DOI: https://doi.org/10.17816/KMJ675775 EDN: EVNMXB

Local Cryotherapy in Traumatology and Orthopedics: A Review of Current Approaches and Potential Clinical Use

Aleksandr V. Pushkarev[1,2], Natalia Y. Saakyan[1], Alexey V. Shakurov[1], Evgeny G. Bychkov[1], Antonina V. Butorina[1,3]

[1] Bauman Moscow State Technical University, Moscow, Russia;
[2] Russian Medical Academy of Continuous Professional Education, Moscow, Russia;
[3] The Russian National Research Medical University named after N.I. Pirogov, Moscow, Russia

ABSTRACT

Local cryotherapy is a treatment method used for injuries, musculoskeletal diseases, connective tissue diseases, and post-surgical rehabilitation. Novel technologies such as non-contact cooling with cold gases, augmented compression, and skin temperature regulation, have improved the effectiveness of cryotherapy and expanded its applications. However, it is still important to improve treatment protocols and determine optimal exposure parameters. Therefore, publications on the use of local cryotherapy in traumatology and orthopedics were reviewed to systematize clinical practice approaches and determine the key principles for the development of the treatment option. This article reviews studies on various local cryotherapy options used to treat musculoskeletal diseases and to rehabilitate patients after joint surgery, sport-related injuries, and bone tissue damage. It describes the mechanisms of action and the factors that influence the treatment effectiveness and safety. Local cryotherapy offers several therapeutic benefits, including reduced inflammation and pain, faster recovery of joint function, and reduced need for analgesics. Although more research is needed to confirm its effectiveness, local cryotherapy shows promise as a treatment for bone tissue healing. Most of the current evidence of effectiveness has been obtained from preclinical studies in animal models. Additional studies are required to confirm the applicability and safety of this treatment option in clinical practice. These studies should aim to optimize treatment parameters and evaluate treatment safety. Further randomized studies in humans are also needed. Local cryotherapy has been shown to effectively treat musculoskeletal diseases and rehabilitate musculoskeletal injuries. However, more research is needed to optimize treatment regimens based on the location of the injury and the area of cooling. Further research is needed to develop personalized, local cryotherapy protocols that consider patient characteristics, therapy goals, and the nature of the disease.

Keywords: local cryotherapy; traumatology; orthopedics; rehabilitation; joint diseases; sport-related injuries; bone tissue.

To cite this article:
Pushkarev AV, Saakyan NYu, Shakurov AV, Bychkov EG, Butorina AV. Local cryotherapy in traumatology and orthopedics: a review of current approaches and potential clinical use. *Kazan Medical Journal.* 2025;106(3):432–445. DOI: 10.17816/KMJ675775 EDN: EVNMXB

Submitted: 28.02.2025 **Accepted**: 04.04.2025 **Published online**: 30.05.2025

DOI: https://doi.org/10.17816/KMJ675775 EDN: EVNMXB

Локальная криотерапия в травматологии и ортопедии: обзор современных подходов и перспектив клинического применения

А.В. Пушкарёв[1,2], Н.Ю. Саакян[1], А.В. Шакуров[1], Е.Г. Бычков[1], А.В. Буторина[1,3]

[1] Московский государственный технический университет им. Н.Э. Баумана (национальный исследовательский университет), г. Москва, Россия;
[2] Российская медицинская академия непрерывного профессионального образования, г. Москва, Россия;
[3] Российский национальный исследовательский медицинский университет им. Н.И. Пирогова, г. Москва, Россия

АННОТАЦИЯ

Локальная криотерапия — метод лечения травм, заболеваний костно-мышечной системы и соединительной ткани, а также реабилитации после хирургических вмешательств. С появлением новых технологий — бесконтактного воздействия охлаждёнными газами, дополнительной компрессии и контроля температуры кожи — повысилась эффективность криопроцедур и расширились возможности метода. Однако совершенствование протоколов лечения, определение оптимальных параметров воздействия остаются актуальными задачами. Нами проведён анализ публикаций по применению локальной криотерапии в травматологии и ортопедии для систематизации подходов в клинической практике и определения ключевых принципов развития метода. Представлены результаты анализа исследований различных методов локальной криотерапии, включая применение при заболеваниях опорно-двигательного аппарата, реабилитации после операций на суставах, спортивных травмах и повреждениях костной ткани с акцентом на механизмы действия, факторы, влияющие на эффективность и безопасность использования. Рассмотрены ключевые терапевтические эффекты локальной криотерапии: снижение воспаления, уменьшение болевого синдрома, ускорение функционального восстановления суставов и сокращение потребности в анальгетиках. Перспективным, но пока недостаточно подтверждённым направлением является применение локальной криотерапии для ускорения заживления костной ткани. На данный момент доказательства эффективности в основном получены в доклинических исследованиях на животных моделях. Для подтверждения применимости и безопасности данной методики в клинической практике требуются дополнительные исследования, направленные на оптимизацию параметров воздействия и оценку безопасности, а также необходимы дальнейшие рандомизированные исследования на людях. Установлено, что локальная криотерапия обладает потенциалом в лечении заболеваний и реабилитации после получения травм опорно-двигательного аппарата, но требует дальнейшего изучения для оптимизации режимов проведения в зависимости от области охлаждения и патологии. Необходимы дальнейшие исследования для разработки персонализированных протоколов применения локальной криотерапии с учётом индивидуальных особенностей пациентов, задач терапии и характера патологии.

Ключевые слова: локальная криотерапия; травматология; ортопедия; реабилитация; заболевания суставов; спортивные травмы; костная ткань.

Как цитировать:
Пушкарёв А.В., Саакян Н.Ю., Шакуров А.В., Бычков Е.Г., Буторина А.В. Локальная криотерапия в травматологии и ортопедии: обзор современных подходов и перспектив клинического применения // Казанский медицинский журнал. 2025. Т. 106, № 3. С. 432–445. DOI: 10.17816/KMJ675775 EDN: EVNMXB

Рукопись получена: 28.02.2025 **Рукопись одобрена**: 04.04.2025 **Опубликована online**: 30.05.2025

BACKGROUND

Local cryotherapy (LC) is method for postsurgical rehabilitation and treating inflammatory processes, injuries, musculoskeletal diseases, and connective tissue diseases. This method involves briefly exposing areas of the body to low temperatures to achieve therapeutic effects [1].

The mechanism of LC involves physiological reactions occurring in response to cold exposure [2–4]. These reactions include the following:

- vasoconstriction, which is defined as the constriction of blood vessels in the area of exposure, resulting in decreased blood flow and reduced inflammation [5],
- analgesia, the reduction in pain sensitivity by slowing down the conduction of nerve impulses and the release of endorphins [6],
- the anti-inflammatory effect, which involves reducing the production of inflammatory mediators, such as prostaglandins and cytokines [7, 8], and
- myorelaxation, which reduces muscle spasms and tension [4].

Novel technologies, such as noncontact cooling with cold gases, augmented compression, and skin temperature regulation, have improved the effectiveness of cryotherapy and expanded its applications. However, treatment protocols need an urgent improvement [6, 9, 10].

A critical component of LC is the selection of an appropriate execution mode. The choice should ensure a therapeutic effect that minimizes the risk of adverse reactions. The concept is based on the idea that moderate-dose stressors have an insufficient stimulating effect to harm the organism. This is achieved through controlled exposure, which safely produces the desired therapeutic effect [11].

This study aimed to analyze current publications on the application of LC in traumatology and orthopedics and to conceptualize the main clinical approaches and trends.

The novelty of this study lies in the review of current clinical approaches to LC and their mechanisms of action based on international practice data and scientific publications. The results are envisaged to help identify promising directions for developing optimized protocols.

