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Title: Variability in tongue pressure among elderly and young healthy cohorts: A systematic review and meta-analysis

Running Title: A systematic review of tongue pressure

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Abstract

Objectives: Tongue pressure (TP) is used for the diagnosis of oral hypofunction, however, the impact of several variables on TP is unclear. Therefore, the current systematic review and meta-analysis aimed to analyze the variability in tongue-pressure among healthy individuals aged ≥ 60 years versus < 60 years. Secondary outcomes were the influence of gender and the type of measuring device (Iowa Oral Performance Instrument (IOPI) vs. JMS tongue pressure measurement device (JMS)).

Methods: PubMed and the Japanese database Ichu-Shi-Web were searched systematically by two independent reviewers for studies reporting TP values in healthy populations. Clinical studies published between 1959 and June 2020 with more than 10 participants, written in English, German, or Japanese were included. A random-effects meta-regression for aggregate-level data was applied ($\alpha < 0.05$).

Results: Sixty-eight studies reported TP for a total of 13773 subjects aged < 60 years ($n=3265$) and ≥ 60 years ($n=10508$). TP was significantly higher in subjects < 60 years (estimated weighted mean (EWM) $\pm$ standard error= 51.9 ± 1.28 kPa; 95%CI= $49.4-54.4$) relative to those ≥ 60 (EWM= 34.7 ± 0.94 kPa; 95%CI= $32.8-36.5$) ($p < 0.001$), men (EWM= 45.9 ± 2.09 kPa; 95%CI= $41.8-50.0$) relative to women (EWM= 39.3 ± 1.68 kPa; 95%CI= $36.0-42.6$) ($p=0.015$), and when assessed with the IOPI (EWM= 51.9 ± 1.32 kPa; 95%CI= $49.3-54.5$) compared to the JMS (EWM= 33.5 ± 0.63 kPa; 95%CI= $32.2-34.7$) ($p < 0.001$). In terms of gender, there was no significant difference in TP among subjects ≥ 60 years ($p=0.282$). However, in subjects younger than 60, a significant difference was observed ($p=0.004$).

Conclusions: Healthy populations aged < 60 years showed significantly higher TP than those aged ≥ 60 years. TP values ascertained by the IOPI are significantly higher than those obtained with the JMS.

(247 words)

Keywords: Tongue Pressure, Muscle Strength, Geriatric Dentistry, Hypofunction, Oral Frailty, Systematic Review

1. Introduction

The tongue is a vital organ for forming and transporting a food bolus. Its specific roles are to carry ingested food to the molars, place it on the occlusal surface, create an easily swallowable bolus by mixing the food with saliva, propel the chewed bolus to the pharynx, and finally push the bolus into the hypopharynx during swallowing.¹ The force applied when the tongue is pressed voluntarily against the palate is measured to assess tongue function and reported as the tongue pressure (TP). TP was found to be a predictive factor for decreased oral and pharyngeal food residue, and it has been used for quantitative evaluation of oropharyngeal swallowing function.² Other studies reported that TP was significantly associated with masticatory performance in oral function.^{3,4} Therefore, TP is used as one of several assessment items to diagnose oral hypofunction in Japan, home to one of the most rapidly aging populations in the world.⁵ Systemic sarcopenia is caused by aging, malnutrition, and low Activities of Daily Living (ADL); simultaneously, dysphagia is caused by the attenuation and decreased power of muscles involved in dietary intake (oral cavity, pharynx), and can be assessed by TP.^{6,7} Hudson et al. reported that the relationship between decreased swallowing function and malnutrition was interdependent.⁸ Therefore, assessing TP helps to recognize the condition of the oral function, especially since TP measuring devices can be used easily, providing an absolute TP value.^{9,10} The most commonly used device for measuring TP is the Iowa Oral Performance Instrument (IOPI) (IOPI Medical LLC, Washington, USA), which was patented in 1992 by Dr. Erich Luschei.^{9,11} The IOPI measures TP by recording the maximum pressure that an individual can produce in a standard-sized air-filled bulb when pressing the bulb against the palate with the tongue. The final pressure is displayed in kilopascal (kPa). The IOPI consists of a tongue bulb, connecting tube, and main body. The air-filled pliable plastic tongue bulb (approximately 35 mm long and 12 mm in diameter) is connected via an 11.5 cm-long clear plastic tube.¹² In Japan, another TP measuring device was developed, which is now globally commercially available and marketed as the JMS tongue pressure measuring device (JMS) (TPM-01, JMS Co., Ltd., Hiroshima, Japan). This device consists of a probe, connecting tube, and main body. The gripping part of the probe has a length of approximately 50 mm, with a 10 mm-long holding piece for the teeth and a balloon with a length of 25 mm and thickness of 15 mm. This device also records TP values in kPa. A recent study revealed

that maximum TP measurements using the IOPI and JMS were significantly different but correlated.²³ Although the average discrepancy between the two methods was relatively low, it remains unclear whether distinguishing such discrepancies is of clinical interest.

Currently, many studies have reported TP values in a large number of healthy adult subjects¹³⁻¹⁵, dysphagic patients, and patients with oral problems¹⁶. TP is assessed to compare the values before training with those after training in order to observe whether tongue function is improved by training for healthy young¹⁷⁻²⁰ or elderly^{21,22} subjects. However, the existing data has not been summarized thus far; therefore, interpreting individual TP measurements in varying age cohorts or with varying measuring devices can be challenging.²³ In addition, it has been reported that muscle mass in the limbs, trunk and the whole body, which might be an indicator of muscle strength of swallowing muscles²⁴, is significantly greater in men than in women, and the muscle mass has gender differences regardless of age.²⁵

The aim of this systematic review and meta-analysis was to assess mean TP values in healthy subjects <60 years and ≥ 60 years, and to clarify differences in TP within the two groups. Secondary outcomes were the influence of gender and the type of measuring device (IOPI or JMS) on TP.

