Infrared thermography-monitored recovery of anterior cruciate ligament rupture in a professional soccer player: A case study

Recuperação de rutura do ligamento cruzado anterior monitorizada por termografia infravermelha num jogador de futebol profissional: Um estudo de caso

10.29073/jim.v5i2.1028

Recebido: 21 de novembro de 2025.
Aprovado: 12 agosto de 2026.
Publicado: 15 de agosto de 2026.

Autor/a 1: Dailson Paulucio, Al Nassr Football Club, Arábia Saudita, dailsonpaulucio@gmail.com.
Autor/a 2 (Correspondente): Igor Mattos, Universidade Salgado de Oliveira, Brasil, igormrangel@gmail.com.
Autor/a 3: Caleb Santos, Universidade Federal do Rio de Janeiro, Brasil, calebguedes@gmail.com.
Autor/a 4: Gustavo Monnerat-Cahli, Botafogo de Futebol e Regatas, Brasil, monnerat1988@gmail.com.
Autor/a 5: Manoel Coutinho, Universidade Federal do Rio de Janeiro, Brasil, manoelcoutinho@yahoo.com.
Autor/a 6: João Grangeiro, Botafogo de Futebol e Regatas, Brasil, grangeiro@globo.com.
Autor/a 7: Fernando Pompeu, Universidade Federal do Rio de Janeiro, Brasil, fernandoamspompeu@gmail.com.
Autor/a 8: João Marins, Universidade Federal de Viçosa, Brasil, joaobouzas@yahoo.com.br.
Autor/a 9: Eduardo Lattari, Universidade Salgado de Oliveira, Brasil, eduardolattari@yahoo.com.br.

Abstract

Introduction: Infrared thermography has been used as a non-invasive tool to analyze inflammatory responses in musculoskeletal injuries. However, no study has followed thermal behavior from pre injury to post surgery recovery in anterior cruciate ligament (ACL) rupture. Therefore, the objective of this case study was to analyze the use of thermography as a form of pre- and post-ACL injury monitoring in a professional soccer player, tracking thermal changes from the period before the trauma to the first months of post-surgical recovery.

Case Presentation: A professional Brazilian first-division soccer player suffered a total ACL rupture of the right knee. Thermographic assessments were conducted before injury (BI), after injury (AI), and during the first (AS1), second (AS2), and third (AS3) postoperative months. Mean temperature asymmetry (MTA) between knees was calculated.

Management and Outcome: The athlete underwent ACL reconstruction with autologous patellar tendon graft and standard postoperative medication. Descriptive comparison of the 95% confidence intervals indicated a marked increase in MTA from BI to AS1, followed by a progressive reduction during the postoperative follow-up. By AS3, the partial overlap with the baseline 95% confidence interval suggested a gradual return toward baseline MTA.

Discussion: Thermography allowed monitoring of inflammatory progression and postoperative recovery. This case suggests that temperature asymmetry may be useful to assist monitoring of rehabilitation in elite athletes.

Keywords: ACL Rupture; Case Report; Infrared Thermography; Knee Injury; Temperature Asymmetry.

Resumo

Introdução: A termografia infravermelha tem sido utilizada como uma ferramenta não invasiva para analisar respostas inflamatórias em lesões músculo-esqueléticas. No entanto, nenhum estudo acompanhou o comportamento térmico desde o período pré-lesão até à recuperação pós-cirúrgica numa rutura do ligamento cruzado anterior (LCA). Portanto, o objetivo deste estudo de caso foi analisar o uso da termografia como ferramenta de monitoramento antes e após uma lesão do ligamento cruzado anterior (LCA) em um jogador

profissional de futebol, acompanhando as alterações térmicas desde o período pré-lesão até os primeiros meses de recuperação pós-cirúrgica.