JOINT DISEASE TREATMENT

Lesions of the synovial membrane, articular cartilage, ligaments, tendons, and bone tissue are common in joint diseases [12]. LC is used to reduce inflammation, relieve pain, improve joint function, and reduce the need for analgesics [13–15]. Table 1 summarizes the key findings of clinical trials on treating diseases, such as knee osteoarthritis [13, 14], hip and knee osteoarthrosis [6, 15], knee and hand rheumatoid arthritis [16, 17], lower limb enthesitis in spondyloarthritis [18], and rotator cuff, elbow, and Achilles tendinitis [19, 20, 21].

Using LC to treat joint diseases significantly reduces pain, improves function, and decreases analgesic use. Positive effects are observed regardless of the method used (contact or non-contact) and after a single treatment or treatment course. Clinical studies have confirmed that the most stable results are achieved with a treatment course consisting of 6–24 sessions, with each session lasting from 20 to 90 min [6, 13–19].

A single application of LC rapidly reduces pain and temporarily improves joint function [17]. Regardless of the method used, the effect lasts up to 3 h and pain relief is achieved faster at lower temperatures [6]. Cold reduces the excitability of nerve endings, which slows down the transmission of pain impulses [22]. Additionally, vasoconstriction reduces blood flow and the secretion of inflammatory mediators, which reduces swelling and pain [5, 22].

LC courses help achieve long-term remission. Decreases in pain intensity and synovitis remission were recorded at three months after 30–90-min contact LC procedures. Patients who underwent 90-min procedures had a significantly lower recurrence rate after one year [13]. This may be due to the deeper cooling of the affected tissue, which enhances the therapeutic effect [23]. Mohammed Sadiq et al. [14] reported that the LC group experienced a significantly more pronounced reduction in pain syndrome and improvement in joint function after 2–3 months than the control group. The LC group received treatment for 8 weeks, with three sessions per week [14].

Several studies have used LC combined with other physical therapy methods [14, 18, 19]. In these cases, LC reduced pain enabling the patients to perform more active movements during therapy, thereby contributing to faster recovery [14, 18, 19]. Therefore, the therapeutic effect cannot be attributed solely to LC; rather, it is due to the combined effects of several methods.

Additionally, Douzi et al. [7, 8] examined changes in the composition of synovial fluid in patients with knee arthritis after LC. The results revealed that using cryopacks resulted in a statistically significant decrease in the concentrations of inflammatory markers (interleukin [IL]-6, IL-1β, and vascular endothelial growth factor [VEGF]). These results confirmed the pronounced anti-inflammatory effect of LC.

Furthermore, several systematic reviews have analyzed the effectiveness of cryotherapy and thermotherapy in treating osteoarthritis and rheumatoid arthritis. LC reduces acute pain and inflammation by decreasing the levels of pro-inflammatory cytokines (IL-6, IL-1β, and tumor necrosis factor alpha), particularly when temperatures below 10 °C are used. In contrast, thermotherapy improves blood circulation and promotes tissue repair, making it more effective for managing chronic pain and enhancing joint function. Cryotherapy is more effective in the acute inflammatory phase, whereas thermotherapy is preferable for treating chronic pain syndromes and restoring joint function [24]. Ice massage reduces swelling more effectively than thermotherapy in patients with osteoarthritis [25].

Thus, LC is an important component of the complex treatment of joint diseases, and it has the potential to mitigate

Table 1. Clinical studies on the use of local cryotherapy in joint diseases

Disease (region)	Patients *(n)*	LC modality/Additional treatment	Number of sessions/ Exposure times	Region/mode	Results	Source
Knee OA	30	Circulating therapy (AGT-01, CryoTechnoMed) + diclofenac	1 × 10 for 30 min	Knee superior recess/t reduction in the joint tissues was achieved in 15 min, with a decrease from 32 °C to 14 °C, followed by the maintenance of t.	Low pain during movement and at rest, absence of synovitis symptoms (100% remission in all three groups) 3 months after LC, comparable to intra-articular GCs; Increase in synovitis after 3 months; Minimal recurrence (13%) in the group with 90-min exposure by the end of the year.	[13]
	30		1 × 10 days for 60 min			
	30		1 × 10 days for 90 min			
	18	Gel pack (48 × 15 × 0.5 cm) + PT	3 × 8 weeks for 20 min	Around the joint/ Starting at −18 °C	Reduced pain and increased function after 2 and 3 months relative to groups without LC.	[14]
Hip OA	20	Nitrogen cryotherapy + kinesiotherapy	1 × 10 days for 3 min	Hip/t −150 °C	A statistically significant reduction in pain after cryotherapy; the greatest effect was observed in the LC group relative to general cryotherapy in terms of analgesic and functional effects.	[15]
Knee and hip osteoarthritis	30	Ice packs	1 × 12 days for 20–25 min	Knee, pectoralis muscle, and lateral hip region (starting at −12.. 14 °C)	All LC methods positively affected the course of the disease. Refused treatment: 6% cold intolerance and 16% diclofenac-induced gastrointestinal side effects; phlebitis in the cryo-SMC group; pain relief: 3 h. Pain relief occurred 3 h after treatment with diclofenac and was equal to the treatment time for the other modalities.	[6]
	30	Ice compress + SMC therapy (simultaneously)	1 × 12 days for 10–12 min			
	30	Air therapy	1 × 12 days for 4–6 min	Same areas at a distance of 3–4 cm for 1 dm^2 of skin for 0.5–1 min, 3–4 fields at a speed of 1370–1,550 L/min and t of 30 °C		
	30	Hyperbaric therapy with CO_2	1 × 12 days for 45–75 s	Same areas/5–6 cm, labile 15–16 s per field, 3–4 fields, t 78 °C		
Knee RA	1	Ice packs	1 for 30 min	t 0°C, interval 15 min	Positive effects on knee pain and function after a single exposure.	[16]
Arm RA	15	Air therapy (Cryo 6)	1 for 10 min	Dorsal and volar wrist/t 30 °C , 5 min on each side	Substantial and immediate reduction in pain and increase in grip strength within 1 h of LC, with no significant difference from the other modality; temporary pain relief without reducing disease activity.	[17]
	15	Ice massage	1 for 10 min	Same areas/ t 0 °C, 5 min on each side		
Heel enthesitis in spondyloarthritis	1	Compression therapy (Cryotool) + PT	2 × 5 weeks for 20 min	Left foot/Light compression	Positive effects of LC combined with PT; may be an alternative to local or systemic treatment for long-term use.	[18]
Tendinitis (rotator cuff)	21	Ice packs + kinesiotaping, PT	5 × 3 days for 20 min	t 0 °C	Kinesiotaping and cryotherapy are effective when combined with home exercises.	[19]
Tendinitis (elbow epicondylitis)	28	Nitrogen therapy (Kriopol R)	1 for 3 min	Lateral epicondyle and forearm/10 cm, labially, t −160°C	Immediate pain relief, improved pain-free grip, and increased muscle arousal.	[20]
Tendinitis (Achilles tendon)	30	Compression therapy (KoldBlue)	1 for 30 min	Mid-tendon/intermittently: 3 × 10 min with 10-min intervals, t 0°C	Reduced capillary blood flow, restored oxygen saturation in 2 min after warming, reduced venous pressure, and improved microcirculation.	[21]

Note: OA, osteoarthritis; RA, rheumatoid arthritis; LC, local cryotherapy; PT, physical therapy; SMC, sinusoidal modulated currents; GCs, glucocorticoids; t, temperature; CO_2, carbon dioxide.

symptoms and improve functional status [6, 13–21]. Tereshenkov et al. [13] suggest that prolonged exposure to LC (30 to 90 min) at temperatures ranging from 0 °C to 10 °C may be more effective [13]. Additionally, Knobloch et al.[21] indicated the potential benefit of intermittent cryotherapy over continuous cryotherapy. Further research is required to determine the most effective application methods [21].