2. Materials and Methods

2.1 Protocol and registration

The study protocol for this systematic review and meta-analysis was registered in the PROSPERO database (registration number CRD42018105606). This work was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.²⁶ The PRISMA checklist is given in the Appendix S1. The focused leading question was set according to the PICO model (i.e. Population, Intervention, Comparison, and Outcome) for clinical questions. The four criteria according to the PICO were: P (healthy people), I (TP of individuals 60 years or older), C (TP of individuals younger than 60 years), and O (absolute TP). Consequently, the PICO question was:

‘among healthy populations, is there a difference in TP among individuals equal to or older than, relative to individuals younger than, 60 years of age?’

2.2 Eligibility criteria

Inclusion criteria were as follows: (a) human clinical studies (randomized controlled trials (RCTs), non-randomized controlled trials (non-RCTs), cohort studies, case-control studies, cross-sectional studies, and before and after studies), (b) generally healthy adults (≥ 18 years old), (c) young cohorts with a maximum age of 59 years and elderly cohorts with a minimum age of 60 years, (d) studies with more than 10 participants, (e) studies reporting TP in kilopascal (kPa), (f) publications in English, German, or Japanese.

Exclusion criteria were as follows: (a) *in vitro* or animal studies, (b) subjects suffering from dysphagia, neuromuscular disorders, malignancies of the tongue, and obstructive sleep apnea, (c) subjects younger than 18 years old or age not reported, (d) fewer than 10 participants in each relevant study arm/cohort, (e) insufficient documentation of TP, (f) measurement of TP in units other than kPa, (g) posterior TP and TP during swallowing, (h) publications not written in English, German, or Japanese.

2.3 Search strategy

An electronic search was carried out by two reviewers (K.I. and I.A.) in the MEDLINE (PubMed) library and the Japanese database Ichu Shi-Web for studies published in English, German, and Japanese between 1959 and June 10th, 2020. The following search terms and combinations were used for the initial search: ((population OR persons OR people) AND (tongue OR lingual OR orofacial) AND (strength OR pressure OR force)). A manual search was performed based on the reference lists of relevant articles and related review articles addressing similar topics in the following journals: Dysphagia, Journal of Rehabilitation Research & Development, Perspectives on Swallowing and Swallowing Disorders (Dysphagia), Journal of Medical Speech-language Pathology, Seminars in Speech and Language. Head & Neck, Journal of Speech Language and Hearing Research. A reference manager software (EndNote X8®) was used to collect references and exclude duplicates.

2.4 Study selection and data extraction

After eliminating duplicates, the titles of the remaining articles were screened for the inclusion criteria, followed by article selection based on their abstracts. Irrelevant titles and abstracts were excluded. If the relevance of a study was inconclusive, it was retained for next step screening. Subsequently, the full texts of the remaining articles were evaluated and the reason for exclusion was recorded. For meta-analysis, studies providing insufficient data, addressing an irrelevant age group, etc., were finally excluded. Study selection was performed independently for each step by two reviewers (I.A., K.I.). Discordance between the two reviewers regarding the inclusion of specific articles was resolved following moderation by the senior author (M.S.).

After reviewing the full texts, data from the remaining articles were extracted by the first author (I.A.) using spreadsheet software (Microsoft Office 2017). For data extraction, all information was tabulated, including the following parameters: authors, year of publication, sample size, gender, age (mean, minimum, maximum), TP value, measurement device, and study design. The accuracy of the extracted data was confirmed by the second author (K.I.). Discrepancies in data extraction between these two authors were resolved by a third party (S.A.A.).

2.5 Risk of bias in individual studies

The methodological quality assessment was independently performed by two authors (I.A., K.I.) using the Cochrane Collaboration's tool for assessing risk of bias (Cochrane risk of bias tool)²⁷ for the included randomized controlled trials (RCTs) and non-RCTs, and the Newcastle-Ottawa-Scale (NOS)²⁸ for the included observational studies. The Cochrane risk of bias tool is a domain-based evaluation comprising the domains "Random sequence generation", "Allocation concealment", "Blinding of participants and personnel", "Blinding of outcome assessment", "Incomplete outcome data", "Selective reporting", and "Other sources of bias." The assigned judgement for each domain is assessed as "Yes (i.e. low risk of bias)", "No (i.e. high risk of bias)", or "Unclear (i.e. unclear risk of bias)". The NOS was used to assess the risk of bias and quality, dividing observational studies into three major domains for case-control studies, cohort studies, before and after studies and cross-

sectional studies. These domains were “selection of the study groups” (four items), “comparability of the study groups” (one item), and “ascertainment of either exposure or outcome of interest” (three items for case-control studies and cohort studies, and two items for cross-sectional studies). Each domain was given a certain number of stars for each numbered item, resulting in a maximum of nine possible stars in case-control studies and cohort studies or ten stars in cross sectional studies. Studies having 7-10 stars were considered to have high, 4-6 intermediate, and 1-3 to have low quality. Any discordance was discussed and decided in consultation with a third author (S.A.A).

