ABSTRACT

Aim: To provide a comprehensive review of the current position in the literature on contemporary cryo-compression applications for musculoskeletal sports injury management.

Methods: Eight databases were searched; Sport Discus, Science Direct, CINHAL, Scopus, PubMed, Cochrane, ProQuest and MEDLINE. Publications restricted to 30-years and English language. Medical Subject Headings (MeSH), free-text words, and limiting descriptors for concepts related to cryotherapy and compression for sports injury were applied. Inclusion criteria determined at least one modality of cryotherapy treatment applied simultaneous to compression or as a comparison, relevant to sports injury management. Modalities included cryo-compressive devices, gel/ice packs, in association with concomitant compression. Populations included male or female, healthy or injured. Two reviewers independently selected eligible articles resulting in twenty-two studies meeting the inclusion criteria following full-text appraisal.

Findings: Inconsistent methodologies, low sample sizes and variability in outcome measures provides uncertainty over optimum protocols. Lack of prior understanding around protocols for isolated cryotherapy/compression applications prevents understanding on the therapeutic benefits of combined cryo-compression. No definitive agreement behind optimal cryo-compression applications were identified collectively from studies other than the consensus that compression aids the magnitude of cooling.

Conclusions: Although compression appears a useful adjunct to cooling modalities for the management of sports injury, no definitive agreement on optimum compression concurrent with cooling protocols were drawn from the studies. This was consequential of several methodological gaps in reporting throughout studies highlighting the gap of studies that represent applications within a sporting context or applied nature.

Key Words: Modalities, Cooling, Physiological, Musculoskeletal, Cryo-compression.

Cryotherapy and Compression in Sports Injury Management: A Scoping Review.

INTRODUCTION

An inflammatory response to musculoskeletal soft tissue trauma presents with characteristics that include pain, oedema and a proliferation in heat from increased blood flow (Capps, 2009; Rigby and Dye, 2017). The simultaneous application of cryotherapy and compression is thought to alter the inflammatory response by initiating therapeutic benefits (Capps, 2009). Current application of cooling often follows the PRICE *(Protect, Rest, Ice, Compression and Elevation)* guidelines (Bleakley et al, 2011), recently developed to the acronym of 'POLICE' *(Protection, Optimal Loading, Ice, Compression and Elevation)* management (Bleakley et al, 2012). The purpose of cryotherapy application is to lower tissue temperatures and occurs through the thermodynamic principles of heat withdrawal from deeper tissues (Chesterton et al, 2002). For immediate injury applications (Swenson et al, 1996; Mora et al, 2002; Galiuto, 2016), rehabilitative management (Bleakley and Hopkins, 2013), or post-exercise recovery (Du Pont et al, 2017) the rationale for cryotherapeutic application varies dependent on the aim (Bleakley et al, 2004). Physiological effects of cooling include analgesia (Ernst and Fialka, 1994); decline of nerve conduction velocity (Bleakley et al, 2004; Nadler et al, 2004; Algafly and George, 2007) and metabolism (Ho et al, 1995); reduction of inflammation (Pournot et al, 2011) in association with decreased vascular permeability and vasoconstriction (Gregson et al, 2011). Although widely accepted for use in sports injury management, cryotherapy modalities differ extensively and it is unknown as to whether an agreement exists concerning optimum protocols of cooling, with or without the addition of compression. The effectiveness of cooling modalities may differ due to several variables surrounding application principles of cooling (Table 1). In brief these include, efficiency (Merrick et al, 1993), location (Kennet et al, 2007), dosage, frequency (Jutte et al, 2001), contact area (Janwantanakul, 2009), phase change and enthalpy of fusion ability of modalities (Merrick et al, 2003; Kwiecien et al, 2020) level of compression (Alexander et al, 2020), or targeted vs circumferential application (Alexander et al, 2021).

Furthermore, the influence of external factors such as; adipose tissue levels, desired target tissue temperature, and therapeutic responses (Rupp et al, 2012) advocate that protocols should be modified on an individual basis to achieve greater outcomes and optimisation of response in sporting contexts (Alexander et al, 2021).

