Title: Influence of body position during Heimlich maneuver to relieve supralaryngeal obstruction: A manikin study

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18 **Abstract**

19 **Aim:** The Heimlich maneuver is a common—yet not always successful—first aid measure for
20 relieving upper airway obstruction caused by choking. Using a choking simulation manikin,
21 we studied the most effective body position for this maneuver.

22 **Methods:** The manikin was connected to a laryngeal model of a child or an adult, and a
23 differential pressure transducer recorded the airway pressure and waveform during the
24 maneuver. The maneuver (5 successive compressions) was performed 6 times each in
25 standing, prone, and supine positions. For cases of children, we added a supine position with a
26 pillow under the back.

27 **Results:** In the adult model, airway obstruction was more frequently relieved in the supine
28 and prone positions than in the standing position (all $p < 0.001$). In the child model, the
29 airway obstruction was relieved significantly more often in the supine position, with a pillow
30 under the back, and in the prone position, than in the standing position (all $p < 0.001$).
31 Without relief, successive Heimlich maneuvers made the airway pressure increasingly
32 negative (standing position, adult: $p < 0.001$, standing position and supine position without a
33 pillow, child: $p < 0.001$ and $p = 0.002$, respectively).

34 **Conclusions:** The Heimlich maneuver was more effective in the supine and prone positions

35 than in the standing position. In children, the prone position may be most effective.

36 Successive Heimlich maneuvers may be harmful when the airway is not relieved after the first

37 compression.

38 **Key words:** adult, airway obstruction, child, Heimlich maneuver, prone position

39

Introduction

Choking on food is one of the most frequent causes of accidental death in children and aged people.[1,2] The Heimlich maneuver was first reported as a first aid measure to prevent choking in 1974, and in 1975, 162 patients were saved by this maneuver.[3] The basis of this maneuver is the creation of an artificial cough by forcefully elevating the diaphragm and forcing air from the lungs. However, not all choking victims are saved by this maneuver.[4,5]

Choking can occur in various ways, such as obstruction in the mouth and nose, oropharynx, supralarynx, and trachea. Because it is difficult to know the level of obstruction, except when it occurs in the mouth and nose, the effectiveness of the Heimlich maneuver has not been evaluated for each kind of obstruction. Few studies have reported on the effectiveness of the maneuver when it is performed at body positions other than standing.

Here, we studied the effectiveness of the Heimlich maneuver, performed in three body positions (standing, supine, and prone position), using a manikin as a choking model. Semi-solid foods pose the highest risk of choking[6]: the FDA and FSA have issued warning of the dangers of choking on a jelly containing konjac[7,8] and the characteristics of materials that contribute to choking have been reported.[9] Between 1995 and 2008, 17 people died from

choking on konjac jelly.[10] Thus, in this study, we chose to use a konjac jelly that could reproduce complete supralaryngeal obstruction.

Methods

Experimental system

A laryngeal model of an adult (Laerdal® Airway Management Trainer; Head, skin, & airways ALS/AMT [25200]; Laerdal, Ampat, Singapore) and a child (Laerdal® Pediatric Intubation Trainer; Pediatric Intub Trainer Torso; Laerdal) was individually connected to a choking simulation manikin (Laerdal Choking Charlie®; Laerdal) (Figure 1). To measure airway pressure, a differential pressure transducer and a polygraph system were used. These were connected to a notebook computer running LabChart®7 v7.2.2 software (Figure 1). An electronic spirometer (SP-370COPD, Fukuda Denshi, Tokyo, Japan) was used to measure the expiratory volume of the manikin.

Study protocol

Five emergency physicians with Immediate Cardiac Life Support certification participated in this study after giving written informed consent.

First, we measured the expiratory volume of the manikin produced by the Heimlich maneuver with no foreign body in the airway. Then, we placed konjac jelly, which is readily commercially available in Japan, of 4.3 × 3.0 × 3.0 cm dimensions, on the larynx of the manikin.

The Heimlich maneuver was performed by each of the participants on the manikin 5 times successively in 1 procedure set. Six sets of the procedure were performed in each of the standing, prone, and supine positions. For the child model in the supine position, an additional position, i.e., the supine position with a pillow placed under the back of the laryngeal model, was adopted.

During each of the maneuvers, in each position, we measured the expiratory volume of the manikin and recorded the waveform of the airway pressure. When the jelly was removed after a single procedure set (i.e., 5 compressions), the procedure was defined as an "opened case", and when the jelly was not removed, it was defined as an "unopened case".

Setting of each position

Standing position: The manikin was set on a table vertically and the experimenter took up the position behind it, with his arms encircling the chest, and compressed the abdomen

immediately above the umbilicus.

Supine position: The manikin was laid on its back on the floor. The experimenter sat astride the manikin body and compressed the abdomen immediately above the umbilicus.

