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ORIGINAL RESEARCH

Comparison of proprioception, strength, and dynamic balance between aquatic and cycling trainings after arthroscopic partial meniscectomy during early rehabilitation in young male athletes

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Abstract

Arthroscopic partial meniscectomy (APM) strives to preserve knee biomechanics and function after the meniscal rupture. However, patients undergoing APM experience long-term impacts like proprioceptive deficit and functional decline. This study aimed to examine and compare the effects of aquatic and leg cycling trainings on young athletes undergone APM. Ninety-seven male athletes with APM were assigned to aquatic training group (ATG, n = 49) and cycling training group (CTG, n = 48). Both intervention trainings were conducted three times a week for 6 weeks after 2 weeks of APM. The rehabilitation training was the same in each session. The International Knee Documentation Committee (IKDC) questionnaire scores, knee joint position sense, Y-balance test, and isokinetic knee strength were measured before and after the interventions. Significant improvements were observed after the trainings regarding measured variables for both ATG and CTG groups. Comparison of the two groups found that ATG group had higher scores in IKDC and Y-balance test, greater muscle power, and lower absolute error in the joint position sense test compared to the CTG group. ATG and CTG are thus considered effective training interventions in early rehabilitation phase following the APM. Moreover, ATG may be more conducive than CTG in improving subjective knee symptoms, proprioception, and muscle power.

Keywords

Arthroscopic partial meniscectomy; Meniscal tear; Aquatic training; Bicycle training; Return to sports; Meniscus; Knee joint

1. Introduction

The meniscus has an important role in knee biomechanics and function. It is a fibrocartilaginous tissue responsible for joint lubrication, shock absorption, load distribution, and stability [1]. Mechanoreceptors including Pacinian corpuscles, Ruffini endings, and Golgi tendon organs are present in the meniscus. Moreover, there are also the anterior and posterior cruciate ligaments. The mechanoreceptors in meniscus transmit proprioceptive information regarding the knee joint's position and movement. This sensory feedback contributes to the subjective knee stability and functional outcomes [2].

The meniscus is therefore essential for the normal biomechanics and knee proprioception. Efforts are made for its preservation to prevent the degenerative arthritis [3]. Preserving the tissue after meniscal injury is important, particularly in young and active athletes [4]. When surgery is inevitable, the orthopedic surgeons prefer meniscal repair rather than meniscectomy and report better results in the long run [5, 6]. However, meniscectomy is performed when repair is not possible because of the size and type of damaged meniscus [7, 8]. Total meniscectomy completely removes meniscus and improves the pain in short term. These alterations in meniscus can disrupt knee's biomechanics with passing times, and cause imbalance in the distribution of internal and external loads on tibiofemoral joint. This imbalance increases the possibility of early onset osteoarthritis [9]. The meniscus preservation through surgical sutures should first be considered to avoid sequelae caused by total meniscectomy. APM is thus recommended as an alternative. Partial meniscus resection maintains biomechanical function as it preserves the soft tissue around the meniscus of knee joint. Arthroscopy-assisted procedures also lower the risk of complications, promote rapid rehabilitation and early functional recovery [6].

Rehabilitation protocols after APM do not actively protect the anatomy during healing process. Without any special considerations, the rehabilitation is based on the tolerance with no limitations or restrictions [6]. However, with APM, wound protection, pain, and swelling control must be considered during the inflammatory phase of healing. Immediate return to sports after the surgery is restricted, and most athletes return to pre-injury sports between 7 and 9 weeks of surgery [10]. Considerable proprioceptive deficits persist after returning to sports despite the conducive clinical results of APM [11]. The proprioception recovery is important for the athletes as it restores sports-related functions and reduces the injury and reinjury risks [12, 13]. Several studies have described the proprioceptive impairment mechanism after the surgery and suggest appropriate interventions for its improvement. However, the most efficient interventions have not yet been clear [2, 14].

Cycling training improves physical and physiological abilities. Moreover, the functional training *via* cycling improves muscle strength and balance during early rehabilitation in athletes undergone APM [15, 16]. After APM, the 12-week stationary ergometer cycling group performed better than the control group regarding pain and function compared to the strength training group [17]. Frizziero *et al*. [15] emphasized to include bicycle ergometer training in the rehabilitation protocol to restore full range of motion and normal muscle strength after APM. However, cycling training has limitations in developing proprioception as it does not adequately reflect the functional movements required in sports, and the rotational axis of movement during pedaling occurs only in single plane [18]. Aquatic training is an effective intervention to compensate these limitations. It minimizes pain and swelling, and improves physiological and physical abilities along with proprioception by stimulating the nerves related to sport-specific movements [19]. Yesil *et al*. [20] found enhancements in pain levels, functional capacity, muscle strength, and life quality of patients undergone APM after engaging in aquatic training for 4 weeks. Hajouj *et al*. [21] reported improved proprioception efficiency after aquatic rehabilitation training in athletes undergone knee surgery.

