Article

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Title: Thermography for defining efficiency of cryotherapy modalities in sport.

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Commentary:

Infrared Thermal Imaging (TI) is well evidenced for the quantification of skin surface temperature (T_{sk}) and abundantly used within cryotherapeutic research (Kennet et al, 2007; Moreira et al, 2017; Alexander et al, 2020a; 2020b). We have published several articles recently on the effects of local cryotherapy with the physiological effects quantified through T_{sk} via TI techniques (Alexander et al 2020a; 2020b). The remit of those studies was based on two key themes: (i) T_{sk} response to contemporary cooling modalities compared to traditional applications (ii) T_{sk} and physiological response to contemporary cryo-compressive devices with varying pressure adjuncts for the management of musculoskeletal injury or as a recovery strategy in sport. Comparison of traditional methods of cryotherapy modalities to modern alternatives in sport provided justification to progress the knowledge in theme (i). Literature to support theme (ii), was evidently lacking and developed naturally to combine multiple contemporary cooling modalities that operate cooling and compression simultaneously. All of which quantified T_{sk} through infrared TI and followed guidance by Moreira et al (2017) for the setup of thermology capture.

Several investigations utilise infrared TI as an objective measure to quantify the efficiency of common cooling modalities used in sport by way of $T_{sk.}$ Preferences on the choice of cooling modality often amount to whether optimal temperatures can be achieved in the target tissues and are quantified via $T_{sk.}$ In our recently published manuscript in the *International Journal of Sports Physical Therapy* (Alexander et al, 2020a), we aimed to determine differences in the cooling ability of three different cryotherapy modalities (Wetted Ice, Crushed Ice and CryoCuff®), in a specific sports population through physiological measures of T_{sk} using TI. Physical characteristics vary between playing positions in rugby union due to the demands of the game and in consideration of this, levels of adipose tissue

vary and influence interference on efficacy of local cooling applications. To date, although studies consider comparison of multiple cooling modalities, typically methods fail to report heterogeneities of participants or properties of the modality. A therapeutic temperature range for target T_{sk} following local cooling applications of 10-15°C has previously been proposed (Kennet et al, 2007). This typically represents a T_{sk} range whereby physiological responses occur and often referred to in publications related to cooling parameters achieved by cryotherapeutic modalities (Kennet et al, 2007). Results from our study (Alexander et al, 2020a) demonstrated differences in T_{sk} response to cooling with wetted ice displaying the greatest reductions. The main findings however highlighted not only the significant differences between T_{sk} when comparing between the three different modalities (Wetted Ice; Crushed Ice and CryoCuff®) but also across playing positions (forwards and backs)**.** Results suggest using TI, to determine the effects of such variable (physical characteristics) is useful to consider in relation to the efficacy of cryotherapeutic applications in the assumption that adipose tissue levels vary between these positional characteristics. This may appear obvious, and cooling applications in terms of duration should be altered to account for the insulating effects of adipose tissue. That said, no evidence was available that compared contemporary cooling to traditional methods, nor contemplated the physical characteristic differences in playing position in specific sports populations at the time. Evidently, analysis using infrared TI results indicate that potential phase change differences alongside characteristic variables may both be responsible for variance in target T_{sk} responses (Alexander et al, 2020a). In terms of an applied practical impact, individualisation of local cooling applications and choice of modality is imperative for optimal response. From an evidenced-based perspective, findings supported using TI, have implications on the development of what may be optimal protocols of cooling in sport through thermology assessment, however further research is required with methods of analysis considering individual response.

One tenet we did not consider in the study (Alexander et al, 2020a) was the effect of compression adjunct to each of the cryotherapy modalities applied. Pressure as a separate outcome was not quantified, however it is apparent from literature that compression may aid the magnitude of cooling. Evidently this has implications on modality choice based on T_{sk} quantification through infrared TI. Therefore, further to this work we investigated cryo-compressive applications measuring T_{sk} following application (Alexander et al, 2020b) utilising T_{sk} measures to determine differences between cryo-compressive modalities and cooling capabilities/magnitudes. This provided key evidence for theme (ii) presented earlier. T_{sk} results using infrared TI demonstrated differences in magnitude of cooling between modalities and pressure adjuncts, supporting earlier suggestions. Both studies (Alexander et al, 2020a; 2020b) followed current guidelines by Moreira et al (2017) for use of thermographic imaging in sports and exercise medicine (TISEM). The rationale for discussing both Alexander et al, (2020a) and (2020b) in this commentary was to acknowledge the impact of pressure adjunct noted through T_{sk} from contemporary cooling modalities typically used in sport, quantified through TI. Considering the

findings, we propose that infrared TI provides an objective measure to quantify T_{sk} differences between various adjunct pressure options offered by contemporary pneumatic cooling modalities, as a safe non-invasive method. Comparison to other methods of thermology may be justified and while there is significant evidence of its use to quantify cooling applications typically applied in sport, recently the accuracy of TI has been challenged by Maley et al, (2020) suggesting overestimation of skin temperature through re-warming periods using TI. A counterpoint made by Havenith and Lloyd (2020) in the same journal however suggests this cannot be strongly affirmed based on current evidence. Furthermore with their methods being anatomically specific to the upper limb (Maley et al, 2020) findings may not be translational across other regions, i.e. the measurement of T_{sk} was performed over the upper peripheral limb, hand and fingers, not the lower limb such as in our studies (Alexander et al, 2020a; 2020b) and the aim of their data was to compare against a skin thermistor. Although the authors might suggest that future studies should contemplate potential overoptimization of peripheral T_{sk} through TI during rewarming periods and make appropriate adjustments where necessary to risk / withdrawal criteria (Maley et al, 2020), there are many approaches in which accuracy of thermographic cameras can be improved for their use in cryotherapeutic studies including; camera configuration, utilisation of reference values, greater number of temperature pixels or advanced camera technology, summarised by Havenith and Lloyd (2020).

In summary TI is useful in quantifying the physiological effects of cooling modalities on T_{sk}, however approaches for its use are dependent on the aim of the research. Individual measures of TI may provide useful data however future studies should consider multiple metrics that represent relevant parameters of investigation in sports-related cryotherapy investigations, beneficial simultaneously to infrared TI measures. Many studies do represent this, and we hope that future study design in our research group will continue to provide data with translational outcomes when investigating cooling protocols in sport. Consideration of individual response analysis rather than group average data is also important and would eliminate positional differences (as one example). Future studies could achieve these investigations through the utilisation of multiple metrics combining physiological, such as TI, biomechanical and psychological measures and individual data analysis, with the aim of greater impact to practice through optimal individualised approaches for contemporary cryotherapeutic applications. Evidently infrared TI is beneficial in challenging preferences of contemporary cooling applications in sport through thermography for decision-making, however further validation of methods is welcomed to provide accurate measurement of T_{sk} in the lower limb.

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