Short-term effect of cryotherapy on knee joint proprioception and quadriceps isometric strength in healthy young females
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Abstract
Cryotherapy is one of the essential modalities in physical therapy being used since the time of the ancient Greeks. The objective of this study was to investigate the short-term effect of cryotherapy on knee proprioception and isometric strength of quadriceps muscle.

Participants and methods
A total of 54 normal healthy female participants participated in this study, with an age between 19 and 28 years. They were divided into two equal groups, control and study, consisting of 27 participants in each group. The active knee joint position sense and isometric strength of quadriceps were tested by Biodex Multi-joint System 4 Pro Isokinetic Dynamometer. These measurements were taken before and after 20 min of resting period for the control group, whereas cryotherapy was applied for the study group instead of resting.

Results
After 20 min of cryotherapy application, the study group showed significant reduction in the proprioceptive error of the knee joint ($P \leq 0.05$) and no significant difference in isometric strength of quadriceps ($P = 0.686$). For the control group, there were no significant differences for both proprioceptive accuracy of the knee joint ($P = 0.469$) and isometric strength of quadriceps ($P = 0.121$). In addition, there were no significant differences between the two groups for both proprioceptive accuracy of the knee joint and isometric strength of quadriceps ($P > 0.05$).

Conclusion
The findings of the study show that cryotherapy does not impair the proprioceptive accuracy of the knee joint or isometric strength of quadriceps muscle, so cryotherapy can be used safely during physical activities and training programs.

Keywords: cryotherapy, healthy females, isokinetic dynamometry, isometric strength of quadriceps, knee proprioception

Introduction
Accurate proprioceptive information and adequate muscular strength are required for preventing knee injuries during dynamic tasks [1]. The proprioception, which includes joint position sense (JPS) and joint movement sense, contributes to the stability of the knee joint by regulating the action of the muscles around knee joint. Therefore, there are different parts of proprioception that could be evaluated by passive or active tests in either weight-bearing or non-weight-bearing positions [2]. Proprioception has an essential role in controlling muscles and coordinating body segments to perform physical skills correctly and safely [3].

Proprioception is the accumulative neural input from mechanoreceptors to the central nervous system. The mechanoreceptors are present in the ligaments, muscles, tendons, joint capsules, and skin to detect different mechanical stimuli. So, the function of these mechanoreceptors is important for functional and sport activities [3]. Proprioceptive acuity is the ability to discriminate limb movements through detecting joint motion, position, and force [4]. JPS is the ability of the participant to accurately replicate and reproduce a predetermined joint angle [5]. The strength of knee muscles, flexibility, and knee position sense are important in the field of sport medicine not only in injured knees but also in healthy knees, as there is an increase in sports participation [6].
Changes in body temperature alter muscle function, so maximum power, speed, endurance, and contraction time are affected by heating and cooling [7]. The isometric contraction (static strength and endurance) plays an important role in all aspects of controlling body during functional activities. It has been proven that muscular endurance plays a major role than muscle strength in preventing injury during daily living tasks and maintaining sufficient postural stability [8].

Cryotherapy is the cold application using ice packs or similar modality to the skin above the muscles to reduce muscle temperature temporarily, resulting in vasoconstriction and inhibition of pain sensation [9]. Reducing skin or muscles temperature is varied depending on the type of cooling modality and method of measurement [10].

Different protocols of cryotherapy, such as water immersion, ice application, and different cooling pads, are used by athletic individuals in spite of lacking of scientific evidence about the possible hazards that may occur in patients or athletes. Many clinicians apply cryotherapy for treating acute injury of the soft tissue and to relieve delayed-onset muscle soreness symptoms; however, they are unaware of the possible adverse effects of cryotherapy itself and unknown possible influence on proprioception, as there is limited evidence to support its effectiveness [3].

Till now there is an argument about the short-term effects of cryotherapy on knee proprioception and isometric strength of quadriceps, as there is limited and conflicting evidence regarding the influence of cryotherapy on JPS, with only few studies being conducted concerning this issue and providing inconsistent results [11]. Nowadays, it is recognized that the knee proprioceptive function is important for joint stability and sports performance. The neuro-physiological and biomechanical changes following cryotherapy application could be critical for athletes. Cryotherapy may lead to inadequate position sense feedback if it is applied before exercise and may change the knee joint biomechanical properties, resulting in increase in the risk of knee injury; therefore, it is important for researchers to provide data on JPS and muscular performance of healthy knees following cryotherapy application to clarify the safety and effectiveness of using this therapy before starting sports activities [6].

