Research Article

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Left Ventricular Perforation Resistance During Pleural Drainage Puncture

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ABSTRACT

Perforation of the left ventricle wall with pleural drainage tubes has been occasionally reported in the past. In this study, we strived to examine the required force on a porcine ex-vivo model with two distinct procedures, namely with mere catheters and with the needle and dilatator involved with the Seldinger technique using the PleurX™ system.

The porcine hearts enveloped in their pericardial sacks were placed on a scale upon which the different catheter systems were then tested as to the necessary perforating force.

The silicone drainage tubes were unable to damage the pericardium or the left ventricle. The needle of the PleurX™ system could perforate the heart with a force of as little as 1.3 N and the dilatator with a minimum force of 8.1 N.

Keywords
Forensic Pathology, Pleural drainage, Seldinger technique, Dilatator, Cardiac injury, Perforating force.

Introduction
The insertion of a pleural drainage tube, either to treat a pneumothorax or to drain effusions or a hemothorax is a routinely performed procedure. There are two principle procedures, either the drainage tube is pushed through a surgical cut and preparation produced to the skin and the chest wall, or according to the Seldinger technique, in which a guide wire is inserted via a needle, upon which the needle is removed and a dilatator is applied over the guide wire and the drainage tube is then lead into the pleural cavity [1-3]. Regardless of the applied technique, pleural tube insertion is generally a safe and easy task and complications are rare and if present, usually mild.

However, severe complications may occur. According to a survey by Harris et al. [4], five cases of misplaced intercostal drains were reported from a total of 101 UK hospital trusts. Several groups have previously published case reports on cardiac injuries, most of which describe an injury to an atrium or right ventricle [5-8]. Although one may argue that the atriae and the right ventricle are much thinner than the left ventricle and thus more prone to perforation, left ventricular perforation due to pleural catheters has been reported, albeit rarely [9-14].

Although the assessment of possible malpractice cases concentrates more on the applied technique, we believe that the force used may also play a role, in as such that a forceful ramming of such a catheter will be seen differently than a prudent probing using only the minimum force necessary. Furthermore, a defendant may claim that he just slipped, a claim being more unlikely, if excessive force is necessary to perforate the left ventricular wall.

Studies dealing with the penetrating force of skin, cartilage and bone using cadaveric tissue, animal parts or even fruit as models, as well as the protective effect of different clothing against sharp injury have been performed in the past [15-20]. The force required to perforate the left ventricle with pleural catheters, is however, to the best of our knowledge, unknown. For this reason and in order to generate data upon which a forensic pathologist can draw upon in possible malpractice cases, we aimed to quantitatively determine how much force must be applied in order to perforate the left ventricle with different pleural catheters and thus performed the present study.

Material and Methods

Hearts

Six adult, fresh porcine hearts within in their respective pericardial sacks were obtained from a local abattoir. The left ventricles of the hearts were filled with lukewarm tap water and the aorta blocked with a bladder catheter and the pulmonary veins clamped off. The hearts were then placed on a precision scale (Mettler Toledo ICS429), which was tared to “0”.

Pleural drainages (Figures 1 and 2)

The following drainage tubes were used:

- Argyle™ Thoracic Catheter, 20 French
- Argyle™ Thoracic Catheter, 24 French
- Argyle™ Thoracic Catheter, 28 French
- PleurX™ Pleural Catheter Mini Kit, 8 French

