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High Contact Pressure Resulting from Bone Marrow Puncture

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ABSTRACT

Cardiac tamponade following sternal puncture is fatal and is caused by an anomaly such as foramen sterni, fragility of the bone, or high pressure exerted by doctors on the bone. Contact pressure associated with bone marrow aspiration is unknown; therefore, we examined the contact pressure resulting from bone marrow puncture for aspiration. Prescale, a pressure-sensitive film, was used for measurements. Contact pressure on wood surface at 2 heights, the knee and hip positions of the hematologists, was examined and was approximately 15 - 21 megapascals. The magnitude of the contact pressure did not change with the type of puncture needle. However, the contact pressure in the needle area at the hip position was higher than that at the knee position height, when doctors aspirated the bone marrow. Contact pressure resulting from bone marrow puncture was found to be high; therefore, hematologists should be aware of this force when dealing with patients.

Keywords: Bone Marrow Aspiration; Cardiac Tamponade; Contact Pressure; Iatrogenic Accident

1. Introduction

Cardiac tamponade following sternal puncture is usually fatal and is caused by 3 mechanisms, namely, an abnormality such as foramen sterni, fragility of the bone itself, or high pressure exerted by doctors on the bone [1,2]. Foramen sterni is often present in the sternal body at the 4th - 5th intercostal position, and its frequency of incidence in the general population is approximately 2% - 8% [3,4]. M. Inoue *et al.* reported that an anterior chest approach to sternal bone marrow aspiration involves a risk of laceration of the ascending aorta when the needle penetrates the sternum [5]. Mispuncturing at an inadequate place might lead to an iatrogenic accident such as cardiac tamponade or aortic rupture [6]. We have previously reported the irregularity and decreased bone density of sternal bodies in patients with multiple myeloma [4]. If the pressure of bone marrow puncture is extremely strong, the needle may easily penetrate fragile sternal bodies. However, no studies have investigated this problem.

Fuji pressure-sensitive films (Fujifilm Co., Tokyo, Japan) have been widely used for studying contact mechanics in artificial joints and hand power [7-10]. The film is usually composed of 2 polyurethane composite films, a microcapsule layer, and a color-developing layer. Five grades of Fujifilm are available, each covering a specific pressure range. Therefore, given that nothing was reported on this topic, we examined the contact pressure resulting from bone marrow puncture by using a Fuji pressure-sensitive film in order to obtain the information that may be useful for improving the medical safety during the procedure.

2. Methods

The Fuji pressure-sensitive film was purchased from Fujifilm Co. Two kinds of needles for bone marrow puncture were purchased from CareFusion Japan (DIN1518X, 15 G; Tokyo, Japan) and TSK Laboratory (SIL-151, 15 G; Tochigi, Japan).

For the assessment of the Fuji pressure-sensitive film on the surface of cork board (Kawai Woodworking Co., Tokyo, Japan), bone marrow puncture was performed by hematologists with at least 10 years of experience. We examined the contact pressure on the wood surface at 2 heights, at the knee and hip positions of the hematologists.

For contact pressure measurements, we used the Fuji Prescale medium grade pressure film with a pressure range of 10 - 50 megapascals (MPa) and an operating temperature range of 20˚C - 28˚C [7,8]. The average ambient room temperature during the trials was approximately 23˚C under dry test conditions. Each Fujifilm patch result was scanned using a Prescale Data Shot

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FPD-100 (Fujifilm Co.). The contact patch scans were analyzed using Prescale pressure imaging and analysis software, FPD-100S version 1.0 (Fujifilm Co.) to quantify the total contact area.

We compared the differences between the 2 groups (*i.e.*, knee position vs hip position, or needle area vs stopper area) using the Wilcoxon signed-rank test. Data were expressed as mean ± standard error of mean values for the groups. All statistical procedures were conducted using JMP version 8.0 software (SAS Institute, Inc., Cary, NC, USA), and significance was set at $P < 0.05$.

3. Results

We measured the contact pressures of both the needle and stopper areas when hematologists used the bone marrow aspiration needle (CareFusion Japan); the results are shown in **Table 1** and **Figure 1**.