Costello and Donnelly [3] in their study, which was a systematic review about the cryotherapy effect on JPS from 1973 to 2009, concluded that there was an inadequate and uncertain evidence about the effect of cryotherapy on JPS, and they could not discourage or support its use before sports activity; moreover, they recommended that until further evidence is provided, care should be taken by clinicians and athletic trainers when returning participants to physical activities after application of cryotherapy. Female athletes demonstrate less absolute strength than their male counterparts [1]; however, there is an increase in female participation in athletic activities nowadays more than before.

The rationale of conducting this study lies on the potential harmful effects of cold on the proprioceptive function, which together with the reduced muscular performance and functional activity could impair motor control, so the risk of injury could increase when the participant start physical training directly after cryotherapy [12]. The outcome of the present study could highlight the short-term effect of cryotherapy on knee proprioception and isometric strength of quadriceps in healthy young female individuals, which will encourage or discourage its use before physical activities or dynamic tasks. We hypothesized that the cryotherapy application decreases knee proprioception accuracy and the quadriceps isometric peak torque (PT).

Participants and methods
This study was conducted at the outpatient clinic of the Faculty of Applied Medical Sciences, King Abdulaziz University in Jeddah, Kingdom of Saudi Arabia. A total of 54 normal healthy female participants were recruited from undergraduate and postgraduate female students of King Abdulaziz University. Inclusion criteria were as follows: age from 19 to 28 years old, BMI from 18.5 to 24.9 kg/m², and having a normal knee function. Participants were excluded according to the following criteria: history of recent or past trauma or surgery to the knee joint, pain or deformity of the knee, contraindications to cryotherapy (such as allergy to cold, sensitivity to local hot and cold, and Reynaud’s disease), previous injuries of lower back in addition to athletic and diabetic patients. Ethical approval was obtained from the local ethics and research committee, and all participants signed a written informed consent before participation.

Design of the study
The current study was a single-blinded randomized controlled trial that was approved by the local ethics and research committee of the faculty of applied medical sciences, King Abdulaziz University. A total of 54 normal female individuals were included in this study. The estimated sample size was calculated using a general
power analysis program (GPower 3.0.10, developed
Franz Faul; University of Kiel, Kiel, Germany),
assuming $\alpha$ error of 0.05 at 80% power and based on
an effect size of 0.55. The estimated sample size was 54
participants. Participants were assigned randomly into
two groups, group A (control) and group B (study), with
27 participants in each group. Randomization was
performed by online GraphPad program (GraphPad
Software, San Diego, California, USA) after assigning
a specific number for every participant. For group A, the
active accuracy of the knee proprioception and isometric
strength of quadriceps were tested before and after 20 min
of resting period. For group B, a cold pack was applied for
20 min over the thigh of the dominant leg. The
participants were asked about the leg they preferred to
use to kick a ball to determine the dominant leg [13]. The
active accuracy of the knee proprioception and isometric
strength of quadriceps were tested before and after
application of cryotherapy.

Instrumentation
Biodex Multi-joint System 4 Pro Isokinetic Dynamometer
(Biodex Medical Inc. Shirley, New York, USA) (Fig. 1) was used to measure knee proprioception accuracy
and isometric strength of quadriceps.

Procedure
Proprioception accuracy, as represented by repositioning
accuracy, was assessed for the dominant knee by the
Biodex Multi-joint System 4 Pro Isokinetic Dynamometer (Biodex Medical Inc.) through active
angle reproduction test by testing the individual’s
ability to actively replicate an angle where the joint
was positioned previously in an open chain position
[13]. The same device was used to measure the
isometric strength of the quadriceps through the
isometric test by testing the individual’s ability to
produce force or torque with a voluntary isometric
contraction at $65^\circ$ in a non-weight-bearing position
[14].

Knee proprioception
At the beginning, each participant assumed sitting
position on the Biodex system backrest chair with
aligning the knee of the dominant leg with the
dynamometer axis in $90^\circ$ flexion (starting position),
and straps were used to stabilize the trunk, pelvis, and dominant lower limb at the thigh. The participants were blindfolded to prevent visual input. The tibial pad was attached and secured at 3 cm directly above the lateral malleolus. The test selected was active angle reproduction of the knee in extension direction with a speed of 60°/s with three repetitions of the test. At first, 45° was set as the anatomical reference angle, and then the participant leg was moved to the starting position [15].

