Mechanism of respiratory failure in fatal crowd accidents using a thoracoabdominal compression model of traumatic asphyxia

Running title: Mechanism of traumatic asphyxia

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Abstract Background: Traumatic asphyxia is a major cause of death in fatal crowd disasters, but the relationship between compression site, load magnitude, load time, and the medical event remains unclear. This study sought to estimate thoracoabdominal compression conditions (load magnitude, load time) resulting in respiratory failure in adults.

Methods: A total of 8 load patterns—A (chest load: 0 kg, abdomen load: 10 kg), B (0, 20), C (10, 0), D (10, 10), E (10, 20), F (20, 0), G (20, 10), H (20, 20)—were applied in 14 healthy adult female subjects. Blood pressure, heart rate, respiratory rate, SpO₂, tidal volume, vital capacity, respiratory phase, and modified Borg dyspnea score were measured over time. The Breathing Intolerance Index (BITI) was also calculated.

Results: Vital capacity decreased in patterns C, D, E, F, G, and H. BITI reached the critical range of ≥ 0.15, where respiratory failure occurs about 45 min later, after 14 min in pattern G and 2 min in pattern H. Vital capacity ≤ 1.85 L and modified Borg scale score ≥ 8.3 corresponded to BITI ≥ 0.15 and were regarded as equivalent to reaching the critical range. Furthermore, the change in chest load was positively correlated with BITI when abdominal load was kept constant.

Conclusions: In human women, respiratory failure could occur within 1 h due to respiratory muscle fatigue even when the total thoracoabdominal load is only about 60% of the body weight. Vital capacity ≤ 1.85 L and modified Borg scale score ≥ 8.3 can be considered as indices for predicting respiratory failure.

Key words: traumatic asphyxia, crowd accident, stampede, respiratory failure, Breathing Intolerance Index (BITI)
Introduction

Traumatic asphyxia is a major form of trauma caused by respiratory and circulatory failure due to severe external compression of the chest, such as when a person is caught in a machine, crushed in a stampede, or buried in sand. This results in death due to hypoxic encephalopathy\textsuperscript{1-5}. Traumatic asphyxia is considered the most characteristic cause of death in human stampede accidents that occur at sports and religious events worldwide. It is characterized by petechial hemorrhage on the face, neck, and palpebral conjunctiva due to obstruction of venous return, and the absence of organic findings such as multiple rib fractures and thoracoabdominal organ injury\textsuperscript{5,11,15,12}.

Eleven people were killed (9 children under 10 years old and 2 women in their 70s) and 247 people were injured (severe: 7; moderate: 19) in a human stampede at a fireworks display in Japan in 2001. It is estimated that all the casualties had fallen underfoot of people in the crowd, resulting in pressure on the chest and causing death due to traumatic asphyxia\textsuperscript{14,15}.

Despite the large number of deaths due to stampede accidents all over the world, the relationship between physical parameters (e.g., compression site, compression load magnitude, and compression load time) associated with traumatic asphyxia and medical events (such as respiratory failure, hypoxic encephalopathy, and death) has not been clarified\textsuperscript{1,5,16}. Clarifying this relationship could provide a medical basis to prevent deaths in crowd accidents, develop strategies for rescue, and establish lifesaving measures. Accordingly, this study aimed to predict the load conditions (load magnitude and loading time of chest and abdomen) under which respiratory failure occurs in healthy women. In an actual accident, death is caused by respiratory failure. Needless to
say, it is not possible to apply a load that would cause respiratory failure to actually occur in scientific studies with human subjects.

In previous studies, compressive loads have been applied to the chest area alone in dogs or mice\textsuperscript{19,20}. In these studies, the animals died when loads several times their body weight were applied to their chests, but it was difficult to discuss the mechanisms leading to traumatic asphyxia.

These previous studies in dogs and mice considered only the magnitude of loads applied to the chests, loading time, and survival status. We hypothesized that in humans, we may be able to simulate the state of dyspnea preceding the occurrence of respiratory failure and death, but under conditions with much smaller load magnitudes than those applied in the animal studies. If maintenance of such dyspnea over a long period could be shown as a potential cause or respiratory failure or death, the load conditions could serve as a predictor of traumatic asphyxia. We also hypothesized that loads applied to the abdomen may be more likely to cause respiratory failure than those applied to the chest, as compressive loads applied to the abdomen restricts the movement of the diaphragm.

