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RESEARCH ARTICLE (ORIGINAL)

The effect of cryotherapy on knee surface temperature after total knee arthroplasty: A quasi-experimental study

Efeito da crioterapia na temperatura superficial do joelho em contexto de artroplastia total: Um estudo quasi-experimental

Efecto de la crioterapia sobre la temperatura de la superficie de la rodilla en el contexto de una artroplastia total: Un estudio casiexperimental

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Abstract

Background: Cryotherapy is used during the postoperative phase of total knee arthroplasty to reduce pain, inflammation, blood loss, cell metabolism, and edema. The therapeutic effects of cryotherapy are achieved when skin surface temperatures are at or below 15ºC.
Objective: To determine the effect of cryotherapy on the skin surface temperature of a knee undergoing total knee arthroplasty using different interfaces.
Methodology: A 1X4X6 quasi-experimental and factorial study was conducted, comparing one modality of cryotherapy (ice bag), four interfaces (Robert Jones-type bandage, tubular mesh bandage, thin pillowcase-type cloth, and non-woven compress), and six periods of cryotherapy administration (10, 20, 30, 40, 50, and 60 minutes) on a knee undergoing total knee arthroplasty. The sample consisted of 60 participants randomly assigned to one of the four experimental groups (interfaces). A total of 720 cryotherapy treatments were administered.
Results: There was no decrease in skin surface temperature to therapeutic levels in any of the experimental groups. The mean values obtained were: Robert Jones-type bandage = 34.13ºC; tubular mesh bandage = 23.90ºC; thin pillowcase-type cloth = 22.84ºC, and non-woven compress = 21.92ºC.
Conclusion: Under the experimental conditions studied, cryotherapy had no therapeutic effect.

Keywords: knee arthroplasty; cryotherapy; skin temperature

Resumo

Enquadramento: A crioterapia é utilizada no pós-operatório da artroplastia total (AT) do joelho, visando a diminuição da dor, processo inflamatório, perda sanguínea, metabolismo celular e contenção do edema. A crioterapia obtém efeitos terapêuticos para valores de temperatura superficial cutânea (TempSC) ≤ 15ºC.
Objetivo: Avaliar o efeito da crioterapia, utilizando diferentes interfaces, sobre a TempSC do joelho da pessoa submetida a AT.
Metodologia: Estudo quase-experimental, fatorial 1X4X6: uma modalidade de crioterapia (saco gelo) *versus* quatro interfaces - ligadura Robert Jones (LRJ), malha tubular (MT), pano fino (PF) e compressa não-tecido (CNT) - *versus* seis tempos de aplicação da crioterapia (10, 20, 30, 40, 50 e 60 minutos). A amostra, de conveniência, inclui 60 participantes, com distribuição aleatória por quatro grupos experimentais (interfaces). Foram realizadas 720 aplicações de crioterapia.
Resultados: Em nenhum grupo experimental foi observado descida da TempSC para valores terapêuticos, obtendo-se as seguintes médias: LRJ = 34,13ºC; MT = 23,90ºC; PF = 22,84 ºC e CNT = 21,92ºC.
Conclusão: Nas condições experimentais em estudo, a crioterapia não obteve efeito terapêutico.

