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Is the Critical Patient with a Septic Limb Too Sick for an Emergent Amputation? A Case Report Illustrating How to Perform a Bedside Physiologic Amputation

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Abstract

A physiologic amputation is an important option for the critically ill patient who has irreversible limb disease with necrotic wounds but who would have a low probability of surviving a standard open amputation, without effective preoperative resuscitation, antibiotics, and correction of metabolic derangements. An open amputation may be required secondary to vascular ischemic disease, necrotizing fasciitis, or thermal injury that has led to the critical and unstable condition. The physiologic amputation stabilizes the patient while preventing further metabolic deterioration. The cryoamputation is intended to rescue the patient's life and is not meant for limb salvage. While physiologic amputation has been described for over a century, it is uncommonly performed. This case report describes a physiologic amputation in a step-by-step fashion for the surgeon attempting to save a critically ill patient's life who might not otherwise survive an open amputation.

Keywords

Physiologic Amputation, Cryoamputation, Critically Ill, Sepsis, Septic Shock, Cryoanesthesia Amputation, Medical Amputation

1. Introduction

Physiologic amputation, also referred to as cryoamputation, utilizes dry ice with tourniquet application to separate the diseased extremity from the clinically unstable patient without an immediate open operation [1]. This serves as a temporizing measure for the critically ill patient that requires resuscitation prior to an open amputation [1] [2] [3]. Patients may require an amputation for any variety of medical reasons including advanced acute limb ischemia where advanced vascular procedures have failed [4], necrotizing fasciitis [5], advanced pedal sepsis [6] or thermal burn injury [7]. The patient may be so hemodynamically unstable that proceeding to the operating room may be an unsuitable location for further care [4]. This is not a limb salvage operation but is meant for rescuing the patient's life [8]. With physiologic amputations, the affected limb is placed in direct, circumferential contact with dry ice. Within minutes, this rapid process freezes the underlying tissues [4]. With subsequent source control established, the surgeon has additional time to treat the patient's medical conditions including sepsis, hemodynamic instability, and metabolic derangements [1] [9]. This changes what would be an otherwise high-risk amputation to a more elective procedure with a lower risk of death [10]. Nonetheless, these patients are so critically ill and hemodynamically precarious that in one series there was still 40% mortality despite the use of physiologic amputation [4]. However, where an emergent amputation is required, cryoamputation may be the patient's only hope of surviving an otherwise clinically lethal outcome.

During a physiologic amputation, the involved neurovascular bundle is quickly frozen, therefore, intravenous pain and sedation medication requirements are diminished [11] [12]. Concomitant rhabdomyolysis with the release of electrolytes can lead to systemic hyperkalemia, hyperphosphatemia, hypercalcemia with subsequent cardiac irritability, and even cardiac arrest [1]. Furthermore, myoglobin pigments when released into the blood stream may create renal tubular casts, ironically leading to acute renal failure aggravating any electrolyte imbalances [1]. Physiologic amputation stops myonecrosis with its concomitant myoglobinuria and decreases the risk of renal failure as a result [13]. Subsequent myoglobinuria can be cleared within 24 hours, in most cases [1] [13].

The majority of hemodynamically stable, middle-aged to elderly, diabetic patients with an ischemic lower extremity can tolerate an urgent open amputation when caught early in their clinical course [9], but a subset of patients may not tolerate an urgent or emergent operation as significant hypotension can occur without first receiving intravenous fluid resuscitation, blood product administration, and systemic antibiotics. Historically, emergent amputations in the critically ill septic patient had operative mortality of 46%. This declined to 6% with the use of cryoamputation because the clinician had enough time to treat the patient's critical illness [14]. One recent cohort study revealed that the incidence of unilateral amputation in the diabetic male was 197 per 100,000 versus 23 per 100,000 in the non-diabetic male population [15]. While there are single-staged and two-staged open extremity amputations that can be performed mechanically, many operative amputations lead to concomitant blood loss and subsequent fluid shifts [16]. Septic patients or patients with significant and potential multiple comorbidities are at greater risk of death from an urgent open amputation [17]. Implementation of a physiologic amputation can convert an emergent amputation to one that can be delayed and performed after 72 hours or longer [4]. One series found the mean duration for the cryoamputation at 15.6 days with a range between 5 to 32 days [13]. Bunt maintained that cryoamputation may be sustained for at least 6 weeks [18]. Another case report had a definitive open amputation after 24 days of cryoamputation, as the patient was being resuscitated and treated for septic shock [10]. Herein is a case report of a critically ill, septic patient that required physiologic amputation, described, and illustrated in a step-by-step fashion. The institutional review board (IRB) at Valleywise Health Medical Center (formerly known as Maricopa Integrated Health System) has determined that this case report (CR2021-018) is exempt from IRB review based on Code or Federal Regulations (CFRs) Title 25, Part 46—Protection of Human Subjects.