There are few comparative studies on the two training methods. Further research is necessary to investigate the efficacy of training interventions in improving physiological, physical, and proprioception abilities. This study evaluated the subjective knee scores, knee joint position sense, Y-balance tests (YBT), and isokinetic knee strength for both groups. The results were analyzed and compared.

2. Materials and methods

2.1 Procedures and participants

Participants volunteered after seeing the recruitment announcements on notice boards at the center. The staff explained study purpose, procedures, results analysis, and publication details. Participants signed the written informed consent before enrollment. The staff consulted participants and assessed medical and surgical history, and injury duration. Patients with medical histories of lower extremities were excluded. Ninety-seven athletes aged 18–22 years were grouped into aquatic training group (ATG: 49) and cycling training group (CTG: 48). They participated in interventional training three times a week for six weeks. Participants conducted questionnaires, muscle strength tests, joint position sense (JPS), and YBT before and after the intervention. The examiner provided explanations and demonstrations before each test, and participants practiced to increase familiarity with the test.

The intervention was initiated 2 weeks after the participants underwent surgery. Assignment to ATG and CTG was random. The ATG was reassigned for ethical testing as some individuals had aversion to deep aquatic environment. The participants' sports events were as follows: soccer (n = 43), basketball (n = 22), badminton (n = 10), baseball (n = 6), handball (n = 5), skiing (n = 2), judo (n = 3), and taekwondo (n = 6). The study adhered to the principles outlined in Declaration of Helsinki.

2.2 Subjective knee score

The questionnaire to subjectively evaluate the knee condition was used by the International Knee Documentation Committee (IKDC) [22]. IKDC questionnaire evaluated the knee symptoms or discomfort during the activities of daily living (ADL) or participation in sports. It included knee pain assessment, stiffness, swelling, and locking. The total score could reach maximum of 100 points by summing up the scores of each item, indicating the absence of knee symptoms, functional limitations, and any restrictions in sports or ADL. Conversely, the lower score indicated poorer knee condition.

2.3 Knee joint position sense

Joint position sense (JPS) was measured to assess the knee proprioception using isokinetic dynamometer (Humac Norm, CSMi, Stoughton, MA, USA). JPS referred to the capacity for perceiving joint position with minimal reliance on external cues and without visual information. This could be evaluated by measuring the ability to actively and passively replicate the target joint position [23]. The participants seated comfortably in examination chair for the measurements. The femur, pelvis, and torso were fixed with straps and participants eyes were blindfolded to block the visual input. The knee's range of motion (ROM) was established with the joint positioned at 0° extension and 90° flexion. First, the active JPS (AJPS) was measured to evaluate whether target joint position could be accurately and actively reproduced. For the participant to recognize the target angle before measurement, the examiner moved the knee joint at an angular velocity of ~10°/s from the starting position of 90° flexion and positioned at 45° angle. The examiner initiated the test after participant recognized the target angle three times. Participants were instructed to reproduce the target angle according to examiner's "reposition" signal. Participants reproducing the target angle maintained the joint position for 3 s and returned to starting position at "return" signal. The measurements were made in triplicate, and absolute error was calculated from difference between average of reproduced measurement angles and the set target angle (Fig. 1).

Second, the passive JPS (PJPS) was measured to evaluate whether target joint position could be accurately and passively sensed. In PJPS test, the target joint position was set at 45°, and the starting position at 0° for flexion and 90° for extension. The examiner passively flexed or extended the participants knee joints from starting angle to target angle. The participant recognized target joint position for 10 s, and returned to starting position. The participant pushed stop button when knee joint was slowly flexed or extended at angular velocity of 2°/s by the dynamometer and felt that the target angle had been reached. Both flexion and extension were measured in triplicate, and the absolute error was calculated from the difference between average of detected measured angles and set target angle.

FIGURE 1. Joint position sense test.