Prone position: The manikin was laid with its face toward the floor and the experimenter placed himself over the manikin from behind, with his arms encircling the chest, and compressed the manikin's abdomen upwards, immediately above the umbilicus.

Data collection and analysis

Data are shown as means ± standard deviation. Statistical analysis was performed using SPSS 22.0 software (IBM®SPSS®, Chicago, IL, USA). The expiratory volume and airway pressure of each position were compared using one-way analysis of variance. The chi-square test was used for comparison of discrete variables. The Jonckheere–Terpstra test was used for comparison of trends of negative airway pressure in unopened cases. A p-value of <0.05 was considered statistically significant.

Results

Expiratory volume produced by the Heimlich maneuver in the absence of a foreign body

The expiratory volume produced from the manikin by the Heimlich maneuver in the absence of a foreign body was significantly greatest in the supine position, and significantly smallest in the standing position ($p < 0.001$) (Figure 2).

Airway pressure in opened and unopened cases

Figure 3 shows the airway pressure produced in the manikin. When there was no foreign body in the airway, there was little change in the airway pressure (top panel). In the case of an obstructed airway, the airway pressure showed a transient positive wave followed by a large negative wave (middle panel). Thus, airway pressure can be used to determine whether the airway is obstructed.

The bottom panel of Figure 3 shows a re-occlusion case. Once a foreign body was removed by the Heimlich maneuver, the airway pressure showed little change with the next compression, but after further compression, airway pressure became negative, in the same way as for an unopened case, indicating that the airway was obstructed again. We confirmed that the airway was relieved when the waveform of the airway pressure returned to baseline (0 mmH_2O) after compression. Thus, opened cases were judged by observing the airway pressure.

Effect of body position during the Heimlich maneuver in the adult laryngeal model

Figure 4 shows the rate of airway obstruction relief in each position in the adult model. In the standing position, the airway could not be relieved at all. In the supine position, the rate of opened cases after 5 compressions was 97%. The single unopened case was a case of re-occlusion. In the prone position, the rate of opened cases after 5 compressions was 80%. Both unopened cases were re-occlusion cases. The rate of opened cases was significantly higher in the supine and prone positions than in the standing position.

Opened cases in both the supine and prone positions included cases classified as re-opened cases after re-occlusion. In the standing position, the airway pressure became negative after the Heimlich maneuver when the airway obstruction was not relieved. In addition, the airway pressure of unopened cases became significantly lower after successive Heimlich maneuvers (Figure 5, top panel).

In the unopened case in the supine position, the airway obstruction was first relieved after the 2^{nd} compression, but was obstructed again after the 4^{th} compression (Figure 5, middle panel). In unopened cases in the prone position, the airway pressure became increasingly negative, but was not significantly different between compressions (Figure 5,

bottom panel).

Effect of body position during the Heimlich maneuver in a child laryngeal model

Figure 6 shows the rate of airway obstruction relief in each position in the child model. In a standing position, the airway obstruction could not be relieved at all. In the supine position, the rate of opened cases was 63% after 5 compressions, while in the prone position, the rate of opened cases was 93% after 5 compressions. In the supine position with a pillow behind the back, the rate of opened cases was 77% after 5 compressions. The rate of opened cases was significantly higher in the supine position with a pillow and in the prone position than in the standing position, but there was no significant difference in the rate of opened cases between the supine position with and without a pillow.

As in the adult laryngeal model, in the standing position, the airway pressure reduced increasingly with 5 compressions when the airway obstruction was not relieved. The airway pressure of unopened cases reduced significantly with each successive Heimlich maneuver (Figure 7, top panel). In unopened cases in the supine position without a pillow, the airway pressure also became significantly lower (Figure 7, 2nd row).

Discussion

Our study showed that re-occlusion may occur with successive Heimlich maneuvers and that the success rate of relieving the airway is higher in the prone and supine positions than in the standing position.

The number of opened cases in the prone and supine positions was significantly greater than in the standing position. The expiratory volume created by the Heimlich maneuver in the prone and supine positions was larger than in the standing position. In the closed space of the obstructed airway, a larger expiratory volume created a higher expiratory pressure. Thus, the foreign body (konjac jelly) could be moved far enough from the larynx by the expiratory air in the supine and prone positions.

Chest compression generates higher pressure than the Heimlich maneuver in recently deceased adults with complete airway obstruction,[11] and lateral chest compression (with the choking victims lying on their side) generates greater airway pressure than the Heimlich maneuver and the anterior chest thrust in anesthetized pigs.[12] Sanuki et al. reported that the abdominal thrust in an individual in a lying-down position was associated with a higher peak airway pressure than that in a standing position.[13] The findings of our manikin study are consistent with those of these previous studies.