2.6 Data synthesis and Statistical analysis

Unweighted TP values from each study were recorded as mean, standard deviation (SD), median, minimum, and maximum values. The meta-analysis was performed by grouping the results according to participant age (<60 , ≥ 60), device type, and gender. A random-effects meta-analysis was used to estimate weighted mean TP (EWM) with a 95% confidence interval (95% CI) for the various subgroups. For estimating the weighted mean difference (WMD) between subgroups and inter-subgroup comparison, a random effects meta-regression was used. Additionally, the influence of age (<60 years vs. >60 years), device (JMS vs. IOPI), and gender (men vs. women) was analyzed using a multivariate random effects meta-regression. Individual mean TPs and estimated overall mean TPs, their confidence intervals, and the weights of the individual studies were visualized as forest plots.

The statistical analysis was performed using Stata/IC 16.0 for Windows (StataCorp LLC 4905 Lakeway Drive, College Station, TX 77845, USA). All statistical tests were two-sided with a significance level of 0.05.

3. Results

3.1 Study selection

The systematic electronic search resulted in 3281 articles, and 25 articles were added after performing the hand search. After the removal of the duplicates, 3277 titles were screened independently by two authors (I.A. and K.I.) to assess their suitability for inclusion, and 2992 titles were excluded. 285

abstracts were assessed, and 113 were excluded. The full-text assessment was performed on the remaining 172 articles, and 104 full-texts were excluded since they did not meet the eligibility criteria due to the following reasons: fewer than 10 subjects (7 articles), irrelevant age group (14 articles), assessment in a unit other than kPa or Pa, no mention of the device (15 articles), ineligible subjects (27 article), and insufficient data (41 articles). A total of 68 full-text articles qualified for inclusion; finally, 68 quantitative articles were included in this systematic review and meta-analysis. Kappa scores showed a moderate-to-high agreement between the two reviewers ($\kappa=0.53$ for title, $\kappa=0.76$ for abstract, and $\kappa=0.96$ for full-text). Figure 1 presents the flow diagram of the study screening and selection. An overview of the included and excluded studies during data extraction is given in the Appendix S2.

3.2 Study characteristics

The included studies were published between 1992 and 2020 and included data on a total of 13773 subjects. 52 cross-sectional studies, three cohort studies, three before and after studies, seven RCTs and three non-randomized controlled clinical studies were included in the meta-analysis. 38 studies reported data for subjects <60 years (young), and 49 studies reported data for subjects >60 years (old). The number of subjects <60 years in the extracted studies was 3265, with a mean age of 28.2 ± 8.2 [range 20.7-54.1] years; for subjects >60 years, 10508 participants were included, with a mean age of 74.5 ± 3.9 [range 63.1-83.4] years. In terms of gender, data from 6065 subjects (male; 2462 (27 studies), female; 3603 (28 studies)) could be analyzed. In terms of the utilized device, TP was assessed with the IOPI in 30 studies ($n=2433$), and with the JMS in 39 studies ($n=11340$). The characteristics of the included studies are summarized in Table 1a. Table 1b provides an overview of the unweighted synthesis of TP values, separated by age, gender, measuring device, and the combination of those parameters. The mean TP of individual studies, their 95%-CIs and weights, as well as the estimated overall mean TP for combinations of age and device, are depicted as forest plots (Figs. 2a – 2d).

3.3 Quality Assessment

The quality assessment of the included 58 analytical studies were assessed with NOS (Table 2a). 22 studies (37.9%) were rated as low quality, 32 studies (55.2%) were rated as intermediate and 4 studies (6.9%) were rated as high quality. The quality of the seven included RCTs and the three non-randomized controlled clinical studies was assessed with the Cochrane risk of bias tool. Three studies were rated as having a high risk of bias and seven studies were rated as having some concerns (Table. 2b).

3.4 Synthesis of results

The EWM TP in subjects <60 years was 51.9 kPa (SE: 1.28 kPa); in subjects >60, it was 34.7 kPa (SE: 0.94 kPa). The WMD between the two groups was 17.2 kPa (SE: 1.57 kPa), demonstrating a significantly higher TP in subjects <60 years ($p<0.001$). A significant difference in TP between young and old cohorts could also be demonstrated, analyzing the data of male ($p<0.001$) and female ($p<0.001$) subjects separately, as well as in the data obtained with the IOPI and the JMS (both $p<0.001$).

The EWM TP was significantly higher when evaluated with the IOPI (51.9 kPa; SE: 1.32kPa) compared to the JMS values (33.5 kPa; SE: 0.63 kPa), with a WMD of 18.4 kPa (SE: 1.46kPa) ($p<0.001$). This difference between devices could also be demonstrated analyzing TP in male and female subjects, and in young and elderly cohorts separately (all $p<0.001$).

A significantly higher TP was observed in men (45.9 kPa; SE: 2.09 kPa) than in women (39.3 kPa; SE: 1.68 kPa) (WMD: 6.5kPa; SE: 2.69 kPa; $p=0.015$). Analyzing the data of young and elderly men and women separately, a significant gender difference could only be demonstrated in the young cohort ($p = 0.004$), whereas TP did not correlate with gender in the elderly cohort ($p = 0.282$). A significant difference between male and female cohorts could be demonstrated with the JMS ($p=0.003$) and the IOPI ($p=0.038$).

A detailed overview on EWM TP in the respective groups and WMD between groups is given in Table 3.

The multivariate random effects meta-regression analysis demonstrated a significant influence of age (<60 vs. >60 years), measuring device (JMS vs. IOPI), and gender (male vs. female) on TP (all $p < 0.001$) (Table. 4).