Apresentação do Caso: Um jogador profissional de futebol da primeira divisão brasileira sofreu uma rutura total do LCA do joelho direito. As avaliações termográficas foram realizadas antes da lesão (AL), após a lesão (PL) e durante o primeiro (1PO), segundo (2PO) e terceiro (3PO) meses de pós-operatório. Foi calculada a assimetria média de temperatura (AMT) entre os joelhos.

Tratamento e Evolução: O atleta foi submetido a reconstrução do LCA com enxerto autólogo do tendão patelar e a medicação pós-operatória standard. A comparação descritiva dos intervalos de confiança de 95% indicou um aumento acentuado da AMT de PL até 1PO, seguido por uma redução progressiva durante o acompanhamento pós-operatório. Em 3PCO, a sobreposição parcial com o intervalo de confiança de 95% da avaliação basal sugeriu um retorno gradual da AMT aos valores basais.

Discussão: A termografia permitiu o monitoramento da progressão inflamatória e da recuperação pós-operatória. Este relato de caso sugere que a assimetria térmica pode ser útil como ferramenta complementar para auxiliar o monitoramento da reabilitação em atletas de elite.

Palavras-Chave: Assimetria de Temperatura; Lesão do Joelho; Relato de Caso; Rutura do LCA; Termografia Infravermelha.

1. Introduction

In sports injuries, inflammatory processes mediated by the innate immune system can be observed, consisting of increased pain, vascular alterations, and other mechanisms that lead to an increase in local temperature (Fernandes et al., 2017). Infrared medical thermography (IMT) has emerged as a fast, non-invasive method capable of detecting these temperature variations, and has been used in sports medicine to support the diagnosis, monitoring and rehabilitation of musculoskeletal and joint injuries (Escamilla-Galindo et al., 2017; Fernandes et al., 2017; Litscher et al., 2014). This radiation free technique provides a detailed thermal map of the body, in which each pixel corresponds to a specific temperature, allowing assessment of muscle tissue condition, identification of injury risk and evaluation of recovery progression (Côrte & Hernandez, 2016; Corte et al., 2019; Moreira et al., 2017).

Based on the principle of anatomical proportionality, contralateral body regions are expected to exhibit similar thermal patterns under normal conditions (Brisoschi et al., 2003; Marins et al., 2015). Small bilateral differences are expected; however, deviations above normal variation may indicate alterations in the region of interest (ROI). Based on the attention level scale proposed by Marins et al. (Marins et al., 2015), asymmetries from 0.5 °C upward justify closer monitoring, with higher values representing progressively more severe alterations. This framework reinforces the relevance of thermal asymmetry analysis in clinical and sports settings.

However, studies have not demonstrated the use of this tool to follow the inflammatory process before and after injury and throughout the rehabilitation process of anterior cruciate ligament (ACL) rupture, a high risk lesion of soccer players (Gornitzky et al., 2016). This gap is clinically relevant, as ACL rupture is one of the most frequent and impactful injuries in soccer, with incidence rates ranging from 0.06 to 10 injuries per 1000 hours of match exposure and higher rates among professional athletes (Bjordal et al., 1997; Brophy et al., 2015; Dvorak & Junge, 2000). Even with accelerated rehabilitation strategies, recovery typically requires four to eight months (Brophy et al., 2015). during which prolonged absence may compromise both the athlete's career and team performance.