Palavras-chave: artroplastia do joelho; crioterapia; temperatura cutânea

Resumen

Marco contextual: La crioterapia se utiliza en el posoperatorio de la artroplastia total (AT) de rodilla para reducir el dolor, la inflamación, la pérdida de sangre, el metabolismo celular y la contención del edema. La crioterapia consigue efectos terapéuticos para valores de temperatura de la superficie cutánea (TempSC) ≤ 15ºC.
Objetivo: Evaluar el efecto de la crioterapia utilizando diferentes interfaces sobre la TempSC de la rodilla de la persona sometida a una AT.
Metodología: Estudio casiexperimental, factorial 1X4X6, una modalidad de crioterapia (bolsa de hielo) frente a cuatro interfaces - vendaje Robert Jones (LRJ), malla tubular (MT), tela fina (PF) y compresa no tejida (CNT) - frente a seis tiempos de aplicación de la crioterapia (10, 20, 30, 40, 50 y 60 minutos). La muestra de conveniencia incluyó 60 participantes, asignados aleatoriamente a cuatro grupos experimentales (interfaces). Se realizaron 720 aplicaciones de crioterapia.
Resultados: En ninguno de los grupos experimentales se produjo un descenso de la TempSC para valores terapéuticos y se obtuvieron las siguientes medias: LRJ = 34,13ºC; MT = 23,90ºC; PF = 22,84 ºC y CNT = 21,92ºC.
Conclusión: En las condiciones experimentales estudiadas, la crioterapia no tuvo ningún efecto terapéutico.

Palabras clave: artroplastia de rodilla; crioterapia; temperatura cutánea

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Introduction

Cryotherapy is a common clinical nursing practice for treating total knee arthroplasty (TKA) during the first three postoperative days. It is used to reduce pain, control inflammation, reduce blood loss, limit edema, and decrease cellular metabolism (Cameron, 2019; Ostrowski et al., 2019; Thacoor & Sandiford, 2019; Ueyama et al., 2018). However, the use of cryotherapy in this context has raised some questions regarding the observation of its therapeutic effects.

Several research studies have attempted to evaluate the therapeutic effects of cryotherapy on a knee undergoing TKA, but the results have been inconsistent (Bélanger, 2015). Nevertheless, the literature review conducted by Thacoor and Sandiford (2019) aimed at synthesizing the evidence regarding the therapeutic effects of cryotherapy on TKA found that this treatment has some therapeutic benefits. Therefore, more evidence is needed to evaluate the effectiveness of cryotherapy to help health professionals decide whether or not to use it. Specifically, it is necessary to determine i) the efficiency of commonly used cryotherapy modalities in cooling tissues to therapeutic values, ii) which interfaces or devices placed between the cryotherapy modality and the skin are the most efficient, iii) how long the treatment should last considering the anatomic location, cryotherapy modality, and interface used, and *iv)* whether the basal skin surface temperature (*SSTemp*) of the knee undergoing TKA influences the thermal efficiency of cryotherapy modalities. One of the questions that motivated our study focused on how interfaces affect the thermal capacity of cryotherapy modalities aimed at reducing and/or maintaining tissue temperature at therapeutic levels. Therefore, the overall objective of our study was to determine the effect of cryotherapy on the SSTemp of the knee undergoing TKA using different interfaces.

Background

The U.S. Agency for Healthcare Research and Quality (2022) reports that over 754,000 TKA procedures are performed each year in the United States of America. This surgical procedure replaces the articular surfaces of a knee damaged by osteoarthritis, rheumatoid arthritis, or post-traumatic arthritis (American Academy of Orthopaedic Surgeons, 2020). Cryotherapy is defined as the use of cooling agents on the skin's surface to lower the temperature of soft tissues for therapeutic purposes (Bélanger, 2015; Cameron, 2019; Ostrowski et al., 2019; Thacoor & Sandiford, 2019; Ueyama et al., 2018). According to Bélanger (2015), the therapeutic effect of applying cryotherapy to a knee undergoing TKA is observed when a SSTemp equal to or below 15°C is reached.

Several factors influence thermodynamic properties and tissue cooling, including *i)* the difference between body temperature and the cryotherapy modality (initial temperatures), *ii)* the dimensions of the cryotherapy modality, *iii)* the body surface in contact with the cryotherapy modality, *iv)* the anatomical location (subcutaneous fat tissue and muscle mass), *v)* the heat absorption capacity of the cryotherapy modality, *vi)* the thermal capacity of the cryotherapy modality, *vii)* the enthalpy (heat) of fusion principle, *viii)* the duration of cryotherapy administration, *ix)* the type of interface, *x)* individual variability, *xi)* the administration of cryotherapy with compression, and *xii)* ambient temperature and physical activity (Bélanger, 2015; Gregório et al., 2014; Knight, 2000; Merrick et al., 2003; Tomchuk et al., 2010).

