The Reliability and Influence of Body Position on Acoustic Pharyngometry and Rhinometry Outcomes

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ABSTRACT

Objectives: The aim of this cross sectional study was to analyze the method error and reliability in acoustic pharyngometry and rhinometry and to analyze the difference between standing and sitting position in acoustic pharyngometry and rhinometry.
Material and Methods: The sample comprised 38 healthy subjects (11 men and 27 women) as part of a control group in another study. The subjects underwent repeated measures of acoustic pharyngometry and rhinometry in standing and sitting position. Upper airway dimensions in terms of volume, minimum cross-sectional areas (MCA) and distances were evaluated using the Eccovision® Acoustic Pharyngometer and Rhinometer. Method error and reliability were analyzed using paired t-test, Dahlberg's formula and the Houston reliability coefficient, and differences between body positions were analyzed using paired t-test.
Results: There was no systematic error in the repeated measures except for the distance to MCA in the left nostril in sitting position ($P = 0.041$). The method error for the pharyngometry ranged between 0.001 to 0.164 cm/cm^2/cm^3, and the reliability was 0.99. The method error for rhinometry ranged between 0.001 to 0.37 cm/cm^2/cm^3 and the reliability between 0.99 to 1. Difference between standing and sitting position was found only in the pharyngeal airway in terms of volume ($P = 0.025$) and mean area ($P = 0.009$) with smaller airway in sitting position.
Conclusions: The results indicate that acoustic pharyngometry and rhinometry are reliable methods to perform repeated measures of the upper airway dimensions especially in the standing mirror position. It may be essential to perform the measures with the patient positioned in the same body position each time.

Keywords: acoustics; healthy volunteers; observer variation; pharynx; posture; reproducibility of results.

Accepted for publication: 19 October 2020
To cite this article:
Knappe SW, Sonnesen L.
The Reliability and Influence of Body Position on Acoustic Pharyngometry and Rhinometry Outcomes
J Oral Maxillofac Res 2020;11(4):e1
URL: http://www.ejomr.org/JOMR/archives/2020/4/e1/v11n4e1.pdf
doi: 10.5037/jomr.2020.11401

INTRODUCTION

Acoustic pharyngometry and rhinometry are non-invasive techniques to measure the dimensions of the upper airway [1-5]. These techniques might be useful in the clinic treating patients diagnosed with sleep disordered breathing (SDB) such as obstructive sleep apnea (OSA). OSA is a serious disease with a prevalence of 2 - 4% in the adult population and 30 - 60% in men ≥ 60 years [6]. On correct indication OSA patients can be treated symptomatically with a mandibular advancement device (MAD) which protrudes the mandible in a forward position and increase the upper airway volume [6]. Acoustic pharyngometry and rhinometry may allow non-invasive examination of the current dimensions of the upper airway e.g. with and without a MAD in the mouth [3-5,7,8].

The upper airway dimension is not static [9], why it might be questioned whether the acoustic pharyngometry and rhinometry outcomes may differ with changing body position. Furthermore, it is well documented on lateral cephalograms and cone-bean computed tomography (CBCT) that the pharyngeal airway dimension and head posture are associated [10-14]. Hence, the body position during acoustic pharyngometry and rhinometry may be crucial in the examination of upper airway dimensions in patients.

The natural head position is determined by the patient's own postural control system and is defined as a standardized and highly reproducible position of the head in an upright position
[15-18]. When obtaining measurements of the patient's upper airway dimension it is desirable to choose a head posture and body position in which the upper airway dimension is reproduced with accuracy. Previous studies have shown that the upper airway dimension is influenced by the head posture causing even the slightest change in the tilting of the head to change the upper airway dimension [9,11,12,14,19]. Therefore, it is essential to obtain the measurements with the patient's head in a natural position determined by the patient's own postural proprioceptive control system, and not in a constructed head position such as the Frankfort horizontal as this may cause misleading results [15,20]. The natural head posture in the mirror position as described by Siersbæk-Nielsen and Solow [21] is a highly reproducible and easily obtained head posture applicable to measure the upper airway dimensions on lateral cephalograms and CBCT [14,21,22].