4. Discussion

This systematic review and meta-analysis analyzed the absolute tongue pressure, and the differences among healthy individuals equal to or older than 60 years relative to healthy individuals younger than 60 years. 68 studies reporting on 13773 subjects were included. We observed a significant difference in TP between individuals <60 years and >60 years. TP assessed with IOPI was significantly higher relative to measurements taken with JMS. TP in men was significantly higher than in women; however, an influence of gender on TP could only be identified in individuals younger than 60 years and when assessed with JMS and with IOPI but not in older individuals.

Most studies reported that TP was significantly higher in younger relative to older cohorts, and that TP decreases with age.^{16,29-42} A significant negative correlation between age and maximum TP was also reported.³² A few studies found no correlation between TP and age.⁴³⁻⁴⁵ The reason why these studies did not observe an age-dependent decrease in TP might be due to the assessment of only a few subjects ($n=10$) in the elderly group⁴³, calculating TP by the number of active muscles⁴⁴, or including the level of physical activity as a co-factor⁴⁵. When comparing TP in subjects <60 to those >60 years in this present meta-analysis, a significant difference could be demonstrated, confirming previous studies. Therefore, TP seems to decrease as an integral part of the physiological aging process. The EWM and SE of TP was 34.7 ± 0.94 kPa in the elderly group, and 51.9 ± 1.28 kPa in the young group across the literature surveyed here. Similar forces have been reported in previous studies.⁴⁶⁻⁴⁸

Regarding the two devices evaluated here, the JMS was reported to show high reliability assessing TP in young subjects.⁴⁹ The IOPI was reported to be reliable for measuring TP in healthy adults.⁵⁰ TP

values assessed with either the IOPI or the JMS demonstrated sufficient reliability; furthermore, data sets obtained with the two devices were significantly correlated.^{23,51} However, in the present meta-analysis, the WMD between JMS and IOPI was -18.4 ± 1.46 kPa ($p < 0.001$), with the TP values assessed with the IOPI being significantly higher than those of the JMS. Furthermore, an EWM difference between the two device groups of -15.38 ± 1.11 kPa when adjusting for age groups, was observed. In addition, both devices demonstrated age-dependent changes in TP; the (elderly-young) combined value was -17.9 ± 1.93 kPa with the IOPI and -9.0 ± 0.87 kPa with the JMS. Therefore, both devices might be considered reliable tools for detecting an age-dependent decrease in TP. Nevertheless, the two devices should not be used interchangeably (e.g. during longitudinal studies) due to the higher values recorded with the IOPI. One reason for those higher TP values might be the challenging positioning of the IOPI in a patient's mouth. The air-filled bulb slides easily on the tongue surface, and there is no hard connector tube to bite on as in the JMS, but a thin flexible tube.⁵¹ The incorrect positioning in a patient's mouth might result in pressure on the bulb itself, and consequently to higher TP values.²³ Additionally, the JMS seems to be more sensitive than the IOPI. The JMS-associated standard error was smaller than that of the IOPI, which might be related to the shape of the devices. The air-filled bulb of the IOPI has only a thin area to be stabilized with the teeth, causing pressure during stabilization when it is not correctly positioned. This might result in higher TPs than those caused by the tongue only.²³ The anchor of the JMS is not part of the bulb itself, and therefore, MTP values are not as sensitive to false positioning as in contrast with the IOPI. This additional pressure might be particularly relevant when TP is lower (females and elderly subjects), as the additional pressure is relatively high. A gender-dependent difference in TP was observed when considering values obtained with either the JMS or the IOPI.

Regarding gender, some studies have reported significantly lower TP in females relative to males^{16,30,34,52}, whereas some studies did not observe a significant difference between genders^{31,43}. Considering divided age groups, TP in young men was higher than young women.^{3,53-57} Males in the 20-49 age range showed higher TP than females.⁴⁶ On the other hand, the literature reports a tendency toward higher TP in elderly men relative to elderly women, although these observations have not been statistically significant.^{44,58-61} The present meta-analysis revealed statistically significant differences in

TP values of <60 year-old subjects between males and females, whereas no difference was observed among >60 year-old subjects, which supports these previous conclusions.

In addition to the heterogeneous study designs resulting in a high risk of bias due to the analysis of mixed datasets, there are some further limitations that should be considered when interpreting the current results. It has been reported that TP was correlated with the number of teeth.⁴¹ Therefore, the subjects in this systematic review were initially categorized according to dental status (natural dentition, removable complete or partial dentures); however, 60 studies (88.2%) did not mention oral conditions. Consequently, the influence of the number of remaining teeth could not be adequately analyzed, and was therefore omitted. However, the presence of complete dentures would have been of particular interest, as muscular retention of these appliances presents a considerable training for the perioral muscles and the tongue. Denture retention largely depends on the tongue, both for pushing the lower denture back into place⁶² as well as replacing the upper denture when the posterior seal breaks during mastication⁶³. The reduced chewing efficiency with complete denture furthermore requires the tongue to add with food comminution, by pushing and rubbing food stuff against the palate before forming a bolus. However, reports on tongue volume related to age alone are still missing, although the decrease in force evinced in this systematic review suggests such decrease in muscle bulk. The absence of a reported effect of age or gender on TP in some of the studies included in this systematic review might have been masked by a training effect of the tongue caused by the presence of complete dentures.