2.4 Y-balance test

Dynamic balance related to postural control was evaluated by Y-balance test (YBT) equipment (Y Balance Test™, Functional Movement Systems, Lynchburg, VA, USA). YBT required strength, stability, flexibility, and coordination of lower extremities related to knee proprioception [24]. A demonstration of test posture and movement sequence was given by the examiner. The participants then practiced for six times with each leg in each of the three reaching directions. The participants took single-leg stance on central stance platform for the examination upon completing the practice. They executed series of movements by maintaining balance to push a reach indicator box with the foot of opposite leg, aiming to reach the furthest distance possible in anterior (ANT), posteromedial (PM), and posterolateral (PL) directions. Contact of both feet with floor during the test was regarded as failure. The examination began with the assessment of healthy leg followed by pained side leg. The series of motions in three standardized directions were measured twice for each knee, and higher score was used for the analysis. The absolute reach distance was recorded in cm and normalized to each participant's limb length.

2.5 Isokinetic knee strength

The strength of knee extensor and flexor muscles was assessed *via* HUMAC NORM dynamometer (CSMi, Stoughton, MA, USA) by measuring the isokinetic knee strength. An external force is applied through computer-controlled speed in isokinetic dynamometer wherein the participant demonstrates muscle strength by resisting this force. It quantitatively and numerically evaluates the strength, power, and endurance of specific joints and muscles [25]. Angular velocities of 60° and 180°/s were utilized for the inspection. Participants seated on examination chair, and the dynamometer axis was aligned with the knee anatomical axis, specifically the lateral epicondyle of femur. The thighs, pelvis, and torso were strapped to minimize the compensatory movements. The examiner explained test method and participants practiced with four trial attempts prior to the main measurement.

The motion range of test joint ranged from 0° extension to 90° flexion. Extension was performed with maximal effort followed by flexion with maximal effort in response to the verbal cues from examiner. Four rounds of flexion and extension were performed by the participants at 60°/s and 10 rounds at 180°/s angular velocities. Peak torque in Newton meter (Nm) was evaluated at 60°/s. The average power in Watts was evaluated at 180°/s. Absolute values were normalized by dividing with body weight.

2.6 Training program

Intervention training for ATG and CTG begun 2 weeks after the surgery with 3 sessions per week for 6 weeks. Training intensity was controlled by the Borg's rating of perceived exertion (RPE) 20 scale or 60–75% of maximum heart rate. An electronic heart rate monitoring device (Polar H10, Polar Electro, Bethpage, NY, USA) monitored the participant's heart rate in real time to control the intensity during training.

2.6.1 Aquatic training

The participants in ATG were engaged in aquatic moderate-intensity continuous training program [26]. ATG performed 4 water aerobic exercises (jumping jacks, front kicks, cross-country skiing, stationary running) in 2 repetitions for 4 min. This program was repeated for 8 sets over 32 min. For the comprehensive training, systemic lower extremity movements were conducted concurrently with bilateral arm push-pulls. Standard RPE scale guidelines were developed by the trained staff to verbalize the perceived effort levels for participants. RPE 13 was the recommended level corresponding to "somewhat hard" [27]. Intensity was monitored by the electronic heart rate device with RPE. It was conducted at the water depth of 1.2–1.4 m, *i.e.*, the chest level from waist of the participants.

2.6.2 Cycling training

CTG trained based on the intensity and duration of moderate-intensity continuous cycling training as suggested in previous study [28]. The leg cycle had friction load tension control device (Monark Model 864; Monark Crescent AB, Varberg, Sweden). The cycle ergometer's saddle height was customized for each participant based on the body structure to fit a knee flexion angle of 25° when one leg was fully extended by sitting on saddle [29]. CTG did continuous leg cycling for 32 min. The load was monitored and adjusted in the way that participant's heart rate did not deviate from target range.

2.6.3 Strength program

Strength training was equally performed by the members of ATG and CTG. All participants started active and passive ROM from the first postoperative day for the recovery. Partial or full weight bearing depended on the pain and swelling. The participants did quadricep sets, straight leg raises, and active knee extensions for 2 weeks after the surgery in open kinetic chain to recover the muscle strength. They performed squats, lunges, step-ups, and heel raises with weight bearing in closed kinetic chain. Tandem stance and single-leg balances were performed to improve balance. Strengthening exercises were repeated as three sets of 20, and balance exercises as three sets of 60 s.