As such, the interface used between the cryotherapy modality and the knee skin is also one of the factors to be considered in the administration of cryotherapy. In the postoperative period of TKA, several surgical dressings (bandages, compresses, or others) are used to protect the surgical wound from the external environment until sutures are removed. The surgical dressing, as well as the material used under some cryotherapy modalities to prevent frostbite (compress, towel, cloth, or others), act as resistance to the exchange of thermal energy between the skin and the cryotherapy modality. Their composition, thickness, and size can limit the thermal efficiency of cryotherapy and therefore the reduction (and maintenance) of knee temperature to values considered therapeutic (Bélanger, 2015; Knight, 2000; Merrick et al., 2003).

Although cryotherapy is a therapeutic intervention frequently used by health professionals, particularly nurses, in the care of knees undergoing TKA, its therapeutic results are not unanimous, highlighting the need for more research to provide a more robust framework for the administration of cryotherapy (Bélanger, 2015; Cameron, 2019; Ostrowski et al., 2019; Thacoor & Sandiford, 2019).

Hypotheses

Hypothesis 1 (H1) - The administration of cryotherapy with an ice bag over a Robert Jones (RJ) -type bandage decreases the SSTemp of the knee undergoing TKA to therapeutic values in the postoperative period;

Hypothesis 2 (H2) - The administration of cryotherapy with an ice bag over a tubular mesh (TM) bandage decreases the SSTemp of the knee undergoing TKA to therapeutic values in the postoperative period;

Hypothesis 3 (H3) - The administration of cryotherapy with an ice bag over a thin pillowcase-type (TPCT) cloth decreases the SSTemp of the knee undergoing TKA to therapeutic values in the postoperative period;

Hypothesis 4 (H4) - The administration of cryotherapy with an ice bag over an unfolded 15X20cm non-woven compress (NWC) decreases the *SSTemp* of the knee undergoing TKA to therapeutic values in the postoperative period.

Methodology

The design of our study was based on the nursing care model used in several Portuguese health units. This model involves applying cryotherapy with an ice bag for three days during the postoperative period in patients who underwent

TKA. A 1X4X6 quasi-experimental and factorial design (Coutinho, 2019) was followed, comparing one modality of cryotherapy, four interfaces, and six periods of cryotherapy administration on a knee undergoing TKA. The study sample comprised 60 patients who were admitted to the orthopedics service of a hospital in the northern region of Portugal. The convenience sampling method was used, and the participants were randomly assigned to one of four experimental groups, each with one interface and a total of 15 participants. The randomization process involved consecutively distributing the participants among the four experimental groups, based on the chronological order of their admission to the care unit. To be eligible for our study, participants had to meet the following criteria: i) to be 18 years of age or older, ii) to have undergone TKA for osteoarthritis, iii) to be mentally competent, and iv) to be hospitalized with at least four days of postoperative care. Participants with i) altered knee skin sensitivity, ii) open knee wounds (blistering or surgical wound dehiscence), iii) cochlear temperature ≥ 38°C, or iv) any health condition that contraindicates the administration of cold (e.g. Raynaud's phenomenon or disease, cryoglobulinemia, phlebitis, or deep vein thrombosis in the lower limb; Cameron, 2019) were excluded from our study. No participants were lost during data collection. The following independent variables were defined: i) the cryotherapy modality (1.2-liter plastic bag with 30cmx40cm, containing 1400mg of ice cubes, and a contact area on the knee skin surface of approximately 900cm^2, fixed to the knee with an elastic Velcro strap of 10X100 cm); ii) the four interfaces: RJ-type bandage, TM bandage, TPCT cloth, and NWC; iii) the anatomical location where the SSTemp was monitored (lateral and medial facets of the knee undergoing TKA); and iv) the periods of cryotherapy administration (10, 20, 30, 40, 50, and 60 minutes). The dependent variable was the SSTemp of the knee undergoing TKA after cryotherapy. Cryotherapy was administered over the surgical dressing and adjacent areas while the participants were lying on their beds. In order not to expose the participants to an increased risk of infection by handling the surgical dressing, the SSTemp was monitored in the areas of the knee not covered by the dressing, using a thermocouple-type measurement device (thermoelectric thermometer), with a software-connected probe to record values. Data were collected between April 1 and December 31, 2021. Table 1 shows the distribution of the periods of cryotherapy administration across the postoperative period and the part of the day in which the treatment was carried out.