The health conditions of study subjects were not clearly reported in all included studies. Therefore, we decided to include studies that reported on participants from independent living communities and outpatients, even though these studies did not describe the subjects' health conditions.^{7,14,22,33,58,64} Regarding the definition of elderly, many countries have accepted 65 years as a cutoff; however, this definition is rather the beginning of pension benefits than an acceleration in the physiological ageing process. The United Nations agreed to use a cutoff of 60 years when referring to the elderly.⁶⁵ Based on this, our study selected 60 years of age as the boundary between young and old groups.

In this systematic review, TP data with IOPI from subjects all over the world, including Asia^{18,20,39,40,48,51,52,66-70}, Oceania⁵⁰, North America^{9,16,17,29-32,34,45,53,58,71}, South America^{36,43,54}, and

Europe^{14,72}, have been collected. All TP values measured using the JMS are in the Japanese studies.^{2-4,7,13,15,19,21,22,24,33,35,37,38,41,42,44,46,47,49,51,55-57,59-61,64,73-83} It has been considered that TP values measured using the IOPI are slightly higher in the Chinese study⁶⁹ than in the European studies^{14,72}, slightly lower than in the United States studies^{16,34}, and close to those in Korean study⁵². It is supposed that these differences among regions are caused by physical constitution such as height, weight or overall muscle mass, and chewing frequency, duration, or patterns⁵² as well as eating habits. However, the influence of ethnicity on TP is still unclear. Therefore, further studies on TP across regions all over the world would be needed to further clarify the factors influencing TP.

The current systematic review summarizes the available information on TP from two scientific databases that are rarely analyzed together, due to their being published in different languages. Therefore, a particularly high number of studies could be included. Few studies have compared the two most commonly applied TP measuring devices. Comparing these devices in the present systematic review is a novel approach and lead to more informative interpretation when considering published TP values assessed with either the IOPI or the JMS. Several reports refer to the relationship between TP and other assessments of oral function, e.g. chewing efficiency³, occlusal force, number of teeth⁸¹ or echo intensity of the tongue⁷³. TP might be used to estimate oral function and as a screening tool for frailty⁸³. It was reported that TP among a non-sarcopenic group was stronger than that of a sarcopenic group for each gender and that sarcopenia was a significant independent variable in determining TP.^{7,74} Only a single study reported on the association between TP and cognitive function.⁷⁵ For future studies, measuring TP in cohorts with different levels of cognitive and/or physical function would add further information of its' influence on TP.

5. Conclusions

Within the limitations discussed above, especially the high degree of heterogeneity among the included studies, it can be concluded that:

- the estimated weighted mean tongue pressure is significantly higher in subjects <60 years old compared to >60 years old, when measuring tongue pressure using either the IOPI or the JMS.

- tongue pressure values obtained using the IOPI are significantly higher relative to JMS values.
- subject gender only seems to influence tongue pressure in subjects <60 years but not in elderly populations.
- the JMS and IOPI devices should not be used interchangeably, especially in longitudinal studies.

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Conflict of interests

The authors have no conflict of interests to declare.

Author contribution

Itsuka Arakawa initiated the study together with Samir Abou-Ayash and Martin Schimmel, and conceptualized and designed the study, collected and analyzed data, drafted and revised the manuscript; Kensuke Igarashi contributed to data collection, and analysis during the systematic search; Yoshiki Imamura contributed to design the study and manuscript editing; Frauke Müller contributed to design the study and manuscript editing; Samir Abou-Ayash contributed to the conception and design of the study, analyzing data, and manuscript editing; Martin Schimmel contributed to the conception and design of the study, and critically revised the manuscript.

Tables

Table 1. (1a) Study characteristics of included studies (n=68) and (1b) descriptive analysis.