**Materials and Methods**

1. Subjects

Crowds typically comprise individuals of a wide range of age and sex, and so it is difficult to set a study sample. It is ethically challenging to use children and the elderly as subjects, but children and elderly people account for the majority of victims in past crowd accidents due to their smaller physique and limited respiratory resistance\textsuperscript{1,6,7,14}. Therefore, this study enrolled young women as subjects as they generally have a smaller physique and less physical strength than men.
In total, 14 healthy women participated in this study.

First, data obtained from an initial experiment conducted with three subjects were used to calculate the appropriate sample size required to detect differences between load patterns, which was determined to be 9 subjects; however, the actual sample size was set at greater than 9.

Assessed parameters were tidal volume (VT) in the standing position, vital capacity (VC) in the standing position, VT in the supine position, and VC in the supine position.

2. Measurements

Subjects were weighed in the supine position with a dead weight load (10 kg iron plate; Irotec, Osaka, Japan) applied to the chest and abdomen (Fig. 1). Using 2 nylon belts (170 × 240 mm) placed over the front of the chest and abdomen of each subject, the weighted load (by gravity) was applied via the chains connected to both ends of the belts.

The center of one belt was aligned with the center of the sternum and the center of the other belt was aligned with the umbilicus. The loads applied to the chest and abdomen were 0, 10, or 20 kg. A total of 8 load patterns (A–H) with various combinations of the weights were used, and each loading pattern was applied to the subjects (Table 2).

Heart rate (beats/min) and SpO₂ were measured continuously, and brachial blood pressure (mmHg) was measured intermittently every 2.5 min using a vital signs monitor (Propaq® encore monitor; ZOLL Medical Corporation, Chelmsford, MA). We also measured the displacement of the anterior surface of the chest and abdomen in the
In addition, VC (L) [intermittent measurement every 5 min (average of 3 measurements)] and VT (L) [intermittent measurement every 2.5 min (average of 5 measurements)] were measured using a spirometer (TKK 11510; Takei Scientific Instruments Co., Ltd., Niigata, Japan). Changes in these parameters over time were analyzed using the Friedman test. Subjective respiratory distress symptoms were evaluated using the modified Borg scale, which ranges from 0 (nothing at all) to 10 (very very severe)\textsuperscript{17} (Table 3).

[Insert Table 3 around here.]

Loading (A-H) was performed after baseline measurement of each parameter for 2.5 min under no load conditions. Loading time was set to a maximum of 20 min for each pattern, and measurements were continued for up to 5 min after unloading. When multiple load patterns were used for the same subject on the same day, an interval of at least 2 h was ensured to allow recovery from respiratory muscle fatigue. The maximum number of patterns was limited to 3 per day.

3. Analysis

To clarify the load pattern and the loading time that could lead to respiratory failure, the following were calculated: the T/_i/_i_/T/_tot ratio, which is the ratio of inspiratory time (T/_i_/) to total time for one respiratory cycle (T/_tot_/); VT/VC, which is the ratio of tidal volume (VT) to vital capacity (VC); and Breathing Intolerance Index (BITI)\textsuperscript{18}, which is an index...
of respiratory muscle fatigue expressed as the product of $T_i/T_{tot}$ and $VT/VC$. Previous studies have shown that the normal value of BITI is less than 0.05, and a value of $\geq 0.15$ is considered to be within the critical range, where respiratory failure occurs about 45 min later.$^{14,18}$.

Changes in HR, sBP, dBP, SpO$_2$, RR, tidal volume, minute volume, VT, Ti/Ttot, $VT/VC$, and BITI from baseline (no load) until 20 min of loading were analyzed for each load pattern using the Friedman test.

To clarify the relationship between conditions that can lead to respiratory failure and the VC and subjective degree of respiratory distress, the correlation between BITI and VC, and BITI and modified Borg scale score were analyzed. Furthermore, to clarify which of the chest or abdominal loads exerted a greater effect on respiratory failure, the change in BITI when the abdominal load was kept constant and the chest load was changed, and that when the chest load was kept constant and the abdominal load was changed, were analyzed using one-way analysis of variance and Kruskal-Wallis test.