The muscle strengthening program included weightlifting where three sets of 12 were repeated with 80% weight of one repetition maximum (1RM) [30]. Weight machines used leg extension, leg press, leg curl, inner thigh, hip abduction, chest press, shoulder press, long pull-down, upper body butterfly, arm curl, and abdominal flexion.

2.7 Data analysis

The data was analysed using IBM SPSS Ver. 25.0 (IBM Corp., Armonk, NY, USA). The data normality was evaluated by the Shapiro-Wilk test. Parametric analysis was made due to the normal distribution of independent variables. For analysing continuous variables, a paired *t*-test was conducted for pre-intervention (1 week) and post-intervention (6 weeks) analyses within groups, and an independent *t*-test was for between-group comparisons. Categorical variables were analyzed by the chi-square test. A repeated two-way analysis of variance (ANOVA) was carried out to verify the interaction between time and group. A $p < 0.05$ was considered statistically significant.

3. Results

3.1 Participants characteristics

Table 1 presents the participants general characteristics. The age, height, weight, body mass index, injured side, and meniscus site showed no statistically significant differences for ATG and CTG groups.

3.2 Subjective knee score

Fig. 2 depicts the change in IKDC score before and after training, and evaluates the subjective knee score. No difference was found between the groups in pre-intervention. Both ATG and CTG showed statistically significant increase in IKDC scores after training, however ATG scores were higher after the training.

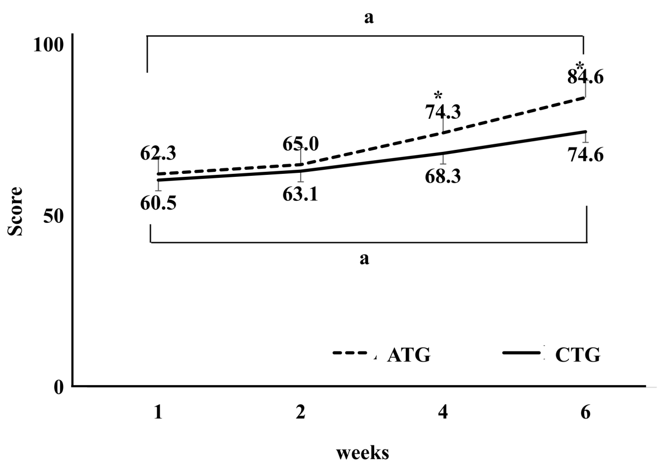

FIGURE 2. Changes in IKDC scores by weeks. $*p < 0.05$; a: 1 week *vs.* 6 weeks; IKDC, International Knee Documentation Committee; ATG, aquatic training group; CTG, bicycling training group.

TABLE 1. Characteristics of study participants based on intervention groups.

Variables	ATG (n = 49)	CTG (n = 48)	t or χ^2	p-value
Age, yr	15.4 ± 1.3	16.3 ± 0.7	−1.670	0.124
Height, cm	173.1 ± 2.9	174.3 ± 3.8	−0.715	0.486
Weight, kg	66.2 ± 2.6	68.4 ± 5.3	−1.059	0.308
BMI, kg/m^2	22.1 ± 0.8	22.5 ± 1.5	−0.702	0.498
Involved side, n (%)				
Left	29 (59.2)	22 (45.8)	1.733	0.225
Right	20 (40.8)	26 (54.2)		
Involved meniscus site, n (%)				
Medial	21 (42.9)	23 (47.9)	0.250	0.384
Lateral	28 (57.1)	25 (52.1)		

$p < 0.05$; ATG, aquatic training group; CTG, bicycling training group; BMI, body mass index.

3.3 Knee joint position sense

Fig. 3 shows changes in joint position sense before and after training, and evaluates the knee proprioception. The difference is not significant between the two groups at pre-intervention. In both ATG and CTG, the absolute error between target angle and measured angle decreased significantly in AJPS and PJPS (extension and flexion) tests after the training. However, ATG exhibited smaller absolute errors than CTG in all joint position sense tests after training.

3.4 YBT

Fig. 4 depicts the changes in YBT before and after training, and evaluates dynamic balance. No statistical difference was observed between the two groups before training. ANT, PM and PL reach distances increased in both ATG and CTG. However, ATG had better PM and PL than CTG after training.

3.5 Isokinetic knee strength

Fig. 5 shows change in isokinetic knee strength before and after training. No significant differences were found between the groups at 1 week. Both ATG and CTG depicted increase in extension and flexion muscle strength at angular velocities of 60°/s and 180°/s after training compared to before training. However, ATG showed more improved muscle power than CTG at angular velocity of 180°/s after training.

