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ORIGINAL RESEARCH

THE EFFECT OF KNEE JOINT COOLING ON ISOKINETIC TORQUE PRODUCTION OF THE KNEE EXTENSORS: CONSIDERATIONS FOR APPLICATION

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ABSTRACT

Background: Cryotherapy is commonly used in sport for the management of injury or during recovery, however the effects on concentric isokinetic strength appear unclear when considering the effect of joint cooling distal to the anterior thigh.

Purpose: The purpose of this study was to investigate the effect of cooling of the knee joint on quadriceps concentric isokinetic torque production. The results will inform the use of cryotherapy in practice.

Study Design: Observational cohort, Repeated Measures

Methods: Fourteen healthy male participants volunteered to take part in the study, all of whom regularly played competitive sports (mean age 20.24 ± 1.51years; body mass 80.34 ± 11.34Kg and height 179.45 ± 6.59cm). 800 g of crushed ice was applied over the anterior knee joint for 20 minutes. Concentric quadriceps strength was measured using an isokinetic dynamometer (IKD) by measuring concentric peak (PkT) and average torque (AvT) outputs at pre-, immediately post and 20 minutes post cooling intervention. Additionally, skin surface temperature (T_{sk}), was measured using a hand-held thermometer at the patella at the same time intervals. Measurement was taken at the mid-point of each participant's patella, which was ascertained by measuring between the base and apex.

Results: Significant main effects reported for PkT, for time post-ice application ($p = 0.02$, $\eta^2 = 0.161$). Post-hoc analysis revealed pre-ice application PkT to be significantly higher ($p \leq 0.003$) than all other timepoints. Quadratic regression analysis revealed a strong correlation between reductions in quadriceps torque production and time post application ($r = 0.82$). The quadratic pattern of recovery displays a minima of 17.28-minutes and maxima of 34.56-minutes post ice application. AvT post-ice application demonstrated significant main effects for time post-ice application ($p = 0.03$, $\eta^2 = 0.152$). Post-hoc analysis revealed pre-ice application AvT to be significantly higher ($p \leq 0.005$) than at all other timepoints. Quadratic regression analysis revealed a strong correlation between reductions in quadriceps torque production and time post application ($r = 0.80$). The quadratic pattern of recovery displays a minima of 18.38-minutes and maxima of 36.76-minutes post ice application. T_{sk} reduced significantly, immediately post intervention ($p \leq 0.05$) without returning to baseline measures at 20-minutes post ($p \leq 0.05$).

Conclusions: Isokinetic peak torque values of the quadriceps diminish after cryotherapy application to the knee joint and are not fully recovered at 20 minutes post application on the knee. These findings could have potential implications for participation in activity immediately following ice application.

Level of Evidence: 2b

Keywords: Cryotherapy, Isokinetic Dynamometry, Knee, Quadriceps

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The authors declare no conflict of interest within or related to the present work.

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INTRODUCTION

Cryotherapy, commonly utilized within sporting populations post injury, initiates multiple physiological changes, including reductions in edema, nerve conduction velocity (NCV), and tissue metabolism,[1,2] while concurrently inducing an analgesic effect. With regard to muscle strength, changes in cold-induced NCV presents no consensus in current literature3 indicating a detriment to muscle performance through reductions in receptor firing rate and muscle spindle activity. Authors suggest that variance in myotatic stretch reflex and ion (Na^+, K^+, Ca^+) diffusion at the motor end plate causes the known reduction in enzymatic activity at lower temperatures,[4,5] with previous research suggesting that cooling impairs Ca^+ release therefore ensuing adenosine triphosphate decline altering cross bridge function. Current literature[6,7] provides evidence of increased muscle stiffness post cooling, suggesting inability to monitor stretch limit within the muscle, potentially increasing the risk of tissue injury. The emerging evidence also suggests that joint cooling also affects joint position sense (JPS).[8,9] Altered mechanoreceptor feedback caused by reductions in proprioceptive control[9] following cooling at the knee, could make a heightened risk of injury to the anterior cruciate ligament (ACL) and medial complex. The effect of cooling on muscle strength around the knee may also have implications deleterious to athletes returning to functional activities immediately following cryotherapy. Although reported widely on in current literature, there are variations across studies and conflicting magnitudes of change in muscle strength following local applications of cold.[7,12,13,24,32] This thought to be due to differences in research design, with some studies failing to analyze muscle strength in conjunction with tissue temperature.[27] Study outcomes are consequently difficult to compare.

