Study of Influence Factor on Maximal Mouth Pressure Part I. —Influence of Posture—

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Abstract. It is clear that maximal mouth pressure (PE_{max}, PI_{max}) is influenced by sex, aging, anthropometric data, lung function and activities. However, the influence of posture has not been studied, and in this study we studied the influence of postures on maximal mouth pressure. Nineteen healthy, young adult students from WCMAS comprised a STANDING study group, and 27 healthy, young adult students from IUHW comprised a LYING study group. Maximal mouth pressure was assessed in the sitting, sitting with elbow on knee (the orthopneic position), standing and supine postures. Changing posture was significantly related to maximal mouth pressure. PE_{max} and PI_{max} in the orthopneic position were stronger than in other postures, and in the comparison of supine and standing posture, PE_{max} while standing was significantly lower than PE_{max} while sitting. It was concluded that respiratory muscle strength changes with posture because of the tension generated by changing interabdominal pressure, and muscle length change with changing posture.

Key words: Maximal mouth pressure, PE_{max}, PI_{max}, Posture.

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INTRODUCTION

Maximal mouth pressure is one of the indices used for the evaluation of respiratory muscle strength in the field of physical therapy¹⁾. Positive mouth pressure at exhalation is termed maximal expiratory mouth pressure (PE_{max}) and negative mouth pressure at inhalation is termed maximal inspiratory mouth pressure (PI_{max})¹⁻³⁾. Maximal mouth pressure measurement is a non-invasive and comparatively easy test, and useful for screening^{3, 4)}. The characteristics of maximal mouth pressure have already been reported in young adults^{5, 6)}, the elderly^{5, 7-9)}, respiratory diseases^{10, 11)}, neuromuscular diseases⁵⁾ and tetraplegia^{12, 13)}. Influential factors on respiratory muscle strength have been examined for the influence of lung volume^{5, 9)}, aging^{5, 7)}, anthropometric data⁸⁾, lung function^{7, 14)}, physical

activity¹⁵⁾ and other data.

Maximal mouth pressure (PE_{max} and PI_{max}) is changed by lung volume. The first report of lung volume influence was made by Rohrer⁹⁾. For example, at Residual Volume (RV) Level, the diaphragm is enlarged to the craniad maximally, and maximal tension of the diaphragm occurs by a length-tension relationship. The reaction is maximal because the thorax and lung are compressed maximally. PI_{max} is the sum of these two factors on pressure. At Total Lung Capacity (TLC) Level, the diaphragm falls to the caudad and presses the viscus. On exhalation, the abdominal muscles press the viscus against the diaphragm, and since the thorax and lung are expanded maximally elastic retraction becomes maximum. PE_{max} is the sum of the power of the internal intercostal and abdominal muscles and elastic retraction.

Accordingly, PEmax and PImax at TLC and RV, respectively, include the elasticity of the lung and thorax, and are not true measures of respiratory muscle strength. For excluding the influence of elastic retraction of the lung and thorax, PEmax and PImax are measured at Functional Residual Capacity (FRC) in which elastic retraction of the lung and restitution of thorax correspond. PEmax and PImax are not therefore measures of maximal diaphragm pressure when the respiratory muscles are most relaxed, however, PEmax and PImax are generally used as representative values of the respiratory muscle strength.

Black and Hyatt⁵⁾ reported measuring PEmax and PImax in a group ranging from 20 to 70 years of age, and that PEmax and PImax decreased with age. However, they said the decrease wasn't significant until 55 years of age after which the decrease became significant with aging. Enright et al.⁸⁾ reported PEmax and PImax were affected by aging, sex, height and weight from the data of 4443 persons aged 65 or older. Yamashita and Takahashi¹⁴⁾ also said the factor of influence on PEmax and PImax was aging but didn't designate a critical point.

McConnell and Copestake¹⁵⁾ reported the influence of anthropometric data. They reported nothing individually correlated with respiratory muscle strength among 41 middle-aged and elderly subjects data. They also said the relationship between respiratory muscle strength and other factors was improved by multi-regression analysis but the result wasn't significant. Nishimura et al.⁷⁾ reported that PEmax and PImax were related to height and weight, but that they weren't influencing factors on PEmax and PImax.