In unopened cases in both the child and adult models, the Heimlich maneuver generated a more negative airway pressure than in opened cases. This was because intrapulmonary air was ejected by the Heimlich maneuver, although new air could not be inhaled because the foreign body re-occluded the supralarynx when it had not been moved into the oral cavity. The Heimlich maneuver therefore poses a risk of lodging the foreign body more firmly in the larynx if it is not removed after the first compression. Continuing with repeated maneuvers will not only cause the airway pressure to become more negative, but will also increase the difficulty of removing the foreign body by reducing the remaining air that can be forced from the lungs. This risk is increased when performing the Heimlich maneuver in the standing position. In order to open the airway successfully, the Heimlich maneuver should rather be performed in a prone or supine position.

In the child model, the airway was relieved less frequently than in the adult model by the Heimlich maneuver performed in the supine position, but more frequently when in the prone position. There may be two reasons for this phenomenon. One is the difference in the size of the laryngeal cavity. Given that a child's laryngeal cavity is smaller than that of an adult, the removed foreign body would remain near the larynx and may be more likely to be relodged by inspiratory negative pressure. Another reason is the narrowing of the airway by

neck anteflexion of a child. A child's head is relatively large compared to the body, so that the neck is likely to be anteflexed in the supine position.[14-17] A pillow under a child's back was useful to avoid such neck anteflexion and increased the success rate of airway obstruction relief. In the prone position, gravity could also exert a positive effect, as the mouth faced toward the ground in the prone position. Because of the smaller laryngeal cavity, a foreign body may more easily fall into the oral cavity due to gravity in a child than in an adult.

In unopened cases, the foreign body could not be removed due to the increasing negative airway pressure and re-occlusion caused by successive performance of the Heimlich maneuver. The current guidelines recommend that the Heimlich maneuver should be applied in rapid succession until a foreign body is relieved,[18] and that is should be performed in the standing (or sitting) and supine positions. However, our findings suggest that it may be better not to perform successive maneuvers, or that the oral cavity should be checked after each maneuver. Moreover, our study showed that it is easier to push up under the diaphragm and to observe the oral cavity in the supine position; furthermore, the supine position has the advantage that cardiopulmonary resuscitation can be performed more easily.[11] Moreover, the prone position requires more effort to maintain the victim's position and to compress the body vertically while performing the Heimlich maneuver. However, in case of a child, it is easier to

maintain the child in the prone position and this position should therefore be used first. If the prone position is not acceptable, the supine position with a pillow behind the back should be used.

Limitations

This study has several limitations. First, although the mechanism for elevating airway pressure is similar to that in a human, a manikin is not quite the same as a human. Second, we used only konjac jellies as the obstruction material; we could therefore not estimate whether other foreign bodies would create a similar obstruction in the larynx. Third, although we used a child and an adult laryngeal model, the choking simulation manikin was that of an adult body. We did not estimate the difference in expiratory volume between a child and an adult. Fourth, because this was a manikin study, the adverse effects of compression in the prone and supine position were not evaluated.

Conclusion

With a complete supralaryngeal obstruction, the Heimlich maneuver performed in the supine and prone positions may be more effective for adults and children, respectively, than that performed in the standing position. Successive Heimlich maneuvers may be harmful when the

airway is not relieved after the first compression.

Conflict of interest

None.

Acknowledgments

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285 **Figure legends**

286 **Figure 1.** Experimental devices.

287 The obstruction (konjac jelly) was set on the larynx of a laryngeal model. The laryngeal
288 model of a child or an adult was connected to both the manikin and the differential pressure
289 transducer. The transducer was connected to the polygraph system. The polygraph system was
290 connected to a notebook computer to record the waveform of airway pressure.

291

292 **Figure 2.** The expiratory volume produced from the manikin by the Heimlich maneuver in
293 the absence of a foreign body

294 The expiratory volume was 0.66 ± 0.04 L, 1.15 ± 0.10 L, and 0.82 ± 0.09 L in standing,
295 supine, and prone position, respectively. These expiratory volumes were significantly
296 different ($p < 0.001$). After Bonferroni correction, the expiratory volume was significantly
297 greatest in the supine position, and significantly smallest in the standing position ($p < 0.001$).

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299 **Figure 3.** The waveform of the airway pressure during the Heimlich maneuver.

300 Opened airway (top): there was no obstruction of the larynx.

301 Unopened airway (middle): the airway was not relieved during successive Heimlich

maneuvers.

Re-occlusion case (bottom): the airway was first relieved and then obstructed again during the successive Heimlich maneuver. This waveform shows one such example (the airway was revealed after the first compression and obstructed again after second compression).

Figure 4. Rate of opened airway cases in each position in adult models.

After the fifth compression, the rate of opened cases was significantly lower in the standing position and significantly higher in the supine and prone position (all $p < 0.001$).

Figure 5. Minimum airway pressure after the Heimlich maneuver in adult models.

