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The Impact of Computerized Cryotherapy on Time to Surgery and Hospital Length of Stay in Ankle Fractures: A Comparative Study

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Abstract

Objective: To evaluate the efficacy of a computerized cryotherapy protocol on time to surgery, Length of Hospital Stay (LOS), pain control, and complication rates in patients with acute ankle fractures and dislocations, compared to conventional management.

Methods: A single-center comparative analysis was conducted on 428 patients. The intervention group (n=180) received early, regulated computerized cryotherapy via a dedicated boot system according to a standardized protocol. The historical control group (n=248) received conventional management with traditional ice packs and immobilization. Primary outcomes were time to surgery (hours) and LOS (days). Secondary outcomes included pain scores (Visual Analog Scale), opioid consumption (morphine milligram equivalents), postoperative wound complications, and patient satisfaction.

Results: The computerized cryotherapy group demonstrated a statistically significant reduction in both primary outcomes. The median time to surgery was reduced by more than 50% (65.5 hours vs. 141.2 hours; $p < 0.001$). Consequently, the mean LOS was nearly halved (3.2 days vs. 6.1 days; $p < 0.001$). Secondary outcomes also favored the intervention group, showing significantly lower 24-hour VAS pain scores (3.1 vs. 5.8; $p < 0.001$), reduced opioid use (12.4 MME vs. 28.1 MME; $p < 0.001$), and a lower rate of wound complications (3.9% vs. 9.7%; $p = 0.022$). Patient satisfaction was significantly higher in the cryotherapy group (89.4% vs. 67.3%; $p < 0.001$).

Conclusion: The implementation of a computerized cryotherapy protocol significantly accelerates the surgical pathway, reduces hospital stay, improves pain management, and decreases complication rates in patients with acute ankle injuries. These findings support its integration as a key component of Enhanced Recovery After Surgery (ERAS) protocols in orthopedic trauma care.

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Keywords: Computerized Cryotherapy; Ankle Fracture; Length of Stay; Time to Surgery; Pain Management; Enhanced Recovery After Surgery

Introduction

Ankle fractures and dislocations represent a frequent yet clinically significant challenge within orthopedic and emergency medicine, accounting for nearly 10% of all fractures presenting to emergency departments [1]. Typically resulting from high-energy mechanisms, such as sports injuries, falls, or motor vehicle collisions, these traumas produce a characteristic triad of severe pain, rapid-onset edema, and marked functional impairment. The ensuing pathophysiological cascade, driven by acute inflammation, soft-tissue swelling, and hematoma formation, not only exacerbates patient discomfort but also complicates timely management and surgical planning. For decades, the standard approach to acute ankle fractures and dislocations has followed a predictable pattern: immediate closed reduction under procedural sedation, often requiring mechanical traction, followed by immobilization in a well-padded splint or cast and subsequent inpatient hospitalization. Hospital admission serves dual purposes, ensuring adequate analgesia, frequently dependent on opioid medications, and enabling close monitoring for potential complications such as compartment syndrome or soft-tissue compromise. While effective in stabilizing the initial injury, this paradigm carries notable drawbacks, including extended hospital stays, increased healthcare expenditures, heightened risk of hospital-acquired infections, and significant patient inconvenience. Furthermore, substantial edema can postpone definitive surgical fixation for days or even weeks as surgeons await optimal soft-tissue conditions to minimize postoperative wound complications, including dehiscence and infection [2]. In the context of Enhanced Recovery After Surgery (ERAS) initiatives and value-based healthcare, new strategies have emerged to optimize the conservative management of musculoskeletal trauma. Among these, computerized cryotherapy has gained particular attention.

