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Comparison of tissue oxygenation and compartment pressure following tibia fracture

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ABSTRACT

Objective: We investigated the ability of direct continuous measurement of intramuscular tissue oxygenation (PmO_2) to detect acute ischaemia in the leg in patients at risk for acute extremity compartment syndrome. Following tibia fracture treated by intramedullary nailing, we compared the proportions of PmO_2 and compartment pressure (CP) measurements that met the warning criteria for compartment syndrome.

Methods: Participants included 10 patients sustaining acute isolated closed tibia shaft fractures treated by intramedullary nailing. A tissue oxygenation probe and a CP probe were percutaneously placed into the anterior compartment of the leg. PmO_2 and CP in the anterior compartment were measured in the injured leg for 48 h postoperatively. Measurements meeting the warning criteria were defined as $PmO_2 < 10$ mmHg, CP > 30 mmHg and perfusion pressure $\Delta P < 30$ mmHg.

Results: None of the patients developed compartment syndrome. Comparison of CP and PmO_2 showed a CP > 30 mmHg in 50.39% of CP measurements in all patients and a $PmO_2 < 10$ mmHg in 0.75% of PmO_2 measurements in two patients ($P = 0.005$). Comparison of ΔP and PmO_2 showed a $\Delta P < 30$ mmHg in 31.01% of ΔP measurements in nine patients and a $PmO_2 < 10$ mmHg in 0.76% of PmO_2 measurements in one patient ($P = 0.01$).

Conclusion: In the absence of compartment syndrome, pressure measurements following tibia fracture treated with intramedullary nailing often met the warning criteria, whereas PmO_2 did not, suggesting that measurement of intramuscular tissue oxygenation may represent a potential method for the identification of acute compartment syndrome that deserves continued investigation.

Introduction

Acute compartment syndrome describes the elevation of pressure within the non-yielding fascial compartments of the extremities, leading to compromise of circulation, local ischaemia and ultimately tissue necrosis. This is a potentially devastating sequela of tibia fracture.[1,2] Delay in diagnosis or treatment may have catastrophic consequences; therefore, timely and accurate diagnosis is imperative. The main objective test in current use is measurement of compartment pressure (CP). However, considerable controversy exists with regard to thresholds for fasciotomy,[3,4] which has resulted in problematic clinical ambiguity.

Because the pathophysiology of compartment syndrome involves pressure-induced ischaemia of muscle, monitoring tissue oxygenation represents a potential method for diagnosis. Use of an intramuscular probe to directly measure the partial pressure of oxygen may represent one strategy of assessing tissue oxygenation. The probe used in this study is a polarographic oxygen probe approved for monitoring brain tissue in the intensive care setting.[5] It has also been studied for applications within skeletal muscle and has been found to be highly responsive to changes in tissue oxygenation.[6–8] Continuous measurement of tissue oxygenation has been shown to be feasible in leg muscle in humans following tibia fracture.[9] A partial pressure of oxygen <10 mmHg has been suggested as a possible threshold for irreversible muscle ischaemia.[10,11]

The purpose of this study is to simultaneously record CP and intramuscular tissue oxygenation (PmO_2) in a cohort of patients deemed at risk for compartment syndrome and to compare the proportion of measurements meeting pre-defined warning criteria for compartment syndrome. We hypothesised that a considerable

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percentage of postoperative CP measurements would meet established warning criteria for compartment syndrome, consistent with the literature, whereas PmO_2 measurements would not meet the warning criteria for irreversible ischaemia in the absence of compartment syndrome.

Patients and methods

This study was approved by the institutional review board (approval H50856-32886-01) and written informed consent was received from all enrolled patients. This was designed as a prospective observational study. We chose to study the anterior compartment of the leg because it is most frequently affected by compartment syndrome.[1,12] The cohort consisted of patients who underwent surgery for a tibia fracture with intramedullary nailing. Continuous measurement of PmO_2 and CP was performed postoperatively.

Inclusion criteria were: age $\geq$18 years, admission via the Emergency Department, unilateral isolated closed acute tibia shaft fracture and minimum 6 h of concurrent measurement of PmO_2 and CP or ΔP. Exclusion criteria were: inability to give consent due to intoxication or head injury, open fracture, bilateral tibia fractures, tibia plateau or plafond fracture, ipsilateral femur or pelvis fracture, impending/established acute compartment syndrome or refusal to participate. Bilateral injuries were excluded because it precluded the ability to obtain control data from the contralateral limb. Open fractures were excluded because of the potential difficulty in placing the probes percutaneously without violating open wounds and risking contamination. Only tibial shaft fractures amenable to intramedullary nail fixation were included to avoid the surgical incisions necessary for open reduction internal fixation.