In the standing position, the airway pressure significantly reduced with successive Heimlich maneuvers ($p < 0.001$). In the supine position, only 1 unopened case had re-occlusion. The airway was relieved after the second compression and obstructed again after the fourth compression. In the prone position, the unopened cases included two re-occlusion cases. In one of these, the airway was relieved after the first compression and obstructed again after the third compression. In the other case, the airway was relieved after the first compression and obstructed again after the fifth compression. Because the unopened cases included

re-occlusion cases, we did not use the Jonckheere–Terpstra test. The horizontal bar shows the mean value of airway pressure in opened cases and unopened cases, respectively.

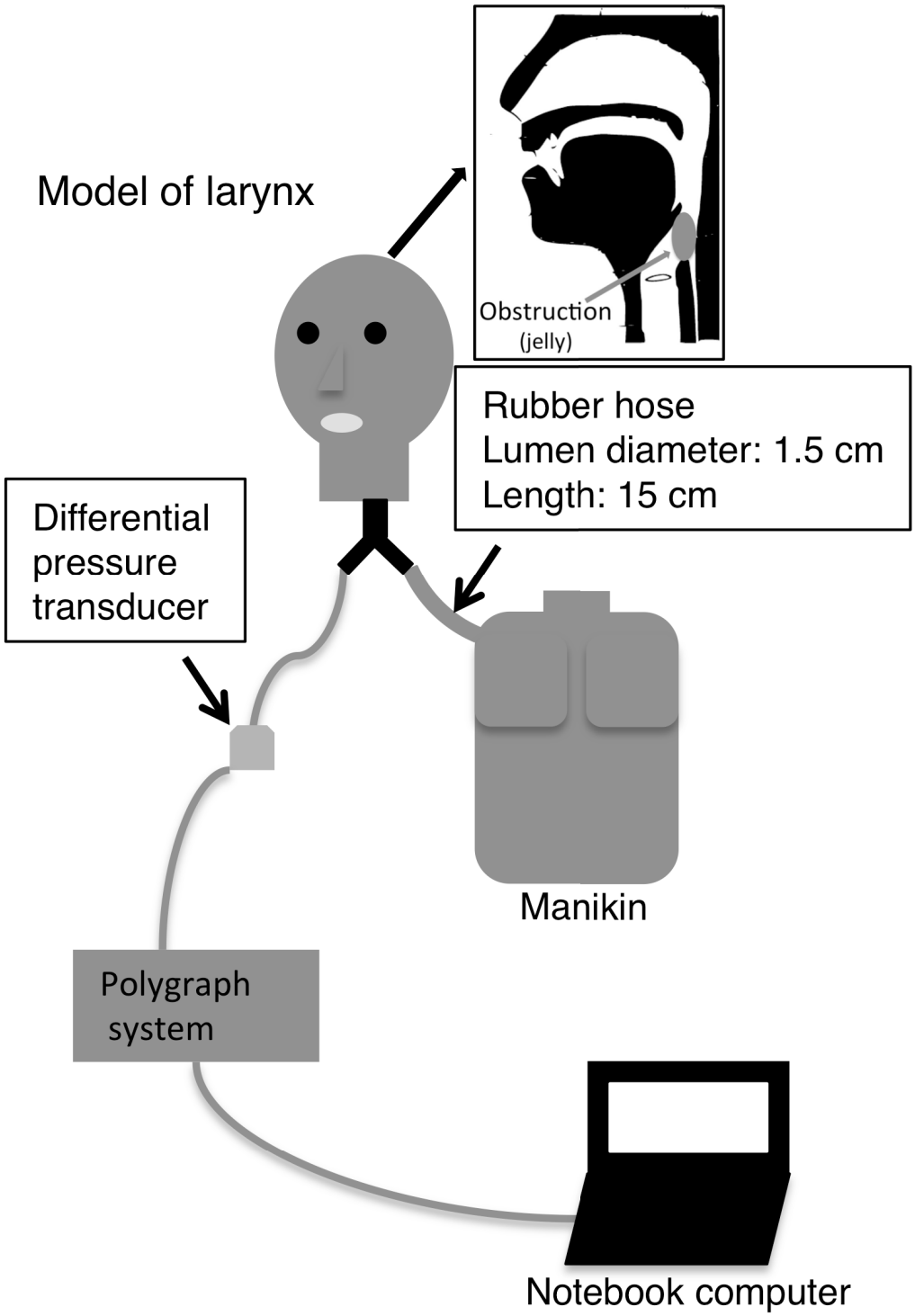
Figure 6. Rate of opened airway cases in each position in the child model.

After the fifth compression, the rate of opened cases was significantly lower in the standing position and significantly higher in the supine position with a pillow and in the prone position ($p < 0.001$).

Figure 7. Minimum airway pressure after the Heimlich maneuver in the child model.

