Assessment of the Effect of Single-joint Type Hybrid Assistive Limb in Knee Rehabilitation after ACL Reconstruction: Correlation with Electromyography Analysis for Co-contraction Index and Muscle Strength

Yuichiro Soma[1,2], Hirotaka Mutsuzaki[3,4], Tomokazu Yoshioka[1,2], Shigeki Kubota[5], Koichi Iwai[5], Yukiyo Shimizu[6], Akihiro Kanamori[1], Masashi Yamazaki[1]

[1]Department of Orthopaedic Surgery, Faculty of Medicine, University of Tsukuba, Japan,
[2]Division of Regenerative Medicine for Musculoskeletal System, Faculty of Medicine, University of Tsukuba, Japan
[3]Center for Medical Sciences, Ibaraki Prefectural University of Health Sciences Hospital, Japan
[4]Department of Orthopaedic Surgery, Ibaraki Prefectural University of Health Sciences Hospital, Japan
[5]Ibaraki Prefectural University of Health Sciences, Japan
[6]Department of Rehabilitation Medicine, Faculty of Medicine, University of Tsukuba, Japan
ysoma@md.tsukuba.ac.jp

Disclosures: None

INTRODUCTION: Decreased muscle strength is a common occurrence after anterior cruciate ligament (ACL) reconstruction, attributed to factors such as muscle mass atrophy and reduced muscle force generation efficiency, including neuromuscular dysfunction and muscle stiffness. Additionally, the ACL contains mechanoreceptors that influence muscle strength, proprioception, and recruitment patterns. The deficiency of the ACL could potentially lead to an array of neuromuscular complications. Hybrid assistive limb (HAL) motion support technologies involve an interactive biofeedback system that establishes a connection between the musculoskeletal system and the motor nerves associated with the brain and spinal cord. Co-contractions (CCI) refer to the simultaneous activation of antagonistic muscle pairs such as knee extensor-flexor muscles. Our hypothesis that HAL training possesses the capacity to optimize muscle activities by coordinating or decreasing higher degrees of muscle CCI. In this study, HAL training was used for participant who had undergone ACL reconstruction. The primary objective was to investigate the correlation between HAL training, electromyography (EMG) examination focusing on CCI index, and muscle strength.

METHODS: The study consisted of 18 participants (ten men, eight women; mean age, 23.4 ± 7.0 years; height, 168.0 ± 8.9 cm; weight, 66.7 ± 13.0 kg) who had undergone arthroscopic ACL reconstruction with soft tissue graft materials (anatomic single-bundle, n = 13; anatomic double-bundle, n = 5). The knee HAL single-joint training commenced 18 weeks after ACL reconstruction and was conducted once a week for a total of three sessions. Each session included five sets of knee HAL single-joint training exercises for knee extension and flexion. Isokinetic muscle strength assessments were performed at postoperative weeks 17 (pre-HAL) and 21 (post-HAL), using an isokinetic dynamometer (Biodex System III) at three distinct velocities: 60°/s, 180°/s, and 300°/s. Within each session, surface EMG (NORAXON) of the quadriceps and hamstring muscles was conducted in 9 of the 18 patients, and the CCI was calculated. The EMG electrodes were placed on the vastus lateralis (VL) and vastus medialis (VM) muscles, in addition to the biceps femoris (BF) and semitendinosus (ST) muscles. Evaluations were conducted both before and after each weekly knee HAL training session. CCI was quantified through the formula: CCI = LEMG/HEMG*(LEMG + HEMG). Medial hamstring and quadriceps muscles (ST–VM) and for lateral hamstring and quadriceps muscles (BF–VL) mean CCIs were derived for each trial. The Limb Symmetry Index (LSI) was calculated to determine the side-to-side difference in muscle strength (injured/non-injured×100%). Disparities between LSI pre-and post-HAL sessions were assessed using either the t-test or Wilcoxon signed-rank test. Additionally, the rate of LSI change was calculated and subsequently subjected to the *t*-test. The relationship between LSI and CCI was analyzed utilizing the Pearson correlation coefficient. Furthermore, the effect of CCI on the recovery of isokinetic muscle strength was evaluated using a generalized linear mixed model (GLMM). IBM SPSS Statistics 24 software (IBM) was used for all statistical analyses, with the significance level set at 5%. Ethical approval for the study was granted by the ethics committees of Tsukuba University Faculty of Medicine (approval number TCRB18-077). Prior to enrollment, all participants provided written informed consent.