As for the influence of lung function, Yamashita and Takahashi¹⁴⁾ reported lung capacity toward the prediction value (%VC) correlated best with respiratory muscle strength. However, %VC wasn't assumed to be a factor of influence on PEmax and PImax because its influence was observed only in females. Enright et al.⁸⁾ reported respiratory muscle strength was related to Vital Capacity (VC) and Forced Vital Capacity (FVC), too. However they didn't use the lung function parameter for the prediction equation of maximal mouth pressure.

Regarding the influence of physical activity, McConnel and Copestake¹⁵⁾ reported respiratory muscle strength was related to average consumption calorie calculated from a diary record. But only 10

persons were involved in the study therefore its reliability is low. The lung volume and aging are the most influential parameters on respiratory muscle strength.

VC and other lung function parameters are changed by posture (e.g. lying, sitting, standing) because the position of the diaphragm is changed by gravity. Therefore, we considered that the diaphragm and other respiratory muscle lengths would be changed by posture. Furthermore, in the field of physical therapy, we experientially know that exhalation and vomiting are enforced by trunk flexion, and that sitting with the elbow on the knee (orthopneic position) is effective for dyspnea of Chronic Obstructive Lung Disease (COPD). In these positions, it is considered that assistant movers are effectually applied to breathing motion. However, the influence of posture on respiratory function measured by maximal mouth pressure has not yet been studied. Thus, the aim of this study was to elicit the influence of posture on maximal mouth pressure.

METHOD

Subjects

The subjects were 46 healthy young adult males from two schools of physical therapy (Waseda College of Medical Arts and Sciences, WCMAS; and the International University of Health and Welfare, IUHW, in Japan). It was confirmed beforehand that the subjects were not suffering from any cardiovascular, pulmonary, neuromuscular or orthopedic diseases. The subjects were divided into two groups. The STANDING group, 19 persons, were studied in the sitting, orthopneic position and standing postures. The LYING group, 27 persons, were studied in the sitting, orthopneic position and lying postures. Informed consent was obtained from all subjects before their participation.

Measurement of maximal mouth pressure (PEmax and PImax)

PEmax and PImax were measured with a KH-101 (CHEST, Ltd; Japan), which comprises a cylinder and pressure sensor. We used a silicon mouthpiece, also manufactured by CHEST, Ltd. We took care that air did not leak from around the subjects' lips, and a nose clip was used to prevent air leaks from the nasopharynx upon inspiration. Black and Hyatt⁵⁾, for presence of influence of buccinator and

Nishimura et al.⁷⁾ for presence of artifact set up an orifice at the canal, but we didn't set up an orifice in order to prevent change of lung volume. Thus, we observed and monitored adopted pressure which could be kept for 1 or 2 seconds without spike through artifact. PImax was transformed to positive pressure for comparison with PEmax.

Maximal mouth pressure was measured 3 times in 3 different trunk positions, sitting and orthopneic position, beginning with PEmax followed by PImax each time. Maximal mouth pressure was measured in the sitting position with the trunk position neutral between flexion and extension, and a hip joint flexion of about 90° on a chair at first, and then at trunk flexion angles of 0° (vertical standing or lying), 30° and 60° at random. PEmax and PImax were measured 15 times, respectively, and the sequence of postures was sitting at first followed by a random choice of the other postures after several practices. PEmax and PImax were measured at TLC and RV, respectively. We used only data from the sitting and orthopneic positions, and from the vertical standing or lying (trunk flexion angles of 0°) in this study for analysis of the influence of posture.

Setting of STANDING group

We used a CYBEX6000 (CYBEX, Ltd) and trunk attachment for control of trunk flexion in the STANDING group. Subjects' knees were bilaterally fixed with slight bending, and the pelvic and upper trunk were lightly fixed for protecting motion of the thorax and abdomen. Standing position (trunk flexion of 0 degree) was set to vertical standing by the ISOMETRIC mode of CYBEX6000. Maximal mouth pressure was measured while sitting at first, and while sitting with elbow on knee (orthopneic position) and in the standing position randomly. We observed by monitor subject strains of trunk flexion and extension during measurement of maximal mouth pressure.