******Insert Table 1 Here******

Independently compression aims to control oedema, decrease overall blood flow (Kraemer et al, 2004) and predominantly to accelerate injury management through the reduction of clinical symptoms such as swelling or pain (Song et al, 2016). Principles behind the effects of external compression include the capacity of influence it has on the lymphatic system, including pressure gradients, gravity, contraction of skeletal muscle, and reduction of oedema (Kraemer et al, 2004; Ostrowski et al, 2019). For the management of sports injuries, compression is rationalised through its ability to manipulate external and internal capillary pressure thus minimising the accumulation of swelling, haematomas and provide mechanical support (Kraemer et al, 2004). Consequently the facilitation of mechanical support through compression is important for recovery processes and achievable because of dynamic immobilisation. The literature suggests that this is due to improved neural input during compression applications (Kraemer et al, 2004). Pneumatic, static, and intermittent compression in association with several levels of pressure are described across some of the studies reviewed (Mora et al, 2002; Knobloch et al, 2007, 2008; Janwantanakul, 2006; Holwerda et al, 2013; Ostrowski et al, 2018; Kwiecien et al, 2019) with compression as low as 14±2 mm Hg reported to affect magnitude of cooling (Kwiecien et al, 2019). Despite recent publications that investigate simultaneous cryotherapy and compression applications (Du Pont et al, 2017; Ostrowski et al, 2019; Holwerda et al, 2013; Kwiecien et al, 2019), a lack of clarity is still evident for single applications of cryotherapy and compression. Simply for the two modalities of cryotherapy and compression, we do not currently know optimum dose for either application. Therefore, it is difficult to determine potential combined interaction effects due to the complexity of multiple variables. Unsurprisingly evidence for the combined application of cryotherapy and compression is lacking through applied studies, and its use in sport is commonly anecdotal (Kraemer et al, 2004). Methodologies that isolate one of the variables (cryotherapy) with the other applied simultaneously (compression) may help determine the effect of simultaneous application through quantification. Therapeutic effects gained from cryotherapy application combined with compression may play an extensive role in the recovery of tissue injury though are generally underreported because of the reasons aforementioned. Notably, former research considers the adjunct of compression with cryotherapy as positive, reporting beneficial outcomes through further reduction of tissue temperature (Merrick et al, 1993; Tomchuk et al, 2010) or recovery enhancement (Du Pont et al, 2017). Many recent technological advancements in cryo-compressive devices are available and allude to the physiological benefits of combining the two. The purpose of the scoping review therefore was to produce a comprehensive review of the current position in the literature on contemporary cryo-compression applications for musculoskeletal sports injury management.

Research Question

What is the current position in the literature on contemporary applications of cryotherapy and compression for the management of musculoskeletal sports injuries?

In order to determine whether a systematic review would be of value to conduct, a scoping review was decided on initially, to explore over a broader topic area the available evidence. With the aim to produce a comprehensive review of the current position in the literature on contemporary cryo-compression applications for musculoskeletal sports injury management, objectives determined three key outcomes:

1. To examine current research and summise the available evidence base for the applications of simultaneous cryotherapy and compression modalities typically applied in the management of musculoskeletal sports injury.
2. To establish whether agreement exists in the optimal application of simultaneous cryo-compressive protocols for the management of musculoskeletal sports injuries.
3. To highlight knowledge gaps in the current evidence base surrounding contemporary cryo-compression applications for musculoskeletal sports injury management that may help inform future research in the topic area.

METHODS

Design and Search Strategy

This scoping review was conducted in accordance with the Preferred Reporting Items for Scoping Reviews (PRISMA-ScR) guidelines. Directed by the Arksey and O'Malley framework for scoping reviews (Arksey and O'Malley, 2005) the following steps were completed; *1) identifying the research question; 2) identifying relevant studies; 3) determine inclusion/exclusion criteria and apply; 4) charting the data, and finally 5) collating, summarising and reporting the results* (Arksey and O'Malley, 2005; Levac et al, 2010).

Two authors (** and **) performed searches to identify relevant studies in the remit of cryotherapy and compression in the management of musculoskeletal sports injury. In order to guarantee a comprehensive search of the available literature, sources include electronic databases, reference lists and the hand searching of key journals. The databases included: Sport Discus, Science Direct, ProQuest, CINHAL, Scopus, PubMed, Cochrane Library, and MEDLINE (via OVID), searched between 31st March to 1st September 2020 and a further search on 25th May 2021 to capture any new and relevant articles. A 30-year date restriction representing the development of physiological justification of cryotherapeutic modalities in sport was applied to the search strategy and captured contemporary development of cryo-compressive modalities. Grey literature searching followed the initial database searches utilising ProQuest and Open Grey. Search terms included a mix of Medical Subject Headings (MeSH), free-text words, and additional limiting descriptors for key concepts related to cryotherapy and compression for musculoskeletal sports injury. MeSH search terms for the Cochrane Library Database and Scopus searches did not apply, however conditions of the search were carried out identically between those databases. A broad range of available literature established through wide classification of key words follows recommendations for scoping review methods (Arksey and O'Malley, 2005).

