Reference

Koehler-McNicholas, Sara R.[1,2,3]; Lipschutz, Robert D.[2,5]; A. Gard, Steven[2,3,4]

The biomechanical response of persons with transfemoral amputation to variations in prosthetic knee alignment during level walking

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Products

3R95 (free single-axis posterior offset knee hinge), 1D35

Major Findings

With 3R95 in different knee alignment conditions (bench, 2cm anterior, and 2cm posterior):

→ **Anterior alignment creates instability and triggers multiple compensatory strategies to coordinate stance-phase knee flexion compared to the bench alignment at the time of opposite toe off**

- decreased loading rate of the prosthesis
- decreased step length (~6% smaller, p=0.023)
- increased trunk flexion (factor ~1.6x higher, p=0.007)
- affected limb in a more vertical posture (~73% more upright, p=0.002)
- significantly decreased extension moment at the knee joint (~38% smaller, p=0.02) → corresponds to a decrease in the margin of stability
- significantly increased early-stance hip extension moment (~46% higher, p=0.019) (interpretation: instability caused by anterior alignment must be compensated using hip extensors to maintain knee joint stability)

→ **Posterior alignment has fewer impact on patients regarding stance-phase, knee joint control compared to the bench alignment**

- significantly longer terminal double support phase (~7% longer, p = 0.007)
- extension moment at the knee joint significantly increased at toe off (factor ~1.3x higher, p<0.001) → corresponds to increase in the margin of stability

→ **hip torque strategy alone might be insufficient to counteract the effect of the alignment perturbation**

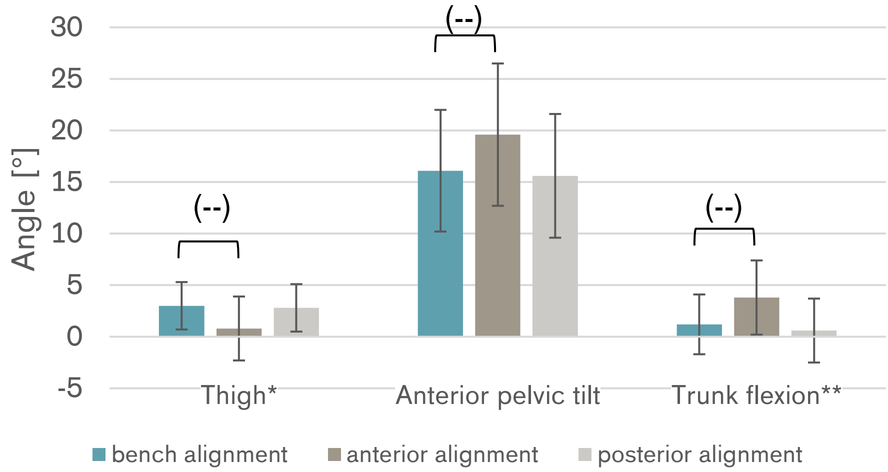


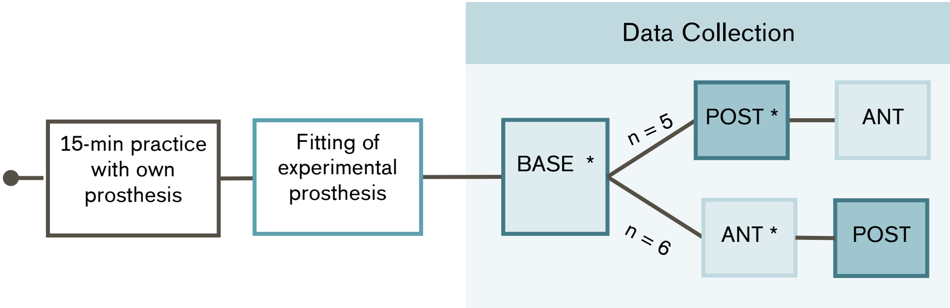
Figure 1. Mean affected-side joint kinematics at opposite toe off during level walking. * thigh angle > 0: distal end of thigh is anterior to proximal end. ** value < 0: extension. (--) significant difference to bench alignment (p<0.025).