Setting of LYING group

We used a reclining bed for control of trunk flexion in the LYING group. Subjects weren't fixed to the bed, but were commanded not to rise from bed. Maximal mouth pressure was measured while sitting on a chair at first, and in the orthopneic and lying positions at random in the same way as for the STANDING group.

Protocol

Subjects' physical characteristics (height and weight) were measured first, and their body mass index (BMI) was calculated. The measurement of respiratory muscle strength was explained to the subjects, and the technique was practiced several times to avoid a learning effect. After PEmax and PImax were measured 3 times in chair sitting, PEmax and PImax were measured on the bed or in the CYBEX or orthopneic positions. Maximal mouth pressure was measured at TLC or RV after each posture change to avoid the influence of compression and expansion of the visceral cavity by trunk flexion and extension. During measurement, verbal encouragement (e.g. "inhale more" or "exhale more") was given to each subject for maximal effort. We provided 3 or 5 min rest to all subjects between each measurement. All measurements were made on the same day; all subjects completed the series in one day; and there was no attrition. Slight air leaks around the mouth in several subjects were ignored, but if the air leaks were obvious, measurement was repeated. Measurement was also repeated when artifacts were noted.

Data analysis

Data used were the values collected in the sitting, lying, standing and orthopneic positions. General characteristics of the STANDING and LYING group subjects were compared by non-paired t-test. Between-group comparisons of PEmax and between-group comparisons of PImax were analyzed by non-paired t-test, too. All 15 measurements were considered based on the order of enforcement, and learning and fatigue effects were analyzed by two-way analysis of variance (ANOVA). Comparisons of each posture were analyzed by two-way ANOVA and Fisher's PLSD post hoc test was used for each posture. The criterion for statistical significance was $p < 0.05$.

RESULTS

Characteristics between groups

Age, height, weight and BMI did not differ statistically between the two groups. Sitting PEmax and sitting PImax also did not differ statistically between the two groups (Table 1).

Table 1. Comparison between STANDING group and LYING group

	Standing	Lying
Age (year)	23.5 ± 3.2	21.7 ± 4.6
Height (cm)	172.0 ± 4.7	171.8 ± 5.3
Weight (kg)	67.5 ± 8.6	63.9 ± 6.7
BMI ^{#1}	22.8 ± 2.6	21.6 ± 2.2
PEmax (cmH ₂ O) ^{#2}	176.2 ± 24.4	174.4 ± 19.5
PImax (cmH ₂ O) ^{#2}	167.1 ± 29.9	151.0 ± 30.0

#1 BMI; Body Mass Index. #2 At sitting.

Influence of learning and fatigue effect

The order of enforcement of the 15 measurements was examined. F values of PEmax and PImax by ANOVA were 0.80 and 0.54, respectively, and there was no order of enforcement which changed them. Thus, learning and fatigue effects were not more influential than the influence of changing posture (Fig. 1).

Influence of changing posture

The changes in maximal mouth pressure by change of posture are shown in Fig. 2a, b and Table 2. PEmax and PImax in the orthopneic position were strongest in the LYING group, and in contrast, PEmax and PImax at standing were weakest in the STANDING group. P values of PEmax and PImax of both groups by two-way ANOVA were $P < 0.001$.

Maximal mouth pressure was significantly different at each posture, and differences in PEmax and PImax between the orthopneic position and supine, the orthopneic position and sitting in the LYING group were significant ($P < 0.05$) by post hoc test, respectively. Further, the differences in PEmax between the orthopneic position and the standing, the standing and sitting in the STANDING group were significant ($P < 0.05$) by Post Hoc test, and differences in PImax between the orthopneic position and standing, and between the orthopneic position and sitting in the STANDING group were significant ($P < 0.05$). Thus, the strongest posture for maximal mouth pressure was the orthopneic position. In contrast, the weakest postures for maximal mouth pressure was standing in the STANDING group, and sitting in the LYING group but the difference between sitting and lying was not significant (Fig. 2a, b). PEmax was 163.5 ± 26.5 cmH₂O, 177.1 ± 22.5 cmH₂O at standing and lying, respectively, and the difference between the two postures was significant. In contrast, PImax was 164.2 ± 33.3 cmH₂O, 156.6 ± 32.1 cmH₂O at standing and lying, respectively, and the difference between the two postures was not significant (Fig. 3).