Therefore, it may be relevant to adapt this method when performing acoustic pharyngometry and rhinometry in order to obtain reproducible results of the patients' physiological upper airway dimensions in the standing position.

Only a few studies have previously investigated the reliability of repeated measures of acoustic pharyngometry and rhinometry [3,4] and the influence of body position (but in the sitting and supine position) on acoustic pharyngometry and rhinometry outcomes [23,24]. Therefore, it seems relevant to investigate the reliability of repeated measures of acoustic pharyngometry and rhinometry as well as the influence of body position on acoustic pharyngometry and rhinometry outcomes in order to discuss the future management and use of these techniques.

It is hypothesized that the method error and reliability of repeated measures of acoustic pharyngometry and rhinometry within a short time interval will be small and reliable in the standardized standing position. Furthermore, it is hypothesized that there will be a difference in acoustic pharyngometry and rhinometry between standing and sitting position.

The aims of this study were to investigate the method error and reliability of repeated measures of acoustic pharyngometry and rhinometry, as well as to evaluate the effect of standing and sitting position on pharyngometry and rhinometry outcomes.

MATERIAL AND METHODS

Subjects

The study included 38 participants (11 men and 27 women) with a mean age of 31.4 years (range 20 to 53 years) and a mean body mass index (BMI) of 23.5 kg/m^2 (range 18.5 to 33.7 kg/m^2).

The subjects were enrolled as part of a control group in another study performed at the Orthodontics Section, Department of Odontology, University of Copenhagen, Denmark from September 2017 to December 2017 [25]. The participants comprised healthy individuals and the inclusion criteria were as follow: no known diseases or syndromes, age range from 20 to 50 years, dental or medical students and employees at the Department of Odontology, neutral occlusion, no previous orthodontic treatment and informed consent [25]. All the controls from the original study [25] were enrolled in the present study except from one participant, who was occupied immediately after the first registration and therefore the second recording was not possible (Figure 1). When power analysis was performed under the assumption that differences were found in 50 % of

