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Research Article

Role of Smart Phone Based Thermal Camera in Predicting the Salvageability and Outcome of Replanted and Revascularized Fingers: A Real Time Cost Effective Method

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Abstract

Background: Monitoring of a replanted finger is a challenging and essential part in its success. Although a number of modalities have been defined for this purpose but no consensus have been seen on any one of these to be the most useful method. The purpose of this study is using a smart phone based thermal imaging camera (FLIR ®) for monitoring of replanted digits.

Material and Methods: Using a smart phone based thermal imaging camera (FLIR ®) was used with Samsung android phone. The FLIR system delivers a thermal image of the entire replanted digit with difference in color, representing temperature differences (between -20°C to 120°C). Images were obtained both pre and post operatively, these were compared with subsequent serial measurement done on bed side.

Results: A total of 30 digits were replanted and re-vascularized in duration of 3 years. All replantation's and revascularizations were done by the same surgeon. Seventy percent involved non dominant hand and 30% involved dominant hand. Majority (72.72%) involved a single digit, 27.27% involved multiple. All replantation were done which were amputated proximal to PIPJ.

Conclusion: Being a non-invasive temperature measuring modality this method aids in prompt decision making for replantation. It also reliably predicts the probability of survival of the replanted digit. Smart phone based monitoring is non operator dependent, depicting the actual temperature difference between the replanted and adjacent digits, which helps in monitoring.

Keywords: Replantation; Monitoring; Thermal Imaging; Smart Phone Based Imaging; Salvageability

Introduction

The term amputation is coined from a Latin word 'Amputare' which means total or partial separation of a part of a body which may be traumatic or surgical [1,2]. Amputations involving the upper limb, more specifically the hand cause devastating psychosocial and socioeconomic consequences affecting both the victim and family [3]. Replanting an amputated limb or a part of a limb is a challenging but life changing procedure. It is defined as the surgical reattachment of a body part, that has been completely cut from a person's body. First ever arm replantation was performed by Malt and McKhann in 1962 at Massachusetts General Hospital in Boston, Massachusetts, United States [4]. Tamai and Komatsu reported the first ever finger replantation in 1968 [5]. Monitoring of a replanted digit/limb can improve early detection and salvageability of the replant. Parameters such as skin color, skin turgor, temperature and capillary refill that are used for monitoring of free flap are routinely used for monitoring of digital replant but are subjected to errors and observer dependent [6-8]. Over a period of years, development in technology led to introduction of number of monitoring devices including Laser Doppler Imaging (LDI), laser speckle imaging, laser speckle contrast analysis, doppler ultrasonography, transcutaneous oxygen monitoring, quantitative fluoroscopy and near infrared

spectroscopy [9-13]. Smart phone-based thermal camera is a non-invasive technology that captures a thermal image providing information on temperature difference and transition zones [14]. This modality has been introduced for monitoring of free flap, detection of occult inflammation and monitoring severity and treatment of diabetic foot [14,15].

Ethical Statement

The project did not meet the definition of human subject research under the purview of the IRB according to federal regulations and therefore, was exempt.

Materials and Methods

This prospective study was conducted during 1st January 2021 to 31st December 2023 at department of plastic and reconstructive surgery, Liaquat National Hospital after Ethical and research committee approval was obtained. Patients presenting to the emergency department with digital amputations were assessed. Preservation of the amputated part and ischemia time were also evaluated. All patients with sharp, clean cut, traumatic amputation, with well-preserved amputee and willing for replantation/revascularization were included in the study. Those with either a poorly/non-preserved amputee or with crush and avulsion amputations were excluded from the study. All anastomosis were done using 10/0, 11/0 or 12/0 prolene suture depending upon the size of the vessel in a continuous fashion. Using a smart phone based thermal imaging camera (FLIR ®) with Samsung android phone (Fig. 1), fingers were evaluated using the FLIR system both pre and post operatively (Fig. 2,3). This system delivers a thermal image of the entire replanted digit with difference in color, representing temperature differences (between -20°C to 120°C). Images were obtained both pre and post operatively and these were compared with subsequent serial measurement done on bed side after replantation/revascularization. Post operatively patients were kept in monitoring setup and routine monitoring was done along with the use of thermal camera. Hourly images were obtained. Initial two-degree temperature difference from surrounding tissue was set as the criteria of relook. Data was collected on a designed proforma and operative note, relevant pictures were taken after taking written and informed consent from patients, keeping patient identity and details confidential.

