CAN *IN VITRO* KNEE SIMULATORS REPLICATE KNEE BIOMECHANICS: A SYSTEMATIC REVIEW

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Introduction

In vitro knee simulators, which replicate kinematic and kinetic conditions in cadaveric specimens, have become increasingly prevalent in assessing medical implants or surgical reconstructions by facilitating invasive measurements and overcoming approximations due to tissue isolation. While these simulators are electromechanically designed to apply repeatable, controlled physiological loads and motions to cadaveric joints, alterations in biomechanical inputs question the biomechanical credibility of the simulator in replicating true joint physiology. Common examples include downscaling of ground reaction forces (GRF) to reduce applied muscle forces thereby preventing possible tendon rupture (1), or applying realistic loads but at much lower speeds while also discounting simultaneous control of multiple muscles owing to practical and computational difficulties encountered in real-time control (2).

This review article aims to summarize the parameters used in *in vitro* knee simulators, and compare it with *in vivo* biomechanical studies to understand the clinical relevance.

Methods

A systematic literature review using PRISMA guidelines was conducted on Google scholar, PubMed, and Web of Science using the keywords "knee simulator," "knee rig," "cadaver," "muscles," "biomechanics," and "in vitro." Cadaveric studies replicating human muscle loading were included in this review; computational simulations and wear-based simulators were excluded. 1036 studies were identified, and finally, 105 studies were filtered after removing duplicates and screening irrelevant abstracts. Trends in commonly altered biomechanical parameters, such as muscle forces, joint range of motion (ROM), and cycle time, were analysed and compared to those reported *in vivo*.

Results

Over the years, simulators evolved from single to multi-actuated devices to replicate *in vivo* physiology. Simulating closed chain activities, such as squatting, kneeling, and jump landing *in vitro*, the quadriceps force was downscaled to 12-66 % of the physiological values reported *in vivo*. For simulating open chain activities, downscaling was not found, probably due to lower muscle loads. Hamstring loads were often statically simulated to a load varying from 0 to 14% of its natural value. The simulator's flexion speed ranges from 1°/s to 12°/s to accurately replicate GRF, which was substantially lower than its physiological value of 65°/s. These simulators' flexion ROM varies from 0° to 130°, limiting the posterior translation of femur and tibial rotation to 16 mm and 12°, respectively.

	In vivo	***In vitro***			
Study	1982s (3)	1999 (4)	2009 (1)	2013 (2)	2021 (5)
ROM (deg)	30-160	15-70	20-130	20-120	10-70
Quad (BW)	5.3 (M)	2.5 (S)	3.5 (S)	0.9 (M)	5.3 (M)
Ham (BW)	2.2 (M)	0.3 (S)	0.15 (M)	0.05 (M)	2.2 (M)
GRF (BW)	0.5	0.3	0.25	0.07	0.5
Time (s)	2	4.6	12	40	0.7

Table 1: Comparison of the biomechanical parameters during squatting in vivo and in vitro (M-Multiple actuator, S-Single actuator)

Discussion

In vitro simulators were found to avoid complete joint ROM due to the risk of tendon rupture and fixation shape. However, a more recent study by Schall et al. applied the true load within a limited flexion range (Table 1). Passive loading of hamstring was unable to replicate the physiology during ascent phase of closed chain activity. Unlike the *in vivo* studies after 30° flexion, the rotation speed is slowed due to reduced quadriceps and constant hamstring load.

To replicate *in vivo* muscle loads and joint ROM on cadaveric specimens, it is important to strengthen the fixation of the actuator cable to the tendon, Individual muscles must be actuated separately to maintain a physiological line of action, Control strategies need to be simplified and improved, possibly even allowing direct feedback from the cadaver to reduce the latency. Finally, these simulator designs need to incorporate other activities of daily living and injuries requiring greater joint mobility. This study could valuable help surgeons and researchers in formulating physiologically meaningful interpretations of *in vitro* experiments.

References

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