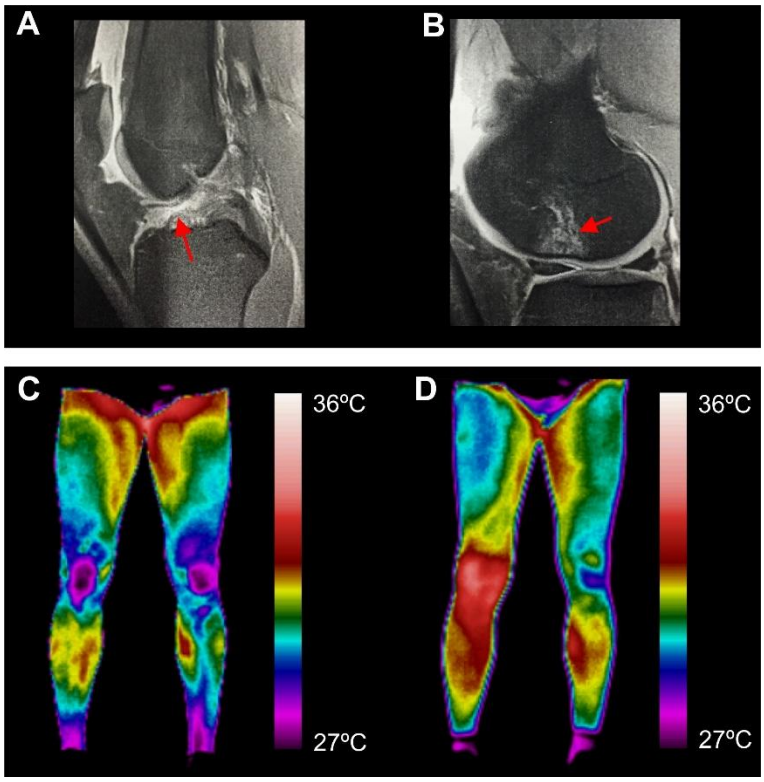
Therefore, the objective of this case study was to analyze the use of thermography as a form of pre- and post-ACL injury monitoring in a professional soccer player, tracking thermal changes from the period before the trauma to the first months of post-surgical recovery. This approach allows us to evaluate the clinical utility of infrared thermography as a complementary tool to monitor the inflammatory process, support decisions in the

rehabilitation process, and contribute to the understanding of thermal responses throughout the recovery from serious injuries in high-performance athletes.

2. Case Presentation

Data were obtained from a professional first division Brazilian soccer player who sustained an acute injury during an official match. The athlete is 1.78 meters tall, weighs 71 kilograms, was born in May 1996 (21 years) and is right foot dominant. He competed as a full back throughout the season. Thermographic assessments were conducted at five predefined time points: before injury (BI), after injury (AI), and during the first (AS1), second (AS2) and third (AS3) postoperative months. The athlete presented with a complete rupture of the anterior cruciate ligament (ACL) in the right dominant knee, confirmed through clinical examination and magnetic resonance imaging (MRI) (Fig. 1A/1B). MRI also demonstrated edema of the lateral femoral condyle, a typical associated finding in ACL injuries. Infrared thermographic images were captured using a Flir® e60 camera (320×240 pixels), following standardized acquisition procedures. Mean temperature asymmetry (MTA) was calculated as the difference between the mean surface temperature of the frontal regions of the injured (right) and uninjured (left) knees. Athlete read and signed an informed consent form.

Figure 1: Clinical images (MRI and thermal) and mean temperature asymmetry levels timeline: A) Magnetic resonance imaging (MRI) sagittal view of knee show the anterior cruciate ligament (ACL) rupture. B) A lateral femoral condyle edema, characteristic of ACL rupture. C) Infrared thermographic image of the subject 11 days before injury (BI). D) Infrared thermographic image of the subject 18 days after surgery.



3. Management and Outcome

3.1. Surgical Management

The athlete underwent isolated ACL reconstruction 22 days after the injury, using the central third of the autologous patellar tendon fixed with biodegradable screws in the femur and tibia. Post operative therapy consisted of: Cefazolin 1g IV every 8 h (4 doses) and Diclofenac 70 mg every 12 h for one week.

