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ORIGINAL ARTICLE

Near Infrared Spectroscopy in Monitoring Compartment Pressure

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Abstract

Introduction: The physiologic changes of trauma-induced hyperaemia have been under-appreciated in the understanding of ACS. Near-infrared spectroscopy (NIRS), a noninvasive method of quantifying tissue oxygenation and perfusion, has been examined as a monitoring tool for ACS. **Methods:** The study was done in the department of orthopaedics, Pushpagiri Institute of Medical Sciences and Research, Thiruvalla, Kerala from January 2021 to February 2022 in patients with fracture both bones of leg. The tissue perfusion was recorded at the time of admission and once every day for three days using Near Infra-Red Spectroscopy. Whenever compartment syndrome was suspected clinically and with NIRS values, the intra compartmental pressure was also recorded using a slit catheter and sphygmomanometer. **Results:** Out of the thirty cases studied, two patients had NIRS value 10 and 12 lower compared to uninjured side. In both of them there was clinical suspicion of acute compartmental syndrome and the intracompartmental pressure were 32 and and 34 respectively. Emergency fasciotomy was performed in both the cases. **Conclusions:** This study has shown that the increased perfusion in the injured leg, compared to the contralateral leg, demonstrates a hyperaemic effect present after injury. In the absence of hyperemia in two of our cases we were able to pick up increased compartmental pressure and perform immediate fasciotomy. NIRS monitoring of extremity injuries especially in unconscious patients could potentially allow early detection of ACS by recording the absence of hyperaemia within the first three days after injury.

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Introduction

The technology of Near Infrared Spectroscopy (NIRS) depends on the basic principles of optics and photonics as they relate to the transmission of light through living tissues and the absorption of light by tissue chromophores [1]. NIRS units use lasers or diodes that transmit pulses of multiple wavelengths of light into tissues and optical sensors that detect returning photons. When NIR light is transmitted through tissue, only a small proportion of the original photons transmitted can be detected returning from the tissue [2,3]. The changes in absorption at discrete wavelengths generate raw optical data that can be converted by mathematical software algorithms into real-time concentration changes for each chromophore using a modification of the Beer—Lambert law [4]. The principal chromophores of interest in physiological and clinical studies using NIRS are oxygenated (O2Hb) and deoxygenated (HHb) species of hemoglobin, which each have a distinct extinction coefficient (absorption characteristic) across the NIR spectrum [5-7].

Compartment syndrome occurs when there is an increase in the intra-compartmental pressure in a closed osteofascial compartment. It may be due to increase in the content of the compartment or due to reduction in the volume of the compartment [8]. Acute compartment syndromes are due to traumatic and non-traumatic causes, whereas the chronic compartment syndromes are following excessive muscle activity as happens following exercises or prolonged waliking. Acute compartment syndrome is considered to be a surgical emergency and hence the monitering and measurement of intra-compartment pressure is very important, especially when the patient is unconscious. Traumatized tissue results in a predictable hyperaemic effect in the injured extremity [8]. This response is critical in understanding the development of acute compartment syndrome (ACS), which is most commonly associated with lower extremity trauma [9,10]. The physiologic changes of trauma-induced hyperaemia have been under-appreciated in the understanding of ACS. Near-infrared spectroscopy (NIRS), a noninvasive method of quantifying tissue oxygenation and perfusion, has been examined as a monitoring tool for ACS. It has been used in studies of muscle perfusion, exertional compartment syndrome, and ACS and has shown promising results [11-13].

The development of ACS typically occurs within the first 3 days after injury and after initial fracture stabilization [14,15]. Understanding the expected NIRS response to injury in the absence of a compartment syndrome must be understood before NIRS can be applied in the setting of potential ACS. Therefore, determining the duration of this hyperaemic response to trauma is vital for interpreting the utility of NIRS in the setting of ACS [16,17]. The purpose of this study was to evaluate patients with leg trauma clinically and with NIRS to detect increased compartmental pressure.

Materials and Methods

The study was done in the patients reported to the department of orthopaedics, Pushpagiri Institute of Medical Sciences and Research, Thiruvalla, Kerala, with fractures of Tibia and Fibula. All participants provided written informed consent for the study after approval from the institutional review board. The study was done on patients reported from January 2021 to February 2022 with fracture both bones of leg fulfilling the inclusion criteria.

