American Journal of Emergency Medicine 34 (2016) 1765–1771

Contents lists available at ScienceDirect

American Journal of Emergency Medicine

journal homepage: www.elsevier.com/locate/ajem

Original Contribution

Comparison of 2 available methods with Bland-Altman analysis for measuring intracompartmental pressure☆,☆☆,★

Shengjie Tian, MD [a], Yaogang Lu, MD [a,*], Ju Liu, MD [b], Ying Zhu, MBBS [b], Yin Cui, MD [b], Jiayun Lu, MBBS [c]

[a] Department of Emergency Traumatic Surgery, Shanghai Pudong New District Zhoupu Hospital, Shanghai University of Medicine and Heath Sciences, Shanghai, China
[b] Department of Orthopedics, Shanghai Pudong New District Zhoupu Hospital, Shanghai University of Medicine and Heath Sciences, Shanghai, China
[c] Department of Emergency Medicine, Shanghai Pudong New District Zhoupu Hospital, Shanghai University of Medicine and Heath Sciences, Shanghai, China

ARTICLE INFO

Article history:
Received 29 April 2016
Accepted 1 June 2016

ABSTRACT

Background: Acute compartment syndrome (ACS) is the result of increased intracompartmental pressure (ICP), and to avoid a delay in diagnosis requires ICP measurement. This study was designed to compare 2 available methods with Bland-Altman analysis for measuring ICP in experimental animal models, healthy volunteers, and patients with suspected ACS to evaluate their agreement and interchangeability.

Methods: In 20 New Zealand White rabbits, we inflated a tourniquet to stop arterial blood flow to establish ACS rabbit models, of which ICP was measured and recorded by the Whitesides apparatus and the invasive arterial blood pressure monitor system (IABPMS) before and after modeling. The same 2 measurements were applied to the tibialis anterior compartment's ICP of 30 healthy volunteers. The experimental data were analyzed using the Bland-Altman method. Once it was considered to be a substitute for the Whitesides apparatus based on statistical analysis, we used IABPMS to measure the ICP of the patients suspected of having ACS to estimate its clinical prospect.

Results: The rabbit models' ICP estimated by the Whitesides apparatus and IABPMS were 9.60 ± 2.74 and 9.55 ± 2.33 mm Hg, with an increase to 30.20 ± 4.44 and 30.05 ± 4.58 mm Hg after modeling, respectively. The limits of agreement for the ICP were $-2.01/2.11$ and $-2.41/2.71$ mm Hg before and after model establishment. The healthy volunteers' ICP were 10.92 ± 6.06 and 10.85 ± 5.87 mm Hg; the limits of agreement for the ICP were $-2.53/2.66$ mm Hg. With IABPMS to continuously monitor the ICP increasing (40.45 ± 10.42 vs 13.82 ± 4.94 mm Hg) and ΔP (34.54 ± 11.77 mm Hg) to guide the diagnosis of ACS, 5 of 11 patients underwent the emergency fasciotomy for decompression.

Conclusion: The invasive pressure monitoring via IABPMS can be used as an alternative to the Whitesides method, thanks to the sufficient agreement between the 2 methods in ICP measurement, and also for its advantages recommended as a novel diagnostic approach to ACS in experimental and clinical applications.

1. Introduction

Acute compartment syndrome (ACS) is defined as a condition in which a critical pressure increase within a confined compartmental space causing a diminishing in the perfusion pressure and microcirculation of the tissues within that compartment [1–5]. The main factors affecting the prognosis are early diagnosis and the timing of surgical treatment [6–8]. However, there is no consensus on the way in which compartment syndromes should be diagnosed [9–11]. Recently, it has been generally accepted that intracompartmental pressure (ICP) is the golden standard for the diagnosis of ACS [7,11–13]. However, most professional devices for measuring ICP are too expensive to be affordable in the developing countries [14,15]. In the current study, we used the invasive arterial blood pressure monitor system (IABPMS; Fig. 1B) to implement invasive pressure monitoring, which was compared with the classic Whitesides method (Fig. 1A), in measuring ICP in experimental animal models, healthy adult volunteers, and the patients suspected of having ACS to address 3 main questions of whether invasive pressure monitoring can be used as the diagnostic method to measure the animal model's ICP, of how IABPMS can be used to measure human ICP, and if the invasive ICP monitoring via IABPMS can be used as a substitute for the Whitesides apparatus. If the answers are affirmative, then we can guide the diagnosis and treatment of the patients suspected of having ACS based on the invasive ICP monitoring.