2. Case Report

A 37-year-old male presented to our medical center having fallen out of bed after injecting heroin that day into his right thigh wound. He had been injecting heroin into the open wounds of his bilateral lower extremities for several years. Multiple attempts at reconstructive closure utilizing myocutaneous flaps to his chronic right open thigh wounds were met with failure secondary to his illicit drug habits. Upon presentation, he complained of shortness of breath and a rash over his bilateral lower extremities. Though initially coherent, he became obtunded with a Glasgow Coma Scale (GCS) of nine. Physical examination revealed a large right thigh purulent wound with exposed femur and muscles as well as multiple left lower extremity wounds with surrounding mottling cellulitis (**Figure 1** and **Figure 2**). The patient was hypotensive (mean arterial blood pressure of 55 mmHg), tachycardic (heart rate of 120 beats per minute), and tachypneic (respiratory rate of 43 breaths per minute) for which he was started on supplemental oxygen by face mask. His basal metabolic index was 17. His initial blood analysis (**Table 1**) revealed severe aberrant values and the urinalysis had large white blood cells, nitrates, leukoesterase, and many bacteria. Subsequent blood and urinary toxicologic screens revealed multiple illicit substances consistent with his drug abuse history. He was diagnosed with impending respiratory failure with hypoxemia, septic shock with cardiovascular collapse, urinary tract infection (possible urosepsis), severe anemia, acute renal failure and coagulopathy despite not being on anticoagulants, lactic acidosis, and severe metabolic acidosis.

The burn surgical service was consulted hours after his initial presentation. With his oxygen saturation less than 90% and persistent tachypnea, the patient was cautiously intubated with minimal sedation. After intubation, he was placed on airway pressure release ventilation (APRV) with a FiO_2 of 100%, P (high) of 32 and positive end-expiratory pressure (PEEP) of 3. The patient was transferred to our burn center for ongoing resuscitation, blood transfusions, intravenous antibiotics (linezolid (Pfizer, NY, NY) and piperacillin-tazobactam, (Pfizer, NY,

Figure 1. The patient's large right thigh wound that was extruding purulent drainage with extension deep to the right femur.

Figure 2. Bilateral lower extremities with a large right thigh open wound with femoral bone exposure and purulence. Scattered left leg and foot wounds are noted. Cellulitis and mottling are noted in both extremities.

Table 1. Admission laboratory values.

WBC	35.7 (10^{-3}/uL)
Hemoglobin	6.2 (g/dL)
Hematocrit	19.8%
pH	6.9
PO_2	77.9 mmHg
HCO_3	<5 mmol/L
Base deficit	−23.2 mmol/L
Anion Gap	>24 mmol/L
Lactic Acid	7 mmol/L
CK (total)	27,957 U/L
BUN	62 mg/dL
Creatinine	5.6 mg/dL
PT	32.3 seconds
INR	2.9

NY)), and carefully administered pain and sedation medications. Two triple-lumen central venous catheters were placed for intravenous resuscitation and a dialysis catheter was placed for initiation of continuous renal replacement therapy (CRRT) for electrolyte correction and removal of nitrogenous waste products. Intravenous, high-dose norepinephrine and vasopressin infusions were necessary to improve his cardiovascular collapse. His blood laboratory examinations were closely monitored every six hours for ventilatory and dialysis manipulation.