Data are expressed as the median of all measurements for each load pattern.

Statistical analysis was performed using SPSS Statistics version 16.0 (SPSS, Inc., Chicago, IL). Significance was set at $p < 0.05$.

4. Ethical issues

Subjects gave written informed consent to participate after being given a full explanation of the objectives, significance, and safety measures of the study. This study was approved by the ethics committee of Nippon Medical School, Chiba Hokusoh Hospital, Chiba, Japan (approval number 572). In the approval process, input was sought from clinical doctors, forensic pathologists, nurses, the general public, and others.
Approval was given by the committee after careful, multidisciplinary investigation of loads applied to the chest and abdomen, including load magnitude and loading time, and of standards for study termination. The study was conducted in accordance with the declaration of Helsinki. Participants were university students who were recruited by public invitation, and none of them were directly acquainted with the researchers. Participants were paid for the time they spent participating in the study (including travel time). To ensure the safety of the subjects, a medical doctor who had no interest in this research prior to the study performed a physical examination, height and weight measurements, chest X-ray examination, and a full medical history.

The doctor, together with other staff, was always present by the subject during load application, and monitored vital signs and subjective and objective findings. Preparation were made to remove the load immediately and to administer appropriate medical treatment. The experiment was stopped if any problem arose regarding safety, if the subject requested to stop, if the modified Borg Scale became 8 or more, or if it was deemed necessary to stop at the doctor’s discretion.

This experiment was conducted at a location adjacent to the emergency department of Nippon Medical School, Chiba Hokusoh Hospital, in order to enable rapid access to emergency medical procedures should the need arise.

The subjects were observed by doctors for 2 h after completing the experiments.

They were further examined at 1 week and 1 month after the experiments to assess whether they had any changes in their physical status or other aspects. No abnormalities were observed in any of the subjects.

Results
In total, 14 healthy women (age 27.5 [21.5–28.0] years, height 159.5 [153.5–164.5] cm, body weight 48.0 [43.0–53.5] kg, body mass index (BMI) 19.1 [17.3–20.6] participated in this study. Tidal volume (VT) in the standing position was 0.73 [0.62–0.93] L, vital capacity (VC) in the standing position was 2.99 [2.79–3.46] L, VT in the supine position was 0.54 [0.41–0.86] L, and VC in the supine position was 2.75 [2.34–3.04] L (Table 1).

Heart rate (Fig. 2), systolic blood pressure (Fig. 3a), SpO$_2$ (Fig. 4), and respiratory minute volume did not change over time in any of the load patterns. Diastolic blood pressure increased significantly over time in pattern H (Fig. 3b). Respiratory rate increased significantly over time in patterns D, E, F, G, and H (Fig. 5). VT was significantly reduced over time in patterns B, E, G, and H (Fig. 6). VC was significantly reduced over time in patterns C, D, E, F, G, and H (Fig. 7).

BITI increased significantly over time in patterns G and H. Linear regression lines are expressed by the equations $y = 0.0025x + 0.1146$ (pattern G) ($p = 0.022$, $R^2 = 0.44$) and $y = 0.0027x + 0.1440$ (pattern H) ($p = 0.021$, $R^2 = 0.43$); BITI reached a level of $\geq 0.15$ approximately 14 min after the start of loading in pattern G and approximately 2 min in pattern H (Fig. 8).

BITI and VC had a strong and significant inverse correlation ($p = 0.000$, Pearson’s correlation coefficient $= 0.509$), represented by the regression equation $y($BITI$) = -0.1456x($VC$) + 0.4188$ ($R = 0.51$, $R^2 = 0.26$). When BITI was $\geq 0.15$, which is the critical threshold value, VC was $< 1.85$ L (Fig. 9).
BITI and modified Borg scale score were weakly correlated (p = 0.000, Pearson’s correlation coefficient = 0.294) with a regression equation of y(BITI) = 0.006x (modified Borg scale) + 0.100 (R = 0.29, R² = 0.09). When BITI was ≥ 0.15, the modified Borg scale score was ≥8.3 (indicating very severe to very, very severe (almost maximal) dyspnea) (Fig. 10).