As a teaching process, the participant actively moved her tested limb to 45° (target angle) [16], and this position was maintained for 10 s so that the participant could remember that position, and after that, the leg was moved to the starting position [15]. Then the participant was requested to actively move her leg to the target angle. When she felt that the target angle was reached, she could use the hold/release button to stop the apparatus. Three trials were done, and the mean angular difference of these trials, which represents the difference between the position of the target angle and the position of the participant perceived end range (absolute error), was documented in degrees as the repositioning accuracy deficit and was used in the statistical analysis [13].

Quadriceps isometric strength
The isokinetic device calibration was done in accordance with the specifications of the manufacturer. Muscle strength was obtained as the PT, which represents the highest single torque output achieved by a muscle action through a range of motion. The participant was seated as for the proprioception test, the quadriceps isometric strength was tested for the dominant leg at 65° knee flexion [17]. The tested limb was moved to target angle (65°) passively by the device. Then, the participant was asked to push her leg forward maximally against the tibial pad as much as she can without holding breath for 5 s followed by 10 s for relaxation between contractions, and this protocol was done for three repetitions. The participants were encouraged to perform up to their maximum effort and received visual feedback through a monitor. The highest PT was measured in Newtons-per-meter (N/m) [17].

Cryotherapy application
After measurement of knee proprioception accuracy and quadriceps isometric strength, the participant was asked to assume half-lying position and instructed to relax to reduce muscle activity [18]. Then a cold pack of 37×14.5 cm in size and approximately at a temperature of 4°C [18] was wrapped in a wet towel and applied over the thigh of the dominant leg for 20 min [19], and the room temperature was maintained at the same level for all participants. After cryotherapy application, the participant was asked to rapidly return to the chair of the Biodex system to be tested again for proprioception accuracy and quadriceps isometric strength.

Statistical analysis
Data were statistically analyzed by using statistical package for the social sciences computer program (version 20; SPSS Inc., Chicago, Illinois, USA). Descriptive statistics including mean and SD were performed. Paired t-test was used to compare between the mean values of the variables within groups whereas the unpaired t-test was used to compare the mean values of the variables between the two groups. The level of statistical significance was set as P value less than or equal to 0.05.

Results
This study was conducted to detect the short-term effect of cryotherapy on knee proprioception and isometric strength of quadriceps muscle for healthy young females. Data were collected from the two groups and then analyzed. Descriptive and analytic statistics were used.

General characteristics of the participants
A total of 54 normal healthy females were included in the current study, and they were assigned into two groups: group A and group B, with 27 participants in each group.

Group A
A total of 27 participants comprised this group. Their ages ranged from 19–28 years, with a mean age of 21.6±2.16 years. Their mean weight was 52.6±5.36 kg, and their mean height was 155.8±4.97 cm, as shown in Table 1.

Group B
In total, 27 participants comprised this group also. Their ages ranged from 19–28 years, with a mean age of 21.7±1.84 years. Their mean weight was 54.5±4.72 kg, and their mean height was 156.9±5.07 cm, as shown in Table 1. Unpaired test between the two groups showed no significant differences for age (P=0.84), weight (P=0.183), and height (P=0.44), as shown in Table 1.

Differences in proprioception error within and between the groups
The results of the paired t-test revealed that there was no significant difference in the proprioception accuracy in the group A before and after 20-min resting period,
where the $t$ value was 0.735 and $P$ value was 0.469, as shown in Table 2. The results of the paired $t$-test showed that there was a significant difference in the proprioception accuracy in the group B before and after cryotherapy application, where the $t$ value was 2.394 and $P$ value was 0.024, as shown in Table 2. The results of the unpaired $t$-test between the two groups revealed that there was no significant difference in the proprioception accuracy before cryotherapy, where the $t$ value was 0.494 and $P$ value was 0.964, and also after cryotherapy, where the $t$ value was 0.802 and $P$ value was 0.426, as shown in Table 2.

### Differences in quadriceps isometric peak torque within and between the groups

The results of the paired $t$-test showed that there was no significant difference in isometric PT of quadriceps muscle in the group A before and after 20-min resting period, as the $t$ value was 1.604 and $P$ value was 0.121, as shown in Table 3. The results of the paired $t$-test showed that there was no significant difference in quadriceps PT in the group B before and after cryotherapy application, where the $t$ value was 0.409 and $P$ value was 0.686, as shown in Table 3. The results of the unpaired $t$-test between the two groups revealed that there was no significant difference in quadriceps PT before cryotherapy, where the $t$ value was 1.697 and $P$ value was 0.096, and also after cryotherapy, where the $t$ value was 1.237 and $P$ value was 0.222, as shown in Table 3.