Re-occlusion cases were not observed in any of the unopened cases, in any of the positions in the child model. In the standing position, the airway pressure of 30 unopened cases was significantly reduced by successive Heimlich maneuvers ($p < 0.001$). In the supine position without a pillow, the airway pressure of 11 unopened cases was significantly reduced ($p = 0.002$). In the supine position with a pillow, the airway pressure of 7 unopened cases did not show this trend to reduce ($p = 0.839$). In the prone position, there were only 2 unopened cases; therefore, we did not calculate the mean airway pressure. The horizontal bar shows the mean value of airway pressure in the opened cases and unopened cases, respectively.

336 Figure.1



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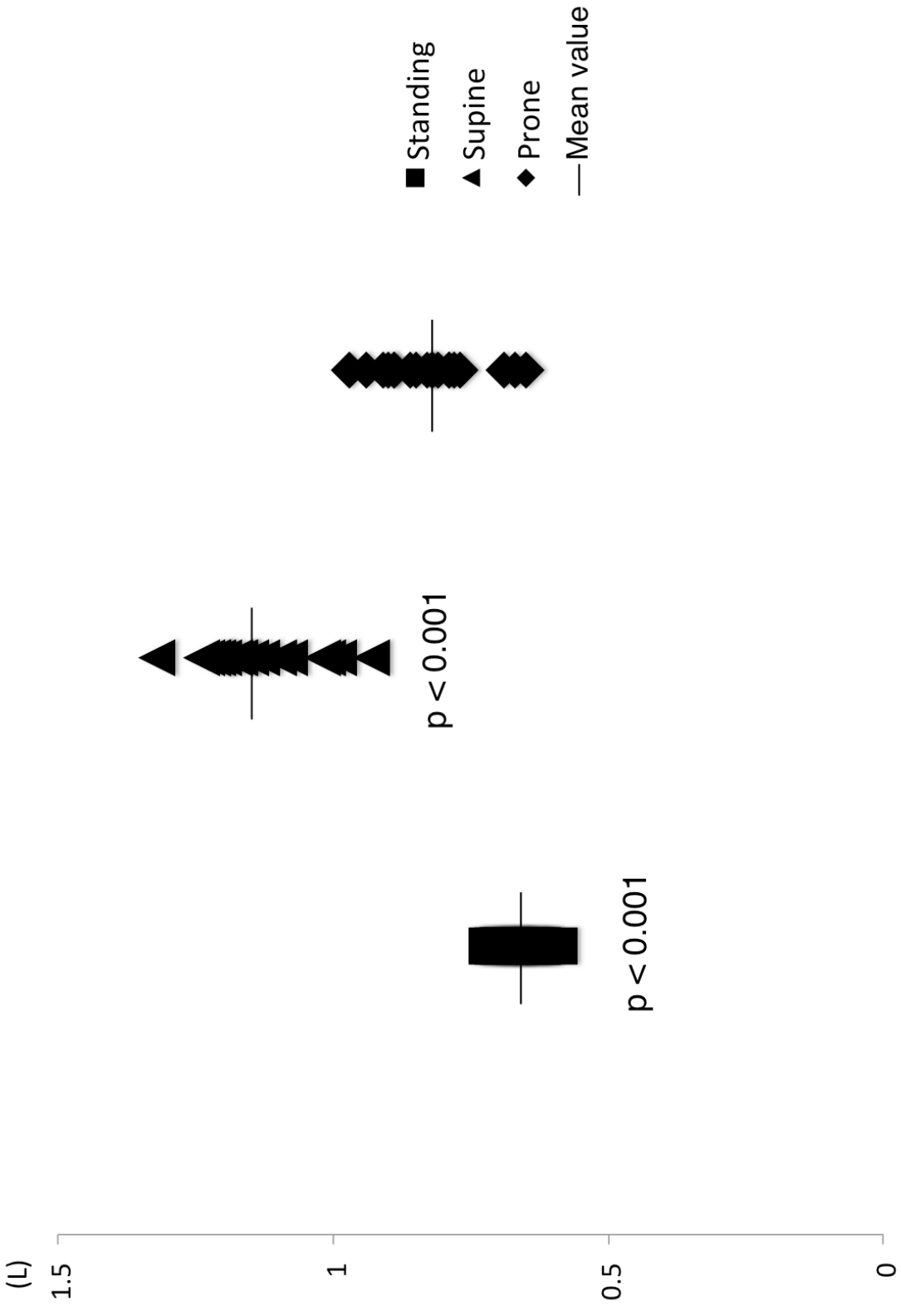
340 Figure.2