3.2. Thermographic Monitoring

Infrared thermography images were obtained using a thermal imager camera (Flir®, model e60, 320x240 pixels) and analyzed with the manufacturer's dedicated image acquisition and processing software (FLIR Tools®, FLIR

Systems Inc., Wilsonville, OR, USA). Before image acquisition, the athlete underwent a 15-min acclimatization period in a standing position while wearing only underwear and avoiding contact with surrounding objects or surfaces that could influence skin temperature. The athlete was instructed to refrain from strenuous exercise, caffeine and alcohol consumption, massage, cryotherapy, and the application of creams or topical agents before the assessment. Image acquisition was performed in a climate-controlled room maintained at 20–22 °C with relative humidity between 40% and 60%. Room temperature and relative humidity were continuously monitored using a digital thermo-hygrometer (Minipa®, model MT241).

All thermographic images were obtained using a fixed camera-to-subject distance of approximately 2 m, with the camera positioned perpendicular to the region of interest to minimize geometric distortion. The human skin emissivity was standardized at 0.98 for all measurements. The region of interest (ROI) occupied a substantial portion of each image and consisted of a manually defined elliptical area encompassing the knee joint. During image acquisition, the athlete remained in a standardized anatomical standing position with the evaluated body regions fully exposed. Three infrared thermography images were acquired during each assessment, and the mean skin temperature was calculated as the average of these three measurements. All assessments were performed under identical environmental conditions by the same evaluator and according to a standardized protocol to ensure measurement reliability and reproducibility (Moreira et al., 2017). Although the thermographic software provided the mean, maximum, and minimum skin temperatures for ROI, only the mean skin temperature was used to calculate inter-limb thermal asymmetry. Mean temperature is considered the most representative measure of the overall thermal behavior of the evaluated region because it is less influenced by isolated hot or cold spots, image noise, and segmentation artifacts, thereby providing greater reliability and reproducibility for longitudinal monitoring and bilateral comparisons (Moreira et al., 2017).

Given the single-case design, data were analyzed descriptively without inferential statistical testing. For each assessment, three infrared thermography images were acquired, and the mean skin temperature was calculated as the average of the three measurements. Descriptive statistics are presented as mean, standard deviation (SD), and 95% confidence interval (95% CI) to characterize the central tendency and within-assessment variability. Thermal asymmetry was calculated as the temperature difference between the affected and contralateral knees. The coefficient of variation (CV) was calculated when appropriate to describe the relative variability of repeated measurements. However, because baseline thermal asymmetry values included both positive and negative observations, resulting in a mean close to zero, the CV was not interpreted for this assessment, as it becomes unstable and may yield misleading values under these conditions. Therefore, baseline variability was described using the SD and 95% CI. Changes across the five assessments were evaluated descriptively by examining the temporal evolution of the MTA and their respective 95% confidence intervals. Given the exploratory nature of this case report and the absence of a comparison group, no hypothesis testing was performed. Instead, the findings were interpreted based on the magnitude and direction of the observed changes together with the consistency of repeated measurements across assessments.

3.3. Results

Table 1 summarizes the MTA values obtained across the five thermographic assessments. For each time point, data are presented as the mean of three repeated infrared thermography images, together with the standard deviation (SD) and 95% confidence interval (95% CI).

Table 1: Mean thermal asymmetry (MTA) values across the five thermographic assessments. Data are presented as the mean of three repeated infrared thermography images, standard deviation (SD), and 95% confidence interval (95% CI).

Time points	Mean	SD	IC95%
BI	-0.03	0.2	-0.5 to 0.5
AI	1.0	0.1	0.8 to 1.3
AS1	3.0	0.4	2.1 to 3.9
AS2	1.8	0.2	1.4 to 2.2
AS3	0.9	0.3	0.1 to 1.6

Descriptive comparison of the 95% confidence intervals demonstrated a marked increase in thermal asymmetry from BI to AI and from AI to AS1, followed by a gradual reduction throughout the postoperative follow-up. By AS3, the 95% confidence interval partially overlapped that observed at BI, suggesting a progressive return toward baseline thermal symmetry.