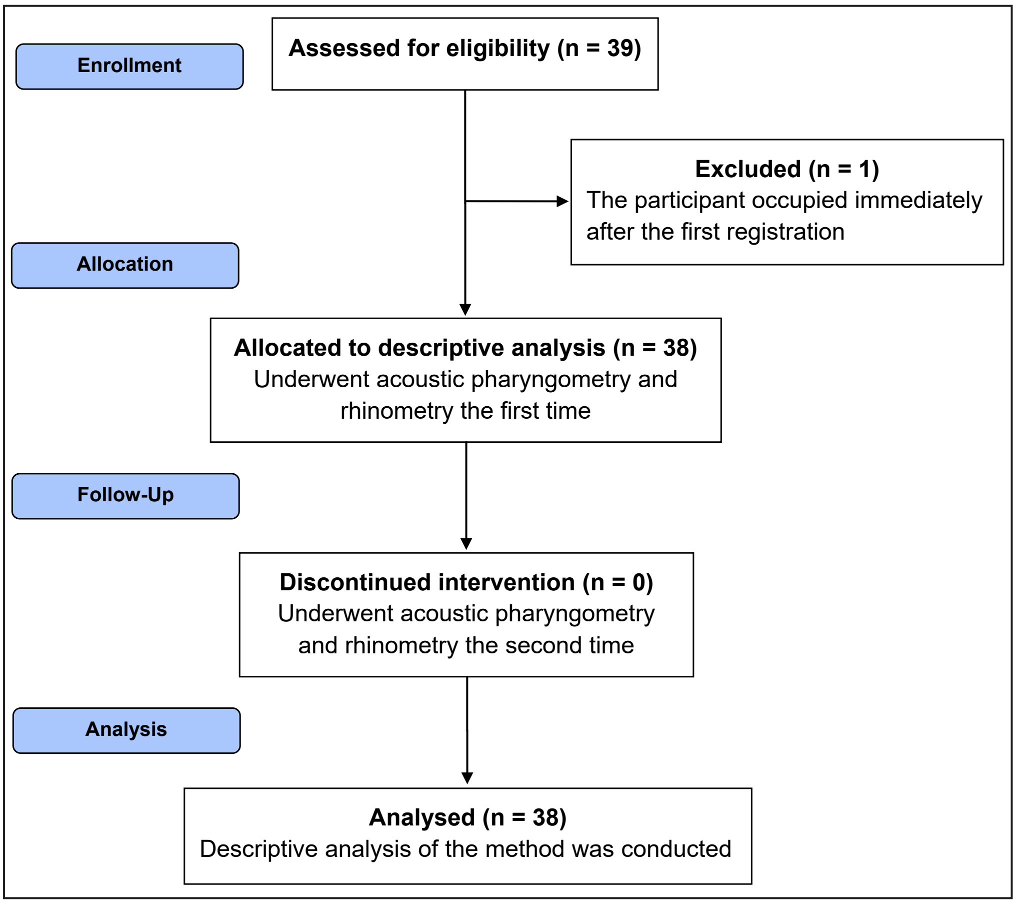

Figure 1. Flowchart depicting the design of the cross-sectional study.

the repeated measurements and in the different body positions, at least 17 participants were required in order to have sufficient power (80%) to identify statistically significant differences at the 5% level of significance. Thus, the 38 participants included in the present study were considered sufficient. The study has been approved by the Ethical Committee for Copenhagen, Denmark (ref. no. H-17015290) and the Danish Data Protection Agency (ref. no. SUND-2017-28).

Methods

All subjects were examined by the same examiner/dentist (S.W.K.) at the Department of Odontology, University of Copenhagen, who was trained according to the exercises described in the operator manuals [26,27]. Eccovision® Acoustic Pharyngometer and Rhinometer (Sleep Group Solutions; Hollywood, Florida, USA) were used to measure the dimensions of the pharyngeal airway and nasal cavity (Figure 2 and 3).

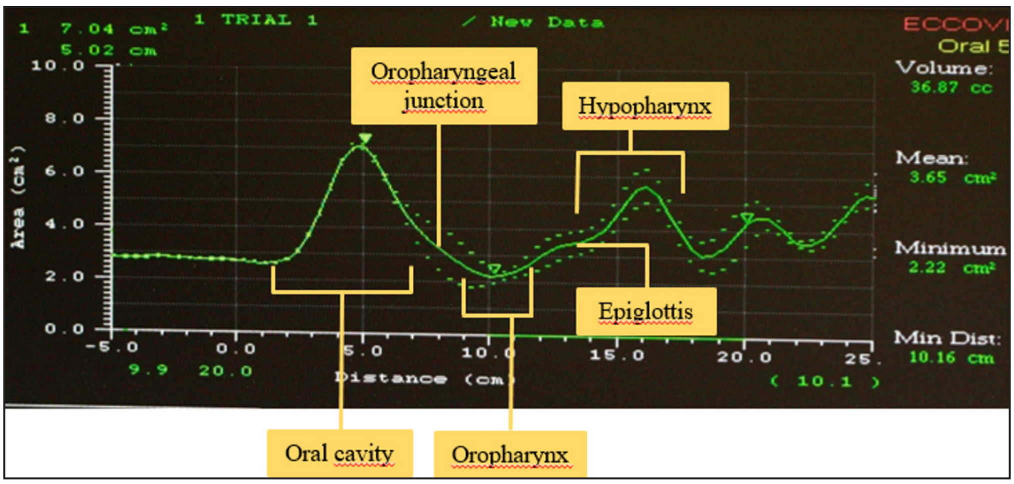

Figure 2. The pharyngeal airway regions examined by acoustic pharyngometry.