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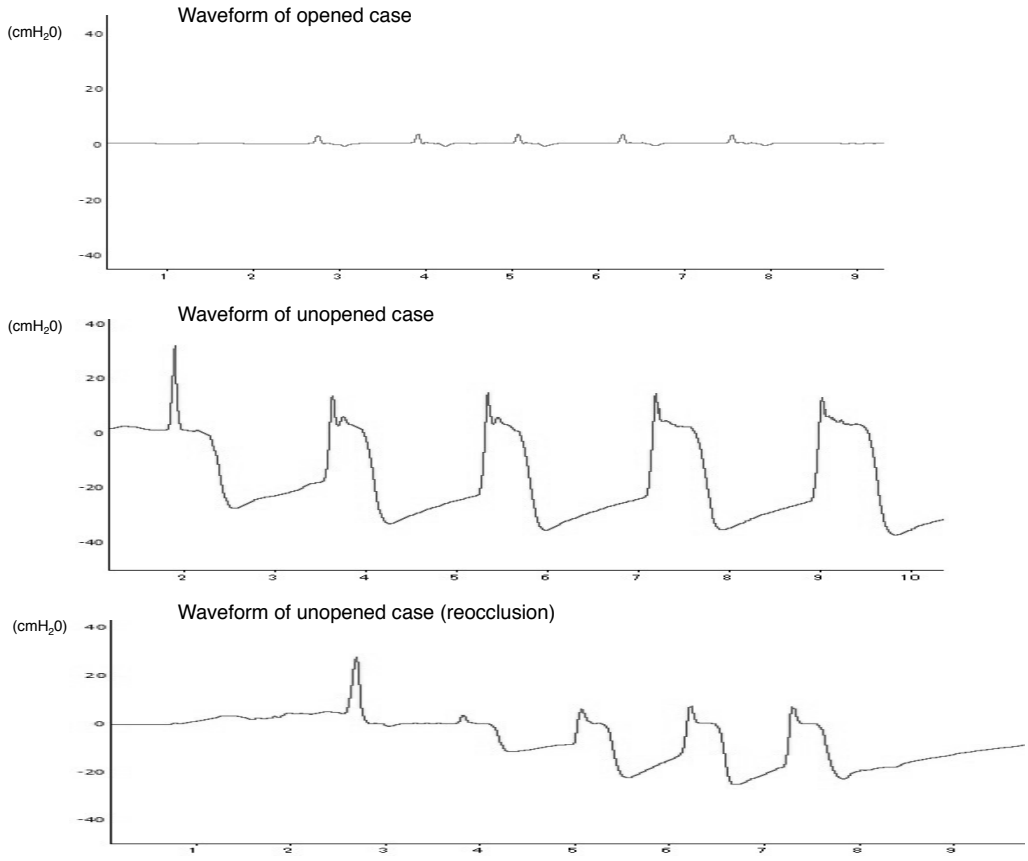
342 Figure.3



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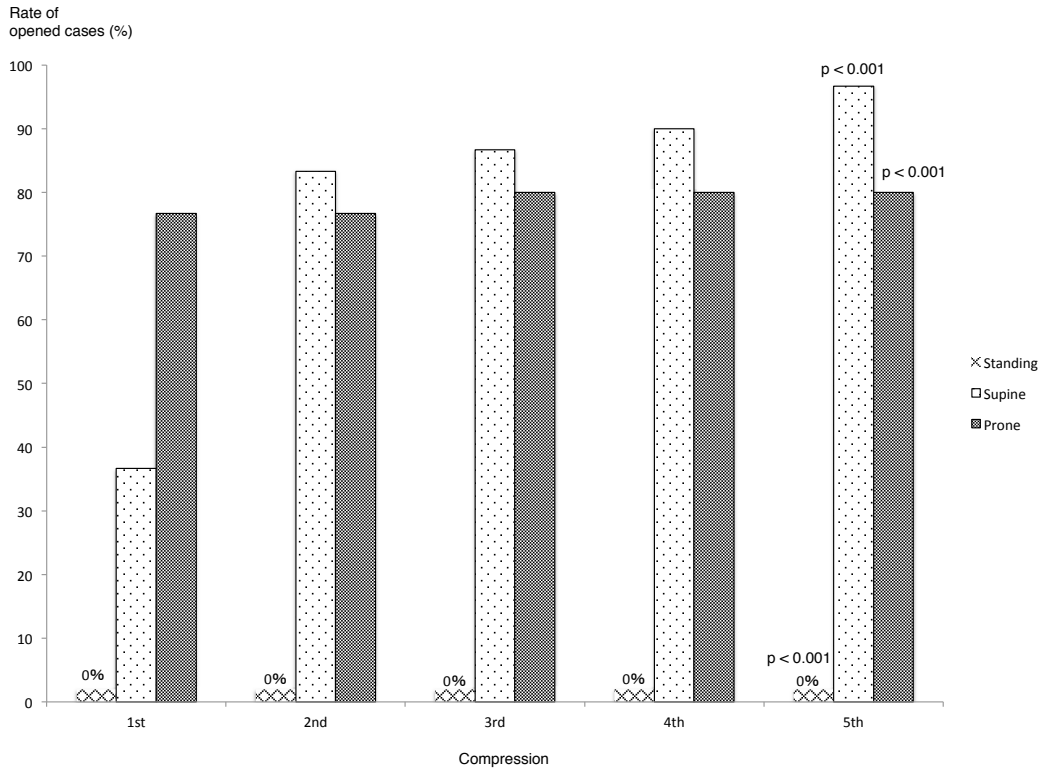
352 Figure.4