Table 1

Distribution of the periods of cryotherapy administration across the postoperative period and the parts of the day

	PO period (days) and treatment duration (minutes)		
Part of the day	**1st PO day**	**2nd PO day**	**3rd PO day**
Morning	10 min	30 min	50 min
Afternoon	20 min	40 min	60 min

Note. PO = Postoperative.

Bearing in mind that each experimental group included 15 participants, each group underwent 90 treatments, with six cryotherapy administrations per participant in the first three postoperative days. The temperature was assessed on the lateral and medial facets of the knee. Regarding the SSTemp, values less than or equal to 15ºC were considered therapeutic, values between 16ºC and 27ºC were considered suboptimal (with the possibility of some therapeutic effects being observed), and values between 28ºC and 35ºC were considered to have no therapeutic effect (Bélanger, 2015). The data were processed using the IBM SPSS statistics software program, version 28.0, with a significance level of $p \leq 0.05$, and descriptive and inferential statistical measures, such as the Wilcoxon test and the Kruskal-Wallis test (Marôco, 2018). Our study obtained approval from both the Ethics Committee for Research in Life Sciences and Health of its supervising higher education institution (CEICVS Opinion 020/2020) and the Ethics Committee for Health and the Board of Directors of the hospital center where it was conducted (Opinion 2021-337- CHPVVC CA). It also adhered to the ethical principles outlined in the Declaration of Helsinki, including the safeguarding of human health and the informed consent of the participants.

Results

Our study included 60 participants with a mean age of 70.2 years (SD = 6.96; min = 49, max = 84) and a mean Body Mass Index (BMI) of 30.1 (SD = 5.51; min=19.3, max.= 40.9). Most participants (73.3%; n = 44) were female and had the surgery (TKA) performed on the right knee (55%; n = 33).

The results are presented in the order in which the four study hypotheses were defined. Table 2 presents the mean SSTemp values for each of the four experimental groups (interfaces) after 10, 20, 30, 40, 50, and 60 minutes of cryotherapy treatment in the two anatomical locations of the treated knee: lateral (KLatF) and medial (KMedF) facets. To determine the validity of each hypothesis, our study considered mean SSTemp values equal to or below 15ºC as therapeutic for each experimental group/ interface (Bélanger, 2015).

Table 2

Mean SSTemp values in the four experimental groups (four interfaces)

Anatomical location of the knee		Robert Jones-type bandage		Tubular mesh bandage		Thin pillow-case-type cloth		Non-woven compress	
		ac	b	ac	b	ac	b	ac	b
Lateral facet		34.19	34.53	25.08	34.43	23.57	34.52	23.02	34.43
Medial facet		34.07	34.49	22.73	33.96	22.11	34.44	20.83	34.33
Lateral + medial facet		34.13	34.51	23.90	34.20	22.84	34.48	21.92	34.38
Lateral facet	10min	33.75	34.00	25.47	34.45	24.24	34.48	22.76	34.31
	20min	34.30	34.59	25.67	34.21	24.25	34.53	23.71	34.54
	30min	34.28	34.72	24.39	34.42	22.89	34.65	22.81	34.54
	40min	34.57	34.91	25.52	34.63	24.79	34.43	23.19	34.12
	50min	34.12	34.77	24.52	34.44	23.77	34.81	23.45	34.69
	60min	34.14	34.20	24.89	34.40	21.48	34.22	22.18	34.40
Medial facet	10min	33.73	34.25	24.43	33.79	23.50	34.22	21.87	34.07
	20min	34.08	34.68	22.70	33.81	21.96	34.25	20.95	34.57
	30min	33.64	34.25	22.61	33.93	22.17	34.42	20.94	34.36
	40min	34.50	34.88	22.29	34.04	22.70	34.44	21.32	33.80
	50min	34.34	34.87	21.79	34.27	21.35	34.75	19.48	34.63
	60min	34.10	34.03	22.57	33.94	20.95	34.53	20.42	34.54

Note. ac = Mean SSTemp after cryotherapy; b = Basal SSTemp.