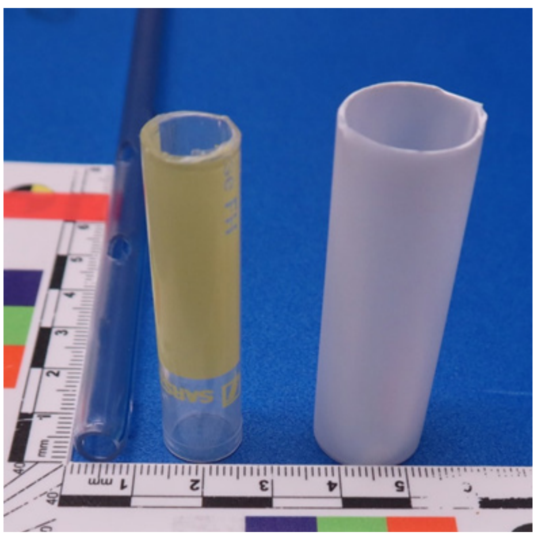

Figure 1: Tip of Argyle™ Thoracic Catheter, 20 French, shown on the left, on the right, the narrow and the wider guidance tubes used for the experiment are shown.

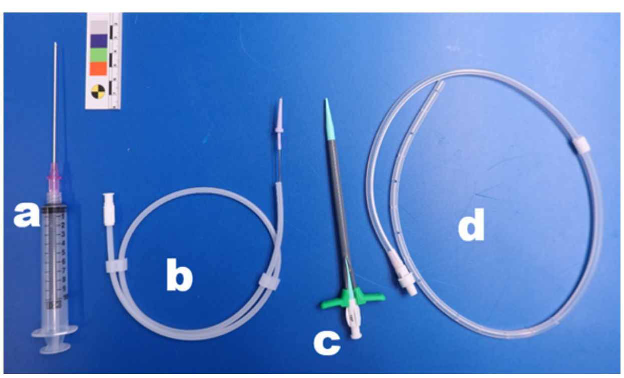

Figure 2: PleurX™ Pleural Catheter. a) Needle and syringe, b) guide wire, c) dilatator, d) drainage catheter, French 8.

Measurements

The three Argyle™ thoracic catheters were lead either in a narrow tube (inner diameter 10 mm) or a wider tube (inner diameter 14 mm) of 3 cm length to simulate the insertion through the chest wall. These tubes were held at a distance of 2 cm or placed directly onto the pericardium surrounding the heart (Figure. 3). The catheter was then gently pushed down to the left ventricle of heart on the scales and the resulting pressure at wall perforation, was noted.

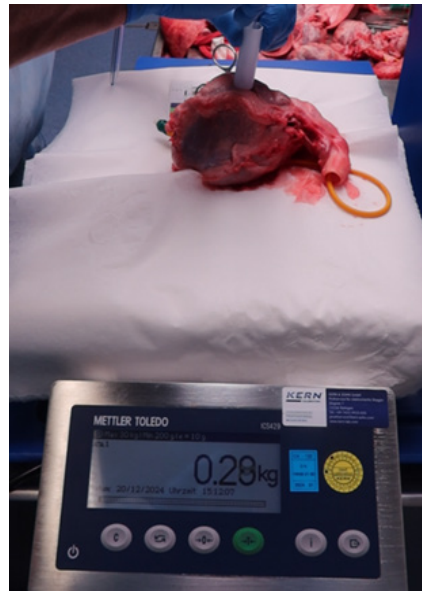

Figure 3: Setup with the heart in the pericardial sack placed on a scale (covered with tissue to avoid slipping). A thoracic catheter – here a French 20 - is forced onto the heart in a wide guide tube placed onto the pericardium, taking care not to push the tube down.

The PleurX™ pleural catheter measurement was performed in two steps; firstly, the perforating force of the pericardium and left ventricle on the heart with the scales with the needle was determined, then the perforating force of the dilatator over the guidewire was measured. After the experiments, the left ventricle was cut at the height of the puncture and the ventricular wall thickness was noted.

Results

None of the Argyle™ thoracic catheters could perforate the left ventricular wall; indeed, the silicone catheters bent before even damaging the pericardial sack. Due to this bending, the experiments were aborted at pressures as low as 5 N with the French 20 catheter in the wide guiding tube at a distance of 2 cm and as much as 22.9 N with the French 24 catheter in the narrow tube placed onto the heart (Table 1).