Study Inclusion and Exclusion Criteria

In this scoping review, on evaluation of relevant studies, if at least one modality of cryotherapy treatment was applied simultaneous to compression or as a comparison to compression alone, the study was included. The application of simultaneous cryotherapy and compression in applicable studies applied to musculoskeletal sports injury management only and did not consider post-operative / surgical musculoskeletal management. Cryotherapeutic treatment modalities could include any cold compression device or gel packs, or ice (wetted/crushed/flaked/cubed), secured with elastic wraps / bandages that suggested concomitant mild, moderate or high compression reported. Populations reported in studies could include both male and female subjects, healthy or injured. The consideration to include studies that represented healthy participants was justified due to the limited availability of evidence for cryo-compressive applications on injured populations. Several factors acknowledged earlier may influence the optimisation of ideal cryo-compressive protocols and currently lead to the poor understanding for optimal protocols in normative populations. Inclusion therefore of both normative and injured populations within the scoping review commenced to ensure current practice in the topic area may be defined. Further inclusion criteria comprised articles written in English, all types of research and from the last 30 years. The 30-year period aimed to represent the potential development of evidence around physiological justification of cryotherapeutic modalities in sport over time.

Exclusion criteria included; articles with applications tested on animal models, the inability to locate or access full-text articles or any study reporting post-operative application of cryo-compression modalities. The area of interest for this scoping review was to be based on the application of these modalities for the acute management of musculoskeletal sports injuries, rather than post-operative injury care. This was due to the need for clarity on current applications of cryotherapy and compression in sport; providing a rationale for exclusion of post-operative applications of cryo-compressive modalities. Table 2 details the full inclusion criteria for this scoping review.

******Insert Table 2 here******

The search strategy was performed by ** and ** independently, and any disagreement relating to the inclusion or exclusion of literature was discussed afterwards. Figure 1 details the full process of article review. Screening of titles and abstracts indicated the subsequent reviews of full texts initially. If the title or abstract did not reveal enough information to determine appropriateness for inclusion to the scoping review, the full article was retrieved for full text review to determine inclusion. Articles were summarised and charted as per the combined framework by both reviewers independently (Arksey and O'Malley, 2005; Levac et al, 2010). Manual cross-referencing was performed after all titles and abstracts from the search were downloaded to Excel to prevent any duplication of studies or missing literature. Reference lists examined from all articles identified additional potentially relevant research. Appropriate studies were assessed independently by both reviewers (** and **), and if articles met the criteria described (Table 2) were included. If any disagreements arose between reviewers these were resolved by discussion and if any differences remained, a third reviewer (**)

settled any arbitration. No disagreements regarding the inclusion or exclusion of any publication occurred during the review process.

****** Figure 1 Insert Here******

Data Extraction

Extraction of data was completed by one reviewer (**) and to ensure accuracy, data was assessed by a second reviewer (**). A narrative synthesis was produced following the extraction of data to provide a summary description for each study which included type of compression, cooling, dose in terms of cooling and compression (Table 3).

RESULTS

A yield of 86 articles resulted from the initial searches. After the deduction of duplicate literature among the database searches and evaluation of the abstracts, 54 potentially eligible studies remained. Title and abstract review excluded a further 33 articles of which did not meet the inclusion criteria. Consequently, 22 full text papers were reviewed, all of which met the inclusion criteria (Table 2). Noteworthy information was extracted from each of the 22 articles and is displayed in Table 3.

Study Characteristics

The scoping review identified a wide variation in research design alongside several methodological differences (Table 3). The evidence typically represented observational or randomised control trials and across the studies several variations in outcomes measures were found. The types of studies included: x1 systematic review (Bleakley et al, 2004), x14 observational studies (Rigby and Dye, 2017; Du Pont et al, 2017; Janwantanakul, 2009; Ostrowski et al, 2019; Knobloch et al, 2007; Janwantakakul, 2006; Holwerda et al, 2013; Ostrowski et al, 2018; Kwiecien et al, 2019; Wilkerson and Horn-Kingery, 1993; Knobloch et al, 2006a; 2006b; Hawkins et al, 2012; Williams et a, 2013), x4 randomised controlled trials (Mora et al, 2002; Merrick et al, 1993; Knobloch et al, 2008; Tomchuck et al, 2010) and x2 narrative reviews (Capps, 2009; Block, 2010). Largely studies presented with low sample sizes or no control group, which may have reduced the ability to draw meaningful conclusions from individual investigations. Although a mix of male (n = 229) and female (n = 173) participants was evident across studies (age: 26.4±8.5 years), mostly were predominantly of young male adults and yielded a total population of ~400 participants. This represented an average number of 22 participants per study reported. From the 22 papers presented, only 11 publications report compression dose (mm Hg) and 18 reported the length of dose application (minutes). A summary of characteristics and data extraction for articles included in the scoping review are represented in Table 3.