### Discussion

The current study was an attempt to study the short-term effect of cryotherapy on knee proprioception and quadriceps isometric strength in healthy young females. The active angle reproduction of knee extension, as a measure of the knee proprioception, and isometric PT of quadriceps were tested before and after 20 min of rest period for group A, whereas cryotherapy application was designed for group B instead of resting period. In this study, proprioception accuracy was measured by active joint reposition test, as it is more functional than passive testing [20]. Active reproduction tests have been used frequently and are accepted tests for proprioception [21].

The results of the control group revealed that there were no significant differences in the proprioception accuracy and isometric strength of quadriceps muscle ($P>0.05$). Regarding the study group, the results showed that there was a significant difference in the proprioception accuracy, as the proprioception error was decreased ($P<0.05$), and there was no significant difference in quadriceps strength ($P>0.05$). There were no significant differences in proprioception error and quadriceps isometric strength between both the groups before ($P>0.05$) and also after ($P>0.05$) the application of their respective treatments.

Regarding the cooling effect on the proprioception accuracy among the study group, it proves that

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**Table 1 Physical characteristics of the participants in each group**

<table>
<thead>
<tr>
<th></th>
<th>Study group (A) (mean±SD)</th>
<th>Control group (B) (mean±SD)</th>
<th>t</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>21.6±2.16</td>
<td>21.7±1.84</td>
<td>0.203</td>
<td>0.84</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>52.6±5.36</td>
<td>54.5±4.72</td>
<td>1.348</td>
<td>0.183</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>155.8±4.97</td>
<td>156.9±5.07</td>
<td>0.777</td>
<td>0.44</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>21.98±2.79</td>
<td>21.96±1.66</td>
<td>0.025</td>
<td>0.98</td>
</tr>
</tbody>
</table>

**Table 2 Comparison between control group (before and after rest) and study group (before and after cryotherapy) regarding mean values of active knee angle reproduction error**

<table>
<thead>
<tr>
<th>Proprioception error (deg.)</th>
<th>Within group (mean±SD)</th>
<th>Between groups</th>
<th>t</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Group A</td>
<td>Group B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before</td>
<td>4.28±1.81</td>
<td>4.3±1.83</td>
<td>0.494</td>
<td>0.964</td>
</tr>
<tr>
<td>After</td>
<td>3.84±1.92</td>
<td>3.43±1.84</td>
<td>0.802</td>
<td>0.426</td>
</tr>
<tr>
<td>t</td>
<td>0.735</td>
<td>2.394</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>0.469</td>
<td>0.024*</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*P≤0.05, significant.

**Table 3 Comparison between control group (before and after rest) and study group (before and after cryotherapy) groups regarding mean values of quadriceps isometric peak torque**

<table>
<thead>
<tr>
<th>Quadriceps isometric peak torque (N/m)</th>
<th>Within group (mean±SD)</th>
<th>Between groups</th>
<th>t</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Group A</td>
<td>Group B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before</td>
<td>87.98±21.31</td>
<td>98.57±24.38</td>
<td>1.697</td>
<td>0.096</td>
</tr>
<tr>
<td>After</td>
<td>92.42±18.48</td>
<td>99.77±24.67</td>
<td>1.237</td>
<td>0.222</td>
</tr>
<tr>
<td>t</td>
<td>1.604</td>
<td>0.409</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>0.121</td>
<td>0.688</td>
<td></td>
<td></td>
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</tbody>
</table>
cooling does not impair the proprioceptive function, as there was a significant reduction in the proprioceptive error. The reason for this could be owing to cryotherapy affects mainly the small myelinated nerve fibers [22] whereas the nerve fibers of proprioception (Ia and II) are large myelinated that have fast conduction, so it may be less and later affected by cooling [23], and JPS is mostly communicated by muscle spindles as confirmed by Proske [24].

Costello et al. [25] reported that the cooling degree experienced in their cooling protocol did not affect the knee JPS in healthy subjects. Another suggested explanation for such result is that the active reproduction test used in our study to measure JPS of the knee through the leg movement involves the hamstring group muscles which were not exposed to cryotherapy. Moreover, the cryotherapy application was not applied directly over the knee joint so the receptors located in the soft tissues around the knee joint (e.g. Ruffini endings, Pacinian corpuscles and free nerve endings) were not greatly affected and the inputs from these joint receptors may compensate for the reduction in muscle and skin afferents which were reduced during cooling as reported by LaRiviere and Osternig [26].