The effectiveness of LC under prolonged or intermittent exposure might be associated with deeper cooling of internal tissues and an impact on localization of the inflammatory process [23]. However, differences in LC methods and protocols used in previous studies prevents comparative analysis and testing for correlation between cooling parameters and clinical outcomes (Table 1). Consequently, there is need for further studies with clearly defined inclusion criteria and standardized methods of effectiveness assessment to determine the optimal exposure modes and duration of courses, as well as to develop scientific LC rehabilitation protocols.

PREOPERATIVE AND POSTOPERATIVE REHABILITATION

Table 2 presents the results of an analysis of clinical studies on the use of LC during rehabilitation after various joint surgeries. The primary objectives of LC administration included reducing postoperative pain, minimizing analgesic consumption, and accelerating functional recovery [26, 27]. In particular, cases of LC after total knee arthroplasty (TKA) [26–31], anterior cruciate ligament (ACL) reconstruction [9, 32], partial meniscectomy [33], and shoulder surgery [34] were reviewed. The reviewed studies used various contact LC methods, including circulating therapy (with and without compression), gel packs, and ice packs. Typically, treatment began during the patient's hospital stay and was performed at 20- to 120-minute intervals during the day, with a long break at night [9, 27, 29, 31, 32, 34], or as 2- to 5-session daily regimens [26, 28, 30, 33]. Additionally, treatment included administering analgesics and other physical therapies [26, 34], tranexamic acid injections [29], vitamin D injections [30], and nefopam administration [9]. LC decreased pain intensity [9, 30, 31] and blood loss [29], the need for analgesics [26, 27, 34], and swelling [30, 33], but increased range of motion and joint function [26, 27, 30, 33].

The reviewed studies used prolonged LC sessions, particularly on day 1 after surgery, when pain, swelling, and accumulation of blood and synovial fluid in the joint were most pronounced. Cold therapy, which was used to manage these symptoms, had analgesic and antiedematous effects [30, 31] and promoted vasoconstriction, thereby reducing blood loss [29]. Chen et al. [27] showed that initiating LC immediately after surgery results in significantly greater flexion amplitude and lesser knee joint swelling than when therapy is started on day 2. This may be due to the more effective suppression of the inflammatory response and improved microcirculation [27].

The results of previous studies highlight the importance of selecting the optimal method of contact LC [30, 33, 36]. Chareancholvanich et al. [31] report that increasing the cooling area to cover the knee joint and the quadriceps and calf muscles leads to a significant reduction in pain in the early postoperative period (8 h after surgery). Additionally, the use of circulating LC more effectively reduces swelling in the later period (72 h after surgery) than when gel packs are used [31]. Circulating cryotherapy provides deeper cooling of the internal tissues than gel packs [31]. Compression LC is also more effective than ice packs when applied for 15 min three times a day for 10 days [33]. Therefore, it can be recommended for longer use during the rehabilitation period.

Thus, contact circulating and compression cryotherapy might be the most effective postoperative strategies. Cryotherapy should be administered immediately after surgery and continued throughout the hospital stay in the form of continuous cooling with short intervals. The joint and surrounding muscles should be covered to increase the effectiveness of anesthesia [31, 36].

Several studies have examined the use of LC after TKA and discharge from the surgical department [35, 36]. One study examined hyperbaric LC with carbon dioxide for 3 min [35], and another one compared compression LC and gel packs, each applied for 30 min [36]. The procedures were performed 2-3 times a week for 2–3 weeks.

Limited mobility of the knee joint after surgery often reduces physical activity and asymmetric loading of the limbs, which emphasizes the importance of early rehabilitation. LC helps reduce pain and swelling, which facilitates the recovery of function. LC might achieve better results in reducing pain and effusion and improving range of motion than traditional methods, such as gel packs [35, 36]. The main mechanism underlying LC is decreasing tissue temperature, which slows the transmission of pain impulses and reduces inflammation and edema [39–41]. Additionally, cooling improves quadriceps muscle activation and reduces arthrogenic muscle inhibition [42].

Up to 25% of patients experience moderate to severe knee pain three months after TKA, which underscores the importance of restoring functionality and managing pain in both the early and later stages of rehabilitation. Therefore, the effectiveness of LC after TKA in later stages has been investigated [37, 38]. Patients received 10 daily sessions of air-assisted LC combined with physical therapy and electrical stimulation of the quadriceps muscle. The findings showed significant reductions in pain and swelling [38], as well as improved joint mobility, indicating that the positive effects of LC are maintained in the long term.

Therefore, LC is critical in preoperative and postoperative recovery, including after TKA, by promoting pain relief, reducing swelling, and improving joint function during the early and late rehabilitation periods.

Table 2. Clinical studies on local cryotherapy used for rehabilitation after joint surgery

Surgery/Area	Patients (*n*)	LC modality/ Additional treatment	Number of sessions/ Exposure times	Region/mode	Results	Source
TKA (from day 1 of surgery)/knee joint	193	Compression therapy (Zamar Therapy Cube)/PT, analgesics	4 × 3 days for 2 h	Knee at 10 °C	Reduced pain and need for analgesics and accelerated functional recovery.	[26]
	30	Gel packs/CPM, analgesics	Day 1: 20-min on/30 min off; thereafter,: uncontrollable	Knee/starting at –18 °C, pack change every 4 h	Decreased analgesia on demand; pain of <2 points on the VAS scale; greater flexion (98° vs. 91°) and less swelling.	[27]
	30		From day 2 postoperation, uncontrollable			
	52	Compression therapy (U-sport bandage)/ analgesics	5 times per day for 20 min	Knee/starting at –18 °C	—	[28]
	100	Circulating therapy (Evercryo)/tranexamic acid, analgesics	7 days after surgery/90 min every 120 min	Knee/t 0 °C, ice every 4 h	Improved function and decreased pain, swelling, blood loss, and p-LOS without serious complications. Knee pain and swelling were similar among the cryotherapy groups, regardless of whether a tranexamic acid injection was administered.	[29]
	100	Compression therapy/vitamin D	4 × 7 days for 30 min	Knee/t 0 °C	Short-term improvements; vitamin D enhanced effects after 1 and 3 months.	[30]
	36	Gel packs (Nexcare™)/analgesics	Continuously	Anterior part of the knee joint up to the middle of the patella, starting at –17°C; change after 6 h	The best pain reduction occurred after 8 h. The maximum reduction in swelling occurred after 72 h accompanied with improved circulation.	[31]
	36	Circulating therapy (Aircast®)/ analgesics		Same/t 0 °C; change after 6 h		
	36	Gel packs in pouch (×3, Nexcare™)/ analgesics		Same/starting at –17 °C, change after 6 h		
ACL reconstruction (from day 1 of surgery)/ knee joint	360	Intermittent compression therapy (CryoNov®)/nefopam administered intravenously, and analgesics	5 days, overnight break; 30 min on/30 min off	Bandage t = 0 °C, low compression	The VAS revealed that the intermittent compression group experienced a rapid decrease in pain on the day of surgery and on day 3. LC resulted in faster recovery from pain than the control.	[9]
	418	Compression static therapy (Igloo®)/nefopam intravenously, analgesics	5 days, overnight break; 30 min on/2 h off			
	8	Gel packs (370 × 290 mm)	12 h; 20 min on/100 min off	Starting at –12.2±1.5 °C	Controlled LC resulted in more effective cooling of internal tissues and skin surfaces the gel pack. Maintaining the temperature using circulating LC was smoother and more energy-efficient.	[32]
	12	Circulating therapy (CTS100)	12 h continuously	t 9–13 °C		
Partial meniscectomy or knee joint	31	Ice packs	3 × 10 days	Knee at 0 °C	Compression LC showed more positive dynamics of functional recovery than ice packs.	[33]
	32	Compression therapy (GIOCO CRYO-2)		Around the knee/t 0 °C		

Table 2 continued.