****** Insert Table 3 here******

Minimal overlap in study findings were noted because of disparity in methodological processes, protocols investigated and outcomes measures defined. Modalites across the studies included Cryo Cuff® (n = 5), Game Ready® (n = 5), Koldblue Cryo Bandage (n = 2), Ice bag (*wetted, chipped, crushed, or salted*) (n = 11), Aircast® with Cryo/Strap (n = 1), Squid Go (n = 1), Hyper Ice® (n = 1), Gel Pack (n = 1), Aquilo Sports® Cryo Compression (n = 1), Power Play™ + Wetted Ice (n = 2) and Power Play™ + Gel Pack (n = 1). Some studies documented the levels of compression (mm Hg) and targeted T_{sk} values within the method protocols, however many failed to successfully report such details as support to determine efficacy of the modality applied. Those studies that reported pressure values of compression adjuncts reported values that ranged from 5-75 mm Hg, with consistent / continuous, pulsatile or intermittent variances in application techniques. With exclusion of the three review studies, all articles reported the length of cooling exposure. Exposure time varied between studies however from 15- to 30-minutes. Some articles reported protocols that included a recovery period and repetition of multiple exposures whilst others reported a single exposure of cryo-compression. Several different types of wrap were identified across studies, including elastic or plastic wrap to custom designed sleeves held circumferentially with Velcro. The most commonly investigated protocols reported continuous pressure, at high levels (*>50 mm Hg*), 30-minute exposures reporting ice bag applications, however not always the type of ice (i.e. *crushed, wetted, salted*) held in place with elastic or plastic wrap or the GameReady® device. Despite this, collective findings are not suggestive these components are the most applicable to the management of musculoskeletal sport injury. Many do not reflect typical half-time or pitchside applications in terms of dose (time) durations and impact the feasibility of evidence based knowledge into applied practice. That said, the benefits of simultaneous compression adjucts were acknowledged in all articles based on greater magnitudes of cooling ability with compression than without. Consequently, and collectively these results create a challenge when interpretating the collective stance on the agreement of cryo-compressive protocols for sports injury management. Clarity of agreement on what may be the optimal application for cryo-compression was therefore difficult to establish.

DISCUSSION

To provide a comprehensive review of the current position in the literature on contemporary cryo-compression applications for musculoskeletal sports injury management was the purpose of this scoping review. Studies generally indicated that cryotherapeutic modalities are one of the most commonly applied therapeutic modes used for musculoskeletal trauma management in sport and the physiological responses of cold applications are well reported (Bleakley et al, 2011; Algafly and George, 2007; Ho et al, 1995; Gregson et al, 2011; Merrick et al, 1993; Jutte et al, 2001; Ostrowski et al, 2019). With several studies recognising the traditional principles of PRICE (Bleakley et al, 2011; Galiuto, 2016; Bleakley and Hopkins, 2013; Block, 2010), the adjunct of compression to cryotherapy appears beneficial across most articles, of which acknowledged the positive effects of compression on the magnitude of cooling (Capps, 2009; Mora et al, 2002; Du Pont et al, 2017; Knobloch et al, 2006a; 2008; Janwantanakul, 2006; Tomchuck et al, 2010; Wilkerson and Horn-

Kingery, 1993). Differences between the terms ‘mild’, ‘moderate’ and ‘high’ levels of compression however were poorly defined within the literature with regards to the actual pressure (mm Hg) these descriptions represented. Additionally, the failure to report skin surface temperature (T_{sk}) values in several studies presented limitations in recognition of whether modalities met therapeutic T_{sk} ranges identified in previous literature (Kennet et al, 2007) for physiological effects to take place. Evidently, the non-reporting of either pressure (mm Hg) or T_{sk} has repercussions on the ability to define optimal protocols through objective measures of tissue response. That said, studies published within the last three years (Rigby and Dye, 2017; Ostrowski et al, 2018; 2019; Kwiecien et al, 2019; Alexander et al, 2020) all successfully reported measures of pressure (mm Hg), T_{sk} and in some cases intramuscular temperature (T_{im}), apart from one article (Du Pont et al, 2017), demonstrating progressive methodological detail and recent popularity in the use of contemporary cryo-compressive modalities. One consideration making it difficult to assess the quality of studies in this scoping review is the lack of quality appraisal. This relates to studies that are prone to bias through weak methodologies for example. The generalisability of publication findings in this scoping review was difficult due to the heterogeneous nature and flaws across methodologies, however the potential for the use of contemporary cryo-compressive modalities is indicative across many individual study conclusions.