Unlike traditional ice application, modern cryotherapy devices deliver continuous, precisely regulated circumferential cooling through specialized boots or wraps connected to a digital control unit. This technology ensures consistent therapeutic temperatures capable of penetrating deep peri-fracture tissues. The rationale for computerized cryotherapy is well supported: by inducing localized vasoconstriction, it reduces regional blood flow, thereby limiting edema and hematoma formation while providing potent analgesia through decreased nerve conduction velocity and elevated pain thresholds [3]. Emerging evidence indicates that improved control of acute inflammation may positively influence critical clinical endpoints, reducing the need for mechanical traction, lowering postoperative pain scores and opioid use, and enabling earlier, safer surgical intervention by accelerating soft-tissue recovery [4,5]. The primary aim of this study is to evaluate the effectiveness of computerized cryotherapy as an adjunct in the acute management of ankle fractures and dislocations. Specifically, the study seeks to determine whether early and continuous application of regulated cryotherapy can reduce time to surgery and overall hospital length of stay compared with conventional management pathways. Secondary objectives include assessing the impact of computerized cryotherapy on postoperative wound complications (such as infection and dehiscence), analgesic requirements, pain control measured through VAS scores, and overall patient satisfaction. By integrating this technology into early trauma care, the study aims to determine whether computerized cryotherapy can enhance soft-tissue optimization, improve clinical outcomes, and decrease resource utilization in a high-volume orthopedic emergency setting.

Methods

This study was conducted as a retrospective–prospective comparative analysis within a single orthopedic trauma center (San Paolo Hospital, Civitavecchia, Rome). The intervention group consisted of all patients treated with computerized cryotherapy from January 2021 through June 2024, representing the period following the implementation of the cryotherapy protocol. The control group included patients managed before the introduction of this technology, from April 2018 to January 2021, and was retrospectively selected to ensure equivalence in fracture type and injury characteristics. The cryotherapy cohort ultimately comprised 180 patients, including bi- and trimalleolar ankle fractures classified as AO 44 (A, B, C), tibial shaft fractures classified as AO 42 (A, B, C), tibial plateau fractures, patellar fractures, and calcaneal fractures. The control group consisted of 248 patients with comparable injury patterns who were treated with conventional methods during the pre-cryotherapy era. Patients were considered eligible if they presented with acute fractures of the ankle or lower limb that were stable after closed reduction or reducible without requiring immediate external fixation, and if definitive surgical treatment was indicated. Exclusion criteria included open fractures necessitating urgent surgical debridement, fractures requiring mandatory external fixation because of instability or significant soft-tissue damage, and contraindications to cold therapy. In the cryotherapy group, treatment was initiated as early as possible upon admission to the emergency department. According to the internal protocol, patients received alternating cycles of six hours of cooling followed by six hours without cooling during the first 24 hours. Cryotherapy was delivered using a walker-type brace incorporating the Zamar computerized cooling system, applied immediately after reduction and immobilization whenever feasible. The protocol mandated uniform compliance by all members of the orthopedic unit to ensure consistency in application and monitoring. Patients in the control group received the standard care customary before the adoption of computerized cryotherapy. This included closed reduction under sedation, with mechanical traction applied when necessary, immobilization with a plaster splint or cast, and traditional ice application as tolerated, followed by inpatient observation until soft tissues were suitable for surgery. No computerized cooling system was used in this cohort. The primary outcomes of interest were the time to surgery, measured in hours from the traumatic event to definitive operative management, and the duration of hospitalization, expressed in days. Secondary outcomes included postoperative wound complications such as infection or dehiscence, subjective pain levels assessed using the Visual Analog Scale, opioid and non-opioid analgesic consumption during hospitalization, and patient satisfaction measured using a simple smile-based scale employed in routine clinical practice. Clinical information, demographic characteristics, radiographic data, and operative reports were extracted from the institutional electronic medical record system.

Statistical Analysis

Statistical analysis was performed by an independent statistician using SPSS software version twenty-seven point zero from IBM Corporation. Statistical analysis was performed using a combination of descriptive and inferential methods. Continuous variables were assessed for normality using the Shapiro–Wilk test and compared using either the Student's t-test or the Mann–Whitney U test as appropriate. Categorical variables were analyzed using the chi-square test or Fisher's exact test. Time-dependent outcomes were additionally evaluated through Kaplan–Meier curves and log-rank tests to explore differences in time to surgery between groups. Multivariable regression models were constructed to control for potential confounders such as age, comorbidities, fracture type, and anticoagulation status. Statistical significance was set at $p < 0.05$ for all tests.

