62	5.41 ± 1.74	0.237	0.002	<0.001
60	5.79 ± 1.61	5.91 ± 1.70	6.26 ± 1.72	0.116	<0.001	<0.001
90	5.25 ± 1.63	5.55 ± 1.64	5.72 ± 1.67	0.051	0.006	<0.001
External Rotation (°)						
0	10.79 ± 2.64	10.91 ± 2.61	11.34 ± 2.82	0.543	0.017	0.004
30	16.42 ± 4.56	16.53 ± 4.23	17.06 ± 4.43	0.566	0.002	<0.001
60	17.91 ± 5.60	18.08 ± 5.34	18.53 ± 5.48	0.395	0.003	<0.001
90	19.33 ± 6.07	19.66 ± 5.82	19.90 ± 5.84	0.099	0.008	<0.001
Internal Rotation(°)						
0	10.41 ± 2.20	10.64 ± 2.28	10.88 ± 2.40	0.177	0.007	0.004
30	20.78 ± 2.45	20.80 ± 2.45	21.37 ± 2.51	0.859	<0.001	<0.001
60	20.49 ± 3.65	20.64 ± 3.50	20.95 ± 3.66	0.559	0.105	0.005
90	19.83 ± 5.13	19.99 ± 5.01	20.35 ± 5.08	0.652	0.073	<0.001
Anterior Translation (mm)						
0	3.54 ± 0.57	3.63 ± 0.66	3.65 ± 0.65	0.281	0.193	0.469
30	3.90 ± 1.14	4.01 ± 1.17	3.97 ± 1.27	0.072	0.365	0.404
60	3.16 ± 1.18	3.39 ± 1.25	3.08 ± 1.30	0.001	0.237	<0.001
90	4.66 ± 1.04	4.74 ± 1.17	4.74 ± 1.18	0.394	0.570	0.802
Posterior Translation (mm)						
0	4.75 ± 0.78	4.88 ± 0.88	4.90 ± 0.87	0.240	0.158	0.592
30	6.07 ± 1.37	6.20 ± 1.42	6.19 ± 1.40	0.016	0.021	0.881
60	4.41 ± 1.43	4.47 ± 1.37	4.62 ± 1.40	0.604	0.030	0.005
90	2.21 ± 1.29	2.26 ± 1.43	2.27 ± 1.37	0.553	0.119	0.813

Table 1. Knee laxity (mean ± SD) at 0°, 30°, 60°, and 90° under Static, Continuous 0→90, and Continuous 90→0. Columns show paired t-test *p* values at each angle for Static vs 0→90, Static vs 90→0, and 0→90 vs 90→0; significant comparisons ($p<0.05$) are shaded yellow. Rotations are in degrees; translations in millimeters; $n = 9$ paired knees.

Flexion	Static	Continuous 0→90	Continuous 90→0
10 Nm Varus Torque (Nm)			
0	0.27 ± 0.14	0.39 ± 0.33	0.41 ± 0.20
30	0.20 ± 0.08	0.26 ± 0.08	0.24 ± 0.08
60	0.23 ± 0.09	0.31 ± 0.11	0.37 ± 0.21
90	0.27 ± 0.15	0.29 ± 0.11	0.19 ± 0.09
10 Nm Valgus Torque (Nm)			
0	0.26 ± 0.12	0.59 ± 0.26	0.77 ± 0.39
30	0.25 ± 0.12	0.48 ± 0.17	0.71 ± 0.27
60	0.26 ± 0.16	0.28 ± 0.12	0.44 ± 0.39
90	0.27 ± 0.18	0.36 ± 0.12	0.23 ± 0.11
5 Nm External Rotation Torque (Nm)			
0	0.13 ± 0.08	0.04 ± 0.02	0.08 ± 0.09
30	0.07 ± 0.04	0.04 ± 0.04	0.04 ± 0.05
60	0.12 ± 0.06	0.05 ± 0.03	0.06 ± 0.04
90	0.11 ± 0.07	0.10 ± 0.06	0.07 ± 0.03
5 Nm Internal Rotation Torque (Nm)			
0	0.09 ± 0.08	0.12 ± 0.08	0.11 ± 0.04
30	0.09 ± 0.05	0.11 ± 0.08	0.11 ± 0.07
60	0.10 ± 0.06	0.10 ± 0.12	0.07 ± 0.05
90	0.13 ± 0.07	0.15 ± 0.13	0.09 ± 0.07
100 N Anterior Force (N)			
0	1.11 ± 1.31	1.96 ± 1.51	3.17 ± 1.18
30	1.08 ± 1.08	1.95 ± 1.22	1.81 ± 0.57
60	1.92 ± 1.73	1.34 ± 0.52	1.72 ± 1.55
90	1.01 ± 0.48	2.66 ± 1.02	2.25 ± 1.90
100 N Posterior Force (N)			
0	1.29 ± 0.89	2.29 ± 1.41	2.54 ± 1.17
30	1.38 ± 1.53	1.10 ± 0.52	1.30 ± 0.71
60	1.70 ± 1.28	2.10 ± 0.91	2.14 ± 0.70
90	1.13 ± 0.94	2.39 ± 1.20	1.46 ± 0.84

Table 2. RMS load-tracking error (desired - actual; mean ± SD) at 0°, 30°, 60°, and 90° for Static, Continuous 0→90, and Continuous 90→0. Torque rows are in Nm and force rows in N; lower values indicate better tracking. $n = 9$ paired knees.