Fig. 1. Learning effect of Maximum mouth pressure.

Fig. 2. Changing posture and Maximum mouth pressure.

Table 2. PEmax and PImax at each posture

Standing group	Orthopneic	Standing	Sitting	ANOVA
PEmax	178.4 ± 20.4	163.5 ± 26.5	176.2 ± 25.9	*
PImax	173.4 ± 25.6	164.2 ± 33.3	167.1 ± 30.4	*
Lying group	Orthopneic	Supine	Sitting	ANOVA
PEmax	183.7 ± 18.7	177.1 ± 22.5	174.0 ± 21.3	*
PImax	168.5 ± 37.0	156.2 ± 32.1	151.0 ± 32.9	*

(UNIT: cmH₂O) *p<0.05.

DISCUSSION

Maximal mouth pressure was measured in various postures for determining the influence of posture on respiratory muscle strength. Maximal mouth pressure was changed by posture, and both PEmax and PImax were strongest in the orthopneic position, but only PEmax decreased in standing. This study was performed on two groups of separate individuals but we considered that this wasn't an influential problem, since the subjects were normal and their age and anthropometric data weren't different. Both PEmax and PImax at sitting were stronger than the data reported by Kikuchi¹⁶⁾. The reason for this is that we used a mouthpiece made of silicon, that didn't leak breath easily, and we didn't

set an orifice that prevented glottal closing.

Maximal mouth pressure as an indicator of respiratory muscle strength was used because it has been widely reported^{5, 7)}. It has been compared with other parameters of which age is considered the most important. Black and Hyatt⁵⁾ said 55 years old was the critical point after which maximal mouth pressure decreased. Thus, we studied comparatively young adult males to eliminate the influence of aging. Cook et al.⁹⁾ did not observe practice and short learning effects, but a long learning effect was observed in certain subjects. Wen et al.⁴⁾ reported the latter of all testing data was stronger than earlier samples of all testing data in 367 repeats of maximal mouth pressure in a retrospective analysis, and that maximal mouth

Fig. 3. Differential PEmax and PImax between standing and lying.

pressure was influenced by learning effect. In this study, we considered that subjects couldn't learn because the maximal mouth pressure measurement was a first trial for them, and we measured after detailed explanation and several practices. All low data were ranged and studied for occurrence of learning and fatigue effects (Fig. 1), but their trends were not specific. Thus, the learning effect was not more influential than the influence of posture.

Change of respiratory function with posture is comparatively well known and spirometric data was reported as being different between sitting and standing^{17, 18)}. Similarly, respiratory muscle activity is changed by posture. De Troyer et al.¹⁹⁾ reported observing external oblique muscle activation as respiratory motion when subjects were set on a tilt table and the table angle was altered. Activity of the external oblique muscle increased as much as to be close to vertical standing. They concluded that the length-tension relationship of the diaphragm is improved by the action of abdominal muscles pushing viscera and the diaphragm. We consider transversus abdominis muscles and/or external oblique muscle activation which pushes the diaphragm upward is advantageous for breathing because an abdominal binder for tetraplegia