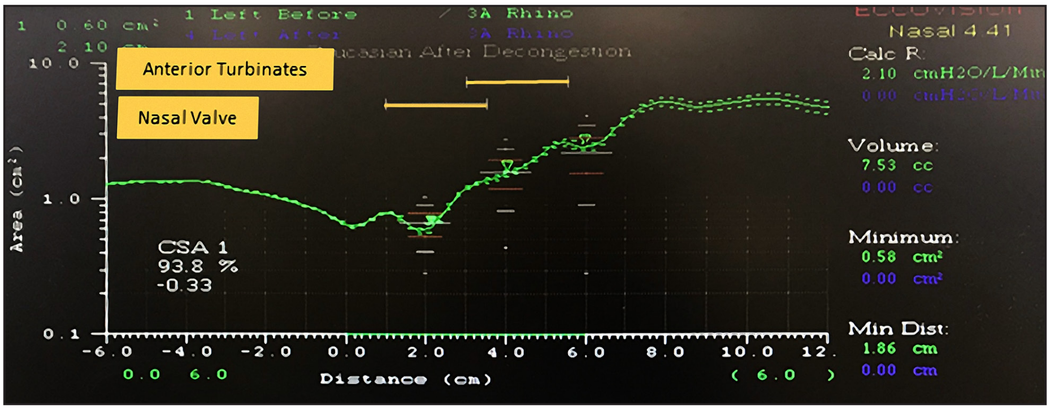

Figure 3. The nasal airway region examined by acoustic rhinometry.

All subjects underwent both acoustic pharyngometry and rhinometry. The examinations were performed in standing position (Figure 4 and 5) and in sitting position (Figure 6) and repeated after a short interval of approximately 20 minutes as the upper airway dimension is not static [9]. The program of the pharyngometry and the rhinometry (Eccovision® Acoustic Pharyngometer and Rhinometer - Sleep Group Solutions) displayed the volume (cm^3), mean area (cm^2), minimum cross-sectional area (MCA, cm^2) and distance to MCA (cm) in the pharyngeal airway and resistance (cm H_2O/L/min), volume (cm^3), MCA (cm^2) and distance to MCA (cm) in the nasal airway (Table 1 and 2).

Measurement procedures

Acoustic pharyngometry

In the standing position the subjects were placed in front of a mirror and instructed to look into their own eyes in the mirror during the measurements (Figure 4) in order to keep their head in a standardized head posture, the mirror position [21].
In the sitting position the subjects were instructed to sit in a normal position on a clinic chair similar to an office chair with wheels (Figure 6).
In both body positions the original mouthpiece made of rubber was placed with the teeth against the flange while the subjects were instructed to bite down on

Figure 4. Acoustic pharyngometry in standing position, the mirror position. The subjects were placed in front of a mirror and instructed to look into their own eyes in the mirror during the measurements.

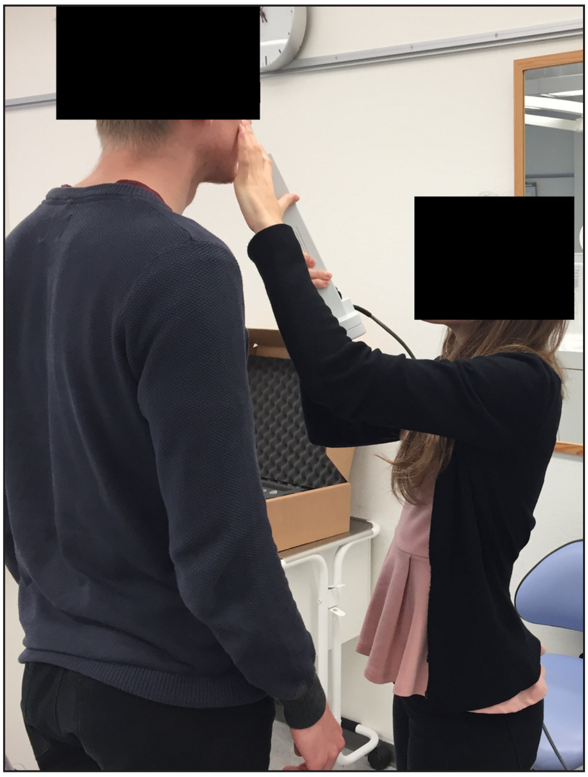

Figure 5. Acoustic rhinometry in standing position, the mirror position. The subjects were placed in front of a mirror and instructed to look into their own eyes in the mirror during the measurements.