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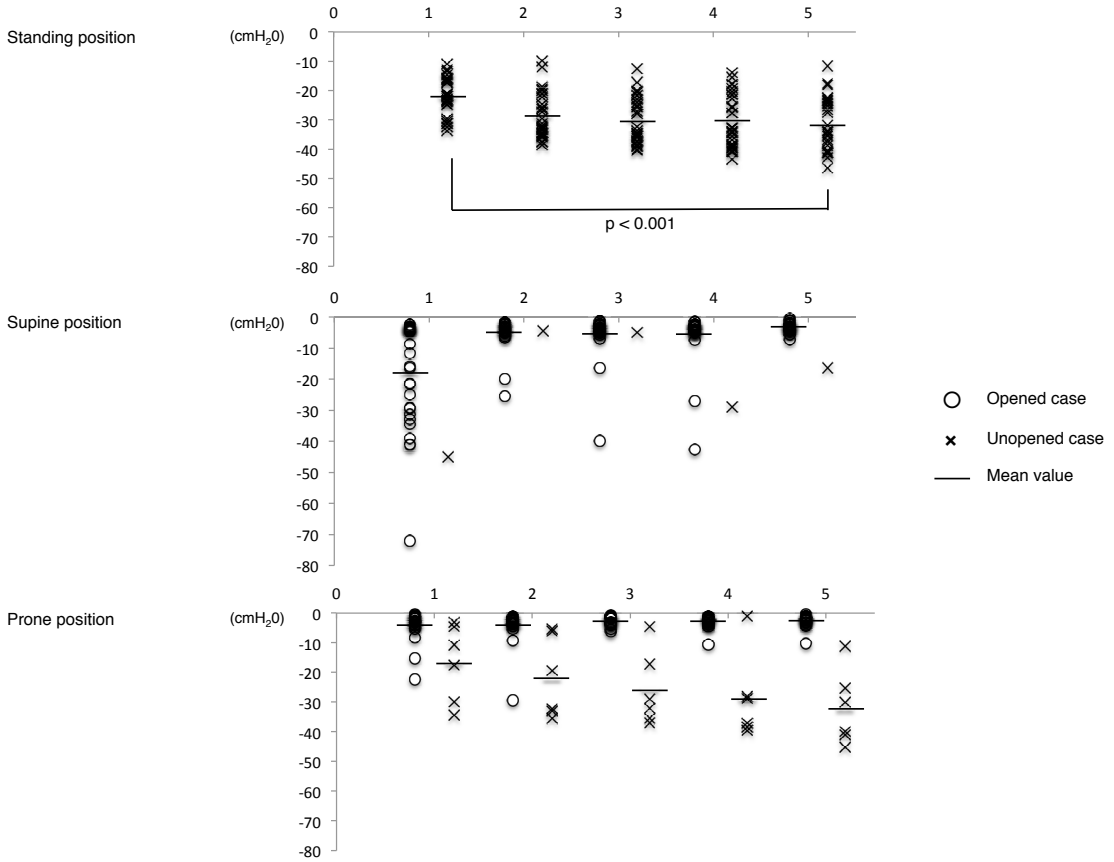
362 Figure.5