improved lung function²⁰⁾. Incidentally, respiratory muscle strength was influenced by lung volume⁵⁾. Expiration is strongest at TLC, contrariwise, inspiration is strongest at RV. Thus, we expected the diaphragm position to be changed by posture, and influenced by visceral weight changing respiratory muscle strength. We expected PEmax to be decreased by visceral weight and PImax to be increased by it. However, in this study, PEmax was significantly different between standing and lying, but PImax wasn't significantly different, because the diaphragm rises against the visceral weight in expiration while standing and expiration is discouraged. PImax at standing was less than at lying, because when exhaling to RV with inspiration effort, trunk flexion was confined, and the transversus abdominis could not contract enough and raising the diaphragm was difficult; the length-tension relationship of the diaphragm couldn't improve, so the subjects couldn't generate enough diaphragm tension. Thus, we regard the most appropriate posture for measurement of maximal mouth pressure is supine because it is the posture in which trunk flexion least influences maximal mouth pressure and reproducibility is higher. In this study, strongest pressures were PImax and PEmax in the orthopneic position. This posture is regarded as having several advantages. First, the pectoral major muscle is utilized easily by fixing the upper extremity and it is easily used as a respiratory assistant mover. Second, this posture easily increases interabdominal pressure because of trunk flexion in this posture. Campbell¹⁷⁾ reported that the pectoral major muscle is activated by inspiration effort. The orthopnea of COPD is regarded as a strategy for efficiently using a respiratory assistant mover. Thus, increment of PImax in orthopnea is regarded as being influenced by the pectoral major muscle.

The rectus abdominis can move forward and backward to some extent because the distance between origin and insertion of the muscle is shortened and moved in the orthopneic position, like in the trunk flexion position. If this is taken into consideration, we regard expiration at TLC as being increased by the interabdominal pressure by the transversus abdominis and/or abdominal oblique muscles' contraction. Conversely, inspiration at RV is decreased by interabdominal pressure by rectus abdominis contraction which pushes the abdominal wall forward. Thus, we regard action of

Fig. 4. Motion of rectus abdominis at standing and sitting. a: In a standing position, the rectus abdominis can't easily move forward and backward because it isn't relaxed. b: In trunk flexion like in the sitting and orthopneic positions, the rectus abdominis is relaxed and can move forward and backward. In expiration, the rectus abdominis and transversus abdominis can increase interabdominal pressure. In inspiration, the rectus abdominis decreases interabdominal pressure after the transversus abdominis pulls the rectus abdominis backwards. Thus transversus and rectus abdominis coordinate in inspiration and expiration. c: In lying (supine), visceral weight pushes up the diaphragm and promotes the length-tension relationship. Accordingly, P_{Imax} and P_{E_{max}} aren't decreased.

the transversus abdominis as an important function here. First, at expiration, the transversus abdominis affects interabdominal pressure by its contraction and raises the diaphragm. Second, it acts to push out air from the thorax through RV and concave abdominal wall from a ventral to dorsal like arch. Accordingly, the transversus abdominis improves the diaphragm length-tension relationship. Thus, a posture in which the trunk is flexed like the orthopneic position and acts on the transversus abdominis is advantageous for expiration and inspiration (Fig. 4). Especially, we regard it as an advantage for severe COPD in which the diaphragm is flattened. In this study, several subjects released the elbow from the thigh when measuring maximal mouth pressure in the orthopneic position. We consider this a P_{Imax} increasing strategy in which they rendered rectus abdominis to ventral by trunk extension and decreased interabdominal pressure. Accordingly, in the field of physical therapy, it is fundamental to do initial breathing training in the

supine position, and it may be possible to improve treatment by adopting it in therapy.

We studied influence of posture on maximal mouth pressure and hypothesized that posture influence is connected with the activity of rectus abdominis and transversus abdominis muscles. However we didn't measure pectoral muscle or other assistance muscle EMGs, intragastric pressure and position of diaphragm. Observation of these other muscles and their activities are needed to prove this hypothesis.

CONCLUSION

We studied the relationship between posture and respiratory muscles by measurement of maximal mouth pressure. Changing posture influences respiratory muscles and maximal mouth pressure is higher in the orthopneic position, especially. P_{E_{max}} was decreased at standing compared to sitting and lying, and it almost didn't change

between lying and sitting. We believe the causes of influence on respiratory muscle strength by posture are participation of respiratory muscles and the influence of gravity promoting advantage in the length-tension relationship of the diaphragm and other respiratory muscles.

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