Shoulder surgery (from day 1 of surgery)/shoulder joint	102	Compression therapy (Game Ready GRPro 2.1 with ATX bandage)/PT, analgesics	Two days continuously; 30-min on/60 min off; overnight if necessary; then 2 times per day	Knee/t 1–4 °C; low intermittent compression; medium compression on day 3	Reduced need for analgesics and improved self-reported function after two weeks.	[34]
TKA (days 3–10)/knee joint	21	Hyperbaric CO^2/PT and CPM	2 times per day; 6 × 2 weeks for 3 min	Knee/t –78 °C, at a distance of 10 cm, labile	LC improved flexion (115.69° vs. 100.75°), reduced pain and swelling, and improved gait.	[35]
	20	Compression therapy (Game Ready®)/massage, PT	3 × 21 days for 30 min	Bandage (Game Ready)/t 4 °C, low compression	LC performed better than the cryopack. Compression cryotherapy improved passive knee flexion and reduced pain and effusion.	[36]
	20	Gel packs (Actipoche®)/massage, PT		Around the knee joint/starting at –18 °C		
TKA (stage 3 of rehabilitation)/knee joint	30	Air therapy (FRIGOSTREAM)/electrostimulation, massage	1 × 10 for 5 min	Quadriceps and calf muscles/t –32 °C, 10 cm, labile	Improved microcirculation, reduced swelling, and enhanced electrostimulation effect.	[37]
	30	Air therapy (CryoJet 200)/PT	1 × 10 for 6–8 min	Same regions/t –30 °C, 9–10 cm, oval slot nozzle, power of 7–8 units	Reduced pain and inflammation; vasocorrective effect; improved mobility and quality of life.	[38]

Note: TKA, total knee arthroplasty; ACL, anterior cruciate ligament; LC, local cryotherapy; PT, physical therapy; CPM, Continuous Passive Motion; VAS, visual analog pain scale; t, temperature; CO_2, carbon dioxide.

JOINT AND BONE INJURIES

LC is a widely used treatment for joint and bone injuries, and it helps reduce inflammation and pain in the early stages [43]. The mechanism of LC involves constricting blood vessels and reducing blood flow to the affected area, thereby accelerating the healing process [5]. Joint injuries frequently affect the ligaments, soft tissues, bones, and synovial fluid [44]. The primary objective of rehabilitation after an injury is to enhance joint functionality, reduce pain, and accelerate the patient's return to normal life [45] or athletic training [46].

Waldén et al. [47] studied progressive Achilles tendon pain in male professional soccer players, focusing on the localization, examination procedures, diagnosis, and treatment of the condition [47]. Muscle and tendon injuries were the most common type of injury. From 2013 to 2018, a total of 4,364 injuries were recorded over five seasons among the 47 elite clubs of the Union of European Football Associations, 95 of which (2.2%) were Achilles tendon injuries. Physical therapy, LC, and eccentric training were the most common nonsurgical treatment methods, with each being used in 72% of cases [47].

Despite the widespread use of LC in sports medicine for treating soft-tissue injuries, its effectiveness in promoting tissue healing in humans is questionable [48]. Racinais et al. [48] evaluated the effect of LCT on soft tissue repair. The study was based on data obtained from animal studies and a few ones involving humans [48]. This systematic literature review analyzed 452 studies, including one human study and 26 animal studies. The results showed that LC might reduce pain in the first 6 h after injury, but using LC for more than 12 h could lead to negative consequences related to delays in tissue repair. Animal studies have found that LC limits inflammation, slows tissue regeneration, and reduces prostaglandin E2 levels in tendons. Despite its popularity, there is still insufficient scientific evidence to support the effectiveness of LC in healing soft tissue in humans [48]. Racinais et al. [48] emphasized the importance of further studies on humans to refine LC application protocols and to determine its role in the recovery process after sports injuries [48].

Table 3 summarizes the main results of clinical studies on the use of LC after injuries. Ankle injuries [49–51] and hamstring strains [52] were also examined. Ligament sprains result in short-term immobility and loss of function, posing a risk of long-term complications and reinjury [51]. The studies used contact LC modalities performed 3–6 times per day, immediately after injury, for 3–7 days [50–52], and two times per day in stage 3 of rehabilitation for 30 days [49].

Sefiddashti et al. [52] studied the effectiveness of LC contact with ice compresses at rest and during static stretching [52]. They found that additional stretching during the procedure improved functional and passive extension scores. There were no significant differences in active extension or pain between the two groups [52]. Additionally, Bleakley et al. [51] compared the effects of continuous ice pack application with a variant that included a 10-min break during

Table 3. Clinical studies on the use of local cryotherapy in injuries

Injury (area)	Patients (n)	LC modality/Additional treatment	Number of sessions/ Exposure times	Region/mode	Results	Source
Ankle joint, stage 3 of recovery	100	Cryo-wrapping (days 1–5); ice massage (days 6–10, 26–30); compression therapy (days 11–15, 21–25); general therapy (cryosauna on days 16–20)/PT	For LC, 2 times a day; for general therapy, once a day (30 days) for 15 min, 10 min, 20 min, and 3 min, respectively	For LC, ankle/t 0 °C; for general therapy, whole body	The experimental group exhibited more pronounced increases in tibial girth, flexibility, stride length, and walking speed than the group that received the standard rehabilitation protocol.	[49]
Ankle ligament sprain (week 1)	101	Compression therapy	3 × 7 days/10 min	Ankle/t 0 °C	Therapeutic exercise combined with LC significantly improved short-term ankle function.	[50]
Ankle ligament sprain	46	Ice packs (20 × 20 cm)	3 days after injury, every 2 h for 20 min	Ankle/t 0 °C	No significant differences were observed in function, swelling, or pain at rest between intermittent and continuous LC. However, one week after injury, intermittent LC was associated with a greater reduction in subjective pain and physical activity.	[51]
	43		3 days after injury, every 2 h for 20 min	Ankle/t 0 °C, break for 10 min		
Hamstring strain (knee joint)	19	Ice pack/home treatment	5 × 6 days/20 min	Painful hamstring area/ t 0 °C	LC combined with stretching demonstrated superior functional and passive extensor performance.	[52]

the session [51]. Intermittent LC significantly caused a more pronounced reduction in subjective pain during active movement one week after mild to moderate ankle ligament sprains than continuous LC. However, no significant differences were observed in function, swelling, or pain at rest [51].

Generally, the use of LC leads to high flexibility, stride length, walking speed [49], joint functionality, passive and active extension, and reduced pain and swelling [51, 52]. Including exercises in LC treatment improves ankle joint function in the short term [50]. Thus, combining LC and with exercise accelerates recovery and enables an earlier start to the training process.

Sferopoulos [53] reported cases of complications arising from incorrect application of LC in four children aged 10–13 years who had suffered severe sports-related injuries (two from soccer and two from volleyball). All patients were diagnosed with soft tissue injuries, and LC was administered for pain management. However, due to violations of the LC technique, such as prolonged use of cooling spray and direct application of an ice pack to the skin without a protective pad, all patients exhibited signs of cold burns (redness, blisters, pain, and swelling) the following day. Re-examination revealed fractures in all cases, indicating an insufficient initial diagnosis. The authors attributed the complications to failure to adhere to standard safety precautions, most likely due to the intense pain associated with the underlying pathology [53]. Sferopoulos [53] described how incorrect use of LC causes complications, demonstrating the need for strict adherence to protocols and safety measures when performing LC, particularly in pediatric practice.