Patients between ages 18 to 64 with unilateral cosed fractures of Tibia and Fibula admitted in the department of Orthopaedics, Pushpagiri Institute of Medical Sciences and Research, Thiruvalla were included in the study. The exclusion criteria included bilateral lower extremity injuries, and any previous diagnosis of pulmonary or vascular disease. The tissue perfusion was recorded at the time of admission and once every day for three days using Near Infra Red Spectroscopy. Whenever compartment syndrome was suspected clinically and with NIRS value the intra compartmental pressure was also recorded using a slit catheter and sphygmomanometer. NIRS measurements were obtained using a portable near infrared spectroscopy device developed by K.J. Hospital, Chennai. The device was validated in Chennai and in our institute and found to have 90% accuracy. This device measures the proportion of hemoglobin saturated with oxygen (rSO2) 2 to 3 cm below the skin [15,17]. NIRS measurements were taken at the mid-diaphyseal region for each of the four muscle compartments from both the injured and contralateral legs [4]. The sensor was applied to the leg for 30 to 60 seconds, to allow the device to generate a stable reading for at least 24 seconds or four cycles. The protocol for obtaining NIRS readings has been previously described and this technique was followed in this study [4].

P value was calculated with independent t tests to detect significant differences in mean rSO2 between compartments of the injured and contralateral (uninjured) legs of study subjects, to test the hypothesis of a hyperaemic effect present for a long period following injury. Independant t tests was used to test whether statistically significant differences existed between both legs by calculating NIRS gradients (rSO2 in the injured leg minus rSO2 in the contralateral leg) in each muscle compartment. All statistical tests were two-sided using p d" 0.0001 as the criterion for significance, and performed using SPSS 20.

Results

Thirty patients with fracture both bones of the leg reported during the study period of one year formed the study cohort (Fig. 1). Baseline characteristics of the study population are shown in Table 1. The most common mechanism of injury was road traffic accident (n = 28). The rest were due to fall (n = 2). Twelve had middle third fracture, ten had upper third and the rest had lower third fractures.

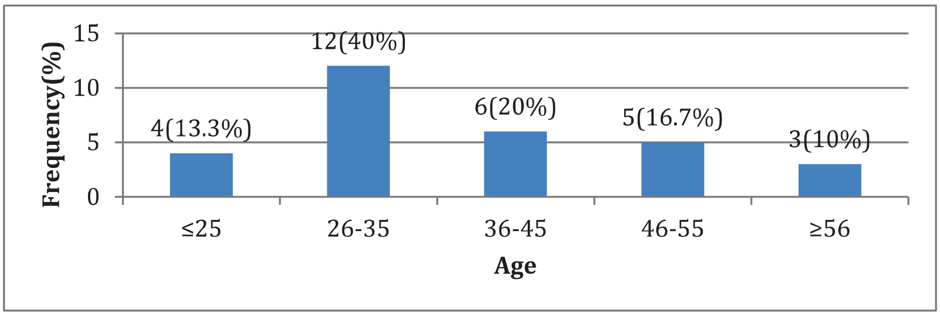

Figure 1: Age distribution of the patients

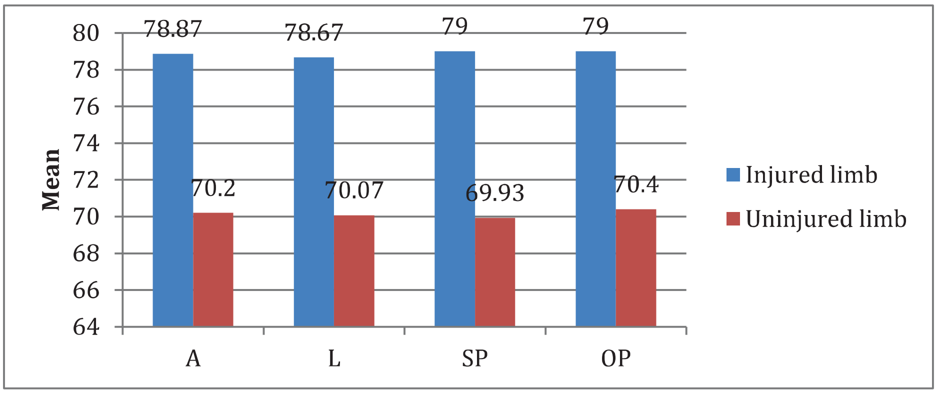

Figure 2: Mean Perfusion values in injured and uninjured leg in all the compartments.