No significant difference was observed in BITI when the abdominal load was increased while the chest load was kept constant (0, kg, and 20 kg). In contrast, BITI increased significantly (p = 0.048, 0.000, and 0.008, respectively) with an increase in chest load under a constant abdominal load (0, 10, and 20 kg) (Fig. 11).

Discussion

Traumatic asphyxia is a major cause of death in human stampede accidents. The 2010 Love Parade accident in Germany resulted in the deaths of 21 people in their 20s to 40s (8 men, 13 women). Also, 347 people were killed at the Khmer Water Festival in Cambodia in 2010. Crowd accidents during the Hajj, an annual Islamic pilgrimage to Mecca, result in deaths every few years: 1,426 in 1990, 270 in 1994, 119 in 1998, 35 in 2001, 14 in 2003, 251 in 2004, and 380 in 2006. Traumatic asphyxia is likely the major cause of death in all the above accidents, but close examination including autopsy to reveal causes of these deaths were not conducted.

Here, we applied loads to the human chest and abdomen to investigate one of the mechanisms involved in deaths that occur in stampede accidents. We attempted to
conduct experiments in pigs before conducting the study with human subjects. Anesthesia was required to secure the pigs on the bench in the supine position. However, even a small amount of anesthesia affected the animals’ respiration, causing respiratory depression. It was extremely difficult to control the depth of anesthesia so that the pigs would continue normal spontaneous breathing on the bench calmly. For these reasons, we had to halted the experiments using pigs once we completed those using 8 pigs.

In this study, our findings suggested that respiratory muscle fatigue increased over time with chest load exceeding 20 kg and abdominal load exceeding 10 kg and that this could lead to respiratory failure. When a load equivalent to approximately 60% of the subjects' body weight was applied to the thoracoabdominal region, analysis of BITI clearly showed that respiratory failure was inevitable within 1 h from the start of loading. Also, with thoracoabdominal compression, a VC of ≤1.85 L and a modified Borg scale score ≥8.3 was equivalent to BITI ≥0.15, which is considered to be a state of dangerous respiratory muscle fatigue. Furthermore, respiratory muscle fatigue was found to increase with an increase in chest load under a constant abdominal load. However, respiratory muscle fatigue did not increase with an increase in abdominal load under a constant chest load.

Kume reported in their chest compression study that all dogs survived for more than 60 min under a load of twice the body weight, but 75% died within 10 min under a load of 4 times the body weight. All dogs died within 10 min under a load of 5 times the body weight\(^{19}\). In addition, a study by Furuya reported that following chest compression in mice (body weight: 480–550 g), all mice survived more than 60 min under a load of twice the body weight. By contrast, all mice died within 40 min under a load of 3 times the body weight and within 10 min under a load of more than 4 times the body weight\(^{20}\).
Taken together, these past studies show that the compression load magnitude and compression load time are important variables in the mechanism of traumatic asphyxia. However, it had not been clarified how these variables affect traumatic asphyxia in humans.

Although load was determined as a percentage of body weight in these animal studies, absolute load calculations are considered more useful for implementing measures to prevent actual crowd accidents. That is why absolute loads (0, 10, and 20 kg) were used in this study.

Ideally, an even more detailed analysis would be possible if loads were set at 5-kg intervals and even more load patterns were studied. However, this would be overly burdensome to the subjects and would lengthen the study period to the point that subjects would not realistically be able to continuously participate in the study; consequently, only eight load patterns were analyzed in this study.

Bellemare and Grassino studied respiratory tolerance (respiratory muscle fatigue) of the diaphragm. They found that respiratory failure could be predicted by the diaphragm time tension index ($TT_{di}$), which is calculated using inspiratory time ($T_i$), total respiratory cycle time ($T_{tot}$), transdiaphragmatic pressure ($P_{di}$) at rest ventilation, and maximum transdiaphragmatic pressure ($P_{dimax}$). Respiratory failure occurred about 45 min after reaching $TT_{di}$ of $\geq 0.15^{21-23}$.

$$TT_{di} = \left(\frac{T_i}{T_{tot}}\right) \cdot \left(\frac{P_{di}}{P_{dimax}}\right)^{21}$$

