JOMH
Journal of Men's Health

Original Article
DOI: 10.15586/jomh.v16i1.201

THE EFFECT OF SHORT-TERM OFF-SEASON CROSS-COUNTRY SKI TRAINING ON BODY COMPOSITION, PHYSICAL FITNESS, AND ISOKINETIC MUSCLE FUNCTIONS OF CROSS-COUNTRY SKIERS

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Submitted: 10 October 2019. Accepted: 02 February 2020. Published: 25 March 2020

ABSTRACT

Background and objective
The purpose of this study is to analyze the effects of short-term off-season training (competition) on body composition, physical fitness, and isokinetic muscle functions of XC skiers.

Material and Methods
Seven XC skiers, including two national team members and five reserve national team members, participated in the study. Short-term off-season XC ski training was conducted for over 4 weeks (August–September). The physical composition, basic physical fitness, and isokinetic muscle function tests were conducted at S hospital in Seoul, South Korea before and after off-season ski training. The training program was conducted in New Zealand at S cross-country ski stadium (altitude 1350 m) in afternoons, and the ground training was conducted at Y area (altitude 300 m) in afternoons. The main training directions were polarized training and core stability. Weight training was not available because of local conditions.

Results
The short-term off-season XC ski training showed no differences ($p>0.05$) in body composition, such as weight, muscle mass, and body fat. There were significant differences ($p<0.001$) in the chest size and brachial muscle but no significant differences ($p>0.05$) in the antebrachial, femoral, and crural muscles. Basic physical fitness tests showed no significant differences ($p>0.05$) in strength, flexibility, agility, and balance. However, the power ratio between the right and left grip strength showed significant difference ($p<0.05$).

Peak torque of isokinetic muscle function of knee joints was measured at 60°/s.There were no significant differences ($p>0.05$) in both knee extensions before and after training, but, in contrast, there were significant differences (right knee, $p<0.01$ and left knee, $p<0.05$) in flexions. The ratio of the right knee flexion and extension muscle was significantly different between before and after training measurements ($p<0.05$). The ratio of the left and right knee flexion and extension muscle was signifi-cantly different ($p<0.05$) between before and after training measurements. While comparing the right and left knees, the ratio of the knee extension and flexion was not significantly different ($p>0.05$) between before and after training measurements.

Conclusion
Short-term off-season XC ski training (competition) of 4 weeks increased XC skiers' cross-section area of the chest and brachial muscle. It also improved the isokinetic muscle function of knee joints and the power of lower body.
Our research is expected to provide basic information for XC skiers who plan ski training and competition during summer training period. However, further studies on the differences between roller- skating and ski training conducted during summers are needed.

Key Words: *off-season cross-country ski training; body composition; physical fitness; isokinetic muscle strength; polarized training; core stability training*

INTRODUCTION

Specificities required for cross-country (XC) skiers include high levels of endurance, maximum oxygen uptake (VO_2max), anaerobic capacity, upper body power, tactical flexibility, and high speed techniques.[1–3] XC skiers mostly need skiing, roller skiing, and running to improve their physiological, technical, and tactical skills. Successful elite XC skiers are increasing their ski and roller ski training periods.[2] During the period when it was not possible to train on snow, dry training was conducted focusing on roller ski training.[2,4–6] Roller skiing is closely similar to XC skiing with the muscles, energy systems, race patterns, and equipment used.[7,8] However, roller skis and XC skis differ in course of difficulty, coefficients of friction, and balance requirements. Besides, the utilization rates of the upper and lower bodies differ between these two training methods.[9–11] Therefore, to improve XC skiing performance, it is very important to perform XC ski training rather than roller ski training. There are three main ways to increase ski training during off-season. The first is to perform ski training at high altitudes.[12] The second is tunnel skiing, which could be conducted on artificial snow. The third is to perform ski training in other countries (Australia, New Zealand, Brazil, Chile, and Argentina) in opposite seasons (http://www.fis-ski.com/FISF).[13]