Decreases in recorded T_{sk} following local cooling correlates to reductions in muscle function.[5] Deterioration in both extension torque and power by around 5% for every 1°C decrease in intramuscular temperature has been previously reported.[10] Colder intramuscular temperatures (~30°C) reported in research were associated with lower concentric isokinetic torque production, at varying speeds from fast to slow.[11] However, Thornley et al., describe moderate or contradictory changes such as, reporting increases in isometric quadriceps strength after 30-minutes of thigh cooling.[12] Recent suggestions imply that an increase in muscle stiffness occurs post cryotherapy application, lowering the available sustained stretch in muscle tissue therefore increasing potential injury risk.[7] Variability in duration of application of cryotherapy modalities noted in published literature recently considers realistic applications (10 minutes) of local cooling in sport, compared to traditional clinical protocols of 20-minute durations.[5] Cryotherapy modality type, duration, and method of application also vary throughout the available studies, including cold-water immersion and crushed ice via local applications, reflecting further difficulty in comparison ability and outcome implications within literature.

Isokinetic Dynamometry (IKD) commonly used in research[17] to evaluate torque production as a measurement of muscle strength, due to its high test-retest reliability.[18] Suggestions for the use of isokinetic dynamometry include measurements of both peak torque (PkT) and average peak torque (AvT) in order to describe muscle function and has been utilized to assess reductions in strength post fatigue protocols.[19] Quadriceps strength or a potential strength deficit is important to consider during the evaluation of knee joint function,[20] as this can have implications on knee function, including stability during performance.[21] When considering muscle strength deficits post cooling[11] (indicative of potential changes in quadriceps strength), awareness must be paid to of possible effects on neuromuscular parameters, which may be related to knee injury risk. Impact on joint control and stabilization may be a result of decreased capability of muscle tension regulation16 impairing knee extensor control of the quadriceps through reduced sensitivity of receptors following cooling. When considering knee injuries in sport, decreases in quadriceps function may present reductions in the ability to prevent abnormal or excessive movement when performing functional movement patterns.[22] Decreases in quadriceps function and control during performance, alongside other neuromuscular considerations, are highly relevant during acceleration and deceleration, and may increase the risk of non-contact musculoskeletal injuries.[22]

Skin surface temperature (T_{sk}) and intramuscular temperature (T_{im}) post cooling presents a highly significant quadratic association.[14] Although fluctuations in the rate of temperature change between various applications of modalities have been reported, research presents consensus on the relationship between superficial and deeper intramuscular cooling.[2] A change in temperature during post-cooling phases occurs as heat from deeper tissue structures transfers to superficial tissues.[14,15] Since muscle continues to cool following removal of cold, while skin re-warms,[14] the delayed effects this may induce in respect to muscle strength and joint control should be considered. Data appears contradictory when considering the effect of cooling distal to the anterior thigh on strength of the quadriceps.[16,23,24] The purpose of the present study was to investigate the effect of cooling of the knee joint on quadriceps concentric isokinetic torque production. The results will inform the use of cryotherapy in practice.