The contact pressure in the needle area at the hip position was 15.2 - 21.4 MPa, which was significantly higher than the contact pressure recorded in the stopper area (7.2 - 11.1 MPa). Similar results were found for the contact pressure at the knee position. As shown in **Table 1**, hematologist #2 also performed the bone marrow puncture using a needle purchased from TSK Laboratory (contact pressure of the CareFusion needle: 21.4 ± 0.5 MPa; contact pressure of the TSK Laboratory needle: 21.1 ± 0.9 MPa, N = 10). After 3 months, hematologist #2 performed the puncture experiments again and the contact pressure in the needle area resulting from bone marrow puncture at the hip position had reduced compared with the first readings (18.9 ± 1.5 MPa, N = 10).

4. Discussion

No papers on contact pressure from bone marrow puncture have been published previously. First, we reported that the contact pressure from bone marrow puncture ranges from approximately 15 MPa to 21 MPa (15 - 21 N/mm^2 or 150 - 210 kg/cm^2), as shown in **Table 1**. Several reports have been published on pressure studies of artificial joints for other medical procedures, using Fuji pressure-sensitive films [7,8]. For example, contact pressure for the knee joint from 1115 N at 20˚C was determined to be approximately 7.3 MPa [7]. Therefore, the contact pressure resulting from bone marrow puncture

(a) (b)

Figure 1. (a) Bone marrow aspiration needle: In this paper, we used two kinds of needles for bone marrow puncture purchased from CareFusion Japan (DIN1518X, 15 G; Tokyo, Japan) and TSK Laboratory (SIL-151, 15 G; Tochigi, Japan). Hematologists (Table 1) performed the bone marrow puncture on wood using a needle purchased from CareFusion Japan, as shown in (a); (b) Pressure sensitive film showing the contact pressure from bone marrow puncture: The Fuji Prescale medium grade pressure-sensitive film with a pressure range of 10 - 50 MPa was used for measuring contact pressure. Hematologist #2 (Table 1) performed the bone marrow puncture on wood using a needle purchased from CareFusion Japan (a). Contact pressure changed the color on the prescale film from the white to pink, or red color dependent on the grade of pressure. Pressure changes were noted at the needle area (center position) and at the stopper area (around the needle area).

Table 1. Contact pressure from bone marrow puncture.

	Pressure changes, MPa	Needle area	Pressure changes, MPa	Stopper area
	Hip position	Knee position	Hip position	Knee position
Hematologist #1 Female	15.2 ± 0.3	14.8 ± 0.5	10.7^{**} ± 1.0	9.8^{**} ± 0.1
Hematologist #2 Male	21.4^{*} ± 0.5	18.8 ± 0.8	7.2^{**} ± 0.3	9.2^{**} ± 1.7
Hematologist #3 Female	20.1 ± 0.9	17.8 ± 0.9	11.1^{**} ± 0.4	11.3^{**} ± 0.5

Each hematologist performed the bone marrow puncture on wood 10 times using a needle purchased from CareFusion Japan at both the hip and knee positions. Data are presented as mean and standard error of mean values. $^{*}P < 0.05$ vs. knee position, $^{**}P < 0.05$ vs. needle pressure.

performed by hematologists was stronger than that at the knee joint in artificial joint experiments. On the other hand, Liau *et al.* suggested that Fuji pressure-sensitive film might overestimate contact pressure compared with other measurements [9]. Moreover, in this study, the measurement of contact pressure was made on wood, not on human bodies, which may be a limitation.

Despite this, attention should be paid to the force used during bone marrow aspiration because of the high contact pressure involved, and particularly in patients with multiple myeloma, which is a hematological malignancy associated with bone fragility [4,10]. High pressure resulting from bone marrow puncture may also induce sternal destruction, resulting in cardiac tamponade. When hematologist #2 repeated the puncture experiments, the contact pressure decreased from 21.4 MPa to 18.9 MPa, suggesting that the degree of force used during bone marrow aspiration might reduce the contact pressure. Three hematologists exerted higher pressure at the hip position than at the knee position. We speculate that it is easier to apply pressure from a lumbar height than at the knee level. The difference in contact pressure resulting from bone marrow puncture at the position of patients from the viewpoint of the performer (*i.e.*, the hematologists) should also be considered. In conclusion, we believe that the information on contact pressure reported in this paper will be useful for improving medical safety during bone marrow aspiration.

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