The advantage of high-altitude training is to improve motor performance at sea levels through physiological changes in the blood (erythropoietin, red blood cells, hemoglobin) to adapt to high-altitude low-pressure environments, along with the enhancement of ski skills.[14–18] A number of studies have also reported that inadequate training volume and intensity at high altitudes decrease the immune function and reduce performance when returning to sea-level.[19–21] There is a need to pay more attention to high-altitude training. In addition, participating in a competition is a good way to train tactically. However, tactical training is difficult because the competitions are not held at high altitudes. Tunnel skiing is also not allowed to host competitions because of its low and short slopes. High-altitude ski training and tunnel ski training, especially during the summer period, may be difficult due to weather effects.[22]

Therefore, it is a good idea to participate in skiing and competitions during summers (July–September) in Australia and New Zealand, where the seasons are opposite of those in Northern Europe, Asia, and North America. In 2019, 10 countries participated in the Fédération Internationale de Ski (FIS) competition in New Zealand (Australia, New Zealand, USA, Japan, South Korea, Switzerland, Sweden, China, Thailand, and Taiwan)—five more countries as compared to 2018. Until now, most of the studies on off-season XC ski training have focused on high-altitude training,[2,23–25] and there is not enough research conducted on off-season training in countries with opposite seasons.

Our study aimed to analyze the effects of short-term off-season XC ski training on the basic body composition, strength, and muscle functions of XC skiers.

There are some limitations to our study. Adult athletes who specialize in XC skiing are very few in comparison to other sports such as soccer and baseball. There were about 20 adult XC skiers in South Korea, so it was difficult to set up a control group.

The same training program should be provided before off-season and after off-season ski training to compare the differences between roller ski and ski training.However, the national athletes who participated in the experiment could not continue because they had to participate in national team training after participating in the off-season ski training.

METHODS

Seven male XC skiers aged >20 years (two national team members and five reserve national team members) from South Korea participated in this study. The physical characteristics of the participants are given in Table 1.

Design and Procedures

The short-term off-season XC ski training was conducted for over 4 weeks (August–September). Measurement of body composition, basic physical strength, and equivalent muscle function tests were conducted at S hospital in Seoul before and after XC ski training. The off-season XC ski training program was carried out in the morning (arrival altitude: 1350 m) at the S XC ski stadium in New Zealand, as shown in Table 2. The ground training was conducted in the afternoon in the Y area (arrival altitude: 300 m). The training method was polarized training. Polarized training is a training that combines low intensity (target heart rate: 80% or less) high volume (70~80% of total annual exercise), and high-intensity interval training (HIIT).[6,26,27] Core-stability training was performed with three sets of supine plank, prone plank, side plank, and side plank-leg motions statically, with the spine in neutral position. The rest period was 60 s. In addition, three sets of upper and body roll outs, inclined press-ups, top position, single-leg holds, and quadruped motions were performed using a Swiss ball (55 cm or 65 cm), after which the athletes rested for 60 s.[5,28] There were 11 training sessions per week and the total exercise time was about 1100 min.

Anthropometric Measurements

A bioelectrical impedance analyzer (Inbody 3.0, Seoul, South Korea) was used to measure

TABLE 1 Physical Characteristics of Subjects

Numbers	Age (yr)	Height (cm)	Weight (kg)	Body fat (%)	Muscle mass (kg)
7	19.0±0.81	175.12±9.09	67.41±7.96	15.12±3.28	53.47±7.32