Table 1a

Author	Year	Mean Age $\pm$ SD (years)	Min Age (years)	Max Age (years)	Subjects (n)	Men (n)	Women (n)	Tongue Pressure $\pm$ SD (kPa)	device
Park	2020	24.4 $\pm$ 1.9	21	28	10	7	3	55.8 $\pm$ 11.1	IOPI
		23.4 $\pm$ 1.5	21	26	10	7	3	59.3 $\pm$ 13.1	IOPI
		23.9 $\pm$ 2.0	21	28	11	7	4	52.5 $\pm$ 13.9	IOPI
Kobuchi	2020	78.8 $\pm$ 7.1	65	NA	54	16	38	28.5 $\pm$ 7.7	JMS
Hwang	2020	NA	20	28	15	NA	NA	49.33 $\pm$ 6.55	IOPI
		NA	20	28	15	NA	NA	50.40 $\pm$ 5.09	IOPI
Van den Steen	2019	79	70	90	15	7	8	36.9 $\pm$ 9.1	IOPI
		81	71	90	16	7	9	34.1 $\pm$ 8.0	IOPI
		77	71	84	16	NA	NA	35.3 $\pm$ 6.8	IOPI
		NA	70	NA	13	NA	NA	39.2 $\pm$ 9.9	IOPI
Satake	2019	68.8 $\pm$ 6.5	60	NA	420	160	260	29.5 $\pm$ 8.2	JMS
		74.4 $\pm$ 7.8	60	NA	47	13	34	24.1 $\pm$ 9.4	JMS
Sagawa	2019	70.4 $\pm$ 3.9	65	87	116	116	0	31.8 $\pm$ 6.6	JMS
		71.0 $\pm$ 4.0	65	87	129	0	129	29.7 $\pm$ 6.4	JMS
Park J S	2019	24.5 $\pm$ 0.5	21	35	15	8	7	52.50 $\pm$ 4.44	IOPI
		25.1 $\pm$ 4.2	21	35	15	7	8	53.81 $\pm$ 3.01	IOPI
Oh J C	2019	21.5 $\pm$ 1.13	21	24	13	8	5	64.8 $\pm$ 9.39	IOPI
Namiki	2019	76.8 $\pm$ 6.2	65	NA	18	11	7	31.5 $\pm$ 8.9	JMS
Morita	2019	77.0 $\pm$ 5.3	65	NA	52	52	0	31.8 $\pm$ 6.4	JMS
		74.1 $\pm$ 4.8	65	NA	179	0	179	30.7 $\pm$ 6.4	JMS
Miyoshi	2019	77.6 $\pm$ 5.7	65	NA	108	0	108	30.5 $\pm$ 8.6	JMS
Liu	2019	27 $\pm$ 6	22	40	40	20	20	NA	IOPI
		NA	22	40	20	20	0	62 $\pm$ 13	IOPI
		NA	22	40	20	0	20	54 $\pm$ 11	IOPI
		75 $\pm$ 7	65	89	28	5	23	49 $\pm$ 12	IOPI
Kugimiya	2019	77 $\pm$ 4.9	70	NA	445	445	0	30.8 $\pm$ 9.0	JMS
		77 $\pm$ 4.5	70	NA	673	0	673	29.8 $\pm$ 7.7	JMS
Kito	2019	75.6 $\pm$ 5.6	65	NA	86	6	80	32.4 $\pm$ 8.0	JMS
Hasegawa	2019	73.2 $\pm$ 6.1	65	NA	223	223	0	31.7 $\pm$ 9	JMS
		72.6 $\pm$ 5.8	65	NA	449	0	449	30.8 $\pm$ 8.6	JMS
Chantaramanee	2019	71.10 $\pm$ 4.13	65	83	94	30	64	30.80 $\pm$ 7.48	JMS
Ohta	2018	33.9 $\pm$ 3.5	21	39	63	NA	NA	39.1 $\pm$ 7.7	JMS
		44.9 $\pm$ 2.8	40	49	39	NA	NA	39.1 $\pm$ 6.5	JMS
		54.1 $\pm$ 2.9	50	59	29	NA	NA	35.2 $\pm$ 7.3	JMS

		66.5±2.7	60	69	26	NA	NA	34.5±5.6	JMS
		74.5±2.9	70	79	23	NA	NA	26.2±7.9	JMS
Yoshimi	2018	NA	69	77	37	37	0	29.63±9.27	JMS
		NA	66	73	81	0	81	30.85±7.74	JMS
Yamanashi	2018	72.8±7.4	60	95	1603	650	953	30.5 ± 10.1	JMS
Tanaka	2018	73.0±5.5	65	NA	2011	994	1017	33.1±7.9	JMS
Steele	2018	NA	20	29	28	28	0	52.88±16.25	IOPI
		NA	20	29	32	0	32	47.99±12.00	IOPI
		NA	30	39	31	31	0	59.0±17.6	IOPI
		NA	30	39	29	0	29	48.85±13.71	IOPI
		NA	40	49	29	29	0	51.6±17.21	IOPI
		NA	40	49	34	0	34	53.14±14.52	IOPI
		NA	50	59	25	25	0	52.13±17.64	IOPI
		NA	50	59	26	0	26	45.08±13.00	IOPI
		NA	60	69	14	14	0	48.09±18.05	IOPI
		NA	60	69	22	0	22	46.95±11.78	IOPI
		NA	70	86	10	10	0	40.96±13.77	IOPI
Oh J C	2018	76.22±4.64	66	83	23	6	17	39.91±12.24	IOPI
Morita	2018	74.2±5.9	60	89	262	56	206	30.9±6.4	JMS
Hara	2018	NA	20	29	65	65	0	41.3 ± 8.8	JMS
		NA	20	29	112	0	112	35.9 ± 7.1	JMS
		NA	30	39	85	85	0	40.9 ± 7.4	JMS
		NA	30	39	93	0	93	36.9 ± 6.8	JMS
		NA	40	49	65	65	0	40.6 ± 8.0	JMS
		NA	40	49	87	0	87	33.4 ± 6.8	JMS
		NA	50	59	29	29	0	37.8 ± 5.8	JMS
		NA	50	59	67	0	67	33.2 ± 6.8	JMS
		NA	60	69	46	46	0	35.6 ± 8.0	JMS
		NA	60	69	106	0	106	32.1 ± 7.7	JMS
		NA	70	79	52	52	0	30.8 ± 8.7	JMS
		NA	70	79	89	0	89	29.4 ± 7.8	JMS
		NA	80	89	37	37	0	24.1 ± 7.7	JMS
		NA	80	89	47	0	47	23.2 ± 7.3	JMS
Yokoyama	2017	23.6 ± 2.1	NA	NA	20	10	10	NA	JMS
		NA	NA	NA	10	10	0	51.2 ± 7.1	JMS
		NA	NA	NA	10	0	10	38.4 ± 6.9	JMS
VanRavenhorst-Bell	2017	20.96 ± 3.22	18	NA	24	12	12	60.13 ± 13.52	IOPI
		65.96 ± 3.72	NA	76	24	12	12	52.71 ± 15.57	IOPI
Oh Dong-Hwan	2017	NA	20	26	60	30	30	57.6 ± 16.3	IOPI
Machida	2017	78.5 ± 6.6	NA	NA	97	97	0	26.3 ± 7.8	JMS
		77.8 ± 6.2	NA	NA	100	0	100	24.6 ± 7.2	JMS
Ito	2017	76.2 ± 5.1	65	NA	31	18	13	27.7 ± 9.2	JMS
		78.1 ± 6.5	65	NA	15	10	5	33.7 ± 13.1	JMS