METHODS

Participants

A priori power calculation was conducted to determine a sample size of fourteen healthy male participants (statistical power > 0.8; $p < 0.05$). Subjects participating in the study regularly took part in competitive sports (age 20.24 ± 1.51 years; body mass 80.34 ± 11.34Kg and height 179.45 ± 6.59cm). All participants provided written consent to take part in the study. The study was conducted according to the Declaration of Helsinki[25] and approved by University of Central Lancashire Ethics Committee. To increase sample homogeneity all-male participants were used due to gender differences found in response to local cooling.[26] Exclusion criteria contained; any contraindications to cryotherapy[27] previous knee joint surgery, lower limb injury in the prior six months, and/or referred pain either to or from the knee.

Intervention Protocol

Testing took place in a movement analysis laboratory. Kinematic data (PkT and AvT) was collected pre- and post- intervention using a Cybex IKD (Cybex, division of Lumex Inc., Ronkonkoma, NY, USA) chosen due to its high reliability (0.9 – 0.98).[18,19.21] Superficial skin temperature was measured using a hand-held digital thermometer (Fora, Gallen, Switzerland, IR19). The digital thermometer meets the required standard in ASTM E1965-98 and EC directive 93/42/EEC. Prior to testing participants acclimatized to a steady thermal state for 15 minutes prior to intervention. Following the acclimatization phase, three measures of T_{sk} were recorded at the center of participants' patella for average baseline data.

Concentric isokinetic torque measurements of the quadriceps were performed. Subjects performed three repetitions of knee extension to at $60^{o} \cdot s^{-1}$ on the dominant leg, passively moving into flexion at $10^{o} \cdot s^{-1}$ between repetitions. The participant's dominant leg was determined by which leg they would normally kick a ball with.[30] The researcher recorded participants' position settings, and the same settings were utilized during each measurement (pre, immediately post-, and 20-minutes post- crushed ice intervention). During isokinetic testing, participants sat in the IKD with straps applied across the chest, pelvis and mid-thigh to minimize extraneous body movements during testing. The rotational axis of the dynamometer aligned with the lateral femoral epicondyle and the tibial strap placed distally at three-quarters of the length of the tibia. Participants were instructed to position their arms across the chest to isolate the quadriceps during torque production.[28] Participants completed each repetition throughout every set to their maximum and were encouraged to do so throughout with verbal and visual feedback.[29] A total of three maximal repetitions were completed at $60^{o} \cdot s^{-1}$ and an average of two consistent repetitions were taken for PkT_{conc} and AvT_{conc} measures. Researchers observed each repetition completed on the IKD ensuring that smooth and consistent effort was exerted, throughout the subject's performance.

Following the collection of baseline data, the researcher applied 800g of crushed ice contained in a clear plastic bag held in place by cling film wrap, following previous protocols[31] over the anterior aspect of the knee, on the dominant leg, for a period of 20 minutes.[5] Post the 20-minute cryotherapy application, the ice was removed from the limb and concentric torque data was collected. This was then repeated at 20-minutes post removal of the ice after the subject had been exposed to a period of rewarming.

Statistical Analysis

A one-way repeated measures ANOVA was used to investigate a within factors main effect for time. The assumptions associated with the statistical model were assessed to ensure model adequacy. To assess residual normality for each dependant variable, q-q plots were generated using stacked standardized residuals. Scatterplots of the stacked unstandardized and standardized residuals were also utilized to assess the error of variance associated with the residuals. Mauchly's test of sphericity was also completed for all dependent variables, with a Greenhouse Geisser correction applied if the test was significant. Where significant main effects were observed, post hoc pairwise comparisons with a Bonferonni correction factor were applied. Measures of significance were supplemented with partial eta squared (η^2) values calculated to estimate effect sizes for each dependant variable, and provide a measure of meaningfulness. As recommended by Cohen (1988), partial eta squared was classified as small (0.01–0.059), moderate (0.06-0.137), and large ($>$0.138).

The temporal pattern of changes in each isokinetic variable over the time collection period was examined using regression analyses. Quadratic polynomial models were applied, with the optimum fit determined by the strength of the correlation coefficient (r). Where a quadratic regression analysis represented the best fit, the regression equation was differentiated with respect to time to elicit the time (torque values post-exercise) at which the data reached maxima (or minima). All statistical analysis was completed using PASW Statistics Editor 22.0 for windows (SPSS Inc, Chicago, USA). Statistical significance was set at $p \leq 0.05$, and all data are presented as mean $\pm$ standard deviation.