RESULTS: The LSI was significantly higher post-HAL peak extension torque at all velocities and peak flexion torque at 60°/s and 300°/s. Additionally, the post-HAL peak extension torque at 300°/s showed a weak correlation with the CCI of the ST–VM during extension in HAL session3 (r=0.389) (Fig 1 A). Notably, the rate of LSI change for peak flexion torque at 300°/s showed a significant strong correlation with the CCI of the ST–VM during flexion in HAL session3 (r=0.725, p=0.027) (Fig 1 B). In both Model 1 and 2, and in the subsequent Model 3, the GLMM investigating the impact of CCI on peak extension torque at 300°/s demonstrated the significance of the CCI of the BF–VL during extension in post-HAL session 3 (Model 1, p=0.015; Model 2, p=0.014; Model 3, p=0.016). Conversely, in model 2, the GLMM showed that for peak flexion torque at 300°/s, the CCI of the ST–VM during flexion in post-HAL session3 was significant. Additionally, across Model 1, Model 2, and Model 3, a significant impact of the CCI of the ST–VM during flexion, transitioning from pre-HAL to post-HAL session3, was observed (Table 1).

Fig 1. Results of correlation between post-HAL peak torque and CCI

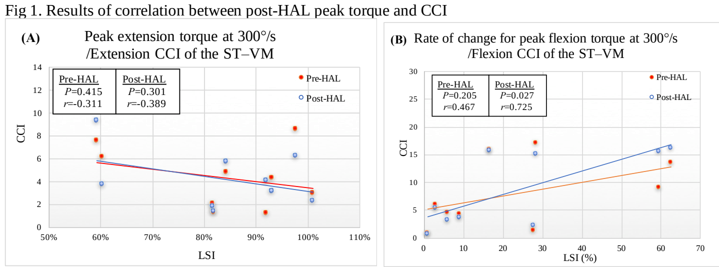

Table 1.
Generalized linear mixed models showing effect of CCI on peak flexion torque at 300°/s

	Model 1		Model 2		Model 3	
	t	P value	t	P value	t	P value
CCI(ST–VM) extension in post-HAL session3	-1.355	0.209	-0.712	0.494	-0.802	0.449
CCI(BF–VL) extension in post-HAL session3	-1.046	0.351	-1.196	0.295	-1.157	0.329
CCI(ST–VM) flexion in post-HAL session3	2.103	0.065	2.370	0.042	2.161	0.064
CCI(BF–VL) flexion in post-HAL session3	-1.288	0.239	-1.521	0.170	-1.276	0.248
age					0.391	0.711
graft materials	-1.857	0.126	-1.992	0.107	-1.838	0.155
weight			-1.116	0.316	-0.916	0.426
CCI(ST–VM) flexion*(Pre-Post HAL session3)	-2.640	0.025	-2.667	0.025	-2.32	0.047
Model goodness of fit						
AICc	18.668		26.858		31.508	
BIC	17.964		25.749		29.902	

AICc: Akaike's Information Criterion Corrected; BIC: Schwarz's Bayesian Information Criterion

DISCUSSION: A previous study found that knee HAL training in a patient who underwent ACL reconstruction improved the LSI of the extension and flexion peak torque. In agreement with the previous study, this study showed an increased LSI in the extension and flexion peak torque. Furthermore, post-HAL peak extension and flexion torque showed a weak to strong correlation with the CCI. To examine the correlation between CCI and LSI, a GLMM encompassing patient-level variables was employed. The outcomes were found to be statistically significant. These notable findings suggest a proclivity for disparities in rapid and forceful movements, which may be influenced by factors beyond equilibrium and proprioception, potentially including graft materials. Despite the commencement of the protocol 18 weeks following ACL reconstruction, it is plausible that knee HAL training contributed to the enhancement of muscle strength by means of CCI amelioration. This is might have been attributable to improvements in neuromuscular coordination, mitigation of muscle stiffness, and the rectification of deficits in spinal reflex pathways.

SIGNIFICANCE/CLINICAL RELEVANCE: Our findings show that knee HAL training may be an effective rehabilitation tool for patients after ACL reconstruction, promoting improved muscle strength and neuromuscular coordination, which could positively impact their recovery and functional outcomes.

ACKNOWLEDGEMENTS: This work was supported by a Grant-in-Aid for Encouragement of Scientists from the Japan Society for the Promotion of Science (grant number 20H01124) and Grants-in-Aid for Scientific Research of the Japan Society for the Promotion of Science (grant number 20K19303).