The maximum effect LC in treating injuries is achieved if LC is combined with therapeutic exercises and stretching. This combination accelerates the restoration of joint functionality and reduces pain. LC should be applied immediately after trauma using the intermittent compression technique to improve microcirculation and reduce swelling. To prevent cold burns in such cases, the exposure parameters and observing precautions should be strictly controlled.

ACCELERATING THE HEALING OF BONE INJURIES

Several studies have investigated the use of LC to stimulate bone tissue regeneration in models of cortical bone defects in mice or rats [54–56]. Castano et al. [54] lowered the temperature of the femoral bone to 19 °C through daily 15-min immersions in water with temperature ranging from 4 to 6 °C. After 28 days, there was an increase in bone regeneration. The enhancement of osteogenesis might be associated with the activation of VEGF receptors, potentially resulting from short-term hypoxia induced by the cold [54]. Concurrent findings were reported by Zakaria et al. [56] who observed that a 28-day regimen of daily ice baths significantly enhanced regenerative processes in bone tissue relative to the control group [56].

Shakurov et al. [55] proposed an alternative LC technique that uses the Kholod-01 device (Elamed, Russia). The device was equipped with a Peltier module with a cooling head with a diameter of 50 mm, providing exposure for 7 min [55]. This approach decreases the temperature inside the biotissue at a depth of 5 mm by 5.3 °C. A more mature stage of bone formation was observed in the LC-treated group than in the control. After six weeks, the original contours of the defect were preserved in the control group. In contrast, the LC-treated group showed complete defect closure. The authors concluded that 7-min exposures to LC twice weekly had a positive effect on bone healing [55].

Zakaria et al. [57] also examined models of femur fractures and cortical defects. Cold exposure accelerated osteoblast differentiation, increased alkaline phosphatase activity, and stimulated bone matrix synthesis and mineralization. The authors opine that the TRPA1 and TRPM8 channels play a key role in these processes by activating reparative mechanisms and vasoconstriction, which increase under hypoxia. High VEGF concentration stimulates angiogenesis necessary for bone formation. The regulation of RBM3 and PGC-1α proteins promotes the adaptation of bone cells to cold conditions and enhances osteogenesis. Consequently, these processes collectively facilitate the effectiveness of cryotherapy for the treatment of bone injuries [57].

A treatment approach combining LC and the use of implants coated with bioactive materials [58, 59] or bone chips [60, 61] is recommended for significant-sized defects. The preliminary results of testing the LC with the coated pins are positive. However, the study was only a pilot study. Further research is necessary to draw reliable conclusions based on quantitative data.

DISCUSSION

A review of clinical and preclinical studies has confirmed the broad use of LC in traumatology and orthopedics. LC is used to treat joint diseases and to facilitate rehabilitation after injuries (including sports injuries) and joint surgery.

When treating joint diseases, LC reduces inflammation and pain and improves joint function, thereby reducing the need for analgesics. This treatment is effective in achieving synovitis remission, which depends on cooling parameters. A single application provides an immediate analgesic effect lasting for at least 3 h. However, there is no consensus on the optimal duration and frequency of treatment. Further research is required to determine these protocols.

LC is an effective component of postoperative care for patients undergoing various surgical procedures, including TKA, ACL reconstruction, partial meniscectomy, and shoulder surgery. In clinical practice, LC should be used until patients are discharged from the surgical department and transition to outpatient care. A promising strategy is continuous contact cooling at temperatures above 0 °C with short intervals, covering both the joint and adjacent muscle tissues. This approach aims to reduce postoperative pain, accelerate functional recovery, and minimize the need for analgesics. Because blood and synovial fluid accumulate within the first few days after surgery, continuous therapy is important to address these symptoms and postoperative pain.

Furthermore, LC plays an important role in the later stages of rehabilitation. It reduces swelling and increases the range of motion of the knee joint, allowing flexion and extension. LC reduces pain and swelling enabling early activation of knee strengthening and restoration of functionality through physical therapy. It is involved even in the late stages of rehabilitation, particularly for patients experiencing intense pain three months after TKA. In such cases, the frequency of LC is gradually reduced to daily procedures.

Additionally, LC is commonly used to treat joint injuries, especially those related to sports. It is used to improve the joint's functional state, reduce pain, and decrease swelling. Repeated application of LC may contribute to a faster return of athletes to training. LC is most effective in treating injuries when it is combined with physical therapy and stretching exercises. It should be used immediately after an injury to control the inflammatory response. However, exposure should be carefully monitored and dosed to avoid the risk of cold burns, especially in children.

The effects of LC in all areas considered so far are attributed to the influence of cryotherapy on metabolism and the nervous system, which promote early functional recovery. The most definitive recommendations from the review concern the methods, duration, frequency, and conditions of LC application during the postoperative period. Further research is necessary to identify the most effective LC modalities for reducing the temperature of damaged tissues, particularly synovial fluid, while ensuring the procedure remains safe.

LC has demonstrated encouraging results in preclinical studies, particularly for treating fractures and defects in the cortical part of the femur in murine models, with a substantial acceleration of the healing process. It is hypothesized that LC enhances osteogenesis by activating VEGF receptors. The immune and bone systems share many molecules; therefore, signals are transmitted to the immune system, which plays a critical role in bone repair, including in locations that have not been cryopreserved. However, results from animal studies cannot be directly extrapolated to humans owing to differences in the metabolic features of muscle tissue, skin thickness, and other anatomical characteristics. Clinical trials are necessary to confirm the effectiveness and safety of LC in stimulating osteogenesis in humans before the treatment is widely practiced. However, LC shows much potential in treating complex cases, such as fractures with delayed consolidation and complex joint fractures, as well as those in patients with diseases that disrupt normal bone regeneration. The goal of this study was to promote bone healing at home using standard medical equipment, thereby reducing the risk of nonunion and improving bone repair outcomes.

CONCLUSION

LC is an effective treatment for joint diseases, postoperative rehabilitation (e.g., after endoprosthetics and ligament reconstruction), and sports injuries at various stages of recovery. The key effects of this treatment include reducing inflammation and pain, improving joint function, and reducing the need for analgesics.

The frequency of LC use with the rehabilitation stage. After trauma or surgery, LC should be used frequently in the acute phase to control inflammatory reactions and synovitis. The frequency of procedures should be gradually decreased. Combining LC with physical therapy is effective because reducing pain and swelling increases the load on the limb and achieves a greater range of motion. This approach strengthens the muscular apparatus and increases joint functionality.

Preclinical studies have confirmed that LC can be used for bone injury treatment. However, further research is necessary to introduce this technique into clinical practice.

Thus, LC has remarkable potential, but further research is needed to optimize regimens for various clinical cases. Further research is needed to develop personalized, LC protocols that consider patient characteristics, therapy goals, and the disease. Further studies should focus on improving LC application modalities, such as intensity, duration, and frequency, as well as evaluating safety.

ADDITIONAL INFORMATION

Author contributions: P.A.V.: conceptualization, investigation, data curation, writing—original draft, writing—review & editing; S.N.Yu.: conceptualization, investigation, data curation, writing—original draft, writing—review & editing; Sh.A.V.: conceptualization, investigation, data curation, writing—original draft, writing—review & editing; B.E.G.: conceptualization, investigation, data curation, writing—original draft, writing—review & editing; B.A.V.: conceptualization, investigation, data curation, writing—original draft, writing—review & editing. All authors approved the version of the manuscript to be published and agreed to be accountable for all aspects of the work, ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Acknowledgments: The authors would like to express their gratitude to the Russian Medical Academy of Continuous Professional Education and the Pirogov Russian National Research Medical University for valuable consultations provided during the preparation of this work.