The results were consistent with the findings of Khanmohammadi et al. [27] who suggested that a 15-min water immersion (at 6°C) is not harmful to JPS at the ankle joint. Moreover, the findings of the current study were in agreement with Costello and Donnelly [28], who found no evidence of impaired knee JPS in healthy individuals following a 30-min water immersion in the form of cold (14°C) or tepid water (28°C). Moreover, the results were supported by the study of Ozmun et al. [29] who studied the effect of 20-min cooling on knee proprioception, and the results showed nondamaging effect on the proprioception. Furthermore, the results were consistent with the study of LaRiviere and Osternig [26].

In contrast, some studies have suggested that cryotherapy has a deleterious effect on proprioceptive accuracy. Trambadia and Trambadia [30] reported impairment in the proprioceptive accuracy of the knee joint after 15 min application of cryotherapy, and they found a significant increase in the proprioceptive error owing to the decreased nerve conduction velocity resulting from cooling. Alexander et al. [31] investigated the effects of a 20-min crushed ice application on knee JPS during a small knee bend and reported a significant reduction in JPS. In addition, Oliveira et al. [18] found a significant decrease of proprioceptive accuracy after 20 min of cryotherapy application over the anterior aspect of the thigh and over the knee joint.

Surenkok et al. [32] showed that JPS deficits occurred in healthy basketball players following cryotherapy application. These conflicting results could be explained as, cooling in the current study was superficially applied on the thigh and not directly over the knee, which mainly affects the superficial mechanoreceptors with less effect on the deepest one and may compensate this effect [33]. Another explanation is the difference in cooling protocols and characteristics of participants participated in these studies. Various methods of cooling can produce different joint cooling degrees, so the cooling methods (ice application, ice-water immersion, or a cooling pad) are critical in controlling the effect on JPS [4].

Regarding the control group, there was a reduction in the proprioceptive error, but it was statistically not significant and that could be owing to the learning effects. Another finding of the current study was that there were no significant differences of the isometric strength of quadriceps muscle among both groups, and this may be owing to the size of quadriceps, as it does not cool easily. This result was supported by the work done by Rubley et al. [34] that measured the changes in submaximal isometric force production variability following 15-min ice bath immersion and reported that there was no influence in isometric force variability.

There are conflicting findings regarding the effect of cooling on isometric strength. Coppin et al. [35] investigated the effects on handgrip strength after arm immersion in 10°C water bath for 30 min, and they found a significant reduction of handgrip strength. Moreover, McGown [36] concluded that isometric contraction decreases after cryotherapy application. However, Moghadam and Dehghane [37] suggested that cold pack over the arm can significantly increase isometric muscle force. Sany and Bello [38] reported that cryotherapy application increases isometric muscle strength. This discrepancy in results may be because of the difference in cryotherapy procedures such as the time of cooling and methods of application, and also these results propose the presence of a discrepancy in the cooling degree of the joint and muscle that occurs with different techniques.

The results also revealed that there were no significant differences between both the groups after the application of respective procedures for proprioception accuracy. This could be explained as the control group showed a reduction in the mean values of the reposition error, but it
was statistically nonsignificant, which may be because of the learning effect during testing, so the difference in the mean values of reposition accuracy between both the groups after cryotherapy was small.

There are, however, some limitations of our study. Temperature changes in skin and subcutaneous tissues before and after cryotherapy application were not measured. We assumed that tissue temperature was altered directly below the surface of the cold bag; however, this was not confirmed. Moreover, only one velocity (60°/s) was used during the JPS test. In the future, it would be worthwhile to conduct the JPS test using different velocities after cryotherapy, thus replicating conditions as similar as possible to natural movement involved in different training activities. Only a single sample of healthy young participants was investigated, so the results are relevant for this study group. Finally, this study involved healthy young participants; therefore, the future extension of such investigations should include more diverse groups of professional athletes and clinical patients and evaluation of more than one aspect of knee proprioception, which seem to be more relevant to clinical practice.

Conclusion
The study results show that cooling for 20 min does not impair proprioceptive accuracy and isometric muscle strength in healthy young females, so cryotherapy can be used safely during physical activities and training programs. However, it is recommended to conduct more studies to show the effects of cryotherapy on other joints and to use other techniques of cryotherapy application and other methods for measuring the proprioception accuracy.

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Conflicts of interest
There are no conflicts of interest.

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