However, $P_{di}$ and $P_{dimax}$ require insertion of an invasive gastroesophageal balloon catheter for measurement. These parameters are therefore difficult to measure in experiments with human subjects. Koga et al. clarified that BITI could be calculated using $T_i$, $T_{tot}$, VT, and VC.
BITI = (T_i/T_{tot}) \cdot (VT/VC)^{18, 24} \tag{2}

Equation (2) substitutes the ratio VT/VC, which can be measured noninvasively, for $P_{di}/P_{dimax}$ in the earlier equation$^{18, 25}$. BITI is expressed as the reciprocal of respiratory endurance and is considered to reflect not only the respiratory reserve of the diaphragm alone but fatigue of all muscles related to breathing$^{18}$.

The normal BITI value is assumed to be <0.05, similar to TT$_{di}$. A value of BITI $\geq$ 0.15 is considered to be in the critical range, after which respiratory failure occurs in approximately 45 min$^{18}$. In recent years, BITI has been used as an indication for withdrawal of mechanical ventilation in the pediatric intensive care unit$^{25, 26}$.

This study showed that BITI reaches the critical range 14 min after loading in pattern G and 2 min after loading in pattern H. It can be speculated that these load patterns would lead to respiratory failure by 59 min and 47 min after loading, respectively.

Previous studies on traumatic asphyxia used only chest compression$^{19, 20, 27, 28}$, and no studies considered compression of the abdomen or fatigue of the diaphragm. However, in actual crowd accidents, load is applied to the abdomen as well as the chest. It is thought that this limits the movement of the diaphragm, which is the most important respiratory muscle, and thus respiratory dynamics are adversely affected$^{29}$. This study is the first to examine the influence of both chest and abdominal loads on respiratory failure.

Our findings also suggested that healthy women in their 20s with a load pattern of 20 kg on the chest and 10 kg on the abdomen (pattern G) or 20 kg on the chest and 20 kg on the abdomen (pattern H) could go into respiratory failure within 1 h even when the total load magnitude is less than the body weight (approximately 60%–80% of body weight). These loads were small compared with those in previous reports$^{19, 20, 27, 28}$. This
may be the result of loading on the abdomen in addition to the chest, based on the actual conditions of the actual crowd accident in this experiment.

Moreover, a VC \( \leq 1.85 \text{ L} \) and modified Borg scale score of \( \geq 8.3 \) indicated a very severe to very, very severe (almost maximal) state equivalent to reaching the critical range. Under such conditions, BITI is \( \geq 0.15 \) based on the correlations between BITI and VC and between BITI and the modified Borg scale score.

For the load range used in this study (maximum load of 20 kg each on the chest and abdomen), an increase in chest load was significantly associated with an increase in BITI. However, BITI did not change with an increase in abdominal load. These results suggest that, in crowd accidents, the effect on respiratory dynamics starts to appear from compression above a certain load magnitude on the chest (20 kg in this study), and this is modified by abdominal load.

This study has some limitations. First, because the subjects were humans, securing a large number of samples was challenging. Second, data on children and the elderly, who are the most vulnerable in actual disaster situations, were unavailable because the subjects were limited to only healthy young women in order to ensure the safety of the experiments. Third, only female subjects were used because they are considered to have smaller physique and respiratory reserve capacity than men, and so the effects of sex differences were not assessed. Nevertheless, this study provides data applicable to the safety of people who would be vulnerable in a crowd accident. Fourth, loading experiments were performed in only the supine position because the loading environment was constructed to use the force of gravity alone; measurements in other positions such as a standing or prone position could not be performed. In an actual disaster, however, it is necessary to consider the influence of postural differences on
breathing\textsuperscript{30,31}. Fifth, although the modified Borg scale was used to grade breathing difficulty, this only represents a degree of subjective respiratory distress and it is not objective. Finally, measurement of arterial blood gas data is especially important for objectively defining respiratory failure using a numerical value, but invasive arterial blood sampling was not performed in this study.

To our knowledge, this is the first study to clarify the relationship between load magnitude, loading time, and respiratory failure in humans. A relationship between VC and subjective breathing difficulty for predicting respiratory failure was also clarified.