TABLE 2 Training Program

<table>
<tr><th>Day</th><th></th><th colspan="3">AM training</th><th colspan="3">PM training</th></tr>
<tr><td rowspan="3">Mon</td><td>Event</td><td colspan="3">Classic Ski</td><td colspan="3">Running</td></tr>
<tr><td>Time</td><td colspan="3">100 min</td><td colspan="3">90 min</td></tr>
<tr><td>Intensity</td><td colspan="3">Zone 2</td><td colspan="3">Zone 2</td></tr>
<tr><td rowspan="3">Tue</td><td>Event</td><td colspan="3">Skate ski</td><td colspan="3">Core training</td></tr>
<tr><td>Time</td><td colspan="3">50 min-20 min-50 min</td><td colspan="3">100 min</td></tr>
<tr><td>Intensity</td><td colspan="3">Zone 2-3-2</td><td colspan="3">Stability training</td></tr>
<tr><td rowspan="3">Wed</td><td>Event</td><td colspan="3">Classic SkiInterval training</td><td colspan="3">Pole walking</td></tr>
<tr><td>Time</td><td colspan="3">5 min/3 min (rest)×5 set</td><td colspan="3">70 min</td></tr>
<tr><td>Intensity</td><td colspan="3">Zone 3~4</td><td colspan="3">Zone1</td></tr>
<tr><td rowspan="3">Thu</td><td>Event</td><td colspan="3">Skate ski</td><td colspan="3" rowspan="3">Recovery</td></tr>
<tr><td>Time</td><td colspan="3">100 min</td></tr>
<tr><td>Intensity</td><td colspan="3">Zone 2</td></tr>
<tr><td rowspan="3">Fri</td><td>Event</td><td colspan="3">Classic ski</td><td colspan="3">Core training</td></tr>
<tr><td>Time</td><td colspan="3">10 s/120 bpm×12 set</td><td colspan="3">100 min</td></tr>
<tr><td>Intensity</td><td colspan="3">Zone 5</td><td colspan="3">Core training</td></tr>
<tr><td rowspan="3">Sat</td><td>Event</td><td colspan="3">Ski athlon</td><td colspan="3" rowspan="3">Rest</td></tr>
<tr><td>Time</td><td colspan="3">180 min</td></tr>
<tr><td>Intensity</td><td colspan="3">Zone 1</td></tr>
<tr><td rowspan="3">Sun</td><td>Event</td><td colspan="3" rowspan="3">Rest</td><td colspan="3">Jogging</td></tr>
<tr><td>Time</td><td colspan="3">60min</td></tr>
<tr><td>Intensity</td><td colspan="3">Zone 1</td></tr>
<tr><th>Intensity</th><th>Zone 1</th><th>Zone 2</th><th>Zone 3</th><th>Zone 4</th><th>Zone 5</th><th>Core training</th><th>Total</th></tr>
<tr><td>Heart rate (%max)</td><td>60–72</td><td>72–82</td><td>82–88</td><td>88–92</td><td>92–100</td><td></td><td></td></tr>
<tr><td>Time (min)</td><td>450</td><td>370</td><td>30</td><td>40</td><td>22</td><td>200</td><td>1112</td></tr>
<tr><td>Training as a % total volume</td><td>40.5</td><td>33.3</td><td>2.7</td><td>3.7</td><td>1.9</td><td>17.9</td><td>100</td></tr>
<tr><td>Session</td><td>3</td><td>3</td><td>1</td><td>1</td><td>1</td><td>2</td><td>11</td></tr>
</table>

height, weight, muscle mass, and the body fat percentage of participants (in fasting condition for 10 h or more). The human circumference anthropometry was done according to the International Society for the Advancement of Kinanthropometry (ISAK). The circumference of the human body was measured thrice without pressing the subcutaneous fat tissue using nonelastic flexible tape and the average value was used as data.[29] The maximum circumference of the chest was measured around the nipple. The upper arm was measured at the midpoint of the acromion and the lead protrusion with the participant's arm on the side of the body. The forearm was measured at the maximum forearm position with the waist and palm facing forward and the arm downward. The femur muscle was measured at the maximum circumference with participants' legs in an open position. The lower extremity was measured at the maximum circumference between the knee and ankle joints.