Results

A total of 428 patients were included in the final analysis: 180 in the computerized cryotherapy group and 248 in the conventional management (control) group. The two cohorts were well-matched at baseline with no statistically significant differences in age, sex, fracture classification, or prevalence of key comorbidities such as diabetes and anticoagulant use, as detailed in Table 1.

Baseline Demographic and Clinical Characteristics of the Study Population

Characteristic	Computerized Cryotherapy Group (n=180)	Control Group (n=248)	p-value
Age (years), mean± SD	48.7± 16.2	51.3± 14.8	0.089
Sex, n (%)			0.452
Male	92 (51.1%)	134 (54.0%)	
Female	88 (48.9%)	114 (46.0%)	
Fracture Type (AO Classification), n (%)			0.387
Ankle (44 A/B/C)	112 (62.2%)	145 (58.5%)	
Tibia (42 A/B/C)	42 (23.3%)	68 (27.4%)	
Other (Plateau, Patella, Calcaneus)	26 (14.4%)	35 (14.1%)	
Diabetes Mellitus, n (%)	21 (11.7%)	35 (14.1%)	0.449
Anticoagulant Use, n (%)	19 (10.6%)	31 (12.5%)	0.525

Table 1: Baseline demographic and clinical characteristics of patients managed with computerized cryotherapy versus conventional therapy.

Primary Outcomes

The implementation of a computerized cryotherapy protocol significantly improved both primary outcomes. The median time to surgery was reduced by over two days in the cryotherapy group compared to the control group (65.5 hours vs. 141.2 hours, $p < 0.001$). Consequently, the mean length of hospital stay (LOS) was nearly halved, with the cryotherapy group averaging 3.2 days compared to 6.1 days in the control group ($p < 0.001$). These results are summarized in Table 2.

Primary Outcome Measures

Outcome	Computerized Cryotherapy Group (n=180)	Control Group (n=248)	p-value
Time to Surgery (hours), median [IQR]	65.5 [48.0 - 84.0]	141.2 [115.0 - 168.0]	**<0.001**
Length of Stay (days), mean± SD	3.2± 1.5	6.1± 2.3	**<0.001**

Table 2: Comparison of primary outcomes (time to surgery and length of hospital stay) between the study groups.

Secondary Outcomes

Patients receiving computerized cryotherapy reported markedly better pain control. The mean VAS pain score recorded 24 hours post-admission was 3.1 in the cryotherapy group, compared to 5.8 in the control group ($p < 0.001$). This superior analgesia translated into a substantial reduction in opioid consumption, with the cryotherapy group requiring the equivalent of 12.4 mg of morphine, less than half of the 28.1 mg required by the control group ($p < 0.001$). Furthermore, the rate of postoperative wound complications (a composite of infection and dehiscence) was significantly lower in the cryotherapy group (3.9% vs. 9.7%, $p = 0.022$). Finally, patient satisfaction was significantly higher among those treated with the computerized system, with 89.4% reporting a "satisfied" or "very satisfied" rating compared to 67.3% in the control group ($p < 0.001$). These secondary outcomes are presented in Table 3.

Secondary Outcome Measures

Outcome	Computerized Cryotherapy Group (n=180)	Control Group (n=248)	p-value
VAS Pain Score (24h), mean± SD	3.1± 1.2	5.8± 1.7	**<0.001**
Opioid Use (MME), mean± SD	12.4± 6.8	28.1± 10.5	**<0.001**
Wound Complications, n (%)	7 (3.9%)	24 (9.7%)	**0.022**
High Patient Satisfaction, n (%)	161 (89.4%)	167 (67.3%)	**<0.001**

Abbreviations: VAS, Visual Analog Scale; MME, morphine milligram equivalents.

Table 3: Comparison of secondary outcomes (pain scores, opioid use, complications, and satisfaction) between the study groups.

Multivariable Analysis

A multiple linear regression model, controlling for age, fracture type, and comorbidities, confirmed that the use of computerized cryotherapy was an independent, significant predictor of a shorter time to surgery ($\beta = -68.4$, 95% CI: -82.1 to -54.7, $p < 0.001$) and a shorter length of hospital stay ($\beta = -2.7$, 95% CI: -3.2 to -2.2, $p < 0.001$).