The current scoping review supports earlier work, which highlights that poor agreement across multiple studies may be due to different combinations of cooling and compression applied and population groups investigated (Bleakley et al, 2004). Perhaps a limitation across some of the literature in this scoping review alludes to the inclusion of only healthy non-injured participants (Knobloch et al, 2006b; Hawkins et al, 2012; Rigby and Dye, 2017; Janwantanakul 2006, 2009; Holwerda et al, 2013; Kwiecien et al, 2019). It is important to consider that different results may occur in response to simultaneous cooling and compression between healthy and non-healthy (injured) tissues. Evidently, findings highlight minimal investigations available on the combination of treatment (cryotherapy and compression) for acute musculoskeletal sports injury presentations. It is important to note however that until further understanding of protocols are achieved in normative uninjured populations, metabolic changes associated with injury may be another variable to consider in the dose/response concept of cryotherapy or that of simultaneous cryo-compressive applications.

Different applications of compression exist, such as pneumatic or manual, intermittent or static. From the literature reviewed it appears that both pneumatic and manual approaches may enhance the effect of local cooling across various cryotherapy modalities. That said, most methods of cryotherapy cannot be applied in isolation, for example there must always be some level of concomitant compression. Continuous compared to intermittent compression simultaneously applied with cold appeared more favourable, albeit weak in the number of papers where this was reported, when comparing multiple modalities (Holwerda et al, 2013; Ostrowski et al, 2019). Although in one study equivalent T_{im} decreases were noted across the comparison of salted ice bag with continuous elastic wrap compression, with intermittent compression via Game Ready®, or PowerPlay devices (Ostrowski et al, 2019). Authors highlighted that application is dependent on treatment goals and stages of rehabilitation (Ostrowski et al, 2019), considered in relation to healing processes and physiological responses. When choosing between intermittent vs continuous compression applications, the consideration of such physiological responses, such as oedema formation were noted (Ostrowski et al, 2019). Although the studies reviewed in this scoping review were favourable of continuous compression in reducing T_{sk} compared to intermittent pneumatic this was only conclusive of two studies (Holwerda et al, 2013; Ostrowski et al, 2019). With distinct differences in outcome measures between the studies (Holwerda et al, 2013; Ostrowski et al, 2019) definitive conclusions were unable to be drawn without further investigation, suggestive of multiple modality, compression (level and mode) and relevant outcomes measures study design, suitable to inform practice. Despite the availability of former studies that also compared intermittent, pneumatic and static compression (Capps, 2009; Knobloch et al, 2008), physiological outcomes measures differed (Knobloch et al, 2008; Capps, 2009; Holwerda et al, 2013; Ostrowski et al, 2019), therefore making it difficult for direct comparison of results. As highlighted earlier a key deficiency observed across several study methods alludes to the lack of pressure (mm Hg) reporting. With only 12 papers out of 22 presenting this information (Table 3), consequently it is difficult to identify whether differences in compression dose or application resulted in the variable responses in those papers that failed to report such information. Therefore, with agreement not easily achieved, optimal cryo-compressive protocols are non-existent, consequently further research is required in this area through study design and methodological protocol development.

From the studies reviewed, literature tends to report on the physiological responses to simultaneous cryo-compressive applications, however little is known about the effect these applications may have on biomechanical, perceptual or biochemical responses for example. The only available literature reported no further decreases in stability or functional performance, comparing simultaneous cryotherapy and compression to cryotherapy application alone (Williams et al, 2013). With only one study investigating this it is difficult to provide any generalisability on the effect of variable compression magnitudes or variations such as constant or intermittent pressure on biomechanical measures relevant to current practice. Studies that investigate the effects of cryotherapy on biomechanical parameters report findings in terms of the effect of cooling alone without measure of accompanying pressure, whether that be intended (cryo-compression modality) or concomitant to the cooling application. Investigation into simultaneous cryo-compression applications on biomechanical parameters whereby pressure is quantified alongside temperature would be beneficial to determine safe thresholds of movement or loading after application once optimal protocols of cryo-compression for targeted tissue temperature reduction are determined.

Previous literature has described the research available on the comparison between cooling with/without compression in sports injury management as having persistent inconsistencies in methodologies (Bleakley et al, 2004). Sixteen papers reported in this scoping review consider comparisons of cooling with and without compression or compare multiple cryo-compressive modalities (Merrick et al, 1993; Mora et al, 2002; Bleakley et al, 2004; Knobloch et al, 2008; Janwantanakul, 2006; 2009; Capps, 2009; Block, 2010; Hawkins et al, 2012; Holwerda et al, 2013; Williams et al, 2013; Rigby and Dye, 2017; Ostrowski et al, 2019). Most studies agreed the addition of compression to cooling is beneficial for physiological changes to occur (Merrick et al, 1993; Janwantanakul, 2009; Knobloch et al, 2008; Capps, 2009; Tomchuck et al, 2010; Bleakley et al, 2012; Ostrowski et al, 2019). It is still evident however that a gap in the knowledge base represents a lack of high-quality research available that provides comparisons of variable compressions, contemporary cryo-compressive applications and outcome measures with sporting relevance. Due to the limited volume of publications specifically comparing multiple contemporary cryo-compressive devices this precludes the ability to distinguish comprehensively which application or protocol would provide optimal therapeutic response for musculoskeletal sports injury management. Further enquiry of contemporary cryo-compressive modalities for musculoskeletal sports injuries should pursue, to reduce the gap in knowledge and ensure quality evidence on their efficacy and therapeutic effects that can be applied in contemporary applied practice. Future studies might consider presenting both group and individual data for full interpretation of individual response to cryo-compressive interventions, particularly in athletic populations where positional characteristics or physical traits are known to influence level of T_{sk} following local cooling applications, supporting the need for individualisation of cooling protocols (Alexander et al, 2021). Yet without a clear understanding of the effects of cryotherapy and compression applied separately, studies that investigate combinations of cooling and compression may fail to progress the remit of this topic successfully due to the evident gaps highlighted by the results of this review.