Administering cryotherapy over a RJ-type bandage

Table 2 shows that the mean SSTemp values in the RJ-type bandage group were never considered therapeutic. The mean SSTemp value observed was 34.13°C after cryotherapy, ranging from 33.64°C (30 minutes, KMedF) to 34.57°C (40 minutes, KLatF). Thus, based on the results obtained, our study concluded that H1 – *The administration of cryotherapy with an ice bag over an RJ-type bandage decreases the SSTemp of the knee undergoing TKA to therapeutic values in the postoperative period* - is false. In other words, the administration of cryotherapy with an ice bag over RJ-type bandages does not reduce the SSTemp of a knee undergoing TKA to therapeutic values in the postoperative period.

Administering cryotherapy over a TM bandage

The analysis of the mean SSTemp observed (see Table 2) reveals that cryotherapy administered with TM bandages as interfaces resulted in suboptimal values, as defined by Bélanger (2015). In other words, the SSTemp did not reach the desired therapeutic standard, remaining between basal tissue temperatures and therapeutic values. The mean SSTemp value observed was 23.90°C, ranging from 21.79°C (50 minutes, KMedF) to 25.67°C (20 minutes, KLatF). Therefore, it is possible to conclude that the administration of cryotherapy with an ice bag over TM bandages does not reduce the SSTemp of a knee undergoing TKA to therapeutic values in the postoperative period. Therefore, H2 – *The administration of cryotherapy with an ice bag over a TM bandage decreases the SSTemp of the knee undergoing TKA to therapeutic values in the postoperative period* - is false.

Administering cryotherapy over a TPCT cloth

Table 2 shows that the mean SSTemp values in the TPCT cloth group never reached therapeutic levels. The observed mean SSTemp value was 22.84°C, ranging from 20.95°C (60 minutes, KMedF) to 24.79°C (40 minutes, KLatF). Similar to the TM bandage experimental group, the mean values recorded in this group were considered sub-optimal. However, this group differed from the previous experimental groups (RJ-type bandage and TM bandage) in that, out of a total of 180 observations, therapeutic SSTemp values were reached in four cases: *i)* three cases were observed on the lateral facet of the knee - two with the administration of cryotherapy for 60 minutes (13.31°C and 13.38°C) and one when cryotherapy was administered for 50 minutes (14.7°C) - and, *ii)* one case was observed on the medial facet of the knee when cryotherapy was administered for 50 minutes (14.43°C). Although these four cases exceptionally reached therapeutic SSTemp values, taking into account the mean SSTemp values observed, no further evidence was obtained that the administration of cryotherapy with an ice bag over TPCT cloths contributes to reducing the SSTemp of the knee undergoing TKA to therapeutic values in the postoperative period. Therefore, H3 – *The administration of cryotherapy with an ice bag over a TPCT cloth decreases the SSTemp of the knee undergoing TKA to therapeutic values in the postoperative period* - is false.