Funding sources: The study was conducted with financial support from the Russian Science Foundation with RSF grants No. 24-79-10153 (https://rscf.ru/project/24-79-10153) and No. 20-79-10190 (https://rscf.ru/project/23-79-50005/) awarded for research into joint diseases, injuries, and preoperative and postoperative rehabilitation.

Disclosure of interests: The authors have no relationships, activities, or interests for the last three years related to for-profit or not-for-profit third parties whose interests may be affected by the content of the article.

Statement of originality: No previously published material (text, images, or data) was used in this work.

Data availability statement: The editorial policy regarding data sharing does not apply to this work, as no new data was collected or created.

Generative AI: No generative artificial intelligence technologies were used to prepare this paper.

Provenance and peer review: This paper was submitted unsolicited and reviewed following the standard procedure. The review process involved three external reviewers, a member of the editorial board, and the in-house scientific editor.

ДОПОЛНИТЕЛЬНАЯ ИНФОРМАЦИЯ

Вклад авторов. П.А.В. — разработка концепции исследования, проведение исследования, работа с данными, написание черновика, пересмотр и редактирование рукописи; С.Н.Ю. — разработка концепции исследования, проведение исследования, работа с данными, написание черновика, пересмотр и редактирование рукописи; Ш.А.В. — разработка концепции исследования, проведение исследования, работа с данными, написание черновика, пересмотр и редактирование рукописи; Б.Е.Г. — разработка концепции исследования, работа с данными, написание черновика, пересмотр и редактирование рукописи; Б.А.В. — разработка концепции исследования, работа с данными, написание черновика, пересмотр и редактирование рукописи. Все авторы одобрили рукопись (версию для публикации), а также согласились нести ответственность за все аспекты работы, гарантируя надлежащее рассмотрение и решение вопросов, связанных с точностью и добросовестностью любой её части.

Благодарности. Авторы выражают благодарность РМАНПО и РНИМУ им. Н.И. Пирогова за ценные консультации, оказанные в процессе подготовки данной работы.

Источник финансирования. Исследование проведено при финансовой поддержке Российского научного фонда: грант РНФ № 24-79-10153 (https://rscf.ru/project/24-79-10153) — в рамках исследований заболеваний и травм суставов, предоперационной и послеоперационной реабилитации; грант РНФ № 20-79-10190 (https://rscf.ru/project/23-79-50005/) — в рамках исследований травм костей.

Раскрытие интересов. Авторы заявляют об отсутствии отношений, деятельности и интересов за последние три года, связанных с третьими лицами (коммерческими и некоммерческими), интересы которых могут быть затронуты содержанием статьи.

Оригинальность. При создании настоящей работы авторы не использовали ранее опубликованные сведения (текст, иллюстрации, данные).

Доступ к данным. Редакционная политика в отношении совместного использования данных к настоящей работе не применима, новые данные не собирали и не создавали.

Генеративный искусственный интеллект. При создании настоящей статьи технологии генеративного искусственного интеллекта не использовали.

Рассмотрение и рецензирование. Настоящая работа подана в журнал в инициативном порядке и рассмотрена по обычной процедуре. В рецензировании участвовали три внешних рецензента, член редакционной коллегии и научный редактор издания.

REFERENCES

1. Hermann J. Kryotherapie [Cryotherapy]. *Z Rheumatol*. 2009;68(7):539–541. (In German) doi: 10.1007/s00393-009-0446-2

2. Kunkle BF, Kothandaraman V, Goodloe JB, et al. Orthopaedic application of cryotherapy: a comprehensive review of the history, basic science, methods, and clinical effectiveness. *JBJS Rev*. 2021;9(1):e20.00016. doi: 10.2106/JBJS.RVW.20.00016 EDN: QGPJIW

3. Bleakley C, McDonough S, MacAuley D. The use of ice in the treatment of acute soft-tissue injury: a systematic review of randomized controlled trials. *Am J Sport Med*. 2004;32(1):251–261. doi: 10.1177/0363546503260757

4. Malanga GA, Yan N, Stark J. Mechanisms and efficacy of heat and cold therapies for musculoskeletal injury. *Postgrad Med*. 2015;127(1):57–65. doi: 10.1080/00325481.2015.992719

5. Kim YH, Baek SS, Choi KS, et al. The effect of cold air application on intra-articular and skin temperature in the knee. *Yonsei medical journal*. 2002; 43(5):621–626. doi: 10.3349/ymj.2002.43.5.621

6. Dashina TA, Agasarov LG. Effectiveness of various methods of cryotherapy in patients with osteoarthritis. *Problems of Balneology, Physiotherapy and Exercise Therapy*. 2020;97(2):20–28. doi: 10.17116/kurort20209702120 EDN: NWQSFZ

7. Douzi W, Guillot X, Bon D, et al. 1H-NMR-based analysis for exploring knee synovial fluid metabolite changes after local cryotherapy in knee arthritis patients. *Metabolites*. 2020;10(11):460. doi: 10.3390/metabo10110460 EDN: LEKNVC

8. Guillot X, Tordi N, Laheurte C, et al. Local ice cryotherapy decreases synovial interleukin 6, interleukin 1β, vascular endothelial growth factor, prostaglandin-E2, and nuclear factor kappa B p65 in human knee arthritis: a controlled study. *Arthritis Research & Therapy*. 2019;21(1):180. doi: 10.1186/s13075-019-1965-0 EDN: PSUIXB

9. Moussa MK, Lefevre N, Valentin E, et al. Dynamic intermittent compression cryotherapy with intravenous nefopam results in faster pain recovery than static compression cryotherapy with oral nefopam: post-anterior cruciate ligament reconstruction. *J Exp Orthopaed*. 2023;10(1):72. doi: 10.1186/s40634-023-00639-3 EDN: LEBABM

10. Liu MM, Tian M, Luo C, et al. Continuous cryotherapy vs. traditional cryotherapy after total knee arthroplasty: A systematic review and meta-analysis of randomized controlled trials. *Front Surg*. 2023;9:1073288. doi:10.3389/fsurg.2022.1073288 EDN: NKGLAE

11. Ehnert L, Geiser C. What is confirmed in Kneipp therapy? The perspective of internal medicine. *Inn Med*. 2022;63(12):1229–1236. doi:10.1007/s00108-022-01423-8

12. *Great medical encyclopedia*. Petrovsky BV, editor. 3nd ed. Moscow: Soviet Encyclopedia; 1974–1989. (In Russ.)

13. Tereshenkov VP, Shevelev OA, Zagorodniy NV, et al. Substantiation of the method of local deep hypothermia for the relief of synovitis of the knee joint in patients with osteoarthritis. *Russian Medicine*. 2023;29(4):300–310. doi: 10.17816/medjrf562715 EDN: HNSDKE

14. Mohammed Sadiq HA, Rasool MT. Effectiveness of home-based conventional exercise and cryotherapy on daily living activities in patients with knee osteoarthritis: A randomized controlled clinical trial. *Medicine*. 2023;102(18):e33678. doi: 10.1097/MD.0000000000033678 EDN: FNCOLC

15. Widłak P, Kaczmarek S, Klimkiewicz P, et al. Effects of local and whole-body cryotherapy on hip pain and general activity in the course of coxarthrosis. *Biomedical Human Kinetics*. 2023;15(1). doi: 10.2478/bhk-2023-0025 EDN: XSIIHA

16. Peres D. Feasibility of the acute physical exercise following Cryotherapy protocol in Rheumatoid Arthritis: A Case report. *Jour of Clin Cas Rep, Med Imag and Heal Sci*. 2023;3(5). doi: 10.55920/JCRMHS.2023.03.001140 EDN: UCBDJU

17. Laktašić Žerjavić N, Hrkić E, Žagar I, et al. Local cryotherapy, comparison of cold air and ice massage on pain and handgrip strength in patients with rheumatoid arthritis. *Psychiatria Danubina*. 2021;33(Suppl 4):757–761.