RESULTS

Peak Torque

Figure 1 displays the effects of a 20 minute ice application on PkT immediately post ice application and 20 minutes post ice application. There was a significant main effect for time post ice application (p = 0.02, η^2 = 0.161).

Post hoc testing revealed that pre ice application PkT was significantly higher ($p \leq 0.003$) than at all other time points. The quadratic regression revealed a strong correlation (r = 0.82), displaying a minima of 17.28 minutes and maxima of 34.56 minutes post ice application.

Average Peak Torque

The acute influence of ice application and the subsequent recovery of AvT post ice application are

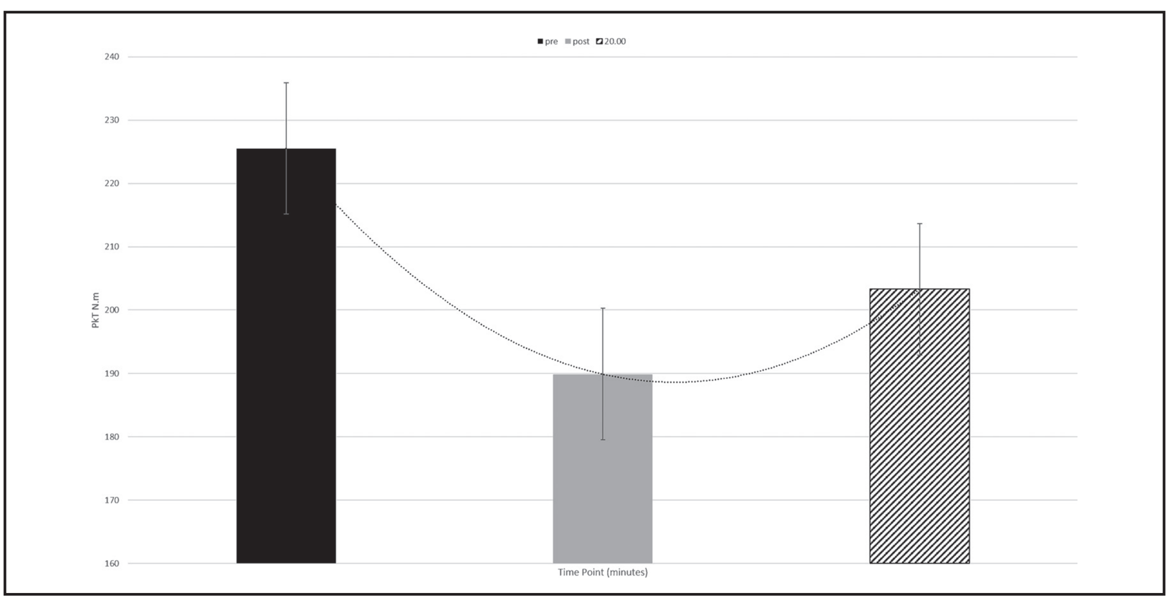

Figure 1. *Mean PkT_{concQ} (Peak Torque Concentric Quadriceps) Values for Pre, Post and 20 Minutes Post Crushed Ice Application for Isokinetic Speed of $60^{o/s-1}$.*

displayed in Figure 2. There was a significant main effect for time post ice application ($p = 0.03$, $\eta^2 = 0.152$).

Post hoc testing revealed that pre ice application PkT was significantly higher ($p \leq 0.005$) than at all other time points. The quadratic regression revealed a strong correlation ($r = 0.80$), displaying a minima of 18.38 minutes and maxima of 36.76 minutes post ice application.