The tissue oxygenation probe used (Licox Combined Oxygen and Temperature Probe CC1.P1, Integra, Plainsboro, NJ, USA) is a Clark type polarographic oxygen probe and temperature measurement system that uses an electrochemical micro-cell for oxygen sensing, expressed as the partial pressure of oxygen (PmO_2). The CP probe used (Synthes Compartment Pressure Monitoring System, Synthes, Inc., West Chester, PA, USA) is a multi-use electronic transducer tipped catheter.[13] Both probes were placed percutaneously into the anterior compartment of the leg under sterile conditions using a Seldinger technique.[14] Detailed description of probe placement technique has been previously reported.[9] The probes were connected to a computer for data recording, which was maintained in a locked box at the patient's bedside.

Both the injured and the healthy legs underwent sterile surgical preparation and draping. The tissue oxygenation probe and the CP probe were placed in the uninjured (healthy) leg while under anaesthesia. PmO_2 and CP were recorded continuously from the healthy leg while intramedullary nailing was performed on the contralateral injured leg. After surgery was completed, sterile conditions were maintained, and both probes were removed from the healthy leg and placed in the injured leg. A sterile band-aid was placed over the probe insertion sites on the injured leg. The injured leg was then placed in a removable walking boot.

While the tissue oxygenation probe could be disconnected from the recording device as needed for patient mobilisation and subsequently re-connected, the pressure probe did not have this capability. Therefore, CP monitoring ended when the patient was mobilised. At the conclusion of the data collection period, the probes were removed from the patient and a sterile band-aid was placed over the probe insertion sites on the injured leg.

CP and PmO_2 were measured continuously and recorded every 2 min. In some patients, data were recorded every 30 s, and in these cases all data were included for all analysis. Measurement began 15 min after insertion of the tissue oxygenation probe to allow time for calibration. After surgery was completed, the pressure and tissue oxygenation probes were placed in the injured leg and measurements were recorded in the same fashion. Continuous monitoring of PmO_2 and CP was performed for up to 48 h postoperatively, except during transport and physical therapy. The patient and treating nurses and physicians were blinded to the PmO_2 and CP measurements, which were contained in a locked box at the patient's bedside.

Warning criteria

The number of measurements meeting prospectively defined warning criteria for compartment syndrome was based on previously published studies: absolute intracompartmental pressure (CP) >30 mmHg,[15,16] perfusion pressure (ΔP = diastolic blood pressure – CP) <30 mmHg[4] and tissue oxygenation (PmO_2) <10 mmHg.[11,17] The number of measurements meeting the tissue oxygenation warning criterion ($PmO_2 < 10$ mmHg) was compared with the number of measurements meeting the warning criteria for CP and ΔP. Blood pressure measurements made in the early postoperative patient were occasionally not accessible for recording. This resulted in shorter durations of ΔP measurements compared to PmO_2 and CP.

Statistical analysis

Descriptive statistics were used to describe PmO_2 and CP measurements (mean, median, 5th–95th percentiles). Because of the large number of measurements recorded for each patient, the pooled means of PmO_2 and CP of the healthy leg and the injured leg were compared using Wilcoxon ranked sums test for paired data. The proportion of measurements meeting prospectively defined warning criteria were calculated and compared for PmO_2 and CP or ΔP using Wilcoxon ranked sums test for paired data.

Results

The experimental arm consisted of 10 patients (7 male, 3 female). Mean age was 40.5 years (range, 25–83 years). The mechanism of injury was: motor vehicle accident ($n = 3$), pedestrian versus automobile ($n = 3$), assault ($n = 2$) and torsional injury ($n = 2$). Probes were well tolerated. No probe-related complications occurred. None of the 10 patients developed compartment syndrome postoperatively. This assessment was based on a normal sensorimotor exam of the lower extremity, adequate pain control on oral medication and ability to mobilise adequately for discharge from the hospital. These patients were followed postoperatively in the orthopaedic clinic and none had physical exam evidence of a missed compartment syndrome.

All patients underwent intramedullary nailing of the tibia under anaesthesia. The average healthy leg mean PmO_2 was 30.45 mmHg and average injured leg mean PmO_2 was 27.24 mmHg; the difference between the healthy and injured legs was not statistically significant ($P = 0.08$). The average healthy leg mean CP (measured in nine patients) was 17.19 mmHg and the average injured leg mean CP was 30.67 mmHg; the difference between the healthy and injured legs was statistically significant ($P = 0.02$). The mean duration of CP measurements was 33.35 h, while the mean duration of ΔP measurements ($n = 9$ eligible) was 27.8 h.

Qualitative analysis of postoperative PmO_2 data revealed no appreciably reproducible pattern. In 8 of 10 patients, CP appeared to be highest immediately postoperatively and then gradually decreased over time. Statistically significant correlations ($P < 0.001$) between PmO_2 and CP were found in all cases, with Pearson correlation coefficients ranging from −0.720 to 0.585 (Fig. 1). The coefficient was negative in eight patients, indicating an