Administering cryotherapy over a NWC

When cryotherapy was applied over the NWC interface, the mean SSTemp value obtained was 21.92°C, with a range from 19.48°C (50 minutes, KMedF) to 23.71°C

(20 minutes, KLatF; see Table 2). These values were also considered suboptimal (Bélanger, 2015). Like the TPCT cloth interface, out of 180 cryotherapy administrations, six observations reached therapeutic SSTemp values: i) two cases were observed on the lateral facet of the knee when cryotherapy was administered for 10 minutes (14.96ºC) and 40 minutes (14.87ºC), ii) four cases were observed on the medial facet of the knee with the administration of cryotherapy for 20 minutes (14.91ºC), and the same participant exhibited therapeutic SSTemp values when cryotherapy was administered for 10 minutes (13.27°C), 20 minutes (14.21°C), and 50 minutes (12.36°C). Similar to the TPCT cloth experimental group, despite these six exceptional cases showing therapeutic SSTemp values, it is possible to conclude that cryotherapy with an ice bag over NWC does not reduce the SSTemp of the knee undergoing TKA to therapeutic values in the postoperative period, considering the mean SSTemp values observed and in agreement with the majority of authors. Therefore, H4 - The administration of cryotherapy with an ice bag over an unfolded 15X20cm NWC decreases the SSTemp of the knee undergoing TKA to therapeutic values in the postoperative period - is false.

Differences in SSTemp before (basal temperature) and after cryotherapy among the experimental groups (intra-group evaluation) and across the six periods of cryotherapy administration

The Wilcoxon test indicates that the administration of cryotherapy to the lateral facet of the knee using the RJ-type bandage did not result in any statistically significant differences in the SSTemp before and after cryotherapy across the six periods of cryotherapy administration, either on the lateral or medial facets. However, the results in Table 3 show statistically significant differences in all six periods of cryotherapy administration and both anatomical locations (lateral and medial facets) for the other experimental groups - TM bandage, TPCT cloth, and NWC ($p < 0.001$).

Table 3

Differences in SSTemp before (basal temperature) and after cryotherapy among the experimental groups and across the six periods of cryotherapy administration

Experimental group *(Interface)*	Anatomical location of the knee	Test	Treatment duration (minutes)					
			10	20	30	40	50	60
Robert Jones-type bandage	Lateral facet	*Z*	-1.477b	-.966 b	-2.215 b	-1.819 b	-2.726 b	-1.193 b
		p	0.147	0.359	0.026	0.073	0.004	0.247
	Medial facet	*Z*	-2.613 b	-2.045 b	-2.359 b	-2.073 b	-2.499 b	-0.170 c
		p	0.007	0.040	0.016	0.036	0.010	0.890
Tubular mesh bandage	Lateral facet	*Z*	-3.408b	-3.408b	-3.408b	-3.408b	-3.408b	-3.408b
		p	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
	Medial facet	*Z*	-3.408 b	-3.408 b	-3.408 b	-3.408 b	-3.408 b	-3.408 b
		p	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Thin pillow-case-type cloth	Lateral facet	*Z*	-3.408 b	-3.408 b	-3.408 b	-3.408 b	-3.408 b	-3.408 b
		p	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
	Medial facet	*Z*	-3.408 b	-3.408 b	-3.408 b	-3.408 b	-3.408 b	-3.408 b
		p	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Non-woven compress	Lateral facet	*Z*	-3.408 b	-3.408 b	-3.408 b	-3.408 b	-3.408 b	-3.408 b
		p	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
	Medial facet	*Z*	-3.408 b	-3.408 b	-3.408 b	-3.408 b	-3.408 b	-3.408 b
		p	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

Note. b = Based on positive ranks; c = Based on negative ranks; *p* = Significance; Z = Wilcoxon test; SSTemp = Skin surface temperature

Differences in the decrease in SSTemp after cryotherapy in each period of cryotherapy administration among the four experimental groups (inter-group evaluation)

According to the Kruskal-Wallis test, there were significant differences ($p < 0.001$) between the four experimental groups across the six periods of cryotherapy administration (10, 20, 30, 40, 50, and 60 minutes) in the reduction of SSTemp of the knee undergoing TKA, both on the lateral and medial facets (see Table 4). Statistically significant differences were found between the four experimental groups, specifically, between i) NWC and RJ-type bandage ($p < 0.001$), ii) TPCT cloth and RJ-type bandage ($p < 0.001$), and iii) TM bandage and RJ-type bandage ($p < 0.001$).