4. Discussion

Athletes undergone APM experience deterioration of muscle strength and proprioception. Recovery to pre-injury levels is necessary for the athletes before returning to sports. This study confirmed the impacts of aquatic and cycling trainings on subjective knee score, knee joint position sense, YBT, and isokinetic knee strength in young athletes.

In previous studies, various evaluation tools objectively determined the functional limitations of patients with APM. They facilitated diagnosis, and evaluated the interventional treatments and postoperative outcomes [6, 31]. IKDC was comprised of detailed evaluation items for knee symptoms, function, and participation in sports. IKDC was also employed to evaluate the knee condition during ADLs, such as going up and down stairs, sitting and standing, squatting, and assess the feasibility of returning to sports [6, 32]. In present study, the IKDC scores improved in both ATG and CTG after training. However, the ATG members achieved higher scores than those of CTG after training. Aquatic training minimized the weight load due to water buoyancy and provided strong external resistance because of hydrostatic pressure and water turbulence [33]. Aquatic training decreased swelling, alleviated pain, and enhanced recovery through blood circulation improvement [34]. These water training attributes had role in achieving improvements of IKDC scores.

Three types of mechanoreceptors in peripheral two-thirds of the meniscus are responsible for knee joint proprioception [2]. Joint motion sensations are primarily mediated by fast-adapting mechanoreceptors such as Pacinian corpuscles. Joint position sensations are predominantly mediated by slow-adapting receptors including Ruffini endings and Golgi tendon organs [35]. The knee joint JPS was measured and members of both groups exhibited improvements after training. This could be attributed to the strength and balance training aspects of rehabilitation program conducted identically for both groups, which positively affected the neuromuscular control and proprioception. These results were consistent with those of previous studies [36, 37]. Neuromuscular control training using single-leg balances improved knee JPS in knee surgery patients [36]. A study by Lai *et al.* [37] investigated the effect of muscle strength exercise on proprioception in patients with knee osteoarthritis. It was revealed that eight passive motion senses for knee flexion were improved after weekly squat training.

In this study, the ATG exhibited smaller error compared to CTG following the training period. The aquatic training might provide superior outcomes in detecting joint position proprioception compared to cycling training. The hydrostatic pressure and hydrodynamic properties of water might yield more sensory feedback than land-based training [38]. Cycling training involved repetitions of flexion and extension by pedaling in single plane. This activated the fast-adapting mechanoreceptors responsible for force control. However, it might be less effective than aquatic training regarding activation of slow-adapting mechanoreceptors associated with JPS [39].

In this study, YBT evaluated the efficacy of two training types to improve dynamic balance after APM. The results revealed that balance improved in members of both ATG and CTG after training. These results were consistent with those of study by Chen *et al.* [19] where all YBT results were improved after aquatic training in amateur athletes undergone meniscal allograft transplantation. Alarcón-Gómez *et al.* [40] reported that high-intensity interval training on cycle ergometer improved YBT. The in between-group comparison of this study depicted that ATG members had higher scores in PM and PL. In aquatic environments, water turbulence induce instability which changes the information relayed to somatosensory system [41]. Unlike cycling training, aquatic training may aid balance recovery by inducing consistent aquatic turbulence throughout the session that activates neuromuscular control of knee and ankle joints. Mira *et al.* [42] investigated the exercise impact on dynamic balance performed in aquatic environment using electromyographic and baropodometric methods. They found significant coactivation percentage and plantar pressure reduction in muscles, contributing to postural stabilization. In addition, water is more viscous than air and has unique hydrodynamic properties. It thus improved the dynamic balance related to neuromuscular control and somatosensory input [38].

Weakness of the quadriceps muscle strength after APM affected the postoperative outcomes and returning to sports. The decreased quadricep strength was associated with functional deficits and limitations in ADLs [43, 44]. The findings of isokinetic knee strength tests in this study revealed improvements in both the strength and power of knee extensor and flexor muscles for ATG and CTG following the training. Members of both ATG and CTG performed individualized programs according to their strength levels. Significant impact