Skin Surface Temperature

T_{sk} (measured at the center or the patella) demonstrated significant reductions post cryotherapy intervention ($p \leq 0.05$). Average T_{sk} immediately post cryotherapy application was 13.9 ± 1.9°C, representing a skin surface temperature response to within therapeutic range, resulting in a percentage change reduction in T_{sk} of 51%. At 20-minutes post removal of the intervention average T_{sk} was reported to be 24.0 ± 2.9°C, supporting the known re-warming curve for T_{sk} but not yet having returned to baseline measures (Figure 3). T_{sk} displayed a 16% reduction at 20-minutes post removal when compared to baseline.

DISCUSSION

Cryotherapy applications are common in sport for the management of injury, however the effects on strength of the thigh when cold is applied to the knee and surrounding soft tissue continues to lack consensus. Musculature at the knee provides feedback for joint stability, with reductions in quadriceps strength known to increase the risk of non-contact injury around the knee.[22] The purpose of the current study was to investigate the effect of cryotherapy on the torque production ability of the quadriceps immediately and 20-minutes post cryotherapy application at the knee. Significant reductions in strength were reported in PkT and AvT when compared to baseline to both immediately post and 20-minutes post. Large effect sizes ($\eta^2 = 0.161$ and $\eta^2 = 0.152$) were reported for both PkT and AvT, indicating that cryotherapy application had a large immediate effect on strength following removal of the ice and up to 20 minutes post application. Quadratic regression analysis indicated that isokinetic strength measures reached a minima at 18.38 minutes post ice application and returned at a predicted 36.76 minutes post icing. These findings support the findings of previous research describing reductions in muscle strength following cryotherapeutic applications[5,7] but differ in the conclusion that even when the quadriceps are not directly cooled, and cooling occurred distal to the muscle belly at the knee joint, reductions in quadriceps strength still occurs. These findings suggest a need for awareness of the effects on surrounding soft tissue structures that may be affected post cooling of

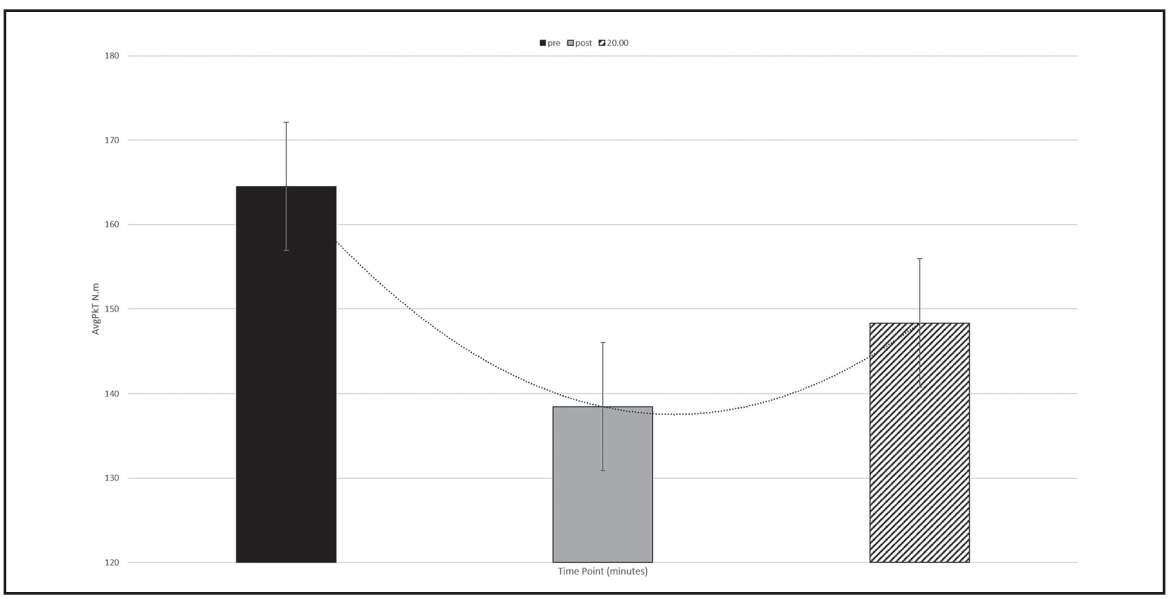

Figure 2. *Mean AvT_{concQ} (Average Torque Concentric Quadriceps) Values for Pre, Post and 20 Minutes Post Crushed Ice Application for Isokinetic Speed of $60^{o/s-1}$.*