With the PeurX™ system, however the left ventricle could be perorated with relative ease (Table 2). The needle with the guide wire could perforate the pericardium and the entire left ventricular wall at an average force of 2.03 N (min 1.3 N, max 2.5 N, SD 0.42 N). The dilatator required greater pressures to perforate the heart; 11.8 N sufficed on average to perforate the pericardium and the left ventricular wall (min 8.1 N, max 15.8 N, SD 2.78 N).

Table 1: The maximum force of the French 20, 24 and 28 catheters denotes the force applied until the tube bent and the test was aborted. None of the catheters sufficed in harming the pericardium or ventricle wall.

Wide guide tube			
Tube distance	**Max. force French 20 (N)**	**Max force French 24 (N)**	**Max force French 28 (N)**
2 cm	5	6.7	14.3
contact	6.6	10.2	22.4
Narrow guide tube			
Tube distance	**Max. force French 20 (N)**	**Max force French 24 (N)**	**Max force French 28**
2 cm	7.7	13.3	14.6
contact	6.3	22.9	10.6

The left ventricular wall thicknesses ranged between 14 and 15 mm (SD 0.58 m). Interestingly, the wall thickness did not appear to have an influence on the required perforating force; a 15 mm thick ventricle wall could be perforated with the dilatator at 9.7 N and a 14 mm thick wall required 15.8 N for the same result.

Discussion

This is admittedly a small study based on experiments on porcine hearts. These hearts displayed left ventricular wall thicknesses of 14-15 mm, which is greater than that of healthy normal human subjects, but is occasionally seen in very highly trained athletes or persons with a hypertrophic cardiac disease. As the experiments were performed on extracted hearts, these displayed a rigor mortis obviously not present in living hearts. However, the living heart contracts and relaxes rhythmically, so that we deem the postmortem rigor as mirroring the systolic situation. Besides being about three times as sensitive to the electrical induction of ventricular fibrillation as are humans [21], the anatomy of the porcine heart also differs slightly to the human heart; the overall appearance is more "Valentine heart" shaped than the human more trapezoidal shape and the apical components of porcine ventricles possess broader trabeculations [22]. Although these differences are not to be expected to play a major role in the force necessary to perforate the mid-left ventricular wall, another aspect may be more limiting; the porcine hearts used were from young, healthy animals, whereas in clinical reality, humans needing a thoracic drainage may be old and display a fibrosis or even scarring of the cardiac musculature, thus making these walls tougher and therefore more resistant to perforation with a catheter.

Regardless of these limitations, we believe this study implies that the soft silicone thoracic drainage catheters are not likely to injure the heart. However, the needle and the dilatator with the Seldinger-technique of the PleurX™-system can perforate the left ventricular wall. The herefore necessary force was surprisingly low; the needle perforated the heart with a minimal force of 1.3 N. The dilatator too, did not require excessive force to perforate the heart with this being possible at as little as 8.1 N. Interestingly, these required forces are well below those reported for knife blades penetrating skin, musculature and ribs [15-18]. Indeed, O'Callaghan et al. [17] showed that human skin, fat and muscle require a maximum stabbing force of 95.5 N, 2 N for fat alone, 37.5 for musculature alone and 35 N for fat and muscle together. That a needle, being very sharp, does not require a great force to penetrate is not surprising. The PleurX™-system dilatator perforating the left ventricular wall at just over 8 N was, however, unexpected. This may be due to the cardiac musculature of the young, healthy pig hearts lacking the fasciae the amputated legs O'Callaghan examined obviously possessed. On second view, the dilatators are essentially big needles. These features may explain why the dilatator perforated the heart with so much ease.

Our results essentially also indicate the greater safety of the method using the surgical procedure with inserting a pleural tube through a surgical cut through the chest wall compared to the Seldinger technique, in which – using very little force – the left ventricle could be punctured.

Conclusions

Application of a pleural drainage with the Seldinger technique bears the risk of perforating the heart with either the needle with a force of low as 1.3 N or the dilatator with a force of 8.1 N or more, whereas the catheters were not capable of doing so in our model.

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