Table 1: Baseline characteristics of the study population

Injury	Frequency	Percent
BB (L- LEG)	11	36.7
BB (R- LEG)	19	63.3
Total	30	100.0
Cause	**Frequency**	**Percent**
FALL	2	6.7
RTA	28	93.3
Total	30	100.0

Table 2: Mean Perfusion values in injured and uninjured legs.

	Injured limb	Uninjured limb	P value (independent t test)
A	78.87	70.2	0.0001
L	78.67	70.07	0.0001
SP	79	69.93	0.0001
DP	79	70.4	0.0001

(A- Anterior, L- Lateral, SP- Uperficial posterior and DP- Deep posterior compartment)

The average three days measurement of percent tissue oxygenation (rSO2) in each compartment is displayed in Fig. 2 and Table 2. Mean rSO2 values in the anterior (A), lateral (L), superficial (SP), and deep posterior (DP) compartments of the injured leg were 8.67,8.6,9.07 and 8.6 points higher, respectively, compared to the contralateral leg ($p < 0.0001$ for all compartments). In two of our patients NIRS value was 10 and 12 lower compared to uninjured side. In both of them there was clinical suspicion of acute compartmental syndrome and the intra compartmental pressure were 32 and 34 respectively. Emergency fasciotomy was performed in both the cases.

Discussion

Compartment syndrome occurs when there is an increase in the intra-compartmental pressure in a closed osteofascial compartment. It may be due to increase in the content of the compartment or due to reduction in the volume of the compartment [8]. Acute compartment syndrome is a surgical emergency and immediate fasciotomy is mandatory to save the limb from the irreversible sequelae of ischemia. If the compartment pressure is more than 30 mm of Mercury, it is an indication for emergency surgical intervention. In most of the centres, the decision is made following clinical diagnosis of increased compartment pressure. The accuracy of clinical judgement of increased compartment pressure is very often questionable especially with the less experienced traumatologist and the diagnosis may be delayed in most of the cases. The routine recording of intra-compartmental pressure is deferred for want of non-invasive measuring devices. The development of ACS typically occurs within the first 3 days after injury and after initial fracture stabilization [14,15].

Traumatized tissues and fractures in the limbs result in a predictable hyperaemic effect in the injured extremity [8]. This response is critical in understanding the development of acute compartment syndrome (ACS), which is most commonly associated with lower extremity trauma [9,10]. The absence of hyperaemic effect following extremity trauma is an evidence of increased compartment pressure resulting in poor perfusion. NIRS can pick up changes in tissue perfusion much before the appearance of clinical signs. The NIRS device is very easy and handy to use and is desirable for any one dealing with the management of trauma because of the non-invasive nature. The advantage of near infrared spectroscopy in determining the compartmental pressure accurately needs validation before routine clinical use in traumatology units.

This study has shown that the increased perfusion in the injured leg, compared to the contralateral leg, demonstrates a hyperaemic effect present after injury [8]. We are not able to comment on the duration of hyperemic effect following fracture, even though many studies have documented increased vascularity at fracture site upto hundred days after the fracture [12,13]. In the absence of hyperemia in two of our cases we were able to pick up increased compartmental pressure and perform immediate fasciotomy. NIRS monitoring of extremity injuries especially in unconscious patients could potentially allow early detection of ACS by recording the absence of hyperaemia within the first three days after injury.

Conclusions

The observations in this study suggests that, in the absence of ACS, NIRS values of the injured extremity should be elevated when compared to the contralateral uninjured extremity. If NIRS values are not elevated during the first 72 hours after injury, a very high suspicion of poor perfusion should be considered.

Conflict of Interest:	All authors declare no COI
Ethics:	There is no ethical violation as it is based on voluntary anonymous interviews
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