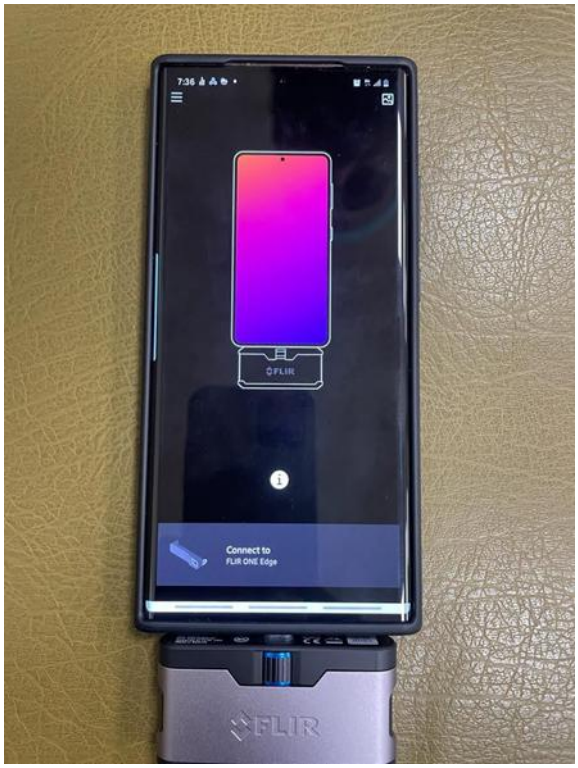

Figure 1: Showing the thermal camera device with android phone.

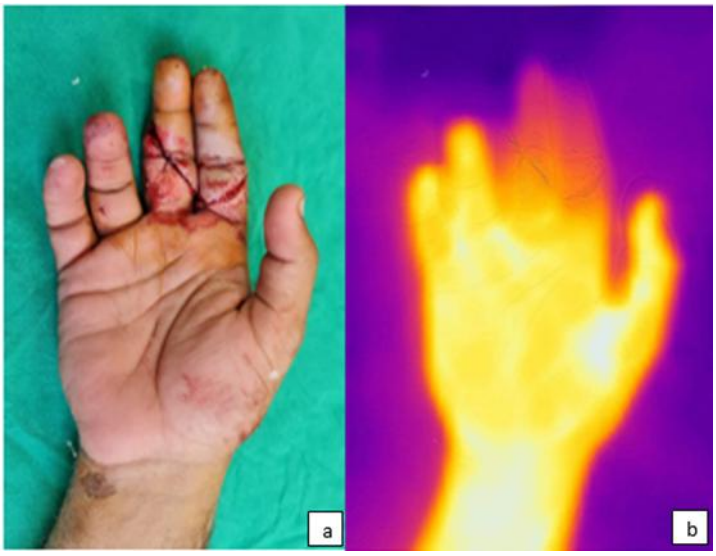

Figure 2: Preoperative images, with and without thermal camera. a) showing the injured index and middle fingers of the right hand; b) showing color difference between non-vascularized (index and middle finger) and vascularized parts of the hand.

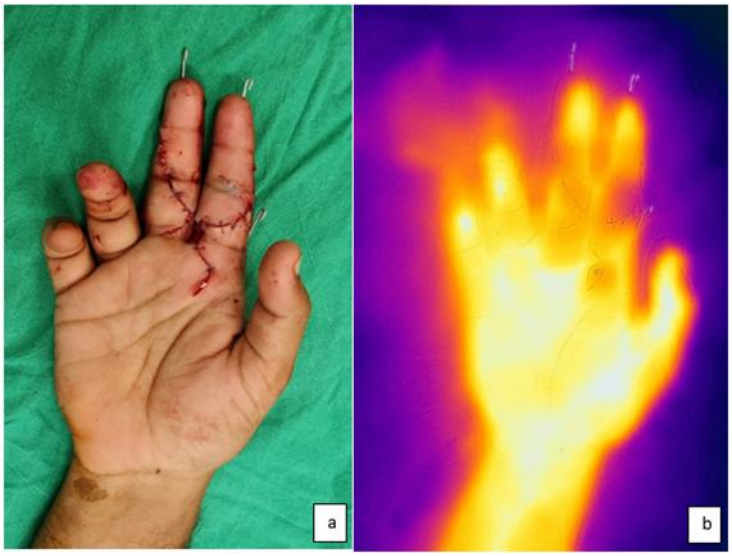

Figure 3: Post-operative images after revascularization, with and without thermal camera. a) showing the injured index and middle fingers of the right hand fixed with k wires; b) showing well perfused revascularized index and middle fingers.