Table 4

Differences in the decrease in SSTemp of the knee undergoing TKA among the four experimental groups and across the six periods of cryotherapy administration

Anatomical location of the knee	Test	Treatment duration (minutes)					
		10	20	30	40	50	60
Lateral facet	X^2	35.880	35.205	34.423	35.529	34.142	36.895
	p	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Medial facet	X^2	34.474	33.865	33.451	34.791	34.706	35.880
	p	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

Note: X^2 = Kruskal-Wallis test; p = Significance.

Discussion

None of the 180 cryotherapy treatments performed in the RJ-type bandage group showed any therapeutic effect. In this group, the mean SSTemp observed after cryotherapy was 34.13°C, which was significantly different (a difference of 19.13°C) from the SSTemp considered therapeutic. Therefore, the use of the RJ-type bandage as the interface did not result in any therapeutic or suboptimal results. On the other hand, a decrease in SSTemp was observed in the TM bandage, TPCT cloth, and NWC groups across all six periods of cryotherapy administration. However, it is important to note that these results do not necessarily indicate therapeutic benefits. The TM bandage group had a mean SSTemp of 23.90°C, which falls short of the therapeutic threshold by 8.9°C. The TPCT cloth group had a mean SSTemp of 22.84°C, which is 7.84°C below the therapeutic threshold. The NWC group had a mean SSTemp of 21.92°C, which is 6.92°C below the therapeutic threshold. These results indicate that cryotherapy applied through the TM bandage, TPCT cloth, and NWC groups did not achieve the mean SSTemp values considered to have a therapeutic effect on the knee after TKA. Instead, the values remained suboptimal, as defined by Bélanger (2015). In addition, although some therapeutic effects were observed within this suboptimal range, they were not as robust, or significant as desired. The results of the Wilcoxon test indicate statistically significant differences across the six periods of cryotherapy administration and in the two anatomical locations (lateral and medial facets) for all experimental groups except for the RJ-type bandage ($p < 0.001$). However, although the results obtained with the other three interfaces (TM bandage, TPCT cloth, and NWC) are noteworthy, they are not clinically relevant because the reduction in SSTemp to therapeutic values only occurred on a few occasions (Bélanger, 2015). The Kruskal-Wallis test results indicate significant differences ($p < 0.001$) in the decrease in SSTemp across the six periods of cryotherapy administration (10, 20, 30, 40, 50, and 60 min) among the four experimental groups, on both the lateral and medial facets of the knee (Table 3).

When assessing the therapeutic impact of cryotherapy on the knee after TKA, it is also relevant to consider the number of cases that achieved therapeutic SSTemp values. No therapeutic values were recorded in the 180 cryotherapy treatments carried out in each of the RJ-type bandage and TM bandage groups. In the TPCT cloth group, four cases out of 180 cryotherapy treatments resulted in therapeutic SSTemp values, and six cases were observed in the NWC group. It is worth noting that the four cases observed with therapeutic SSTemp values in the TPCT cloth group represent only 2.2% of the total 180 treatments (90 on the lateral facet and 90 on the medial facet of the knee). This is a low percentage considering the goal of reducing SSTemp values to therapeutic levels. Similarly, out of the 180 cryotherapy treatments performed in the NWC group, only six cases resulted in therapeutic SSTemp values, which accounted for a mere 3.3%. This percentage is also considered low. Based on the mean SSTemp values obtained across the six periods of cryotherapy administration and the absence of cases with therapeutic SSTemp values, the use of RJ-type bandages is not recommended. Although some therapeutic effects of cryotherapy were occasionally observed in the TM bandage, TPCT cloth, and NWC groups, the values obtained were suboptimal and did not meet the magnitude, robustness, and frequency desired. Nevertheless, the results indicate that the NWC group had values closest to the therapeutic standard.