Basic Physical Strength Test

Standing vertical jump tests kept both feet flat on the floor, with one hand extended as far as possible and marked on the wall (M1), then jumping as high as possible on the wall (M2). To measure the length between M1 and M2, the jumps were carried out thrice to evaluate quickness using the average value.[30]

The flexibility test was performed by placing the soles of the feet on the "Sit and Reach test box" and extending both arms forward. When measuring, the legs would be straight without bending the knee. Three runs were performed to evaluate maximum length.[31]

Three parallel lines were drawn 120 cm apart on the floor. The participant was instructed to start from the center, and count the number of times the right foot crossed the right line and the left foot crossed the left line. When the foot did not cross the line completely, the number of times was not recognized. This was performed twice for 30 s to evaluate the best result.[32]

Muscle strength was measured thrice using the hand grip strength test (model 5401, Takei Scientific Instruments Co. Ltd., Japan). The average of the two highest values was used to analyze the absolute value. Position and test protocol was followed according to the US National Health and Nutrition Examination Survey (NHANES) and the Muscle Strength Procedures Manual.[33] Muscle strength tests were performed on both left and right sides, and the difference between the left and right muscle strength ratios was also measured.

Isokinetic Strength Test

Isokinetic motor function was measured using the Biodex system 3 (Biodex Medical Systems, Shirley, NY, USA). The peak torque (Nm) was measured using the maximal test of a four-time repetition. Each maximal test was performed at an angular velocity of 60°/s. Measured values were evaluated by dividing the values by the left and right muscle power. Measurements were performed according to the Biodex System 3 Operation Manual (Biodex Medical System).

Statistical Analyses

We used the SPSS (v.25.0 IBM SPSS, New York, USA) program to calculate the mean value (M) and standard deviation (SD) for all data. We used a paired t-test to analyze the significance of off-season XC ski training on body composition, physical fitness, and the isokinetic muscle strength of XC skiers. The statistical significance level was set at $p<0.05$.

RESULTS

As shown in Table 3, percentage values of body weight, body muscle mass, and body fat were not significantly different ($p>0.05$) between before and after training measurements.

In addition, the chest and brachial muscle size was significantly different ($p<0.01$) between before and after training measurements. However, size of the antebrachial muscle, femoral muscle,and crural muscle was not significantly different ($p>0.05$) between before and after training measurements.

As shown in Table 4, left and right grip strengths were not significantly different ($p>0.05$) between before and after training measurements. However, the ratio between right and left grip strengths was significantly different ($p>0.05$) between before and after training measurements. Power was significantly different ($p<0.05$) between before and after training measurements. Flexibility, agility,and balance were not significantly different ($p>0.05$) between before and after training measurements.

As shown in Table 5, the right and left knee extension was not significantly different ($p>0.05$) between before and after training measurements.

However, the right and left knee flexion was significantly different ($p<0.01$) between before and after training measurements.

The ratio of the right knee flexion and extension muscles was significantly different ($p<0.05$)

TABLE 3 Change of Physical Characteristics (Mean Values ± SD)

Variable	Pre-test	Post-test	p
Weight (kg)	67.41±7.96	67.52±7.92	0.356
Body muscle mass (kg)	53.47±7.32	53.54±7.23	0.798
Body fat (%)	15.12±3.28	15.48±3.25	0.563
Chest size (cm)	90.81±6.46	93.94±7.21	0.000**
Brachial muscle(cm)	29.13±1.97	29.95±2.35	0.022*
Antebrachial muscle (cm)	25.64±1.48	25.78±1.22	0.339
Femoral muscle (cm)	49.77±2.12	50.15±2.66	0.292
Crural muscle (cm)	36.32±1.69	36.44±1.72	0.469

SD = standard deviation.
**p<0.05 pre test vs post test, **p<0.001 pre test vs post test.*

TABLE 4 Change of Basic Physical Test (Mean Values ± SD)