Because of his critical clinical condition upon admission, the decision was made to hold off on an emergent, open amputation due to the associated high mortality rate in this setting. Instead, a right lower extremity physiologic amputation was performed from the proximal, open femur wound distal to the foot. This was done at the patient's bedside in the intensive care unit. As there were no familial contacts available for medical direction, a temporizing cryoamputation allowed social services time to try and find a family contact. After 72 hours of dry ice application and the achievement of right lower extremity physiologic amputation, the metabolically and hemodynamically improved patient underwent a formal, open right hip disarticulation with skin closure. Consequently, the left lower extremity below the knee became progressively more ischemic despite aggressive wound care and resuscitation. This was believed to be secondary to the intravenous, dual, high-dose vasopressors required for his previously treated septic shock which he received for well over 3 days. It was determined that the left lower extremity had become non-salvageable and would require a left below the knee amputation.

The family was finally identified. After 48 hours of indecision, as they did not believe the patient would want to live as a bilateral amputee, the family ultimately elected for comfort care/withdrawal of care measures despite the patient's expected survival. With the implementation of comfort measures per the family's medical guardianship, the patient subsequently expired.

3. "How to" Perform a Physiologic Amputation

Once the dry ice is brought to the medical center's intensive care unit (**Figure 3**), the affected lower extremity must be completely exposed with all bandages removed. A distal tourniquet above the level of cellulitis, ischemic mottling, or open wound, is tightly applied to restrict arterial, venous, and lymphatic flow (**Figure 4**). Approximately three to five cm proximal to the distal tourniquet, another tourniquet is applied around the affected extremity at the level of the intended future amputation closure site. Each tourniquet serves as a visual reminder to the surgeon where the frozen and warm levels are located. Dry ice must be placed on the bottom of a red contamination bag. The extremity is then laid directly on a dry ice bed followed by additional dry ice to circumferentially cover the affected limb. The dry ice is applied to the level of the distal tourniquet. The red contamination bag is then twisted tightly and clamped shut (**Figure 5**). The red bag containing the dry ice and limb is then wrapped in a blanket.

Figure 3. Chunks of dry ice delivered in individual containers being crushed into smaller pieces with a hammer in the intensive care unit.

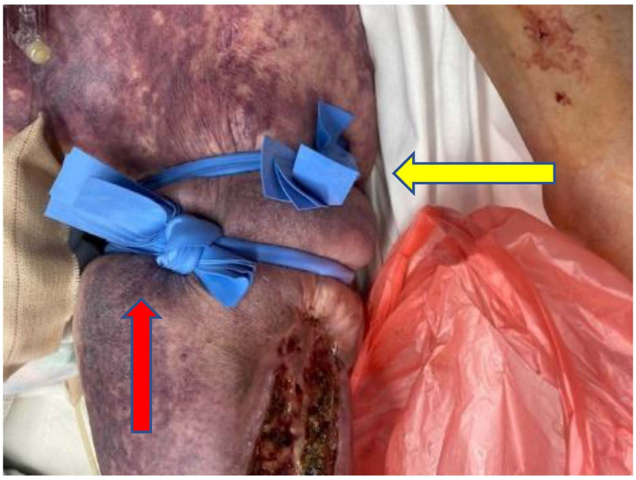

Figure 4. Application of two tourniquets (proximal (yellow arrow) and distal (red arrow)) to the right thigh with the right lower extremity being placed into the red contamination bag. Note the 3 to 5 cm separation between the proximal and distal tourniquets.