4. Discussion

The present case study investigated the use of infrared thermography to monitor thermal changes before and after anterior cruciate ligament (ACL) injury in a professional soccer player, from the pre-injury period through the first three postoperative months. Overall, the findings suggest a temporal pattern characterized by a marked increase in mean thermal asymmetry (MTA) from the pre-injury assessment to the first postoperative month, followed by a progressive reduction during the postoperative follow-up. By the third postoperative month, the partial overlap of the 95% confidence interval with the baseline assessment may indicate a gradual return toward pre-injury thermal symmetry. These observations suggest that infrared thermography may provide complementary information on the temporal evolution of thermal changes during rehabilitation following ACL reconstruction.

Infrared thermography has been widely used to evaluate pre, intra and postoperative thermal behavior in orthopedic procedures, as well as in rehabilitation contexts (Litscher et al., 2014; Omar & McKinley, 2018; Windisch et al., 2016). Despite these established applications, no previous study has monitored thermal responses from before injury (BI) through the immediate post injury stage (AI) and across the first three postoperative months (AS1–AS3) in elite athletes. The present case helps to address this gap by providing a longitudinal thermal profile spanning the pre-injury period, the acute inflammatory phase and the early stages of postoperative recovery. This extended follow up suggests temporal changes in thermal asymmetry that may be associated with injury, surgical trauma, and the subsequent healing process.

Previous reviews, such as that by Marins et al. (Marins et al., 2015), highlighted the potential of thermography in sports but emphasized the scarcity of longitudinal assessments in high performance athletes. More recently, studies such as Escamilla-Galindo et al. (Escamilla-Galindo et al., 2025) demonstrated that thermographic behavior during ACL rehabilitation is closely related to functional progression and may support return to play decisions. The pattern observed in this case, characterized by an increase in MTA after injury, a thermal peak during the first postoperative month, and a gradual return toward baseline, is consistent with these observations and suggests that a pre-injury assessment may provide an individualized thermal baseline for future comparisons.

Our data revealed that the athlete presented minimal asymmetry before the injury (BI: −0.03 ± 0.5 °C), followed by a sharp increase after the ACL rupture (AI: 1.0 ± 0.1 °C) and a pronounced postoperative peak during the first month (AS1: 3.0 ± 0.4 °C). These elevations may reflect the acute inflammatory response associated with the injury and the subsequent inflammatory response following surgical trauma. As rehabilitation progressed, MTA progressively decreased (AS2: 1.8 ± 0.2 °C) until returning to pre-injury levels in the third postoperative month (AS3: 0.9 ± 0.3 °C), coinciding with the athlete's clinical recovery. This pattern is consistent with the concept

proposed by Gomez-Carmona et al. (Gomez-Carmona et al., 2020), suggesting that thermal asymmetry may represent a physiological marker responsive to tissue stress and recovery. Consequently, infrared thermography may have potential not only for injury prevention but also for monitoring rehabilitation following ACL reconstruction in elite athletes.

Skin temperature is known to be influenced by various intrinsic and extrinsic factors, including circadian rhythm, metabolic rate, age, genetics and nutritional state (Fernández-Cuevas et al., 2015). Because these variables may affect absolute temperature values, the use of MTA has been recommended as a more reliable indicator, since it minimizes systemic interference and better reflects localized physiological alterations (Christensen et al., 2012). Adopting this metric aligns with broader methodological recommendations in the thermography literature and enhances the interpretability of the present findings (Marins et al., 2015).

Taken together, the results of this case substantiate the utility of infrared thermography as a clinically accessible method for daily or weekly monitoring of orthopedic injuries, postoperative inflammatory responses and recovery evolution. Nevertheless, this case has inherent limitations, including the analysis of a single athlete and the absence of control for all environmental or physiological variables. As such, caution is needed when generalizing these findings. Future studies involving larger cohorts and standardized monitoring protocols may help establish clinically meaningful MTA thresholds associated with different stages of healing, enhancing the utility of thermography in guiding return to sport decisions for elite athletes.