Our study found statistically significant differences ($p < 0.001$) in the decrease of SSTemp on both the lateral and medial facets of the knee (see Table 4) across the four interfaces and six periods of cryotherapy administration. Several studies have shown that cryotherapy has positive effects on the knee after TKA. However, other studies conducted within the same context did not observe these effects (Aggarwal et al., 2023; Bélanger, 2015; Demoulin et al., 2012; Thacoor & Sandiford, 2019). These differences may be related to suboptimal SSTemp values obtained after cryotherapy and the NNT (Number Needed to Treat) applied.

Demoulin et al. (2012) reported therapeutic SSTemp values (≤ 15°C) after applying gas cryotherapy (“Cryotron TM”) to a knee undergoing TKA. In this case, cryotherapy was applied directly to the skin, and the SSTemp obtained was 14°C, assessed with an infrared thermometer. However, considering that the only common element with our study was the type of surgery (knee undergoing TKA), it was not possible to compare the results.

When comparing the results of our study with others where cryotherapy was applied to different anatomical locations such as the ankle, thigh, and triceps surae, it is possible to observe therapeutic SSTemp values (Ibrahim et al., 2005; Kanlayanaphotporn & Janwantanakul, 2005; Janwantanakul, 2004; Love et al., 2013; Merrick et al., 2003; Ostrowski et al., 2019; Santos et al., 2015; Tassignon et al., 2018). However, some reasons justify the differences in results between these studies and our study. Specifically, i) the participants were younger (with a mean age of 31.3 years), ii) cryotherapy was administered to a different anatomical location (cryotherapy was only administered to the knee in the studies conducted by Ibrahim et al. (2005) and Tassignon et al. (2018)), and iii) cryotherapy was administered to individuals who were not in the immediate postoperative period after TKA.
In the TPCT cloth group, two participants had four observations of therapeutic SSTemp values, and in the NWC group, three participants had six observations of therapeutic SSTemp values. The fact that the same participants reached therapeutic SSTemp values during different periods of cryotherapy proves that each person has an individual thermal profile when it comes to reacting to cryotherapy. Additionally, therapeutically effective SSTemp values were observed during longer cryotherapy treatments (50 and 60 minutes). This may suggest that longer treatments can yield better results in reducing SSTemp. The thermodynamic system consisting of the ice bag, four interfaces, and skin tissue in our study was unable to achieve the necessary thermal robustness to reduce the SSTemp of the knee to therapeutic values after TKA. Although there were differences between the experimental groups and some suboptimal mean SSTemp values were observed (Bélanger, 2015), the system failed to meet the required standards.
Our study faced some limitations. First, as it was conducted in a real-world context, specifically in a hospital inpatient unit, the ambient temperature could not be controlled. This factor may have influenced SSTemp before and after cryotherapy. Second, individual variability in body temperature, even in an apyretic state, varies from person to person, which may affect the effectiveness of cryotherapy on SSTemp. In addition, body weight, including fat tissue and muscle mass, also influences the effectiveness of cryotherapy on SSTemp. This factor was also not controlled.

Conclusion

In our study, the NWC group demonstrated the most significant reduction in SSTemp after cryotherapy. Cryotherapy is frequently used in clinical settings, both in the immediate postoperative period of patients undergoing TKA and throughout the rehabilitation process, as an effective therapeutic tool. However, there is not enough robust evidence to justify the use of one cryotherapy modality over the other, because knowledge about their effectiveness in reducing SSTemp to values considered therapeutic is still insufficient. Based on the findings of our study and the absence of alternative cryotherapy modalities or thermodynamic frameworks, nurses should use NWC as the interface for cryotherapy in patients undergoing TKA for a duration of 50 to 60 minutes. Moreover, our study demonstrated that, despite being commonly used in clinical practice, the RJ-type bandage was the least effective in reducing SSTemp.
To compare our study's results with those found in the literature, it is necessary to analyze carefully the thermodynamic systems used to monitor the SSTemp of the knee after TKA, as they may produce different results. Our study provides evidence that supports the effectiveness of cryotherapy as a postoperative therapeutic intervention for patients who have undergone TKA. However, additional research is necessary to develop cryotherapy devices that ensure both safety and thermal efficiency when cooling the body to therapeutic levels.

Author contributions

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