Figure 6. Acoustic pharyngometry in sitting position.

the protruding tabs and place the tongue under the crossbar and the lips over the flange to form a seal [26]. The wave tube for acoustic pharyngometry was held in a position parallel to the floor by the operator according to the operator manual [26]. The subjects were instructed to breathe slowly through their mouth while closing their nose with the fingertips.

Acoustic rhinometry

In the standing position the subjects were placed in front of a mirror and instructed to look into their own eyes in the mirror during the measurements (Figure 5) in order to keep their head in a standardized head posture, the mirror position [21] - similar body posture as for the acoustic pharyngometry.

In the sitting position the subjects were instructed to sit in a normal position on a clinic chair similar to an office chair with wheels - similar body posture as for the acoustic pharyngometry.

In both positions the original nose tip made of rubber was placed against the subject's nostril with the angle of the nose tip sloping down towards the septum to form a seal [27]. The wave tube for acoustic rhinometry was held in a position parallel to the subject's nasal bridge by the operator [27]. The subjects were instructed to "pause" in breathing on the count of 3 while their mouth and lips remained sealed [27]. The measurements were then obtained from the right nostril and from the left nostril.

Statistical analysis

The systematic error between the repeated measures of the pharyngometry and the rhinometry in standing and in sitting position were assessed by paired t-test. The method error was assessed by Dahlberg's formula [28] and the reliability was assessed by the Houston reliability coefficient [29]. Differences in means between standing and sitting positions were assessed by paired t-test. Parametric data were expressed as mean and standard deviation (M [SD]). The results from the tests were considered significant at P-values below 0.05. The statistical analyses were performed using SPSS version 25.00 (SPSS Inc.; Chicago, Illinois, USA).

Table 1. Method error and reliability for the repeated measurements in acoustic pharyngometry tested in an identical way in standing position and in sitting position. Mean difference: the second measurement subtracted from the first measurement

	Mean difference	Standard deviation	Method error (s(i))	Reliability (Houston)
Standing position				
Volume (cm^3)	-1.428	4.456	0.164	0.999
Mean area (cm^2)	-0.142	0.446	0.016	0.999
Minimum cross-sectional area (MCA, cm^2)	-0.113	0.453	0.013	0.999
Distance to MCA (cm)	-0.092	3.948	0.011	1
Sitting position				
Volume (cm^3)	-1.03	4.066	0.123	0.999
Mean area (cm^2)	-0.009	0.529	0.001	1
Minimum cross-sectional area (MCA, cm^2)	-0.054	0.368	0.006	1
Distance to MCA (cm)	0.211	2.552	0.025	1

MCA = minimum cross-sectional areas.

Table 2. Method error and reliability for the repeated measurements in acoustic rhinometry tested in an identical way in standing position and in sitting position. Mean difference: the second measurement subtracted from the first measurement

	Mean difference	Standard deviation	Method error (s(i))	Reliability (Houston)
Standing position, right nostril				
Calculated resistance (cm H_2O/L/min)	-0.477	6.969	0.055	1
Volume (cm^3)	-0.013	3.033	0.001	1
Minimum cross-sectional area (MCA, cm^2)	0.005	0.177	0.001	1
Distance to MCA (cm)	-0.058	1.445	0.007	1
Standing position, left nostril				
Calculated resistance (cm H_2O/L/min)	-1.328	4.791	0.152	0.999
Volume (cm^3)	0.173	1.539	0.02	1
Minimum cross-sectional area (MCA, cm^2)	0.027	0.116	0.003	0.999
Distance to MCA (cm)	-0.114	0.552	0.013	0.999
Sitting position, right nostril				
Calculated resistance (cm H_2O/L/min)	-0.396	3.593	0.048	1
Volume (cm^3)	0.594	1.934	0.072	0.999
Minimum cross-sectional area (MCA, cm^2)	0.035	0.135	0.004	0.999
Distance to MCA (cm)	-0.156	0.936	0.019	1
Sitting position, left nostril				
Calculated resistance (cm H_2O/L/min)	-3.053	15.616	0.37	0.999
Volume (cm^3)	0.57	1.837	0.069	0.999
Minimum cross-sectional area (MCA, cm^2)	0.043	0.149	0.005	0.999
Distance to MCA (cm)	-0.29	0.793	0.035	0.999