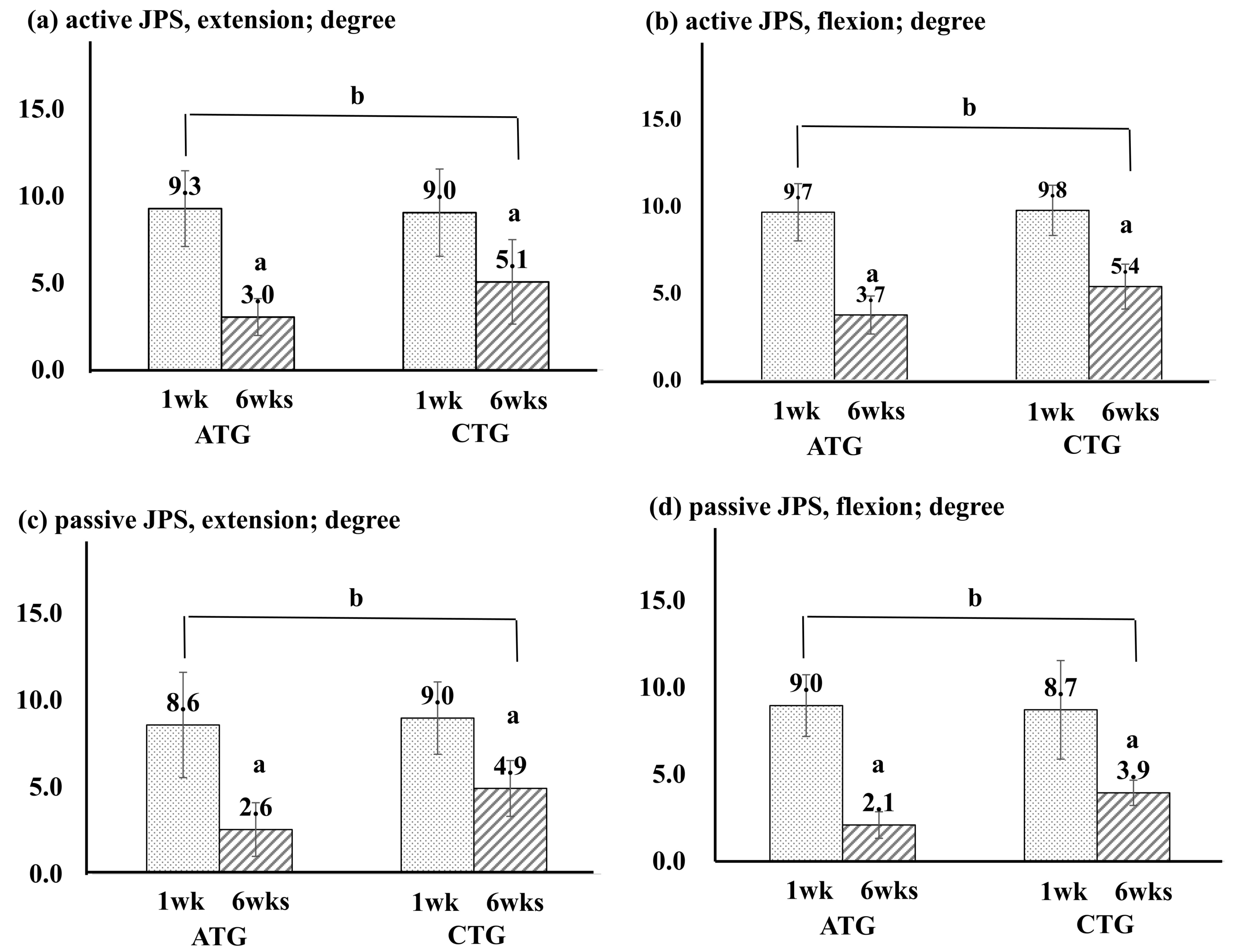

FIGURE 3. Changes in JPS before and after intervention. (a) active JPS during knee extension, (b) active JPS during knee flexion, (c) passive JPS during knee extension, (d) passive JPS during knee flexion. $p < 0.05$; a: 1 week *vs.* 6 weeks; b: Changes over time and groups (time × group); ATG, aquatic training group; CTG, bicycling training group; wk, week.