Children and the elderly account for the majority of victims of traumatic asphyxia in crowd accidents. Respiration resistance is lower in children with high thoracic extensibility and older people with low respiratory reserve capacity than in the adult female subjects in this study. Thus, there is a possibility of relatively early respiratory failure and death when children or the elderly are subjected to an equivalent load per body weight.

Elucidation of the mechanism of traumatic asphyxia, including identification of the load magnitude and load time of thoracoabdominal compression leading to traumatic asphyxia, can provide a foundation for prevention of traumatic asphyxia in crowd accidents through space design based on crowd control simulation\textsuperscript{32-34} and restrictions on entering the venue, as well as for efficient rescue activities and emergency medical services at the accident site.

Because victims of crowd disasters where rescue efforts are taking place may fall into respiratory failure due to respiratory muscle fatigue over time, the results of this study may aid in developing new rescue strategies such as emergency response plans and approaches for making decisions about medical interventions during rescue efforts.
**Conclusion**

A model experiment of traumatic asphyxia caused by thoracoabdominal compression was performed in healthy adult female subjects. Respiratory failure could occur within 1 h due to fatigue of the respiratory muscles even when the load on the chest and abdomen is approximately 60% of the body weight of a young woman. The pathophysiology of respiratory failure was more strongly affected by increasing chest load than by increasing abdominal load. Under a chest and abdominal loading environment, a VC of $\leq 1.85$ L and a modified Borg scale score of $\geq 8.3$ can be considered as indices for predicting respiratory failure.

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**Conflicts of Interest**

The authors declare that they have no conflicts of interest.
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Figure Legends

Fig. 1. Experimental setup for applying loads to the chest and abdomen. Loads (0, 10, and 20 kg) were applied using two nylon belts (170 × 240 mm) to the front of the chest and abdomen of the subjects in the supine position. An ECG monitor, SpO₂ oximeter, spirometer, and laser displacement meter were used to measure each parameter. HR, heart rate; BP, blood pressure; SpO₂, percutaneous oxygen saturation; RR, respiratory rate; VT, tidal volume; VC, vital capacity.

Fig. 2. Change over time in heart rate (/min). No significant changes over time were observed for any pattern. Changes over time from baseline (no load) until 20 min of loading were analyzed for each load pattern using the Friedman test. (*p < 0.05, **p < 0.01)

Fig. 3a. Change over time in systolic blood pressure (mmHg). No significant changes over time were observed for any pattern. Changes over time from baseline (no load) until 20 min of loading were analyzed for each load pattern using the Friedman test. (*p < 0.05, **p < 0.01)

Fig. 3b. Change over time in diastolic blood pressure (mmHg). Diastolic blood pressure increased over time in pattern H. Changes over time from baseline (no load) until 20 min of loading were analyzed for each load pattern using the Friedman test. (*p < 0.05, **p < 0.01)

Fig. 4. Change over time in SpO₂ (%). No significant changes over time were observed
for any pattern. Changes over time from baseline (no load) until 20 min of loading were analyzed for each load pattern using the Friedman test. (*p < 0.05, **p < 0.01)

Fig. 5. Change over time in respiratory rate (breaths/min), which increased in patterns D, E, F, and H. Changes over time from baseline (no load) until 20 min of loading were analyzed for each load pattern using the Friedman test. (*p < 0.05, **p < 0.01)

Fig. 6. Change over time in tidal volume (L), which decreased in pattern B, E, G, and H. Changes over time from baseline (no load) until 20 min of loading were analyzed for each load pattern using the Friedman test. (*p < 0.05, **p < 0.01)

Fig. 7. Change over time in vital capacity (L), which decreased in patterns C, D, E, F, G, and H. Changes over time from baseline (no load) until 20 min of loading were analyzed for each load pattern using the Friedman test. (*p < 0.05, **p < 0.01)

Fig. 8. Change over time in BITI, which increased in patterns G and H and reached the critical range (≥ 0.15) at 14 min and 2 min after the start of loading, respectively. BITI; Breathing Intolerance Index. Changes over time from baseline (no load) until 20 min of loading were analyzed for each load pattern using the Friedman test. (*p < 0.05, **p < 0.01)

Fig. 9. Inverse correlation between BITI and vital capacity (VC). There was an inverse correlation between BITI and vital capacity (VC) (p = 0.000); the regression equation was y(BITI) = -0.1456x(VC) + 0.4188 (R = 0.51, R^2 = 0.26). BITI; Breathing
Intolerance Index.