18. Alito A, Talotta R, D'Amico V, et al. The effect of therapeutic exercise and local cryotherapy on lower limb enthesitis in non-radiographic axial spondyloarthritis: A case report. *Journal of Personalized Medicine*. 2024;14(10):1035. doi: 10.3390/jpm14101035 EDN: WPTSMG

19. Durgut E, Gurses HN, Bilsel K, et al. Short-term effects of cold therapy and kinesio taping on pain relief and upper extremity functionality in individuals with rotator cuff tendonitis: A randomized study. *Medicina*. 2024;60(8):1188. doi: 10.3390/medicina60081188 EDN: NTBOQS

20. Radecka A, Lubkowska A. Direct effect of local cryotherapy on muscle stimulation, pain and strength in male office workers with lateral epicondylitis, non-randomized clinical trial study. *Healthcare*. 2022;10(5):879. doi: 10.3390/healthcare10050879 EDN: BOTUXU

21. Knobloch K, Grasemann R, Spies M, Vogt PM. Intermittent KoldBlue cryotherapy of 3×10 min changes mid-portion Achilles tendon microcirculation. *Br J Sports Med*. 2007;41(6):e4. doi: 10.1136/bjsm.2006.030957

22. Portnov VV. Local cryotherapy in clinical practice. *Kremlin medicine*. 2017;4(2):157–164. (In Russ.) EDN: YODBDX

23. Saakyan NY, Pushkarev AV. Local cryotherapy investigation on the biotissue phantom. *Refrigeration Technology*. 2022;111(3):181–188. doi: 10.17816/RF112350 EDN: INKTMQ

24. Yao Yu, Xie W, Opoku M, et el. Cryotherapy and thermotherapy in the management of osteoarthritis and rheumatoid arthritis: A comprehensive review. *Fundamental Research*. 2024. doi: 10.1016/j.fmre.2024.07.008 EDN: OADQHL

25. Brosseau L, Yonge KA, Robinson V, et al. Thermotherapy for treatment of osteoarthritis. *Cochrane Database Syst Rev*. 2003;2003(4):CD004522. doi: 10.1002/14651858.CD004522

26. Duffaydar H, Dong H, Jebur M, Mughal E. The effects of cryotherapy on early rehabilitation following total knee arthroplasty: a prospective cohort study. *Cureus*. 2023;15(12):e50279. doi: 10.7759/cureus.50279 EDN: HTRXXA

27. Chen MC, Lin CC, Ko JY, Kuo FC. The effects of immediate programmed cryotherapy and continuous passive motion in patients after computer-assisted total knee arthroplasty: a prospective, randomized controlled trial. *Journal of Orthopaedic Surgery and Research*. 2020;15(1):379. doi: 10.1186/s13018-020-01924-y EDN: KRYOIP

28. De Vries AJ, Aksakal HK, Brouwer RW. Effects of 6 weeks of cryotherapy plus compression therapy after total or unicompartmental knee arthroplasty: protocol for a single-centre, single-blind randomised controlled trial. *BMJ Open*. 2024;14(1):e077614. doi: 10.1136/bmjopen-2023-077614 EDN: LYCNVI

29. Huang X, Li F, Shi W, et al. Efficacy of perioperative cryotherapy combined with intra-articular injection of tranexamic acid in total knee arthroplasty. *Medicine*. 2023;102(29):e34381. doi: 10.1097/MD.0000000000034381 EDN: JWTBDM

30. Li F, Mo Y, Huang X, et al. Cyclic cryotherapy with vitamin D facilitates early rehabilitation after total knee arthroplasty. *Frontiers in Medicine*. 2024;11:1380128. doi: 10.3389/fmed.2024.1380128 EDN: ORELKB

31. Chareancholvanich K, Keesukpunt W, Pornrattanamaneewong C, et al. Comparison of three cryotherapy techniques for early post-TKA pain control in terms of efficacy and patient satisfaction: a randomized controlled trial. *Arthroplasty*. 2025;7(1):5. doi: 10.1186/s42836-024-00287-7

32. Rashkovska A, Trobec R, Avbelj V, Veselko M. Knee temperatures measured *in vivo* after arthroscopic ACL reconstruction followed by cryotherapy with gel-packs or computer-controlled heat extraction. *Knee Surg Sports Traumatol Arthrosc*. 2014;22(9):2048–2056. doi: 10.1007/s00167-013-2605-x

33. Hrubar YO, Hrubar IY, Hrabyk NM, et al. Influence of cryotherapy with pulse compression on the functional condition of the knee joint after partial meniscectomy. *Wiad Lek*. 2023;76(1):182–188. doi: 10.36740/WLek202301125 EDN: IFVHDT

34. Khan M, Phillips SA, Mathew P, et al. Cryo–pneumatic compression results in a significant decrease in opioid consumption after shoulder surgery: a multicenter randomized controlled trial. *Am J Sports Med*. 2024;52(11):2860–2865. doi: 10.1177/03635465241270138 EDN: QKQWOJ

35. Lee B, Yoon D, Yim J. Effects of an early exercise program with cryotherapy on range of motion, pain, swelling, and gait in patients with total knee arthroplasty: a randomized controlled trial. *Journal of Clinical Medicine*. 2024;13(5):1420. doi: 10.3390/jcm13051420 EDN: TSIVTA

36. Quesnot A, Mouchel S, Salah SB, et al. Randomized controlled trial of compressive cryotherapy versus standard cryotherapy after total knee arthroplasty: pain, swelling, range of motion and functional recovery. *BMC Musculoskeletal Disorders*. 2024;25(1):182. doi: 10.1186/s12891-024-07310-7 EDN: IMYBNC