This allows for the immediate environment to remain extremely cold, freezing through all tissue layers of the affected limb. A barrier must also be placed between the two adjacent lower extremities such as a foam wedge to physically separate them (Figure 6). The bedside nurse with the treating physician must assess the patient's cryoamputation every hour to see if more dry ice is required secondary to CO_2 sublimation and for pain and sedation medication adjustment. Additional dry ice must be added around the extremity as needed. The physiologic amputated limb, once frozen, should never be thawed as the patient is

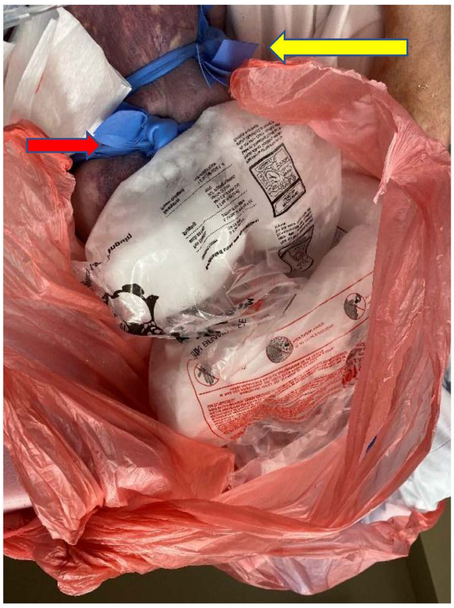

Figure 5. Packing of the affected limb onto a dry ice bed as additional dry ice is added over the rest of the lower extremity for circumferential placement up to the level of the distal tourniquet (red arrow). The proximal tourniquet (yellow arrow) is 3 to 5 cm proximal to the distal tourniquet.

Figure 6. A red contamination bag's top is twisted, and a large clamp (white arrow) are applied to hold the dry ice in place as the right lower extremity undergoes cryoamputation. Note the placement of the tourniquets in relation to the red bag containing the dry ice. A pink foam wedge (yellow arrow) is placed between the right limb undergoing cryoamputation and the left limb to prevent unintended injury. In addition, there is a thick padding applied between the right penis/scrotum and right thigh which is packed in dry ice.

eventually delivered to the operating room for the definitive open amputation. The red contamination bag should be changed if there is a hole preventing cold retention, or if the patient soils the outside of the red bag that cannot be adequately cleaned. If this does occur, the red bag and dry ice must be exchanged rapidly. Of note, once in the operating room, the leg will appear alabaster white, inflexible, as well as hard and cold to the touch (**Figure 7** and **Figure 8**).

The proximal tourniquet must have a heating pad (warming element) placed immediately adjacent to keep the proximal extremity at a normal body temperature. This should prevent proximal extension of the freezing past the distal tourniquet [2]. The proximal tourniquet represents the normal tissue that will be used for closure once the patient has an open amputation. The boundary between the proximal and distal tourniquet is a "no-man's land" where the temperature is neither frozen nor warm. The skin temperature is "luke-cool" to the touch. This area must be assessed frequently to ensure that the "no-man's land"

Figure 7. Intra-operative photographs of the right lower extremity (anterior/posterior image) that has undergone cryoamputation prior to right hip disarticulation with patient on the operating room table. Note the frozen appearance of the right thigh at the high thigh level.

Figure 8. Intra-operative photographs of the right physiologic amputation lower extremity (lateral image) prior to right hip disarticulation. Note the frozen appearance of the right thigh open wound at the high thigh level including the right thigh open wound (red arrow).

tissue has not become frozen [8]. This region provides a buffer so that if the freezing moves more proximal, either the dry ice or the heating element must be adjusted.

4. Discussion

There are several important considerations when performing the physiologic amputation. First, the cryoamputated extremity must remain frozen once the process is initiated. If allowed to thaw, there will be a release of prokaryotic organisms, toxins, free oxygen radicals and pro-inflammatory mediators negating the initially positive role of the physiologic amputation. Second, once the cryoamputation is initiated the patient or medical guardians must understand and consent to a definitive, open amputation as the second half of the already initiated amputation process. Third, the intra-tourniquet region, "no-man's land" or "frost line" [1], must be assessed hourly to evaluate whether the heating and cooling elements need to be adjusted [1] [8]. Fourth, adjacent structures, such as the contralateral extremity, torso, or perineum/genitalia, must not contact the dry ice, and an intervening barrier must be placed. For instance, the contralateral unaffected extremity can be protected by wrapping that limb in a warm, bulky blanket or an intervening foam, abduction wedge can help separate the two lower extremities. Unintended injury to other parts of the patient's body from the dry ice can also be avoided by placing the affected extremity in a Styrofoam cooler containing dry ice. However, such a container may represent an additional cost [4]. In addition, medical equipment such as central lines, intravenous tubing and Foley urinary catheters must never come in direct contact with the dry ice [8].