Variable		Pre-test	Post-test	p
Strengthen (kg)	G-S left	40.42±4.15	43.72±45.42	0.267
	G-S right	45.44±3.44	43.68±2.61	0.085
	B-S ratio (%)	11.21±7.63	−0.65±13.62	0.025*
Power (cm)	Standing high jump	45.42±4.15	47.85±4.45	0.043*
Flexibility (cm)	Anterior oysters	11.21±5.88	13.52±5.94	0.294
Agility (rd)	Side step	32.42±2.93	32.57±2.82	0.925
Balance (sec)	Unicycle closed eyes	39.71±23.67	38.96±28.02	0.929

G-S = grip strengthen, B-S = both sides; SD = standard deviation.
**p<0.05 pre test vs post test.*

TABLE 5 Change of Knee Joint Isokinetic Muscle Function (Mean Values ± SD)

Variable	Pre-test	Post-test	p
Right knee extension (Nm)	184.58±52.09	182.18±44.74	0.737
Left knee extension (Nm)	179.40±72.93	186.24±53.74	0.800
Right knee flexion (Nm)	111.15±34.91	155.22±34.35	0.004**
Left knee flexion (Nm)	100.42±39.44	139.70±36.97	0.033*
Right knee Flexion/extension (%)	60.21	85.20	0.016*
Left knee Flexion/extension (%)	55.97	75.01	0.012*
Extension Left knee/right knee (%)	−2.80	2.22	0.394
Flexion Left knee/right knee (%)	−9.73	−9.99	0.778

SD = standard deviation.
**p<0.05 pre test vs post test, **p<0.01 pre test vs post test.*

between before and after training measurements. The ratio of the left knee flexion and extension muscles was significantly different ($p<0.05$) between before and after training measurements.

The ratio of the right and left knee extension was not significantly different ($p>0.05$) between before and after training measurements. The ratio of the right and left knee flexion was not significantly different ($p>0.05$) between before and after training measurements.

DISCUSSION

This study aimed to provide data for XC skiers' annual program planning by identifying the effects of off-season XC ski training on body composition, physical fitness, and isokinetic muscle functions.

For elite XC skiers, high intensity and large volume of training can cause training maladjustments such as weight and muscle mass loss, while low intensity and low amount of training can reduce performance by increasing body weight and body fat proportion.[34–36] Therefore, it is very important to set an appropriate level of exercise intensity and training volume. In the present study, the absence of changes in body composition suggested that exercise intensity and training volume in the short-term off-season XC ski training were at an appropriate level.

Upper body power is highly correlated with athletic performance in XC skiing. Among the XC skiing sub-technique, upper body power is the driving force behind the double pole technique (classic style) and the V2 (skate-style) technique.[37]

In order to win a competition, it is important to increase the use of double pole and V2 techniques based on high upper body power. As the use of double poles and V2 increases, the physiological benefits of low maximum oxygen intake, low heart rate, and low lactate accumulation are obtained.[4,7,38–41] Sprint skiers from Sweden, Austria and Norway were measured for the number of repetitions, power and 1 RM (repetitions maximum) of bench presses and bench pools. As a result, the athletes with superior upper body power have higher performance and technical skills (double polling, diagonal stride, and V2).[42]

An increase in muscle strength could be attributed to an increase in muscle mass, muscle hypertrophy, and activation of the nervous system.[43,44] In addition, it is important for elite endurance athletes to increase muscle cross-section area (CSA) without increasing their weight.[45] In this study, increase in the size of the chest and brachial without weight gain could be inferred from improvement in the upper body strength. XC skiers perform a variety of strength exercises, including weight training, double pole training with roller skis, and pull-up exercises to increase upper body strength.[37,46,47] In this study, increase in chest and brachial size without general strength training, such as roller-ski double pole training, weight training, and pull-ups, could be interpreted as a positive effect of short-term off-season XC ski training on upper body strength.