Limitations

Despite the review offering a current perspective on contemporary applications of simultaneous cryo-compression for musculoskeletal sport injury management, some limitations exist. The methodological quality of the included papers was not considered following the Arksey and O'Mally (2005) framework for scoping reviews. We appreciate this limits the appraisal of the available studies which met the inclusion criteria, and that further critical appraisal for the methodological quality of papers may be beneficial in terms of a systematic review process in future. Furthermore, our search criteria excluded studies where cryo-compression was used post-operatively and therefore may have excluded studies that evaluate simultaneous cryo-compression in this scope. Potential bias to the selection process of papers in this scooping review may include the exclusion of papers in languages other than English. The generalisability of findings to injured populations is limited by the lack of studies that investigate simultaneous cryo-compressive modalities.

CONCLUSIONS

Available research that investigates simultaneous cryotherapy and compression for the management of sports injury is limited, diverse and consequently difficult to précis. Methodological differences surrounding the efficacy of cryo-compressive applications prevents the ability to provide a strong argument as to what may be optimum protocols in the management of musculoskeletal sports injuries. Suggestions that compression aids the efficiency of cooling is evident, however studies should report explicitly compression pressure values (mm Hg) to provide clarity on dose-response findings. There is no definitive understanding available on individual parameters of optimal cooling temperature, time, or compression in isolation. Therefore, it is difficult to determine the combination of effects that may occur from simultaneous applications of cryotherapy and compression. This is due to the multiple variables that require consideration for cryo-compressive application (Table 1) and the dynamic interplay that takes place with the body's homeostatic mechanisms. Further enquiry of contemporary technological advancements in cryo-compressive modalities require significant investigation. A focus on dose-response through the examination of variable compression pressures not yet defined in current literature may be beneficial. Defining contemporary protocols of simultaneous cryotherapy and compression applications is required to enhance understanding in current practice of cryo-compressive modalities. Unless full consideration of multiple variables that affect the interpretation of outcome measures are deliberated in future studies however, the impact of findings into current practice will be limited. Furthermore, individual responses were not considered across studies and future research should observe this to optimise cryo-compressive protocols for sports injury management.

KEY POINTS

- Differences in the efficacy of cryo-compressive applications is evident and influenced by several variables that should be considered when devising optimal cryo-compression applications.
- Studies generally agree that compression aids the magnitude of cooling.
- Definitive practices for the application of simultaneous cooling and compression cannot be drawn from the current available literature because of inconsistencies in methodological investigations.
- Lack of prior understanding around protocols for cryotherapy/compression applied separately is evident.
- Further enquiry of contemporary cryo-compressive devices and dose-response is required to develop optimal protocols for use in sports injury management and should consider multiple measurable outcomes and individual responses reflective of current applied practices.

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References

1. Alexander J, Rhodes D, Birdsall D, Selfe J. 2020. Comparison of cryotherapy modality application over the anterior thigh across rugby union positions: A crossover randomised controlled trial. Int J Sports Phys Ther. 15(2):210-220.
2. Alexander J, Greenhalgh O, Rhodes D. 2020. Physiological parameters in response to levels of pressure during contemporary cryo-compressive applications: Implications for protocol development. J Athletic Train. 9(1):1-6.
3. Alexander J, Carling C, Rhodes D. 2021a. Utilisation of performance markers to establish the effectiveness of cold-water immersion as a recovery modality in elite football. Biol Sport. 39(1): 19-29.
4. Alexander J, Selfe J, Greenhalgh O, Rhodes D. 2021. Exploratory evaluation of muscle strength and skin surface temperature responses to contemporary cryotherapy modalities in sport. J Iso Ex Sci. Pre Press. 1-9.
5. Algafly AA, George KP. 2007. The effect of cryotherapy on nerve conduction velocity, pain threshold and pain tolerance. Br J Sports Med. 41(6):365-369.
6. Arksey H, O'Malley L. 2005. Scoping studies: Towards a Methodological Framework. Int J Soc Res Methodol. 8(1):19-32.
7. Bleakley CM, Glasgow P, Philips N, Hanna L, Callaghan M, Davison GW, Hopkins TJ, Delahunt E. 2011. Management of acute soft tissue injury using protection, rest, ice, compression and elevation recommendations from the Association of Chartered Physiotherapists in Sport and Exercise Medicine (ACPSM). Physios in Sport. 1:1-22.
8. Bleakley C, McDonough S, MacAuley D. 2004. The use of ice in the treatment of acute soft-tissue injury: a systematic review of randomized controlled trials. Am J Sports Med. 32(1):251-261.
9. Bleakley CM, Glasgow P, MacAuley DC. 2012. PRICE needs updating, should we call the POLICE? Br J Sports Med. 46(4):220-221.