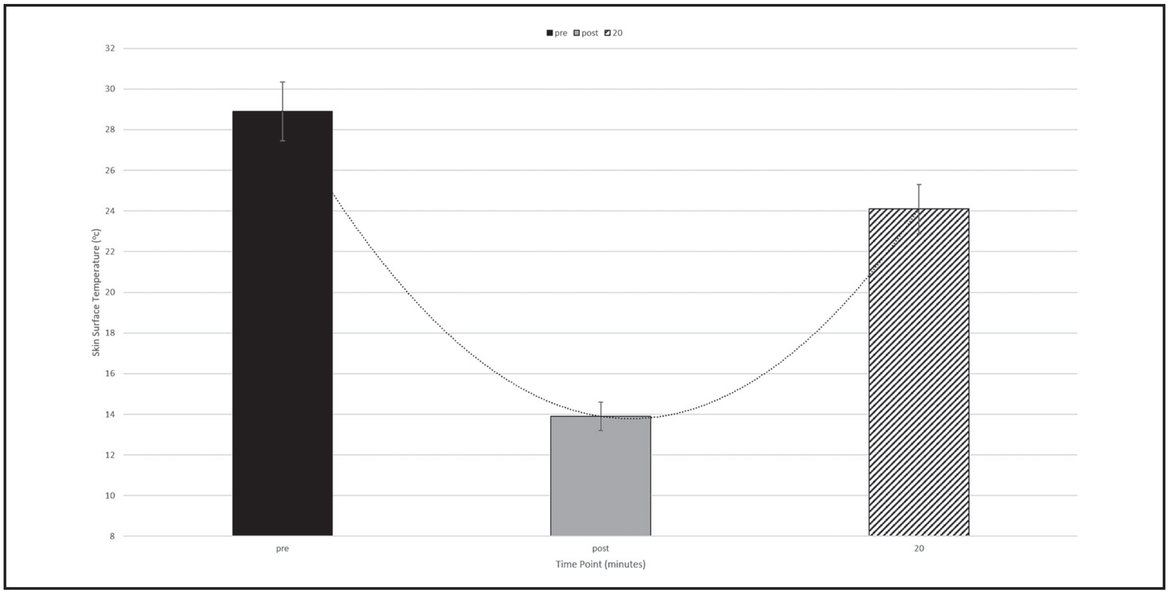

Figure 3. *Mean Skin Surface Temperature (T_{sk}) for baseline, Immediately Post and 20 Minutes Post Crushed Ice Cryotherapy Intervention.*

Table 1. *Average + SD data for all measures of PkT, AvT and T_{sk}.*

	Time Point		
Measure	Pre	Post	20 Minutes Post
T_{sk} (°C)	28.9±2.5	13.9±1.9	24.0±2.9
PkT	225.51±30.99	189.90±36.20	203.29±38.30
AvT	164.51±26.73	138.45±25.33	148.36±26.54

the knee joint, as an important consideration regarding performance of functional tasks.