MCA = minimum cross-sectional areas.

RESULTS

Method error and reliability in repeated measures

No systematic error was found in the repeated measurements in the standing mirror position. In the sitting position for the rhinometry a systematic error was found in the distance to MCA in the left nostril (P = 0.041) due to the fact that the measurements were mainly larger the second time of recording (Table 2).
The method error and the reliability in the repeated measurements for the pharyngometry tested in an identical way in standing and sitting positions are shown in Table 1. The method errors for the pharyngeal volume ranged from 0.123 to 0.164 cm^3, the mean area ranged from 0.001 to 0.016 cm^2, the MCA ranged from 0.006 to 0.013 cm^2 and the minimum distance to the MCA ranged from 0.011 to 0.025 cm. For all the measurements the reliability coefficient was 0.99.
The method error and the reliability in the repeated measurements for the rhinometry tested in an identical way in standing and sitting positions are shown in Table 2. The method error for the nasal calculated resistance ranged from 0.048 to 0.37 cm H_2O/L/min, the volume ranged from 0.001 to 0.072 cm^3, the MCA ranged from 0.001 to 0.005 cm^2 and the minimum distance to the MCA ranged from 0.007 to 0.035 cm. For all the measurements the reliability coefficient ranged from 0.99 to 1.

Difference in means between standing and sitting position

Regarding the pharyngometry the volume and mean area of the pharyngeal airway was significantly larger in standing position than in sitting position (P = 0.025 and P = 0.009, respectively, Table 3).
Regarding the rhinometry no significant differences were found between standing and the sitting position (Table 4).

DISCUSSION

This study indicates that acoustic pharyngometry and rhinometry are reliable methods to perform repeated measurements of the dimensions of the upper airway in healthy subjects over a short time in the standing mirror position. In one variable, a significant systematic error was observed in the repeated measurements as a larger distance to MCA in the left

Table 3. Mean difference between standing and sitting position in acoustic pharyngometry

	Mean		Mean difference	Standard deviation	P-value[a]
	Standing position	Sitting position			
Volume (cm^3)	35.8	34.6	1.205	3.035	0.025
Mean area (cm^2)	3.58	3.44	0.137	0.292	0.009
Minimum cross-sectional area (MCA, cm^2)	2.36	2.29	0.071	0.331	0.213
Distance to MCA (cm)	12.54	12.05	0.491	3.348	0.392

[a]Difference between means, t-test. P-value was considered significant when $P < 0.05$.
MCA = minimum cross-sectional areas.

Table 4. Mean difference between standing and sitting position in acoustic rhinometry

	Mean		Mean difference	Standard deviation	P-value[a]
	Standing position	Sitting position			
Right nostril					
Calculated resistance (cm H_2O/L/min)	5.83	4.81	1.38	4.894	0.11
Volume (cm^3)	4.91	4.56	0.436	2.772	0.366
Minimum cross-sectional area (MCA, cm^2)	0.41	0.42	-0.003	0.171	0.929
Distance to MCA (cm)	1.85	1.96	-0.049	0.88	0.745
Left nostril					
Calculated resistance (cm H_2O/L/min)	6.15	8.65	-2.497	16.607	0.38
Volume (cm^3)	4.7	4.15	0.553	2.566	0.211
Minimum cross-sectional area (MCA, cm^2)	0.37	0.36	0.019	0.141	0.421
Distance to MCA (cm)	2	2.13	-0.131	0.736	0.301