10. Bleakley CM, Hopkins JT. 2013. Is it possible to achieve optimal levels of tissue cooling in cryotherapy? Phys Ther Rev. 15(4):344-350.
11. Block JE. 2010. Cold and compression in the management of musculoskeletal injuries and orthopaedic operative procedures: a narrative review. J Sport Med. 7(1):105–113.
12. Capps S. 2009. Cryotherapy and intermittent pneumatic compression for soft tissue trauma. Athl Ther Today. 14(1):2-4.
13. Chesterton LS, Foster N, Ross L. 2002. Skin temperature response to cryotherapy. Arch Phys Med Rehab. 83(4):543-549.
14. Du Pont WH, Meuris BJ, Hardesty VH, Barnhart EC, Tompkins LH, Golden MJP, Usher CJ, Spence PA, Caldwell LK, Post EM, Beeler MK, Kraemer WJ. 2017. The effects combining cryocompression therapy following an acute bout of resistance exercise on performance and recovery. J Sports Sci Med. 16(3):333-342.
15. Ernst E, Fialka V. 1994. Ice freezes pain? A review of the clinical effectiveness of analgesic cold therapy. J Pain Symptom Manage. 9(1):56-59.
16. Galiuto L. 2016. The use of cryotherapy in acute sports injuries. Ann Sports Med Res. 3(2):1060.
17. Gregson W, Black M, Jones H, Milson J, Morton J, Dawson B, Atkinson G, Green D. 2011. Influence of cold water immersion on limb and cutaneous blood flow at rest. Am J Sports Med. 39(6):1316-1323.
18. Hawkins J, Shurtz J, Spears C. 2012. Traditional cryotherapy treatments are more effective than GameReady® on medium setting at decreasing sinus tarsi tissue temperatures in uninjured subjects. J Athl Enhancement. 1(2):1-5.
19. Ho SSW, Illgen RL, Meyer RW, Torok PJ, Cooper MD, Reider B. 1995. Comparison of various icing times in decreasing bone metabolism and blood flow in the knee. Am J Sports Med. 23(1):74-76.

20. Holwerda SW, Trowbridge CA, Womochel KS, Keller DM. 2013. Effects of cold modality application with static and intermittent pneumatic compression on tissue temperature and systemic cardiovascular responses. J Athl Train. 5(1):27-33.
21. Janwantanakul P. 2006. Cold pack/skin interface temperature during ice treatment with various levels of compression. Physio. 92(4):254-259.
22. Janwantanakul P. 2009. The effect of quantity of ice and size of contact area on ice pack/skin interface temperature. Physio. 95(2):120-125.
23. Jutte LS, Merrick MA, Ingersoll CD, Edwards JE. 2001. The Relationship Between Intramuscular Temperature, Skin Temperature, and Adipose Thickness During Cryotherapy and Rewarming. Arch Phys Med Rehab. 82(6):845-850.
24. Kennet J, Hardaker N, Hobbs SJ, Selfe J. 2007. Cooling Efficiency of 4 Common Cryotherapeutic Agents. J Athl Train. 42(3):343-348.
25. Knobloch K, Grasemann R, Jagodzinski M, Richter M, Zeichen J, Krettek C. 2006a. Changes of Achilles midportion tendon microcirculation after repetitive simultaneous cryotherapy and compression using a cryo/cuff. Am J Sports Med. 34(12):1953-1959.
26. Knobloch K, Kraemer R, Lichtenberg A, Jagodzinski M, Gosling T, Richter M, Krettek C. 2006b. Microcirculation of the ankle after cryo / cuff application in healthy volunteers. Int J Sports Med. 27(3):250-255.
27. Knobloch K, Grasemann R, Spies M, Vogt PM. 2007. Intermittent KoldBlue cryotherapy of 3x10 min changes mid-portion Achilles tendon microcirculation. Br J Sports Med. 41(6):1-7.
28. Knobloch K, Grasemann R, Spies M, Vogt PM. 2008. Midportion Achilles tendon microcirculation after intermittent combined cryotherapy and compression compared with cryotherapy alone. A Randomised Trial. Am J Sports Med. 36(11):2128-2138.
29. Kraemer WJ, French DN, Spiering BA. Compression in the treatment of acute muscle injuries in sport: review article. Int Sports Med J. 5(3):200-208.

