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REVIEW ARTICLE

Hand Replantation is not adversely affected by Prior Ice Immersion: The Physiological Role of Ice in the Transport of Amputated Limbs

Harnarayan P,[1] | Seepaul T,[1] | Lalla R,[2] | Islam S.[3]

1 Department of Clinical Surgical Sciences, University of The West Indies, St. Augustine, Trinidad & Tobago, West Indies

2- Department of Plastics and Reconstructive Surgery, San Fernando General & Teaching Hospitals, San Fernando, Trinidad & Tobago, West Indies

3 Department of Surgery, San Fernando General & Teaching Hospitals, San Fernando, Trinidad & Tobago, West Indies

Abstract

Background: One of the most challenging operations in reconstructive surgery is the replanting of an amputated hand. Instituted protocols for the transport of the limb to hospital exist to allow it to remain cooled and therefore salvageable to the surgical team for replantation. This paper looks at limb preservation prior to replantation with the transport medium being analysed, to see how it relates to the existing evidence on limb cooling. Methods: Three cases of hand amputation were referred for replantation with two cases transported in ice arriving at hospital in a viable state without icicle formation nor maceration of the tissue. One was transported neither in a plastic container placed in ice nor directly in ice. All three underwent replantation, two being the dominant hands. Results: The outcomes of three cases were matched with the method of transport used for each limb. The two limbs which were transported in ice were replanted with very favorable short and long-term outcomes. The other hand initially appeared to be viable but intrinsic hand muscle necrosis lead to a poor outcome. Conclusion The significant change that occurs during cooling has been experimentally shown to be alkalinization of muscle cells which offsets the deadly effects acidosis, produced by muscle ischemia, has on the muscle cells. This and not the decrease in metabolic activity due to the temperature drop,causes tissue preservation prior to and during replantation. Direct immersion on ice is therefore not a contraindication to surgical repair.

Key words: Hand-amputation;ice-immersion; limb-cooling; replantation;

1 | INTRODUCTION

The replanting of an amputated limb is construed as one of the most challenging operations in reconstructive surgery [1], Replantation can be defined as reattachment of the part that is completely severed from the body, there being no connection between the severed part and the patient [2]. The goal here is not to preserve tissue through nonselective replantation[3] but to preserve the quality of life by the restoration of anatomical continuity as well as production of a good functional outcome [4]. The mechanism of injury, cold ischemic time and method of transport to hospital are factors in eventual outcomes although there is no correlation between survival and preoperative duration of ischemia in limb replantation[5].Clean-cut proximal amputations and cold preserved amputated parts have highest survival rates [6]. It is accepted that on retrieval of the amputated part, it should be kept cool, preferably wrapped in sterile clean gauze and placed in a plastic bag on ice in order to preserve it and present it to the surgeons for replantation [7].The wrong transport medium can sometimes be used, with the amputated part being placed in ice, plunged into ice-cold water or wrapped in a clean piece of cloth. We discuss the physiological effect cooling by ice has on tissue preservation and whether transport directly in ice prior to replantation, affects the surgical outcome.

2 | MATERIALS

Over a four-year period, three (3) cases of traumatic upper limb amputations presented to the Emergency Department (ED) of San Fernando General & Teaching Hospitals in Trinidad & Tobago, Caribbean Islands lying off the Atlantic Coast of South America. All three patients presented with the hand severed at the wrist by a machété during domestic disputes, a common type of personal felony assault seen in this region. In the first two cases, the amputated hand was placed directly on ice and transported to hospital whilst the third was only placed on ice after arriving at the ED. All three patients were referred to the surgical team for consideration of hand replantation. We herein present three cases of hand replantation in which each amputated part was presented to hospital in an atypical fashion with respect to the medium in which it was transported.

Case 1: A 44year-old male handyman was brought in to Emergency Department (ED) with his left hand completely severed by a machete blow aimed at his neck. In self-defence stance his non-dominant hand was completely severed and he endured some minor injuries to the face. Patient was resuscitated in the ED, and the severed hand retrieved. It was placed directly in ice not in a plastic bag to create an ice-barrier, and brought to hospital in a clean container. [Figure 1].

Corresponding Author: Patrick Harnarayan
1- Department of Clinical Surgical Sciences, University of The West Indies, St. Augustine, Trinidad & Tobago, West Indies

Since time from injury was 4 hours, and hand was kept cool in ice, a decision was taken to attempt replantation. The injury was a transverse laceration across the wrist causing amputation, with patient in a defensive posture.