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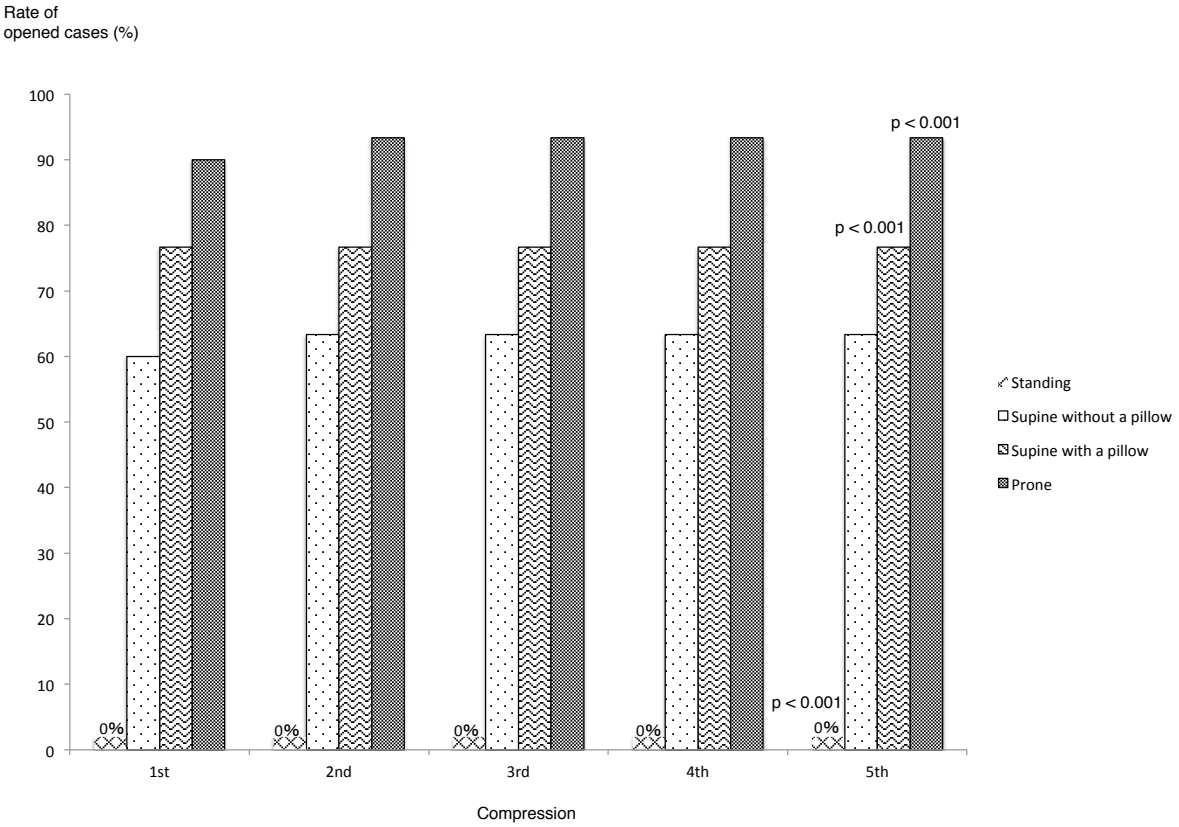
372 Figure.6



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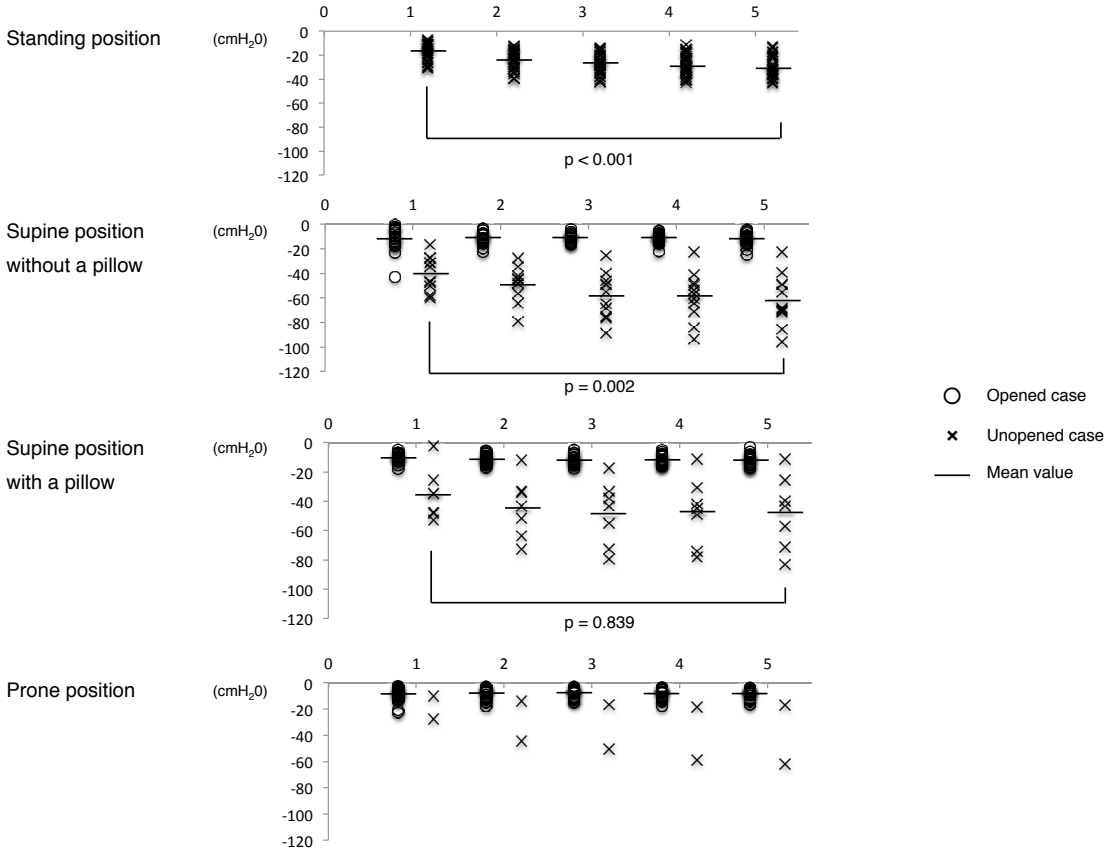
383 Figure.7



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