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Effects of Water Immersion in Different Water Depths on Respiratory Function and Respiratory Muscle Strength among Elderly People: An Observational Study

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Abstract

The aim was to investigate the effect of three water levels (umbilical, 4th rib, and clavicular) on the respiratory function and respiratory muscle strength among elderly. Spirometry and respiratory strength were measured on land as baseline data. Next, water depth conditions were determined randomly, and spirometry and respiratory muscle strength were measured at each water level. The Vital Capacity and Expiratory reserve volume in the clavicular level were significantly lower than those in the land and umbilical trials. No significant difference was observed in other respiratory functions. Chest circumference and respiratory muscle strength were not significantly different among all conditions.

Keywords

Respiratory Functions, Respiratory Muscle Strength, Water Immersion, Elderly People

1. Introduction

Aquatic exercise has recently been introduced as a part of health enhancement plans in rehabilitation and sports clubs [1] [2]. Aquatic exercise can reduce the self-weight load, thus allowing persons with obesity, joint diseases, or lumbago to perform exercise safely [3] [4]. In addition, water viscosity and pressure can be used as exercise loads to enhance extremity muscle strength [5] [6].

Breathing underwater requires great effort mainly for the following two reasons: first, the blood volume shifts into the chest cavity due to increased venous return from the lower extremities; and second, the chest wall and diaphragm inflexibility shifts toward the cranial side due to the hydrostatic pressure, resulting in restricted pulmonary compliance [7] [8]. Regarding the effects of water depth on respiratory function, the pulmonary vital capacity (VC), forced expiratory volume during the first second ($FEV_{1.0}$), and functional residual capacity (FRC) decrease during water immersion at the clavicular or cervical level [9] [10]. Furthermore, de Andrade *et al.* reported that decreased maximum inspiratory muscle strength during water immersion was greater when the water level was at the clavicle than at the xiphoid process due to the higher water pressure at the clavicular level (CL) [11]. We also suggested that forced respiration during upright water immersion up to the CL resulted in greater inspiratory muscle fatigue than at shallower depths in healthy young men [12].

As mentioned above, underwater environment exercises have been incorporated in various rehabilitation programs and are widely adopted in respiratory, heart, and other diseases. However, although several studies have investigated the effect of different water depths on respiratory function in young people, studies investigating this effect in elderly people are limited and with unclear findings.

Therefore, this study aimed to investigate the effect of three water levels (umbilical, 4th rib, and clavicular) on the respiratory function and respiratory muscle strength among elderly people.

2. Patients, Material and Methods

2.1. Participants

A total of 14 elderly people were included in the study. Participants with history of respiratory or cardiovascular disease, hypertension (resting systolic blood pressure [BP] of ≥140 mmHg and/or diastolic BP of ≥90 mmHg), diabetes, or obesity (body mass index [BMI] of ≥30 kg/m^2), or smoking habit were excluded. In addition, those with kyphosis were excluded to eliminate the influence of spinal deformity. Eligible participants who met the inclusion criteria were included in the study after familiarizing themselves with the experimental protocol, such as the measurement method using spirometry described below. Of the 14 registrants, two had a history of smoking and two had kyphosis and hence, they were excluded from the study. Therefore, statistical analyses were carried out using data from 10 participants. The participant characteristics are summarized in **Table 1**.

This study was approved by Aino University Research Ethics Committee and conformed to the standard set by the Declaration of Helsinki. Written informed consent was obtained from all participants prior to the experiment.

2.2. Material and Methods

An underwater treadmill (HOKKODENKI treadmill KRT-2500P) was used as

Table 1. Participants characteristics.

Number	10
Age (years)	67.3 ± 2.2
Height (m)	1.65 ± 0.06
Weight (kg)	65.5 ± 7.6
BMI (kg/m^2)	23.8 ± 2.1
Data are means ± SD	

the water tank, and the water level was set to three settings: umbilical level (UL), 4th rib level (RL), and CL trials. The water temperature was 32˚C ± 1˚C. As measurement items, VC, inspiratory capacity (IC), inspiratory reserve volume (IRV), and expiratory reserve volume (ERV) were measured using a spirometer (AS-507, Minato., Osaka, Japan) as respiratory function indices. Maximum inspiratory (PImax) and expiratory (PEmax) pressures in the oral cavity were also evaluated using a spirometer with the measuring unit of the respiratory muscle strength (Chest spirometer HI801) and considered as surrogate indices of inspiratory and expiratory muscle strength, respectively. The chest circumference (CC) was measured at the xiphoid process level.

Measurements were performed according to the protocol below. At the laboratory, participants' weight and height were measured before the first experiment. BMI (kg/m^2) was calculated as body weight (kg) divided by height (m) squared. Then, participants practiced spirometry and respiratory muscle strength measurement methods, and all of them were trained. Then, 30 minutes after completing the practice, the experiment was started. Spirometry, respiratory strength, and chest circumference were measured 10 minutes after sitting on land and recorded as baseline data. Next, water depth conditions were determined randomly, and spirometry and respiratory muscle strength were measured 10 minutes after assuming a sitting position at each water level.