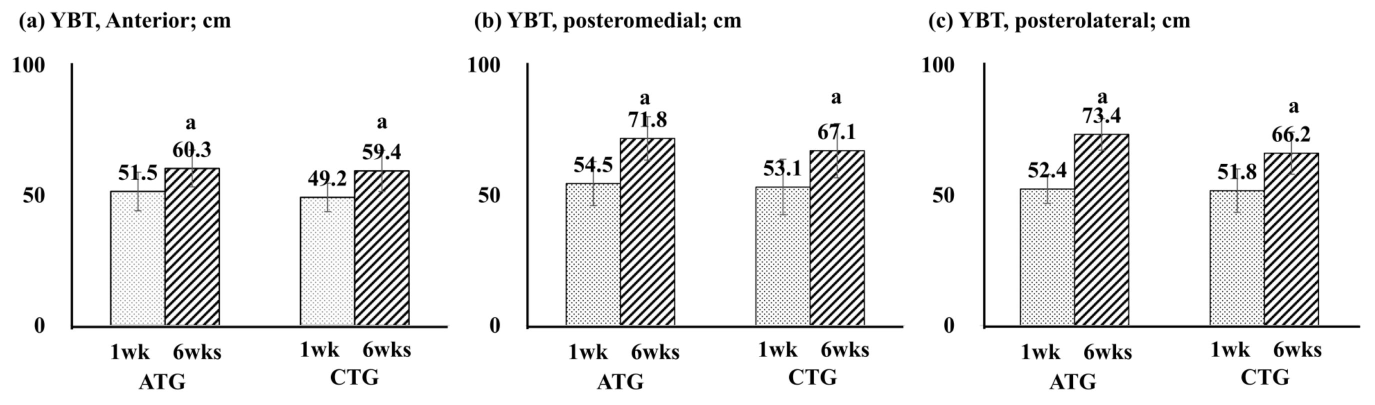

FIGURE 4. Changes in YBT before and after intervention. (a) anterior direction of YBT, (b) posteromedial direction of YBT, (c) posterolateral direction of YBT. $p < 0.05$; a: 1 week *vs.* 6 weeks; b: Changes over time and groups (time × group); ATG, aquatic training group; CTG, bicycling training group; wk, week; YBT, Y-balance tests.