Case 2: 48-year old female arrived at the ED with right (dominant) hand severed at a slight angle at wrist by a machete. Injuries to other parts of body were noted and she was resuscitated and having had 3-4 hours of ischemic time, she was referred to Plastic and Vascular teams to seek replantation. Her hand was retrieved from site of injury and placed directly in ice without an ice barrier and brought to ED with patient. A decision was taken to replant this dominant hand and patient was taken the operating theatre for the procedure. The injury was an oblique laceration across the palm from ulna to radial and through the wrist.

Case 3: A 58-year old patient was seen in ED with an amputated right dominant upper limb at level of the wrist. His injury was by machete and he was sent to a peripheral health facility for stabilization prior to transfer to trauma centre. His severed hand was never placed in ice, either in transport to the primary care facility nor during his transfer to the trauma centre. It was only placed in ice when he was seen by the surgical team just before surgery, after more than 4 hours had elapsed. The injury was a transverse laceration across the wrist from anterior to posterior or palmar to dorsum in a defensive posture. Surgical repair was at that time considered despite the length of warm ischemic time since it was his dominant hand. The hand was replanted and initially appeared to be viable but though the proximal aspect of the hand appeared perfused, the distal aspect of the palm and digits remained ischemic and unfortunately patient ended with an amputation.

3 | RESULTS

Although the first and second limbs were transported directly in ice there was no evidence of gross maceration, icicle formation nor freezing of tissue noted at the time of surgery. They appeared viable and were prepared for replantation by flushing of proximal vessels which were patent. After vessel anastomoses good flow was noted in the arteries then veins with perfusion of the hand. In terms of the medium and long term recovery periods, the first patient regained full sensation and function with competence and was able to use his hand to hold household implements [Figure II] at 3 months. He was able to use the gears on a lever-operated stick-shift automobile after 1 year and was re-integrated into the work-force.

Figure II-Competence and was able to use his hand to hold household implements

The second patient was noted to have a well-perfused hand post-surgery and continuous monitoring showed pulse oximetry of 98-100% on all fingers of her replanted dominant hand. The hand was reattached and was viable after surgery and well perfused [Figure III].

[Figure III]- The hand viewed in the early post-operative period

She was able to appreciate sensation in the hand and had anatomic restoration. She remained with limited ability to flex and extend her digits [Figure IV]. She trained her left hand to do many of the functions of her right, including writing and went back to work at her previous job.

Figure IV- Ability to appreciate some movement days after suture removal

The third patient arrived at the Surgical unit greater than four hours' post-injury and his hand was not transported in ice and only placed on it after arrival. Despite a good flush of his vessels and uncomplicated replantation and good radial and ulna pulses, his small vessels in the hand appeared to have been thrombosed displaying the "no flow" phenomenon. This "no flow" phenomenon is typically seen when there is good arterial inflow as evidenced by palpable radial and ulna pulses. However irreversible ischemic occurred in the microcirculation likely due to the prolonged muscle ischemia.

The short term results appeared reasonably good in the first two patients (Patient 1 and 2) and long term (now 7 and 3 years respectively) both patients went on to have a good degree of function with both returning to work. The patient (3) who had an unsuccessful attempt at replant, had no benefit of the cooling effect of ice, and a longer ischemic time (>4 hours) than the other two, so the chance of revascularization was very minimal.

DISCUSSION

The warm ischemic time for a hand differs from that of a digit due to* the presence of muscle tissue in the hand so that minimizing both the warm and total ischaemic time is highly desirable for replantation to be successful [7].For digits a warm ischemic time over 12 hours and a cold ischemic time over 24 hours are contraindications to attempting surgery [8]. In wrist amputations, these times are much shortened due to presence of muscle since of all the tissue types in the limb, muscle is the least tolerant to ischemia [1]. It is therefore important for the amputated segment to be kept hypothermic from the time of the injury to the time of surgical intervention [9].

The preservation of the part is important to the outcome since a limb that may be initially viable may be inadequately cooled rendering it unsalvageable. Transportation has been reportedly done in ice water, formalin solution, wrapped in dry gauze as well as without any cooling agent. The chances of arriving at hospital with an improperly or non-cooled part, in a macerated, near-frozen state or conversely, with thermal burns is therefore quite possible.[7]

The modern method of transport involves wrapping of the part in gauze moistened by lactated Ringer's solution or normal saline [10],placing it in a plastic bag and immersing it in a mixture of crushed ice and water [7].Alternately, it can be wrapped in moist gauze placed in ice or placed in a plastic bag then onto ice.

The first studies carried out on the effect of temperature, on the tolerance of tissues to ischemia in the extremities, were done in 1934 by immersing mammalian tissue in an ice bath [11].It was believed that the benefits of the cold were due to the decrease in metabolic activity and the energy needs of the tissue, based on the assumption that the lowest possible temperature just prior to freezing would be the best [11]. Hardly any scientific data has been generated to challenge or verify this very basic assumption that temperature change can affect preservation of an appendage during extended periods of ischemia. Even the most recent works describing tissue preservation prior to replantation go back to the immersion of tissue in ice water by Allen in 1934 [12].