Gender	Male - 20
	Female - 2
Hand dominancy	Right - 90.09%
	Left - 9.09%
Age	<25 years - 12
	25 - 50 years - 8
	>50 years - 2
Ischemia time	<6 hours - 18
	>6 hours - 4
Preservation	All digits were well preserved
Arterial repair	One artery - 6

	Two arteries - 24
Venous repair	<2 - 4
	>2 - 26
Vein graft	Yes - 4
	No - 26
Level of injury (Tamai Level)	I -0
	II -1
	III -10
	IV -15
	V -4
Nerve repair	Yes - 30
	No - 0
Anesthesia	Local - 16
	Regional - 1
	General - 5
Comorbidities	Diabetes - 4
	Hypertension - 2
	None - 16
Digit	Thumb - 4
	Index -10
	Middle - 8
	Ring - 6
	Little - 2

Table 1: Observation details.

Results

During the study period of 3 years, a total of 22 patients were included, of which 20 (90.9%) were male and 2 (9.09%) female patients. Ninety percent of patients were right hand dominant, with 70% acquiring injury to the non-dominant extremity. Among the injured patients 6 patients acquired injury to multiple digits, two with injury to three digits, four patients with injury to two digits and rest with injury to single digit. Out of total of thirty digits, 7 fingers were revascularized and 23 were replanted. Twenty of these had an unremarkable recovery. Ten replanted digits needed re-exploration which was picked up using thermal camera (FLIR ®) based on temperature difference from the surrounding tissue. There was no change in other parameters used for monitoring during the same time. Average time after which change in temperature was noted was 3.4 hours, these digits were kept on continuous monitoring and micro vascular surgeon was informed about the change. Digits were re-explored if there was no improvement in temperature or the temperature did not return to normal in next 2 hours. The time elapsed between suspicion of vascular compromise to intervention was 2.5 hours. Vascular thrombosis at the anastomotic site was observed in 7 digits and compression of the vessel due to tight skin closure in 3 digits. Among these 6 were salvaged with timely re-exploration. We lost 4 digits which were later terminalized.

Discussion

In order to detect any disturbances in the blood flow post-operative monitoring of the replanted digits has a crucial role in the success of the replant. In addition to the conventional methods of monitoring which include color, capillary refill, surface temperature and blood on pin prick, a multitude of monitoring devices are available to detect early changes in perfusion of the replanted digits and limbs [8,9,16]. These modalities are also in use for monitoring of free flaps in reconstructive surgeries. Temperature monitoring is one of the most widely used modality [17,18]. This can be done using a number of methods, including thermometry, infrared thermography and smart phone based thermal imaging. We utilized smart phone based thermal camera for imaging and monitoring of replanted digits. This non-invasive technology has already been described in microsurgery for purpose of identification of perforators and monitoring of free flaps [15,19-21]. We utilized FLIR one ® thermal camera for

monitoring of replanted digits. In order to predict salvageability and outcome, serial pre-operative and post-operative images were obtained. Adequacy of perfusion after reperfusion was checked intra-operatively by absolute temperature measurement of the replanted digit/s and its comparison with the neighboring digits as a control digit. Difference of 2°C compared with control digits is an indicator of compromised perfusion [16]. In addition, any persistent drop in temperature below the range of 29°C - 30°C is suggestive of high possibility of vascular compromise [11,16,17]. FLIR one ® thermal camera is an easy and repeatable, non-operator dependent modality with a sensitivity of 96.15%, specificity 98.9% and positive predictive value of 96.15% and negative predictive value of 98.9% [21].

These handheld, smart phone-based devices deliver effective, non-invasive imaging for the assessment and monitoring of the replanted or revascularized digit. Besides measuring temperature variations, they produce thermal image that can be compared to subsequent ones. These images can be stored documentation and serve as valuable data to support clinical decision making.

Conclusion

The use of smartphone-based, non-invasive temperature monitoring in replantation procedures enhances decision-making by providing reliable, real-time data on the viability of the replanted digit. By detecting temperature differences between the replanted and adjacent digits, this method helps predict the likelihood of survival, allowing for prompt and informed clinical actions. Its non-operator-dependent nature ensures consistency and accuracy in monitoring, ultimately improving patient outcomes in replantation surgeries.

Conflict of Interest

The authors declared no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

Financial Disclosure

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None.

Author's Contribution

All authors read and approved the final manuscript.

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