2.3. Statistical Analysis

All statistical analyses were performed using the StatView statistical software package (Ver5.0, SAS, Cary, NC, USA). Data were expressed as mean ± standard deviation (SD) unless otherwise indicated. One-way analysis of variance with repeated measurements and subsequent multiple pairwise comparisons (Scheffe method) was performed to evaluate the effect of upright water immersion at different water depths on the respiratory function and respiratory muscle strength. Statistical significance was defined by a P value of <0.05.

3. Results

Effects of Water Immersion at Different Water Depths on the Respiratory Function and Respiratory Muscle Strength

Table 2 shows the respiratory function and respiratory muscle strength parameters

Table 2. The effect of water immersion on the respiratory function and respiratory muscle strength.

	Land	Umbilical level	4th-rib level	Clavicular level
VC (L)	3.6 ± 0.3	3.7 ± 0.4	3.5 ± 0.5	3.3 ± 0.3*#
IC (L)	2.1 ± 0.4	2.1 ± 0.5	2.2 ± 0.4	2.5 ± 0.3
ERV (L)	1.5 ± 0.3	1.6 ± 0.2	1.4 ± 0.3	0.7 ± 0.5*#
CC (cm)	78.1 ± 5.4	77.7 ± 5.2	77.0 ± 6.7	77.3 ± 3.1
PEmax (cmH_2O)	81.4 ± 11.6	80.7 ± 11.5	82.9 ± 18.1	81.5 ± 12.7
PImax (cmH_2O)	90.2 ± 14.6	88.9 ± 13.6	87.8 ± 16.3	90.4 ± 15.1

Values are means ± SD. *$p < 0.05$ vs. land, #$p < 0.05$ vs. umbilical level. Abbreviations: VC, vital capacity; IC, inspiratory capacity; ERV, expiratory reserve volume; CC, chest circumference; PEmax, maximal expiratory pressure; PImax, maximal inspiratory pressure.

on land and during water immersion. The VC and ERV in the CL were significantly lower than those in the land and UL trials. No significant difference was observed in other respiratory functions. Chest circumference and respiratory muscle strength were not significantly different among all conditions.

4. Discussion

This study demonstrated that VC and ERV in the CL were significantly lower than those in the land and UL trials. Agostoni *et al.* stated that respiratory functions, such as VC and forced expiratory volume in 1 s of water immersion, were reduced in proportion to the water depth and that the reduction become remarkable when the depth reached the CL [9]. Dahlback and Buono *et al.* also reported that VC was significantly decreased by water immersion at the CL [13] [14]. Our results are consistent with those of previous studies. Kurabayashi *et al.* reported that CC was reduced by 0.5 cm underwater at the CL depth than that before submergence [15]; however, our results did not show a significant difference regardless of water depth. Chest compliance has been reportedly reduced in elderly people [16]. Therefore, they are less likely susceptible to CC changes due to hydraulic pressure on the chest wall. The abdominal and chest walls are speculated to be compressed by hydrostatic pressure during water immersion, resulting in a cranial shift of the diaphragm, which decreased VC. This cranial shift also minimizes the alveolar size at the end-expiratory phase, which may decrease ERV.

In this study, neither PImax nor PEmax was affected just by water immersion at any depth. In terms of PImax, our results were consistent with that of Schoenhofer *et al.*'s, which showed that PImax tended to decrease from the baseline after water immersion at the CL depth. PImax is generally recommended to be measured at the maximum expiratory phase based on the length-tension relationship theory [17]. Briefly, the maximum expiratory phase is determined by the balance between expiratory muscle contraction and opposing elastic dilatation pressure of the lungs and thorax. At this phase, the inspiratory muscles and diaphragm are extended to the maximum and demonstrate maximal tensile strength to generate maximal inspiratory pressure with support from the elastic dilatation pressure in the lungs and thorax. Water immersion could promote easy retention in the maximum expiratory phase; this may be the reason why PImax was not impaired by water immersion in this study. In terms of PEmax, our results support Andrade *et al.*'s findings that regardless of the water depth, PEmax during water immersion was not different at the iliac crest, xiphoid process, or CL [11]. Primarily, the decreased VC that is accompanied by submergence may be unfavorable to measure PEmax from the above length-tension relationship perspective. However, hydrostatic pressure against the entire thorax at the CL depth is speculated to have assisted expiration, resulting in the minimum influence on PEmax.

There are some limitations in the present study. The results of the present study with the small number of subjects suggest that VC and ERV decreased when water immersion was at the CL. We will increase the number of subjects more from now on, and have to consider whether it'll be a similar result. In addition, water resistance changes depending on the movement speed, moving with low resistance may be possible by changing the speed even if the movement is the same. Therefore, when performing respiratory exercises underwater, the exercise load may be reduced if the inspiratory speed is slow. Further detailed exercise methods that affect the respiratory function should be investigated in future studies.

5. Conclusion

In conclusion, we demonstrated that VC and ERV decreased when water immersion was at the CL in the elderly, but did not affect the respiratory muscle strength. Further studies are needed to develop an exercise regimen that can be utilized in the field of health promotion for elderly that makes the most of the characteristics of submersion and aquatic exercise.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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