Endoh	2017	73.7 ± 5.4	NA	NA	32	12	20	32.9 ± 7.7	JMS
		74.7 ± 6.2	NA	NA	35	19	16	31.0 ± 6.9	JMS
Yasuhara	2016	25.66 ± 6.43	18	46	47	47	0	45.60 ± 9.23 (mini24.9-max74.3)	JMS
		23.48 ± 4.23	18	39	54	0	54	38.68 ± 7.37 (mini18.2-max53.2)	JMS
Takahashi	2016	25.8 ± 2.1	NA	NA	40	40	0	45.8 ± 11.6	JMS
Satake	2016	70.7 ± 7	60	NA	176	176	0	29.8 ± 8.7	JMS
		69.6 ± 6.5	60	NA	299	0	299	28.4 ± 8.3	JMS
Park Ji-SU	2016	23.3 ± 2.5	20	29	40	20	20	65.29 ± 5.64	IOPI
		68.3 ± 5.5	65	80	40	20	20	50.45 ± 6.67	IOPI
Oh Dong-Hwan	2016	26.2 ± 3.5	20	39	30	15	15	55.46 ± 5.10	IOPI
		63.1 ± 5.6	67	75	30	15	15	35.93 ± 6.32	IOPI
Kobayashi	2016	74.2 ± 7.0	65	NA	40	12	28	25.5 ± 7.1	JMS
		21.4 ± 0.8	NA	NA	25	0	25	31.9 ± 9.0	JMS
Izuno	2016	NA	70	88	17	17	0	33.0 ± 9.1	JMS
		NA	70	88	20	0	20	30.2 ± 6.5	JMS
Furuya	2016	75.9 ± 6.1	67	92	169	169	0	31.7 ± 7.8	JMS
		75.4 ± 5.6	67	92	195	0	195	29.1 ± 7.1	JMS
Shintani	2015	21.1±1.9	19	30	64	37	27	NA	JMS
		NA	19	30	37	37	0	42.7 ± 7.5	JMS
		NA	19	30	27	0	27	32.9 ± 9.0	JMS
Saito	2015	20.7 ± 0.6	20	22	27	9	18	32.3 ± 10.4	JMS
		74.1 ± 4.5	65	84	17	11	6	27.1 ± 5.6	JMS
Prandini	2015	23	18	28	51	18	33	NA	IOPI
		NA	18	28	18	18	0	63.94 ± 12.92	IOPI
		NA	18	28	33	0	33	50.27 ± 15.29	IOPI
Park	2015	NA	20	39	49	49	0	68.04 ± 8.34	IOPI
		NA	20	39	47	0	47	56.30 ± 8.07	IOPI
		NA	40	59	51	51	0	64.16 ± 5.45	IOPI
		NA	40	59	45	0	45	50.64 ± 11.12	IOPI
		NA	60	79	50	50	0	50.08 ± 10.13	IOPI
		NA	60	79	58	0	58	52.21 ± 10.98	IOPI
		NA	80	93	42	42	0	36.74 ± 10.43	IOPI
		NA	80	93	40	0	40	33.10 ± 9.83	IOPI
		25.8	21	35	10	3	7	64.5 ± 13.05	IOPI
Nakahigashi	2015	77.4 ± 6.6	70	NA	21	0	21	29.6 ± 10.3	JMS
Mendes	2015	30.37 ± 6.75	18	39	30	NA	NA	56.57 ± 14.85	IOPI
		49.13 ± 5.07	40	58	30	NA	NA	51.97 ± 10.81	IOPI
		69.63 ± 8.06	60	86	30	NA	NA	43.20 ± 13.58	IOPI
Laguna	2015	UK	NA	NA	NA	NA	NA	NA	NA
		NA	65	69	14	NA	NA	34.07 ± 14.97	IOPI
		NA	70	74	20	NA	NA	33.62 ± 12.94	IOPI
		NA	75	79	28	NA	NA	33.59 ± 13.04	IOPI