[a]Difference between means, t-test. P-value was considered significant when $P < 0.05$.
MCA = minimum cross-sectional areas.

nostril in sitting position at the second measurement compared to the first measurement. This may be due to the fact that the patients became a bit more familiar with the procedure and felt more comfortable the second time of examination and because the sitting position is not a validated body position. The results of the present study are comparable to other studies, which investigated same-day test-retest of acoustic pharyngometry and found the methods to be valid for repeated measurements of the upper airway dimensions [3,4]. Furthermore, the results are comparable to another study, which investigated test-retest of acoustic rhinometry over five days and also found the method to be valid for repeated measurements [30].

The method errors and the reliability for the repeated measurements of the pharyngometry and rhinometry in standing and sitting position have not been reported before in the literature. The present study found the method error to be small and the reliability to be very good for the pharyngometry and the rhinometry in both body positions over a short period of time. It was expected that the method error and reliability was good in the standing position as this is a well described, standardized and validated position [14-18,21,22,31]. The method error and reliability was also good in the siting position, which was surprising, as there is neither a standard description of a sitting position nor validation of a sitting position. This may be the reason why a systematic error was found only in the sitting position, and the sitting position may therefore be more sensitive for the patient's experience of the method. However, the patients were not placed in the mirror position, in the sitting position which may be a limitation of the present study.

The present study showed significant differences in volume and mean area of the pharyngeal airway with larger pharyngeal airway dimensions in standing position compared to sitting position. This is comparable to a study that found volumetric measures of the vocal tract to be significantly smaller in supine position compared to upright position in healthy subjects [23]. Furthermore, a study found the nasal MCA to decrease from sitting to supine position in healthy subjects [24].

This indicates that it might be essential to perform the measurements with the patient positioned in the same body position every time if the measurements should be compared over time (repeated measurements) or compared with measurements from other subjects. Furthermore it is important to use a standardized validated position where the subject is positioned with the head in a natural head position determined by the patient's own postural proprioceptive control system, and not in a constructed head position because the upper airway dimension is influenced by the head posture [9,11,12,14,19]. Previous studies have found that the most accurate head positions for measurements of the upper airway dimensions is the standing natural head posture in the mirror position [9-14,18,19,22,31]. Therefore, the head posture in the mirror position might be considered to be adopted in the reflectometry techniques as this position is already well described, standardized and validated [14-18, 21,22,31].

These findings are valuable in dentistry as well as in medicine as the findings may contribute to improve the operator guidelines for acoustic pharyngometry and rhinometry. This might result in more accurately obtained measurements of the pharyngeal airway dimensions in the patients and hence improve the diagnostics and treatment planning of the patients in the future.

CONCLUSIONS

Acoustic pharyngometry and rhinometry are valid methods to perform repeated measurements of the dimensions of the upper airway in healthy subjects especially in the standing mirror position. Furthermore, it might be essential to perform the measurements with the patients placed in the same validated body position for comparable results.

ACKNOWLEDGMENTS AND DISCLOSURE STATEMENTS

The authors report no conflicts of interest related to this study.

Maria Kvetny, MA, University of Copenhagen, Denmark, is acknowledged for linguistic support. We would also like to thank the funds and corporations who sponsored the research in Dental Sleep Medicine, Department of Odontology, University of Copenhagen: The Danish Dental Association; the Independent Research Fund Denmark; Ingeborg and Leo Dannis Scholarship, ResMed, Denmark and the Sleep Group Solutions, USA.

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To cite this article:
Knappe SW, Sonnesen L.
The Reliability and Influence of Body Position on Acoustic Pharyngometry and Rhinometry Outcomes
J Oral Maxillofac Res 2020;11(4):e1
URL: http://www.ejomr.org/JOMR/archives/2020/4/e1/v11n4e1.pdf
doi: 10.5037/jomr.2020.11401