☆ Source of Funding: This study was supported by the Health and Family Planning Commission of Shanghai Pudong New District (PW2013B-13).
☆☆ Compliance with ethical requirements: This study was approved by the institutional ethics committee, and written informed consent was obtained from all volunteers and patients.
★ Conflict of interest: All authors declare that they have no conflict of interest related to the current study.

* Corresponding author at: Department of Emergency Traumatic Surgery, Shanghai Pudong New District Zhoupu Hospital, No. 1500, Zhou Yuan Road, Shanghai, P.R. China. Tel.: +86 21 6813 5590x3901.
E-mail address: luyaogang1968@hotmail.com (Y. Lu).

http://dx.doi.org/10.1016/j.ajem.2016.06.010
0735-6757/© 2016 Elsevier Inc. All rights reserved.

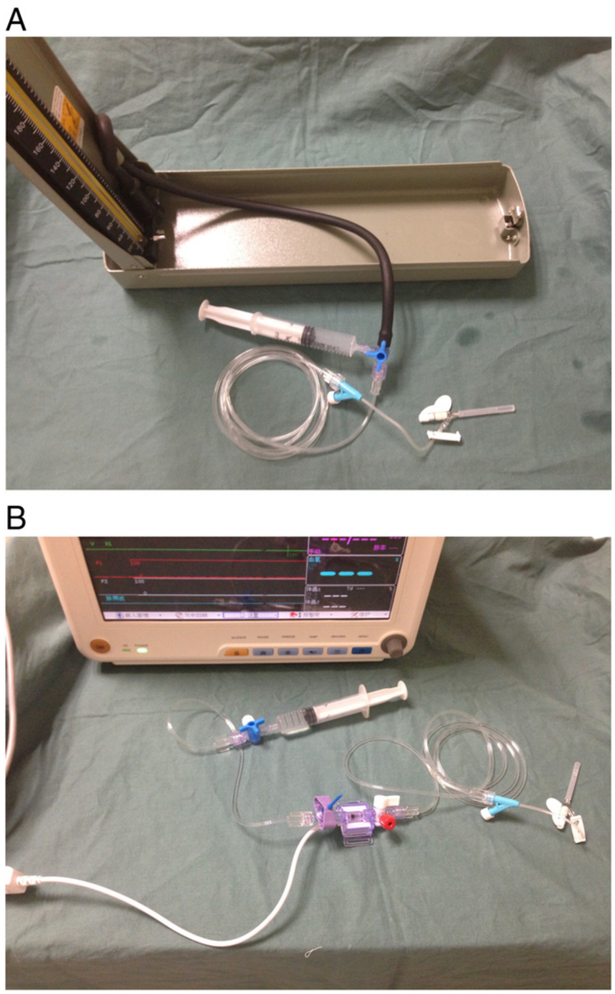

Fig. 1. A, The Whitesides apparatus. B, The IABPMS.

2. Materials and methods

2.1. Animal experiment

2.1.1. Animal model established to compare 2 methods in measuring ICP to diagnose ACS

For the current study, a total number of twenty 6-month-old New Zealand White male rabbits weighing 2.5 to 3.0 kg were provided by the Experimental Animal Center of Shanghai University of Traditional Chinese Medicine. The investigation was approved by Shanghai University of Traditional Chinese Medicine Animal Ethics Committee.

Each rabbit was anesthetized with an injection of 2% pentobarbital sodium 30 mg/kg into the ear vein. When the animals were anesthetized, their tibialis anterior compartment's ICP was measured by the Whitesides apparatus and invasive pressure monitoring.