Population

Subjects:	11 participants (9 = male, 2 = female)
Amputation Level:	unilateral transfemoral (n = 10), unilateral knee disarticulation (n = 1)
Previous prosthesis:	n.a.
Amputation causes:	trauma (n = 8), cancer (n = 3)
Mean age:	46 ± 16 years
Mean time since amputation:	n.a.
MFCL:	K3 or higher

Study Design

Single-blinded, pseudo-randomized crossover design:



*BASE: knee bench-aligned, ANT: 2 cm anterior knee translation, POST: 2 cm posterior knee translation

First, the subjects underwent a physical examination where residual limb length, hip range of motion and muscle strength were examined. The participants could practice for about 15 minutes on the treadmill, or until comfortable and select their personal walking speed.

All subjects started with the BASE condition. To accommodate to the BASE condition, the subjects could walk overground for <5 minutes. Next, the participants walked at a self-selected speed on a level treadmill surface for 2.5 minutes. After 2 minutes, quantitative gait data was recorded for 30 seconds. Subsequently, the protocol was repeated with the same constant speed for the 2 other alignment conditions (ANT, POST) in a randomized order. Prior to each condition, they were again offered an accommodation time of <5 minutes.

For the anterior knee alignment, the knee was translated 2 cm in anterior direction (ANT). Similar in posterior direction (POST). All subjects completed all three alignment conditions.

Results

Functions and Activities						Participation			Environment
Level walking	**Stairs**	**Ramps, Hills**	**Uneven ground, Obstacles**	**Cognitive demand**	**Metabolic Energy Consumption**	**Safety**	**Activity, Mobility, ADLs**	**Preference, Satisfaction, QoL**	**Health Economics**

Category	Outcomes	Results for 3R95	Sig.[a] (vs. BASE)

Category	Outcomes	Results for 3R95	Sig.[a] (vs. BASE)
Level Walking [b]	Spatiotemporal characteristics		

BASE and POST: slightly longer step length on the affected side compared to the intact side
ANT: significantly decreased step length on the affected side compared to BASE

	BASE	ANT	POST	Sig.[a] (vs. BASE)
Intact Limb Step length [cm]	52 ± 7	54 ± 5	53 ± 6	0
Affected Limb Step length [cm]	54 ± 8	**51 ± 7**	55 ± 8	––
Stance phase [ms]	874 ± 115	859 ± 134	884 ± 123	0

Initial double support phase:
- significantly longer for ANT compared to BASE
- shortest overall for POST

Terminal double support phase:
- significantly shorter for ANT
- significantly longer for POST

	BASE	ANT	POST	Sig.[a] (vs. BASE)
Initial double support [ms]	219 ± 61	**238 ± 75**	207 ± 59	––
Single support [ms]	442 ± 41	426 ± 50	450 ± 48	0
Terminal double support [ms]	214 ± 33	**196 ± 31**	**229 ± 33**	––

Affected-side joint kinematics [°] [c]

Opposite Toe Off

ANT compared to BASE:
- persistent significant increase in trunk flexion & anterior tilt
- thigh: subjects maintained their affected limb in a significantly more vertical posture

	BASE	ANT	POST	Sig.[a] (vs. BASE)
Ankle	-3.9 ± 2.4	-3.2 ± 2.5	-3.9 ± 2.5	0
Knee	-4.8 ± 3.0	-5.4 ± 2.5	-5.0 ± 2.7	0
Hip	19.6 ± 5.7	21.1 ± 5.6	19.0 ± 5.7	0
Thigh	**3.0 ± 2.3**	**0.8 ± 3.1**	2.8 ± 2.3	––
Pelvis	**16.1 ± 5.9**	**19.6 ± 6.9**	15.6 ± 6.0	––
Trunk	**1.2 ± 2.9**	**3.8 ± 3.6**	0.6 ± 3.1	––

Knee Break (late-stance initiation of knee flexion)

ANT compared to BASE:
- persistent significant increase in trunk flexion & anterior tilt