The implications of reduced muscle strength of the quadriceps may include increased risk of non-contact injury at the knee complex.[22] Strength reductions in the current study were still evident at 20-minutes post removal of the intervention displaying a 16% reduction in PkT and AvT respectively. Although perhaps a poor comparison due to a difference in location of cryotherapy application and protocol, these findings contrast with an earlier study that observed no delayed reductions in isokinetic concentric strength at 20-minutes post ice application.[32] The amount of ice and location of application differs between studies, with 5lb directly over the quadriceps[33] compared to 800g in the current study. Both studies tested concentric isokinetic strength at $60^{o} \cdot s^{-1}$. It may be postulated that cooling at the knee joint disrupted feedback mechanisms affecting strength capability more than cooling directly over the muscle belly alone. This is only an assumption in consideration of previous research as the current study only had a single placement of cooling. Current literature highlights increases in muscle stiffness post ice application attributing the increases in stiffness to alterations to the mechanical properties of the tissue and desensitization of the mechanoreceptors in the tissue. This may lead to reduced PkT due to alterations in the ability to sense tissue stretch to the point of sustainability prior to consequent injury, postulating a guarding mechanism resulting in reduced strength output on concentric quad activation.

T_{sk} met therapeutic range, therefore thought to induce an analgesic effect and did not return to baseline measures at 20-minutes post. A quadratic relationship exists between T_{sk} and T_{im} suggesting as T_{sk} re-warms, T_{im} continues to cool.[14] This may be the reason as to why PkT and AvT values did not return to baseline concentric strength at 20-minutes post removal of the intervention. It would however have been useful to measure T_{sk} over the quadriceps as well as over the patella in order to investigate potential distribution of cooling dispersed away from the site of application. Although the cryotherapy modality was placed over the anterior aspect of the knee, it is suggested that involvement of the quadriceps tendon insertion as a feedback mechanism for knee stability may be affected by cold application, although not quantified in the current study. Accurate indication of the required force the muscle needs to exert to stabilize the knee may not have occurred resulting in a decrease in PkT and AvT output compared to baseline following cooling. In consideration of the decreases in NCV[1] following cryotherapy, it is thought that the combination of physiological change occurring within soft tissue muscle structures and desensitization of superficial mechanoreceptors disrupting neuromuscular response may be also responsible for the reported reduction in muscle strength occurring at the quadriceps. Although contradictory to these considerations, a review on the effects of joint cryotherapy on muscle function reports increases in muscle activation (Electromyography) and strength (isokinetic), but decreases in reflexive reactions in patients with joint effusion.[33] In consideration of the contribution to the role reflexive behaviour on motoneuron recruitment and force production this may provide implications following joint cooling on proximal muscle concentric strength, as noted in the current study.

Specific mechanisms through which cryotherapy altered quadriceps strength in this study may include the additional involvement of deeper joint structures. It is suggested that structures within the joint continued to remain cool after removal of the crushed ice intervention, although this outcome was not measured in the current study. Desensitization of deep joint mechanoreceptors may have affected neuromuscular response; supporting earlier literature proposing a change in proprioceptive feedback following cooling occurs.[34] This however may not be isolated to the effects on JPS but also could affect the muscular strength of associated musculature proximal or distal to the cooling site.

LIMITATIONS

The current results cannot be generalized to other peripheral joints and muscles, weight-bearing joints in the lower limb, or females. Other limitations include variations in cryotherapy durations and modalities applied in the current study that may not be comparable to other cryotherapeutic modalities used in sport. Eccentric muscle strength was not considered in the current study however should be examined in future protocols.

Future studies should investigate combined dynamic stability following similar protocols and involve myoelectrical activity and JPS assessment to support the proposed physiological mechanisms in the current study. It would be useful to observe a longer period of delayed response to determine a suggested timescale for when muscle strength actually returns post removal of the intervention. This may help establish boundaries regarding safe return to functional activity following cooling exposures of the lower limb, and consideration by sports medicine practitioners regarding the possible strength changes following cryotherapy.

CONCLUSIONS

A 20-minute cryotherapy application at the knee induces immediate and longer-term reductions in concentric quadriceps strength. Concentric isokinetic torque production of the quadriceps does not fully recover 20-minutes post ice application to the knee. This is in support of previous findings.[32] Current findings have potential implications for injury management and athlete participation in activity immediately following and up to 20- minutes post cryotherapy application at the knee.

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