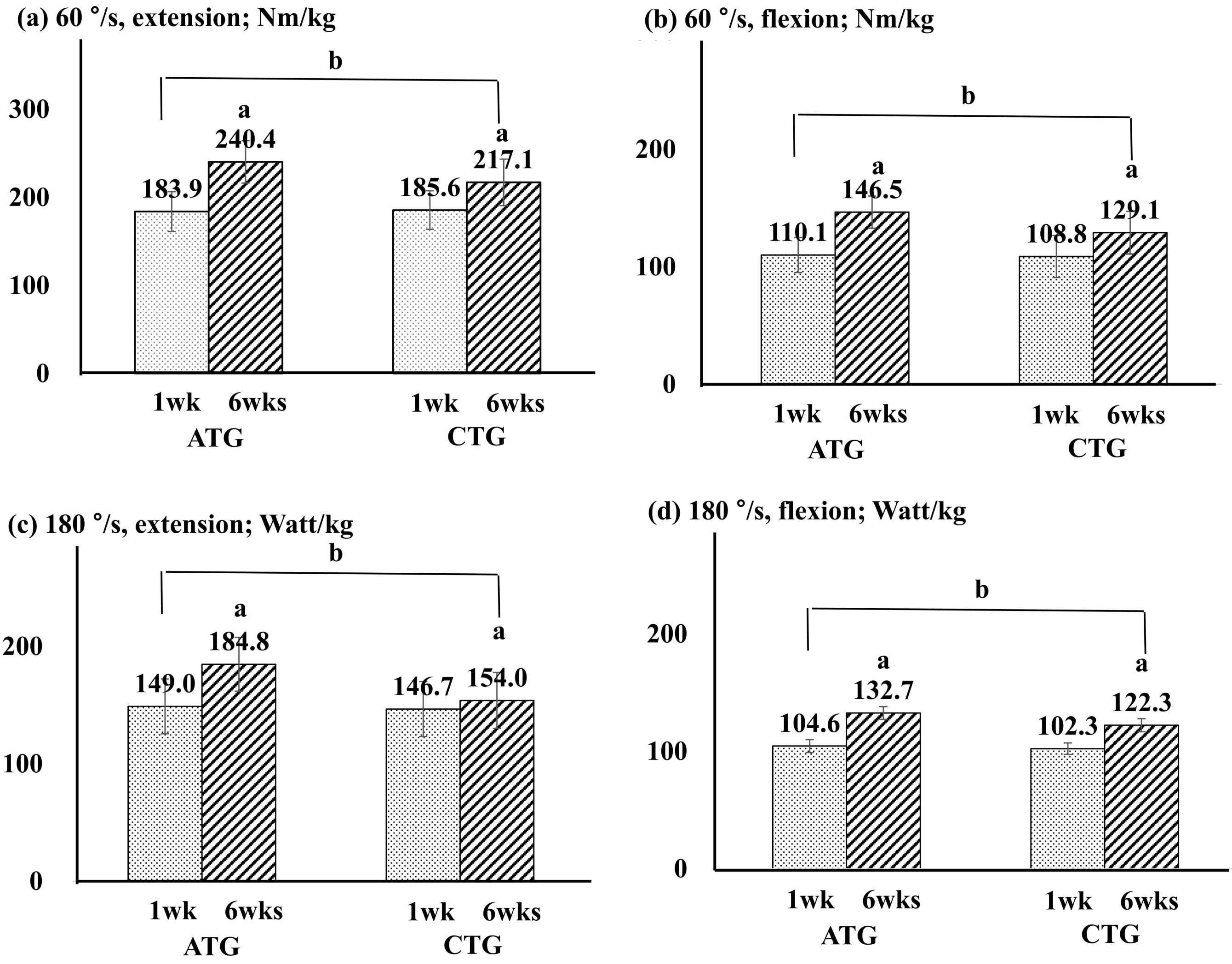

FIGURE 5. Changes in isokinetic strength before and after intervention. (a) knee extension strength, (b) knee flexion strength, (c) knee extension power, (d) knee flexion power. $p < 0.05$; a: 1 week *vs.* 6 weeks; b: Changes over time and groups (time × group); ATG, aquatic training group; CTG, bicycling training group; wk, week.

had been observed in the recovery of knee extensor and flexor strength. However, ATG members showed greater average power than those of CTG based on muscle power after the training. The aquatic training was thus more effective than cycling training for improving muscle power in post-APM patients. In a previous study, Rocha *et al.* [45] induced muscle atrophy with joint fixation in animal experiments and declared aquatic training being effective in stimulating muscle hypertrophy and plasticity of motor endplates. Moreover, it improved the neuromuscular function and motor performance.

Water resistance has greater dynamic viscosity and density than air which causes more fatigue in water than on dry land [34]. Hydrostatic pressure is the pressure developed when a body is immersed in water and is proportional to the immersion depth, density and viscosity of liquid [38]. Greater resistance is applied onto the body with larger surface area hitting the water. In this study, ATG participants immersed bodies in water to the chest depth and maintained a vertical standing posture. Movement in this position increased water flow, wave resistance, friction, and hydrostatic pressure [38]. Holmberg *et al.* [34] demonstrated increased hydrostatic pressure in improving the blood flow to the muscles through venous and lymphatic systems. This is linked to the metabolic waste dissipation and increased oxygen and hormone delivery to fatigued muscles [46]. The aquatic training program in this study involved movements that induced knee joint resistance in various ways. It provided larger and complex stimulation to develop the lower limb muscle nerves.

This study had several limitations. It did not include a control group as the possibility of spontaneous recovery after surgery cannot be ruled out. The participants were recruited using the bulletin board in the center. It was difficult to form a control group as patients visited the center for treatment purpose. In future studies, more diversified recruitment methods would allow comparisons between control and intervention training groups. Furthermore, assignment to the intervention training group was not entirely random as individual preferences were also reflected. More positive impacts can be attained for those who are already familiar with pool environment and bicycle training. The applicability to older men and women of all ages is unknown as the participants were young males. Future studies are thus required to investigate the frequent injuries in more participants and athletes.

5. Conclusions

In this study, the participants of aquatic or cycling training rehabilitation for six weeks after APM showed improved IKDC scores, knee joint position sense, YBT, and isokinetic knee strength. Between-group comparisons revealed that ATG members achieved higher IKDC and YBT scores, and stronger muscle power after training than those of CTG, and depicted fewer errors in the active and passive JPS tests. Based on these findings, the aquatic or cycling training could be effective training interventions in early rehabilitation stages after APM. Aquatic training is more effective than cycling training in improving subjective knee symptoms, proprioception, and muscle power.

AVAILABILITY OF DATA AND MATERIALS

The data presented in this study are available on reasonable request from the authors.

AUTHOR CONTRIBUTIONS

SY and YK—Conceptualization, writing-review and editing; SY—methodology, formal analysis, investigation, writing-original draft preparation, supervision.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

All participants gave their written consent for examination and publication for the purpose of the study. This study was approved by the Research Ethics Committee of the Gangneung-Wonju National University (2021-11).

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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