Discussion

This comparative analysis demonstrates that the integration of a computerized cryotherapy protocol into the acute management of ankle and lower limb fractures yields significant improvements across multiple clinical domains. Our findings indicate that patients receiving regulated cryotherapy experienced a drastic reduction in time to surgery and length of hospital stay, superior pain control with reduced opioid requirements, fewer postoperative wound complications, and higher overall satisfaction compared to those managed with conventional methods. These results strongly support the hypothesis that early, controlled cooling is a highly effective adjunct for optimizing soft-tissue conditions and facilitating a more efficient patient pathway. The most striking finding was the more than 50% reduction in median time to surgery (65.5 vs. 141.2 hours). This aligns with the physiological rationale that targeted cryotherapy mitigates the inflammatory cascade, thereby accelerating the resolution of edema. As posited by Lee et al. [3], the primary mechanisms are localized vasoconstriction and reduced capillary permeability, which limit hematoma formation and soft-tissue swelling. Our results provide robust clinical validation of this theory, suggesting that by creating a more favorable soft-tissue envelope sooner, surgeons are no longer compelled to delay surgery. This directly addresses a major bottleneck in trauma care identified by Shah and Wilson [2]. who emphasized that soft-tissue status is the critical rate-limiting step for surgical timing. The consequent halving of the hospital stay (3.2 vs. 6.1 days) represents a substantial advancement in operational efficiency. This reduction in LOS is a cornerstone of value-based healthcare, as it directly decreases resource utilization, lowers costs, and minimizes a patient's exposure to hospital-associated risks, such as infections [6-8].

The significant improvement in pain scores and the 56% reduction in opioid consumption are equally consequential. The potent analgesic effect of continuous cryotherapy, achieved by reducing nerve conduction velocity and raising pain thresholds [3], offers a non-pharmacological strategy for pain management.

This is of paramount importance in the current medical climate, which emphasizes opioid-sparing protocols to combat the risks of dependence and side effects like sedation and respiratory depression. Our findings corroborate those of The COOL-AID Investigators [4], who also reported significantly lower pain scores and opioid use in their randomized trial. Effective pain control in the immediate post-injury period not only improves patient comfort but may also facilitate earlier mobilization and physical therapy, potentially contributing to better long-term functional outcomes. The observed reduction in wound complications (3.9% vs. 9.7%) is a clinically vital outcome. Postoperative infection and dehiscence are dreaded complications that lead to re-operations, prolonged antibiotic courses, and worse functional results. The ability of computerized cryotherapy to control edema effectively reduces tension on the surgical incision and improves local microcirculation after the cooling cycles cease, creating a healthier environment for wound healing. This finding suggests that cryotherapy's benefits extend beyond merely speeding up the timeline to include genuinely improving the quality and safety of the surgical intervention itself. This study has several limitations. First, its single-center design may limit the generalizability of the findings, and the non-randomized, historical control selection introduces the potential for confounding despite statistical adjustments. While the groups were well-matched, unmeasured variables such as subtle differences in surgical technique or perioperative protocols over time could influence outcomes. Second, the use of a simple smile-based scale for patient satisfaction, while practical, is less rigorous than validated Patient-Reported Outcome Measures (PROMs). Future studies would benefit from a multi-center, randomized controlled design and the incorporation of standardized PROMs like the FAAM (Foot and Ankle Ability Measure) or PROMIS (Patient-Reported Outcomes Measurement Information System) to capture functional recovery more comprehensively.

Conclusion

The implementation of a computerized cryotherapy protocol for acute ankle and lower limb fractures is associated with a dramatically accelerated pathway to surgery, a shortened hospital stay, improved pain control with less opioid use, and a reduction in serious wound complications. These results position computerized cryotherapy not as a mere comfort measure, but as a fundamental component of modern ERAS protocols in orthopedic trauma. By effectively managing the initial inflammatory response, this technology enables a safer, more efficient, and more patient-centered approach to care. We recommend its strong consideration for integration into standard treatment algorithms for managing these common injuries.

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