	BASE	ANT	POST	Sig.[a] (vs. BASE)
Ankle	7.1 ± 4.0	7.7 ± 4.2	7.1 ± 3.8	0

Category	Outcomes					Sig.[a] (vs. BASE)
		Knee	0.6 ± 2.5	-0.2 ± 2.1	0.9 ± 2.5	0
		Hip	-5.6 ± 6.9	-4.5 ± 6.3	-6.0 ± 6.5	0
		Thigh	-20.7 ± 3.2	-22.2 ± 3.3	-21.1 ± 3.2	0
		Pelvis	**17.0 ± 6.1**	**19.1 ± 6.6**	17.0 ± 6.2	––
		Trunk	**1.2 ± 2.8**	**3.1 ± 3.2**	1.1 ± 3.1	––

Results for 3R95

Affected-side joint kinetics and GRFs [d]

Opposite Toe Off

ANT compared to BASE:
- extension moment at the knee joint significantly decreased
- significantly increased internal hip extension moment
- fore/aft braking force significantly decreased

POST compared to BASE:
- extension moment at the knee joint significantly increased
- no sig. difference in the hip extension or flexion moment

	BASE	ANT	POST	Sig.
Knee Moment [Nm/kg]	**-0.13±0.08**	**-0.08 ± 0.07**	**-0.30±0.08**	––
Hip Moment [Nm/kg]	**0.26 ± 0.16**	**0.38 ± 0.19**	0.23 ± 0.14	––
Fore/aft GRF [N/kg]	**-0.05±0.04**	**-0.02 ± 0.04**	-0.06 ± 0.04	––
Vertical GRF [N/kg]	0.84 ± 0.08	0.84 ± 0.08	0.87 ± 0.09	0

Knee Break (late-stance initiation of knee flexion)

ANT compared to BASE:
- propulsive force significantly increased

POST compared to BASE:
- propulsive force significantly decreased

	BASE	ANT	POST	Sig.
Knee Moment [Nm/kg]	0.009 ± 0.03	0.008 ± 0.03	-0.004 ± 0.04	0
Hip Moment [Nm/kg]	-0.69 ± 0.43	-0.60 ± 0.36	-0.75 ± 0.49	0
Fore/aft GRF [N/kg]	**-0.0004 ± 0.01**	**0.011 ± 0.01**	**-0.01 ± 0.01**	––
Vertical GRF [N/kg]	0.38 ± 0.21	0.39 ± 0.22	0.35 ± 0.21	0

[a] no difference (0), positive trend (+), negative trend (–), significant (++/––), not applicable (n.a.)
[b] Results shown as Mean ± standard deviation (SD);
self-selected walking speed: 0.8 ± 0.2 m/s
[c] Positive angle indicates the distal end of the thigh is anterior to the proximal end.
[d] Positive values indicate: external knee flexion moment, internal hip extension moment, anterior-directed fore/aft GRF, and a superior-directed vertical GRF.

Author's Conclusion

"In summary, subjects responded to a destabilizing alignment perturbation by increasing their hip extension moment during early stance phase, which confirmed our hypothesis that persons with transfemoral amputation rely on a hip extensor strategy to maintain knee joint stability. However, subjects also decreased the rate at which they loaded their prosthesis, decreased their step length, increased their trunk flexion, and maintained their limb in a more vertical posture at the time of opposite toe off, suggesting that a hip torque strategy alone was perhaps insufficient to counteract the effect of the alignment perturbation. Although we hypothesized that subjects would respond to a stabilizing alignment by increasing their hip flexion moment to initiate knee break during late stance, our results did not support this hypothesis. Instead, knee break was delayed for the posterior alignment condition. From a clinical perspective, these results suggest that a bias toward posterior alignment may have fewer implications for the patient in terms of knee joint control. However, it is possible that an overly stable knee joint may also have negative consequences for swing phase. To our knowledge, this is the first systematic study of prosthetic knee joint alignment in which lower-extremity and trunk kinematics were investigated in conjunction with sagittal-plane hip and knee kinetics to understand the mechanisms of prosthetic knee joint control. Accordingly, we believe the results from this study may provide new insights into the biomechanical mechanisms contributing to the sagittal stability and control of a passive prosthetic knee joint." (Koehler-McNicholas et al., 2016)

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