Fig. 10. Correlation between BITI and modified Borg scale score. There was a positive correlation between BITI and Borg scale (p = 0.000); the regression equation was $y(\text{BITI}) = 0.006x(\text{Borg scale score})+0.100(R = 0.29, R^2 = 0.09)$. BITI; Breathing Intolerance Index.

Fig. 11. Changes in BITI with change in chest load and constant abdominal load; abdominal load was 0, 10, or 20 kg. BITI increased significantly when the chest load was increased (p = 0.048, 0.000, and 0.008 respectively) (Kruskal-Wallis test). BITI; Breathing Intolerance Index.
ECG monitor

HR, SpO₂ (continuous)
BP (2 min)

Modified Borg scale (2.5 min)

spirometer

VT (2.5 min)
VC (5 min)

Laser displacement meter

Chest and abdominal depth displacement, RR (continuous)
Solid lines indicate a significant change over time.
Fig. 4

A(0,10) ○
B(0,20) △
C(10,0) □
D(10,10) ●
E(10,20) ▲
F(20,0) ◇
G(20,10) ■
H(20,20) ◆
Solid lines indicate a significant change over time.

* p<0.05
** p<0.01
Solid lines indicate a significant change over time.

* p<0.05
** p<0.01

Fig. 6
Solid lines indicate a significant change over time.

*   p<0.05
**  p<0.01
Solid lines indicate a significant change over time.

* p<0.05
** p<0.01
Fig. 9
Fig. 10

Modified Borg scale

BITI

Modified Borg scale
Abdomen 0 kg

Abdomen 10 kg

Abdomen 20 kg

Chest (kg)

Chest (kg)

Chest (kg)

p=0.048

p<0.01

p<0.01

BITI

Fig.11
Table 1. Basic characteristics of subjects (median [IQR])

|                     | Median [IQR]   |
|---------------------|---------------|
| Age (years)         | 27.5 [21.5–28.0] |
| Height (cm)         | 159.5 [153.5–164.5] |
| Weight (kg)         | 48.0 [43.0–53.5] |
| Body mass index     | 19.1 [17.3–20.6] |
| Standing position   |               |
| Tidal volume (L)    | 0.73 [0.62–0.93] |
| Vital Capacity (L)  | 2.99 [2.79–3.46] |
| Supine position     |               |
| Tidal volume (L)    | 0.54 [0.41–0.86] |
| Vital Capacity (L)  | 2.75 [2.34–3.04] |

Subjects in this study were 14 healthy women in their 20s. Age, height (cm), weight (kg), BMI, tidal volume (L) and vital capacity (L) in standing and supine positions are shown.
Table 2. Chest and abdominal load patterns

| Load pattern | Chest (kg) | Abdomen (kg) | Chest (kg) | Abdomen (kg) |
|--------------|------------|--------------|------------|--------------|
| 0            | 0          | No load (Control) [0%] | C (10, 0) [21%] | F (20, 0) [42%] |
|              | 10         | A (0,10) [21%] | D (10,10) [42%] | G (20,10) [63%] |
|              | 20         | B (0,20) [42%] | E (10,20) [63%] | H (20,20) [83%] |

Loads 0, 10, and 20 kg were applied to the chest and abdomen respectively. Load patterns (A-H) (chest load (kg), abdominal load (kg)) are shown.

[ ]: Percentage of total loading load on average weight (48 kg)
Table 3. Modified Borg dyspnea scale.

| Point(s) | Degree of breathlessness                        |
|----------|-------------------------------------------------|
| 0        | Nothing at all                                  |
| 0.5      | Very, very slight (just noticeable)             |
| 1        | Very slight                                     |
| 2        | Sight                                           |
| 3        | Moderate                                        |
| 4        | Somewhat severe                                 |
| 5        | Severe                                          |
| 6        |                                                 |
| 7        | Very severe                                     |
| 8        |                                                 |
| 9        | Very, very severe (almost max)                  |
| 10       | Maximal                                         |

Subjective respiratory distress symptoms were recorded using the modified Borg dyspnea scale over time.