37. Kulchitskaya DB, Fesyun AD, Konchugova TV, et al. The use of electrical stimulation, local air cryotherapy, massage and robotic mechanotherapy with biofeedback in patients after knee replacement in the late postoperative period. *Russian Journal of Environmental and Rehabilitation Medicine*. 2023;1:11–15. EDN: CAQYOD
38. Kolbakhova SN, Samoilov AS, Fesyun AD, et al. Experience in the use of cryotherapy in patients after total replacement. *Russian Journal of Physiotherapy, Balneology and Rehabilitation*. 2024;22(2):81–86. doi: 10.17816/117482 EDN: GBPVUQ
39. Jette DU, Hunter SJ, Burkett L, et al. Physical therapist management of total knee arthroplasty. *Phys Ther*. 2020;100(9):1603–1631. doi: 10.1093/ptj/pzaa099 EDN: GZWIEW
40. Kunkle BF, Kothandaraman V, Goodloe JB, et al. Orthopaedic application of cryotherapy: a comprehensive review of the history, basic science, methods, and clinical effectiveness. *JBJS Rev*. 2021;9(1):e20.00016. doi: 10.2106/JBJS.RVW.20.00016
41. Chughtai M, Sodhi N, Jawad M, et al. Cryotherapy treatment after unicompartmental and total knee arthroplasty: a review. *J Arthroplasty*. 2017;32(12):3822–3832. doi: 10.1016/j.arth.2017.07.016
42. Ewell M, Griffin C, Hull J. The use of focal knee joint cryotherapy to improve functional outcomes after total knee arthroplasty: review article. *PM R*. 2014;6(8):729–738. doi: 10.1016/j.pmrj.2014.02.004
43. Jabbar AW. The use of cryotherapy and heat in the recovery of tendon injuries in running athletes. *Am J Soc Sci Educ Innov*. 2024;6(8):72–83. doi: 10.37547/tajssei/Volume06Issue08-06 EDN: CAQYOD
44. Petrov SV. *General Surgery: Textbook for Higher Education Institutions*. 2nd ed. Moscow; 2004. 768 p. (In Russ.) ISBN: 5-318-00564-0
45. Jones CA, Voaklander DC, Johnston DW, Suarez-Almazor ME. Health related quality of life outcomes after total hip and knee arthroplasties in a community based population. *J Rheumatol*. 2000;27(7):1745–1752.
46. Ardern CL, Glasgow P, Schneiders A, et al. 2016 Consensus statement on return to sport from the First World Congress in Sports Physical Therapy, Bern. *Br J Sports Med*. 2016;50(14):853–864. doi: 10.1136/bjsports-2016-096278
47. Waldén M, Gajhede Knudsen M, Ekstrand J, et al. Achilles tendon pain in male professional football players — a prospective five-season study of 88 injuries from the UEFA Elite Club Injury Study. *Open Access J Sports Med*. 2024;15:171–179. doi: 10.2147/OAJSM.S493843 EDN: KASYAM
48. Racinais S, Dablainville V, Rousse Y, et al. Cryotherapy for treating soft tissue injuries in sport medicine: a critical review. *Br J Sports Med*. 2024;58(20):1215–1223. doi: 10.1136/bjsports-2024-108304 EDN: ADPRGB
49. Simonyan NR, Tkachenko SA. Rehabilitation methods after ankle joint injuries. *Modern Humanities Success*. 2024;6:142–149. doi: 10.58224/2618-7175-2024-6-142-149 EDN: IGBULC
50. Bleakley CM, O'Connor SR, Tully MA, et al. Effect of accelerated rehabilitation on function after ankle sprain: randomized controlled trial. *BMJ*. 2010;340:1964. doi: 10.1136/bmj.c1964
51. Bleakley CM, McDonough SM, MacAuley DC, Bjordal J. Cryotherapy for acute ankle sprains: a randomized controlled study of two different icing protocols. *Br J Sports Med*. 2006;40(8):700–705. doi: 10.1136/bjsm.2006.025932
52. Sefiddashti L, Ghotbi N, Salavati M, et al. The effects of cryotherapy versus cryostretching on clinical and functional outcomes in athletes with acute hamstring strain. *J Bodyw Mov Ther*. 2018;22(3):805–809. doi: 10.1016/j.jbmt.2017.08.007
53. Sferopoulos NK. Skin burns following cryotherapy in misdiagnosed pediatric injuries. *J Bodyw Mov Ther*. 2018;22(3):556–559. doi: 10.1016/j.jbmt.2017.09.006
54. Castano D, Comeau-Gauthier M, Ramirez-GarciaLuna JL, et al. Noninvasive localized cold therapy: a new mode of bone repair enhancement. *Tissue Eng Part A*. 2019;25(7–8):554–562. doi: 10.1089/ten.tea.2018.0191
55. Shakurov AV, Lukina YS, Skriabin AS, et al. Enhanced bone healing using local cryostimulation: in vivo rat study. *J Therm Biol*. 2023;113:103501. doi: 10.1016/j.jtherbio.2023.103501 EDN: KPMMFQ
56. Zakaria M, Allard J, Garcia J, et al. Enhancing bone healing through localized cold therapy in a murine femoral fracture model. *Tissue Eng Part A*. 2019;25(7–8). doi: 10.1089/ten.tea.2018.0191 EDN: FPYFEI
57. Zakaria M, Matta J, Honjol Y, et al. Decoding cold therapy mechanisms of enhanced bone repair through sensory receptors and molecular pathways. *Biomedicines*. 2024;12(9):2045. doi: 10.3390/biomedicines12092045 EDN: GJYVCI
58. Skriabin AS, Tsygankov PA, Vesnin VR, et al. Electrophoretic deposition of calcium phosphates on carbon–carbon composite implants: morphology, phase/chemical composition and biological reactions. *Int J Mol Sci*. 2024;25(6):3375. doi: 10.3390/ijms25063375 EDN: ZDLXAU
59. Skriabin AS, Shakurov AV, Vesnin VR, et al. Titanium membranes with hydroxyapatite/titania bioactive ceramic coatings: characterization and in vivo biocompatibility testing. *ACS Omega*. 2022;7(51):47880–47891. doi: 10.1021/acsomega.2c05718 EDN: OICVGA
60. Lukina YuS, Mishchenko BP, Zaytsev VV, et al. Osteoplastic material based on bone matrix resistant to osteoplastic resorption under conditions of express regenerative process in form of carrier for RHBMP. *Inorganic Materials: Applied Research*. 2021;10:26–36. doi: 10.31044/1684-579X-2021-0-10-26-36 EDN: KNTTWT
61. Lukina YS, Zaitsev VV, Gavryushenko NS, et al. Macroporous calcium phosphate matrices prepared using the technology of self-setting cements *Inorganic Materials*. 2021;57(1):81–88. doi: 10.31857/S0002337X21010103 EDN: CJFEMB

AUTHORS' INFO

*** Aleksandr V. Pushkarev**, Cand. Sci. (Engineering), Leading Engineer, Depart. 3.1, Acting Head, Depart. of Medical Equipment; address: 1 Lefortovskaya Naberezhnaya st, Russia, Moscow, 105005; ORCID: 0000-0002-1737-7838; eLibrary SPIN: 5796-8324; e-mail: pushkarev@bmstu.ru

Natalia Y. Saakyan, Student, Engineer, Depart. 3.1; ORCID: 0000-0001-6799-5450; eLibrary SPIN: 4390-3138; e-mail: saakyan@bmstu.ru

Alexey V. Shakurov, Dr. Sci. (Engineering), Head, Depart. 3.1; ORCID: 0000-0001-6110-8101; eLibrary SPIN: 1894-4707; e-mail: shakurov@bmstu.ru

Evgeny G. Bychkov, Cand. Sci. (Engineering), Senior Researcher, Depart. 3.1; ORCID: 0000-0002-2050-5298; eLibrary SPIN: 5499-9080; e-mail: bychkov.eg@bmstu.ru

Antonina V. Butorina, MD, Dr. Sci. (Medicine), Chief Researcher, Depart. 3.1, Professor of the Depart. of Rehabilitation, Sports Medicine, and Physical Education; ORCID: 0000-0001-8465-0593; eLibrary SPIN: 8832-1995; e-mail: avbutorina@gmail.com

ОБ АВТОРАХ

*** Пушкарёв Александр Васильевич**, канд. техн. наук, ведущий инженер, отдел 3.1, и.о. зав., каф. медицинской техники; адрес: Россия, 105005, Москва, ул. Лефортовская набережная, д. 1; ORCID: 0000-0002-1737-7838; eLibrary SPIN: 5796-8324; e-mail: pushkarev@bmstu.ru

Саакян Наталия Юрьевна, студент, инженер, отдел 3.1; ORCID: 0000-0001-6799-5450; eLibrary SPIN: 4390-3138; e-mail: saakyan@bmstu.ru

Шакуров Алексей Валерьевич, д-р техн. наук, заведующий, отдел 3.1; ORCID: 0000-0001-6110-8101; eLibrary SPIN: 1894-4707; e-mail: shakurov@bmstu.ru

Бычков Евгений Геннадьевич, канд. техн. наук, старший научный сотрудник, отдел 3.1; ORCID: 0000-0002-2050-5298; eLibrary SPIN: 5499-9080; e-mail: bychkov.eg@bmstu.ru

Буторина Антонина Валентиновна, д-р мед. наук, главный научный сотрудник, отдел 3.1, профессор, каф. реабилитации, спортивной медицины и физической культуры; ORCID: 0000-0001-8465-0593; eLibrary SPIN: 8832-1995; e-mail: avbutorina@gmail.com

* Corresponding author / Автор, ответственный за переписку