5. Conclusion

Infrared thermography allowed the longitudinal monitoring of knee thermal asymmetry throughout the recovery of this elite athlete following ACL injury and reconstruction. The findings suggest that thermography may provide complementary information on temporal changes during rehabilitation. However, these observations are limited to a single case and should be interpreted with caution. Further longitudinal studies involving larger cohorts are warranted to investigate the relationship between thermal asymmetry, tissue healing, and clinical recovery following ACL reconstruction.

Acknowledgements

The authors appreciate the assistance of Medical, Physiology, Physiotherapy and Administrative Departments of Botafogo de Futebol e Regatas.

List of Abbreviations

Anterior cruciate ligament (ACL), before injury (BI), after injury (AI), after first month of surgery (AS1), after second month of surgery (AS2) and after third month of surgery (AS3), magnetic resonance imaging (MRI), Mean temperature asymmetry (MTA)

Competing Interests

The author(s) declare that they have no competing interests

Authors' Contributions

DP study design, data collection. statistical analysis, manuscript writing, discussion of results, figure design; IM manuscript writing, discussion of results, critical review; CS manuscript writing, discussion of results, quality assurance and control; GM discussion of results, figure design; MC data collection, critical review; JG and CF clinical procedures and surgery, data collection, discussion of results, figure design; RA discussion of results, critical review; FP discussion of results, critical review, quality assurance and control JM discussion of results, critical review, quality assurance and control.

Availability of Data and Materials

Data will be shared upon reasonable request. Please contact:

Dailson Paulucio. M.Sc

Biometrics Laboratory, School of Physical Education and Sports, Federal University of Rio de Janeiro.
Av. Carlos Chagas Filho, 540 Cidade Universitária; ZIP: 21941-599. Rio de Janeiro, RJ, Brazil.
dailsonpaulucio@gmail.com

References

Bjordal, J. M., Arnly, F., Hannestad, B., & Strand, T. (1997). Epidemiology of anterior cruciate ligament injuries in soccer. *The American Journal of Sports Medicine, 25*(3), 341–345. https://doi.org/10.1177/036354659702500312

Brisoschi, M., Macedo, J., & Macedo, R. (2003). Termometria cutânea: Novos conceitos. *Jornal Vascular Brasileiro, 2*, 9.

Brophy, R. H., Stepan, J. G., Silvers, H. J., & Mandelbaum, B. R. (2015). Defending puts the anterior cruciate ligament at risk during soccer: A gender-based analysis. *Sports Health, 7*(3), 244–249. https://doi.org/10.1177/1941738114535184

Christensen, J., Matzen, L. H., Vaeth, M., Schou, S., & Wenzel, A. (2012). Thermography as a quantitative imaging method for assessing postoperative inflammation. *Dentomaxillofacial Radiology, 41*(6), 494–499. https://doi.org/10.1259/dmfr/98447974

Corte, A. C., Pedrinelli, A., Marttos, A., Souza, I. F. G., Grava, J., & Jose Hernandez, A. (2019). Infrared thermography study as a complementary method of screening and prevention of muscle injuries: Pilot study. *BMJ Open Sport & Exercise Medicine, 5*(1), Article e000431. https://doi.org/10.1136/bmjsem-2018-000431

Côrte, A., & Hernandez, A. (2016). Application of medical infrared thermography to sports medicine. *Revista Brasileira de Medicina do Esporte, 22*(4), 315–319. https://doi.org/10.1590/1517-869220162204160783

Dvorak, J., & Junge, A. (2000). Football injuries and physical symptoms: A review of the literature. *The American Journal of Sports Medicine, 28*(5_suppl), S3–S9. https://doi.org/10.1177/28.suppl_5.s-3

Escamilla-Galindo, V. L., Estal-Martinez, A., Adamczyk, J. G., Brito, C. J., Arnaiz-Lastras, J., & Sillero-Quintana, M. (2017). Skin temperature response to unilateral training measured with infrared thermography. *Journal of Exercise Rehabilitation, 13*(5), 526–534. https://doi.org/10.12965/jer.1735046.523