Since dry ice reaches a temperature of −78.5 degrees Celsius, it can freeze deep tissues including nerves within minutes [1]. Dry ice is the preferred cryogenic substance for freezing an extremity. Standard wet (H_2O) ice can be used, if necessary, but this technique may not freeze the extremity completely like dry ice will and is messy [1]. When standard wet ice melts (above 0 degrees Celsius), it produces cold water that must be contained away from the patient, whereas dry ice simply sublimates into CO_2 [4]. Adequate ventilation is required around the patient's cryoamputation as the CO_2 off-fumes. Finally, it behooves the surgeon or critical care physician to know the local dry ice manufacturer's or vendor's location within the immediate community to secure the delivery of dry ice to the patient. Dry ice needs replacing every 8 to 24 hours to continue the physiologic amputation process [1]. Dry ice sublimates from a solid to gas form at a rate of five to ten pounds every 24 hours [1]. The dry ice should be promptly delivered to the medical center's intensive care unit for immediate application.

Vaso-occlusive tourniquet application must be tight enough to prevent flow through thick-walled arteries as well as in the thin-walled lymphatic vessels and veins [3] [19]. Veins collapse with minimal to mild pressure as seen with ultrasonic compression during central venous access placement, and thereby the same must be true for the lymphatics [19]. Arteries are clearly thicker-walled and may be atherosclerotic, especially in the diabetic patient or in a patient that has an atherosclerotic or non-reconstructable vascular disease that has led to the ischemic or toxic limb. An extremely, tight-fitting tourniquet must still be applied to limit arterial inflow and venous/lymphatic outflow of the diseased limb.

Several case reports have recently described the medical physiologic amputation in a "how-to" manner [1] [4] [10]. While seemingly appropriate to be used in such cases, this critical care operation is curiously not widely published [10]. Nonetheless, this is an excellent example of damage control surgery [20]. Only surgical procedures are conducted that would save the patient's life returning the patient to physiologic stability. The diseased extremity is isolated or compartmentalized so as not to affect or cause the death of the critical-ill patient [1]. Even in the most austere environment that has access to a freezing element (refrigeration, dry ice, or wet ice) [1] [4] [10] [11] [21] salvaging a patient in septic shock from a diseased limb utilizing cryoamputation could be simple lifesaving, critical care, damage control maneuver. Many surgical fields could benefit from knowing how to perform cryoamputation especially the acute care, vascular, trauma, orthopedic and military surgeons, as well as the surgical or medical critical care intensivist [22].

5. Conclusion

Physiologic amputation is a clinical adjunct that can help the surgeon manage a critically ill patient in septic shock from an ischemic or infected limb utilizing circumferential immersion into dry ice. Cryoamputation will freeze the extremity and provides immediate source control, allowing the surgeon time to place intravenous lines, initiate crystalloid, or blood product resuscitation, manage the patient's respiratory status, correct metabolic derangements, initiate antibiotics, and potentially start dialysis in the attempt to improve the physiologic status of the critically ill patient before taking the patient for an open amputation. Additionally, studies are needed to further define the indication, optimal patient selection, and timing of cryoamputation and its potential impact on decreasing mortality in the critically ill patient.

Conflicts of Interest

Dr. Luis G. Fernandez is a surgical consultant and on the speaker's bureau for 3M/KCI, Urgo North America/SteadMed, Inc. None of these companies' products were used during this case report.

Dr. Samantha A. Delapena1, Dr. Devin O'Connor1 and Katharine A. Dishner have no conflicts of interest.

Dr. Marc R. Matthews is a surgical consultant and on the speaker's bureau for 3M/KCI, Urgo North America/SteadMed, Inc; MIMEDX. None of these companies' products were used during this case report.

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