With the ICP measured by the Whitesides apparatus, the mercury sphygmomanometer (XJ11D; Shanghai Medical Instruments Co, Ltd, Shanghai, China) was placed at the same horizontal plane with the rabbit. The sphygmomanometer was connected with a syringe and a 22-gauge intravenous catheter (Becton Dickinson Medical Pte Ltd, Singapore) with extension tubes by a 3-way stopcock. The syringe was filled with 20 mL of air, and the intravenous catheter, with normal saline. The intravenous catheter was vertically penetrated into the tibialis anterior compartment at 2 cm below the rabbit's knee. The syringe was pushed to inject a little of saline into the compartment, with the catheter ensured not to be blocked by the muscle and other tissues, and with the mercury column displaying the reading of ICP (Fig. 2B).

After the measurement of the Whitesides apparatus, the pressure measuring transducer (ADDCON Technology Co, Ltd, Shenzhen, Guangdong, China) was linked to the invasive arterial blood pressure monitor (ADDCON Technology Co, Ltd) to set up IABPMS, and exposed to the atmospheric pressure to set the invasive pressure measuring module to 0. When the 22-gauge intravenous catheter with a 3-way stopcock and a syringe filled with normal saline were connected with the pressure measuring transducer, the intravenous catheter was penetrated into the same compartment measured by the Whitesides apparatus, and the transducer and rabbit were kept at the same horizontal plane. The pressure readings were displayed on the monitor screen (Fig. 2C).

According to the pathophysiology of ACS, a tourniquet was placed on the upper thigh to stop the arterial blood flow for 120 minutes to establish the rabbit models (Fig. 2A). After modeling, the 2 methods were used to detect the tibialis anterior compartment's ICP of the rabbits, the pairwise readings of which were applied to further analysis.

2.2. Human experiment

2.2.1. Measurement of the tibialis anterior compartment's ICP of healthy volunteers to compare 2 methods

With approval from the Ethical Committee of Shanghai Zhoupu Hospital, and written informed consent, we enrolled 30 healthy volunteers aged 20 to 50 based on the exclusion criteria of arterial hypertension, peripheral neuropathy, peripheral vascular disease (arterial or venous), chronic pain, use of analgesics and antithrombotics/anticoagulants, or history of tibial or fibular fracture.

When the volunteer was lying on the examination bed, the measuring sites were set to be the tibialis anterior compartment at 10 cm below the lower edge of the patella. Upon skin disinfection, the 22-gauge intravenous catheter filled with normal saline was pierced into the tibialis anterior compartment at an angle of 45° to the skin. The mercury sphygmomanometer was connected to measure its ICP with the Whitesides apparatus. With the position and depth of the intravenous catheter maintained, the pressure-measuring transducer and invasive arterial blood pressure monitor were connected for detecting the tibialis anterior compartment pressure (Fig. 3). The pairwise readings of the Whitesides apparatus and invasive pressure monitoring were to be used for further analysis.

2.3. Clinical application

2.3.1. ICP measurement of patients with clinically suspected ACS by IABPMS

Approved by the Ethical Committee of Shanghai Zhoupu Hospital and providing written informed consent, all the patients with the clinical evidence of possible ACS were recruited between July 2014 and June 2015. The measuring sites were set within 5 cm around the swelling area, with blisters and skin abrasions avoided. After skin disinfection with iodine, to measure pressure, the 22-gauge intravenous catheter filled with normal saline was pierced into the target compartment at an angle of 45° to the skin while fixed by transparent dressings. The catheter was connected with IABPMS to measure and monitor continuously the target compartment's ICP. The same compartment's ICP of the contralateral healthy limb was simultaneously measured as a control. The readings of blood pressure were also recorded for each patient (Fig. 4). The ICP was significantly higher in the affected limb than in the contralateral healthy limb, with an increase of greater than 30 mm Hg and the patients' diastolic pressure of less than 30 mm Hg, which suggested strongly ACS in the affected limb [16,17]. Afterward, the emergency fasciotomy was necessary to decompression.

2.4. Statistical analysis

The data were presented as mean $\pm$ SD. Bland-Altman analysis was approached to the comparison of the 2 ICP measurement methods. For each subject (rabbit or volunteer), the average of ICP was calculated