Escamilla-Galindo, V. L., Luis Felipe, J., Alonso-Callejo, A., Van-der-Horst, R., de la Torre-Combarros, A., Minafra, P., Fernandez-Munoz, D., & Fernandez-Cuevas, I. (2025). Return-to-play criteria based on infrared thermography during anterior cruciate ligament rehabilitation in football players. *Biology of Sport, 42*(2), 161–167. https://doi.org/10.5114/biolsport.2025.144295

Fernandes, A., Pimenta, E., Moreira, D., Marins, J., & Garcia, E. (2017). Application of infrared thermography in the assessment of muscle damage in elite soccer athletes. *MOJ Orthopedics & Rheumatology, 8*(5), Article 00328.

Fernández-Cuevas, I., Bouzas Marins, J. C., Arnáiz Lastras, J., Gómez Carmona, P. M., Piñonosa Cano, S., García-Concepción, M. Á., & Sillero-Quintana, M. (2015). Classification of factors influencing the use of infrared thermography in humans: A review. *Infrared Physics & Technology, 71*, 28–55. https://doi.org/10.1016/j.infrared.2015.02.007

Gomez-Carmona, P., Fernandez-Cuevas, I., Sillero-Quintana, M., Arnaiz-Lastras, J., & Navandar, A. (2020). Infrared thermography protocol on reducing the incidence of soccer injuries. *Journal of Sport Rehabilitation, 29*(8), 1222–1227. https://doi.org/10.1123/jsr.2019-0056

Gornitzky, A. L., Lott, A., Yellin, J. L., Fabricant, P. D., Lawrence, J. T., & Ganley, T. J. (2016). Sport-specific yearly risk and incidence of anterior cruciate ligament tears in high school athletes: A systematic review and meta-analysis. *The American Journal of Sports Medicine, 44*(10), 2716–2723. https://doi.org/10.1177/0363546515617742

Litscher, G., Litscher, D., Ofner, M., Gaischek, I., & Malliga, D. E. (2014). Temperature measurements in rehabilitation in patients with completely ruptured anterior cruciate ligament before and after RegentK and physiotherapy. *Medicines, 1*(1), 12–21. https://doi.org/10.3390/medicines1010012

Marins, R., Fernández-Cuevas, I., Arnaiz-Lastras, J., & Sillero-Quintana, M. (2015). Applications of infrared thermography in sports: A review. *Revista Internacional de Medicina y Ciencias de la Actividad Física y del Deporte, 15*, 19.

Moreira, D. G., Costello, J. T., Brito, C. J., Adamczyk, J. G., Ammer, K., Bach, A. J. E., Costa, C. M. A., Eglin, C., Fernandes, A. A., Fernandez-Cuevas, I., Ferreira, J. J. A., Formenti, D., Fournet, D., Havenith, G., Howell, K., Jung, A., Kenny, G. P., Kolosovas-Machuca, E. S., Maley, M. J., … Sillero-Quintana, M. (2017). Thermographic imaging in sports and exercise medicine: A Delphi study and consensus statement on the measurement of human skin temperature. *Journal of Thermal Biology, 69*, 155–162. https://doi.org/10.1016/j.jtherbio.2017.07.006

Omar, N. A., & McKinley, J. C. (2018). Measurement of temperature induced in bone during drilling in minimally invasive foot surgery. *The Foot, 35*, 63–69. https://doi.org/10.1016/j.foot.2018.02.002

Windisch, C., Brodt, S., Roehner, E., & Matziolis, G. (2016). Regional differences in temperature course after knee arthroplasty. *Knee Surgery, Sports Traumatology, Arthroscopy, 24*(8), 2686–2691. https://doi.org/10.1007/s00167-015-3809-z

Declaração Ética

Revisão por Pares: Aberta.

Conflito de Interesse: Nada a declarar.

Financiamento: Nada a declarar.