30. Kwiecien SY, Mathew S, Howatson G, McHugh MP. 2019. The effect of varying degrees of compression from elastic vs plastic wrap on quadriceps intramuscular temperature during wetted ice application. Scand J Med Sci Sports. 29(8):1-6.
31. Kwiecien, SY., McHugh, MP., and Howatson, G. 2020. Don't lose your cool with cryotherapy: The application of phasechange material for prolonged cooloing in athletic recovery and beyond. Frontiers in Sports and Active Living. 2(118): 1-12.
32. Levac D, Colquhaun H, O'Brien K. 2010. Scoping Studies: Advancing the methodology. Implementation Sci. 5(69):1-9.
33. Mora S, Charalampos G, Zalavras M, Wang L, Thordarson DB. 2002. The Role of Pulsative Cold Compression in Edema Resolution following Ankle Fractures: A Randomized Clinical Trial. Foot Ankle Int. 23(11):999-1002.
34. MacAuley DC. 2001. Ice Therapy. How good is the evidence? Int J of Sports Med. 22(5):379-384.
35. Merrick MA, Knight K, Ingersoll CD, Potteiger JA. 1993. The effects of ice and compression wraps on intramuscular temperature at various depths. J Athl Train. 28(3):236-245.
36. Merrick MA, Jutte L, Smith M. 2003. Cold modalities with different thermodynamic properties produce different surface and intramuscular temperatures. J Athl Train. 38(1):28-33.
37. Nadler SF, Weingand K, Kruse RJ. 2004. The Physiologic Basis and Clinical Applications of Cryotherapy and Thermotherapy for the Pain Practitioner. Pain Physician. 7(3):395-399.
38. Ostrowski J, Purchino A, Beck M, Leisinger J, Tucker M, Hurst S. 2018. Examination of intramuscular and skin temperature decreases produced by the PowerPlay intermittent compression cryotherapy. J Sport Rehab. 27(3):244-248.
39. Ostrowski J, Purchino A, Beck M, Leisinger J. 2019. Effectiveness of salted ice bag versus cryocompression on decreasing intramuscular and skin temperature. J Sport Rehab. 28(2):120-125.

40. Pournot H, Bieuzen F, Louis J, Fillard JR, Barbiche E, Hausswirth C. 2011. Time-Course of Changes in Inflammatory Response after Whole-Body Cryotherapy multi exposures following severe exercise. PLoS ONE. 6(7):1-8.
41. Rigby JH, Dye SB. 2017. Effectiveness of various cryotherapy systems at decreasing ankle skin temperatures and applying compression. Int J Athl Ther Train. 22(8):32-39.
42. Rupp KA, Herman DC, Hertal J, Saliba SA. 2012. Intramuscular temperature changes during and after 2 different cryotherapy interventions in healthy individuals. J Ortho Sports Phys Ther. 42(8):731-737.
43. Song M, Sun X, Tian X, Zhang X, Shi T, Dai W. 2016. Compressive cryotherapy versus cryotherapy alone in patients undergoing knee surgery: a meta-analysis. SpringerPlus. 5(1):1-9.
44. Swenson C, Sward L, Karlsson J. 1996. Cryotherapy in sports medicine. Scan J Med Sci Sports. 6(4):193-200.
45. Tomchuk D, Rubley MD, Holcomb WR, Guadagnoli M, Tarno JM. 2010. The magnitude of tissue cooling during cryotherapy with varied types of compression. J Athl Train. 45(3):230-237.
46. Wilkerson GB, Horn-Kingery HM. 1993. Treatment of the inversion ankle sprain: comparison of different modes of compression and cryotherapy. J Sports Phys Ther. 17(5):240-246.
47. Williams EE, Miller SJ, Sebastianelli WJ, Vairo GL. 2013. Comparative immediate functional outcomes among cryotherapeutic interventions at the ankle. Int J Sports Phys Ther. 8(6):828-883.

Figure Legends

Figure 1. PRISMA Flow Diagram of included studies.

Table Legends

Table 1. Key variables to consider that may influence the optimisation of cryo-compressive applications.

Table 2. List of inclusion eligibility criteria utilised for article screening.

Table 3. Study characteristics and data extraction of included articles.