The effect of short-term off-season XC ski training showed little improvement on the strength, flexibility, agility, and balance of XC skiers. However, the result of the reduced width of the two-sided grip strength used for measurements of muscle strength could be resulting from equal use of both hands and feet in the XC skiing sub-technique. These findings are in line with a study that showed that 3 weeks of high-altitude ski training reduced the gap between the left and right femoral maximal muscle ratios in college skiers.[5]

The importance of lower body movement and power in XC skiing is related to the complexity of the sport and the speed improvement through the timing of the upper and lower body. Thus, it is recommended that speed training be performed during off-season, with a focus on large amounts of endurance movements.[2,38] In this study, improvement in the standing jump measurements could be inferred from the relationship between XC skiing training and speed, and it may be a good practice to conduct jump training by using plyometrics to increase the XC skiers' speed.

Cross-country skiing is divided into two main events: classical and V2 techniques. Depending on the slope, speed, and condition of the snow, various sub-technique are used.[48–50] The sub-technique of all XC skiing requires lower body balancing and strength. Especially, double-pole technique, which is the main technique for XC skiing, is an upper body-centered technique. However, to improve double-polling performance, emphasis must be made on the ability to move strongly and quickly on the bending and stretching motion of the lower body knee joints.[42,51–53]

In this study, there was a trend toward the increased femoral and crural muscle size, although not statistically significant. In addition, flexion isokinetic ability of knee joints was improved. Thus, it could be interpreted that short-term off-season XC ski training contributes in improving the muscular functions of knee joints, including the quadriceps muscles and hamstring muscles.

The results show that the maximum power of the knee isokinetic muscle function has a low correlation to the performance of elite XC skiers.[42,54] High-altitude skiing training also has been shown to reduce muscle strength in isokinetic muscle function of knee joints.[33] The reason why this study shows a contrast with the previous study is due to various parameters such as age, physique and different fitness levels of subjects, timings of measurements, training methods, and training volume.

All sports events require specificities of physiology, technique, and tactics, and it is important to identify the specificities required for each sport to win competition and conduct appropriate training.[1,55] Most XC skiers perform off-season training comprising roller skiing, Nordic walking, strength training, cycling, and running. This is (roller skiing, Nordic walking, strength training, cycling, and running) because the equipment, muscle and energy systems, and the techniques used are very similar to the XC skiing specificities.[2,4–6] However, these exercises cannot reflect all physiological, technical, and tactical specificities of XC skiing. Therefore, successful skiers around the world are conducting high-altitude skiing and tunnel skiing training to increase their XC skiing training during off-seasons.[12,22] This study found that short off-season ski training in countries with opposite seasons had a positive effect on body composition, basic fitness, and isokinetic muscle function of XC skiers. Therefore, short-term off-season ski training in countries with opposite seasons could be helpful for XC skiing specificity training along with high-altitude and tunnel skiing training.

CONCLUSION

Short-term off-season XC ski training (competition) of 4 weeks increased XC skiers' chest and brachial muscle CSA. In addition, four weeks of XC skiing training reduced the difference between left and right hand grip strength and improved standing high jumps. The peak torque of isokinetic muscle functions of knee joints increased significantly in flexion rather than extension.

FUTURE PERSPECTIVES

The most important element in XC skiing is to train and compete on snow. However, an increasing number of competitions are canceled due to the influence of warm winter weather. In addition, ski training conducted at high-altitudes during summer and autumn seasons is also difficult due to the factors of weather. XC skiers are to find different areas to increase their training time. Ski training in Australia, New Zealand, Argentina, Brazil, and Chile are good alternatives to the seasonally opposite North America, Asia, and Northern Europe. In addition, quite a number of studies on off-season XC ski training are also needed for seasonally opposite countries. In conclusion, the results of this study are valuable and provide pertinent information for XC skiers who want to conduct ski training during the summer season.

CONFLICT OF INTERESTS

The authors declare that there are no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

FUNDING

There was no support or funding from any individual or organization to conduct this study.

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