Physiologically the effect of cooling has always been assumed to be beneficial by decreasing the metabolic activity of the tissue hence slowing down deterioration caused by prolonged ischemia. In fact, the effect that cooling has on muscle tissue is to produce alkalinisation of

the muscle cells which in turn counteracts the dreaded effect of acidosis caused by ischemia by acting as a buffer. Excess hydrogen ions have been noted to have an association with muscle cell injury caused by prolonged ischemia [13].Previous scientific observations had shown an alarming increase in hydrogen ion concentration at the level of muscle cells during ischemic injury [13]. Experimentally iced-tissue cooling produced a dramatic initial rise in cellular pH which was significant in its ability to offset the degree of acidotic changes caused by ischemia [14].The alkalinisation produced by this cooling negates the effect that acidosis has on muscle cells [14].

The rise in pH has surprisingly never been mentioned in the preservation and replantation of limbs although this is well known in physiology [15,16,17]. This changes our understanding of how hypothermia preserves ischaemic tissue [14].It was previously assumed to work on the principle of decreased tissue metabolism conserving cellular Adenosine triphosphate (ATP) levels, but now, the benefit in cooling appears to lie in this cellular alkalinisation achieved by cooling of the tissue [18].

Based on these findings, researchers developed a modified protocol for limb preservation. Metabolically the best way to cool an amputated limb is to drop the temperature of the deep tissue down to 10-15ºC as quickly as possible, then maintain it around 10 ºC [18].No experimentally existing method is quicker than an ice-bath [19], so the first phase of this modified protocol was immersion in an ice bath with the temperature dropping from 37-36ºC down to 10-15ºC. Having achieved a quick drop in temperature of the deep muscles, it was found that the best way to maintain temperature at about 10º C was suspending the amputated part over ice in a Styrofoam 'chest.' A special container has been developed with the preceding features and is currently identified as the Universal medical container or "limb-bin" [20].

Both direct contact with ice and even indirect contact with wet gauze wrapped in a plastic bag inadvertently allows the temperature to drop to < 5º C [10]. Sapega et al were quick to point out that in theory, thermal burns and freezing were in fact as much as possible with the amputated part placed in ice as it would if placed in a plastic bag on ice [18].

Therefore, it is technically incorrect even to wrap the limb in gauze and place in a plastic bag and rest on ice although it is used universally and does in fact appear to work. Direct immersion in ice though incorrect, is not a contraindication to surgical replantation, as seen in limb salvage of hands which were immersed in ice and loss of the hand which was not placed in ice.

CONCLUSION

When amputated limbs are placed in ice,the cooling effect on the limb tissue produces a dramatic initial rise in cellular pH which offset the acidotic changes caused by ischemia of the tissue after amputation. The alkalinisation produced by this cooling negates the effect that acidosis has on muscle cells, not the decreased muscle cell activity with decreased ATP usage.

The limb just has to be cooled down to 5 to 10 ^{0}C and then maintained at 10 ^{0}C for tissue viability to be maintained and even if temperature drops below this once it is not macerated, replantation should be attempted. Having the hand in ice is not physiologically a contraindication since the hands that were immersed in ice were safely replanted with good short and long term outcomes. The "non-iced" hand was replanted but suffered many adverse events including recurrent thrombosis and small vessel occlusion and therefore this, rather than immersion, could be considered a contraindication to replantation.

Conflicts of Interest
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Ethical approval
Institutional Review was sought from the San Fernando General &Teaching Hospitals/South-West Regional Health Authority's Bioethics Committee but not required for this review article. This study was conducted in accordance with The Declaration of Helsinki.
Author Contributions
All authors contributed to data analysis, drafting or revising the article, have agreed on the journal to which the article will be submitted, gave final approval of the version to be published, and agree to be accountable for all aspects of the work.

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Figure Legends:

Figure 1-Patient 1: Grossly viable hand without icicles

This figure demonstrates that even though the amputated hand is immersed in an ice bath, there are is no gross icicle formation and replantation can be performed.

Figure 2-Patient 1: Gripping water bottle with replanted hand

Six months after replantation, patient has wide range of movement, sensation and can grip objects comfortably.

Figure 3-Patient 2: Early postoperative periodwith movement

Appearance after a few days showing a viable limb with good perfusion and “pincer” motion.

Figure 4-Patient 2: Viable hand post replantation

This figure shows patient whose dominant hand was immersed in ice, but grossly viable. It was replanted with good postoperative perfusion and anatomical continuity.