		NA	80	84	12	NA	NA	30.62 ± 12.24	IOPI
		NA	85	89	14	NA	NA	29.39 ± 13.08	IOPI
		NA	90	94	14	NA	NA	21.88 ± 9.68	IOPI
		Spain	NA	NA	NA	NA	NA	NA	NA
		NA	65	69	13	NA	NA	30.69 ± 19.49	IOPI
		NA	70	74	7	NA	NA	32.86 ± 22.33	IOPI
		NA	75	79	16	NA	NA	25.79 ± 11.08	IOPI
		NA	80	84	24	NA	NA	26.90 ± 14.38	IOPI
		NA	85	89	25	NA	NA	21.17 ± 11.18	IOPI
		NA	90	94	18	NA	NA	25.31 ± 12.21	IOPI
Hiramatsu	2015	29.96 ± 4.84	21	38	23	13	10	38.08 ± 9.67	JMS
		76.65 ± 4.86	70	84	23	14	9	26.85 ± 0.68	JMS
Ezaki	2015	75.3 ± 7	65	88	41	41	0	31.8 ± 9.2	JMS
		73.4 ± 5.8	65	88	58	0	58	31.1 ± 5.4	JMS
Arakawa	2015	24.8±2.3	NA	NA	32	18	14	NA	JMS
		NA	NA	NA	18	18	0	45.03 ± 6.19	JMS
		NA	NA	NA	14	0	14	34.99 ± 6.59	JMS
Shimada	2014	73.5 ± 5.7	65	87	13	13	0	36.1 ± 8.1	JMS
		74.4±5	65	87	27	0	27	32.2 ± 7.0	JMS
Adams	2014	28.2 ± 9.3	19	57	51	21	30	55.3 ± 11.5	IOPI
Takahashi	2013	24.9±2.4	NA	NA	56	30	26	NA	JMS
		NA	NA	NA	30	30	0	49.0 ± 8.1	JMS
		NA	NA	NA	26	0	26	33.1 ± 5.1	JMS
Okuno	2013	77.9 ± 5.6	68	100	100	39	61	23.81 ± 10.43	JMS
Buehring	2013	81.3 ± 6.3	70	95	48	48	0	50.6 ± 12.7	IOPI
		80 ± 5.5	70	95	49	0	49	47.0 ± 10.2	IOPI
Neel	2012	30.1	20	40	16	16	0	74.1 ± 11.8	IOPI
		31.8	22	40	12	0	12	64.6 ± 9.8	IOPI
Gingrich	2012	22.87 ± 4.07	18	34	15	15	0	73.33 ± 12.03	IOPI
		23.5 ± 3.39	18	34	15	0	15	61.27 ± 14.80	IOPI
Clark H M	2012	22.9 ± 3.5	18	29	68	25	43	55.8 ± 13.5	IOPI
		44.7 ± 8.8	30	59	60	35	25	62.8 ± 13.0	IOPI
		70.8 ± 7.1	60	89	43	28	15	51.0 ± 15.0	IOPI
Yoshikawa	2011	25	21	29	22	13	9	49.2 ± 9.5	JMS
		25	21	29	22	13	9	63.9 ± 13.1	IOPI
		31	21	39	22	13	9	32.7 ± 5.3	JMS
Vitorino	2010	NA	20	40	35	NA	NA	57.62 ± 7.78	IOPI
		NA	61	80	10	NA	NA	54.4 ± 5.94	IOPI
Okada	2009	86.5 ± 6.6	69	99	11	2	9	28.4 ± 6.8	JMS
		89.8 ± 5	69	99	11	2	9	28.7 ± 11.4	JMS
Kikutani	2009	72 ± 4.6	65	88	190	60	130	34.9 ± 8.9	JMS
		76.3 ± 5.8	65	88	78	26	52	34.2 ± 11.0	JMS
Utanohara	2008	NA	20	29	299	153	146	41.7 ± 9.7	JMS
		NA	30	39	126	70	56	41.9 ± 9.9	JMS

Stierwalt	2007	NA	40	49	123	67	56	40.4 ± 9.8	JMS
		NA	50	59	104	53	51	40.7 ± 9.8	JMS
		NA	60	69	140	46	94	37.6 ± 8.8	JMS
		NA	70	79	61	19	42	31.9 ± 8.9	JMS
		NA	19	39	95	NA	NA	62.02 ± 13.90	IOPI
		NA	40	59	45	NA	NA	60.42 ± 12.25	IOPI
		NA	60	91	60	NA	NA	55.01 ± 14.32	IOPI
Ono	2007	83.4	65	93	14	6	8	32.22 ± 6.03	JMS
Youmans	2006	NA	20	39	15	15	0	72.0 ± 13.4	IOPI
		NA	20	39	15	0	15	55.7 ± 12.5	IOPI
		NA	40	59	15	15	0	63.9 ± 11.8	IOPI
		NA	40	59	15	0	15	59.1 ± 14.0	IOPI
		NA	60	79	15	15	0	56.1 ± 11.6	IOPI
Lazarus	2003	NA	60	79	15	0	15	52.9 ± 10.7	IOPI
		26	20	29	31	8	23	NA	IOPI
		NA	20	29	10	5	5	69.8 ± 17.71	IOPI
		NA	20	29	10	2	8	63.90 ± 6.96	IOPI
		NA	20	29	11	1	10	64.80 ± 9.48	IOPI
Crow	1996	NA	19	39	16	7	9	75.7 ± 17.3	IOPI
		NA	40	59	27	14	13	75.2 ± 23.6	IOPI
		NA	60	79	43	25	18	69.5 ± 17.3	IOPI
Robins	1995	NA	80	96	13	6	7	53.7 ± 13.3	IOPI
		75	67	83	14	14	0	49.5 ± 3.0	IOPI
		25	22	33	10	10	0	64.5 ± 2.7	IOPI
Robin	1992	22.9	18	48	12	8	4	65.25 ± 11.74	IOPI
		25.9	18	49	12	8	4	65.98 ± 12.70	IOPI

NA: not applicable

Table 1b

					unweighted mean tongue pressure (kPa)			
		studies	subgroups	subjects	mean	sd	median	min-max
Age	<60 years old	38 (43.7%)	85 (47.8%)	3265 (23.7%)	52.2	11.9	52.5	31.9-75.7
	>60 years old	49 (56.3%)	93 (52.2%)	10508 (76.3%)	34.9	9.4	31.8	21.2-69.5
Gender	Men	27 (49.1%)	44 (50.6%)	2462 (40.6%)	46.1	13.9	45.3	24.1-74.1
	Women	28 (50.9%)	43 (49.4%)	3603 (59.4%)	39.6	11.2	33.4	23.2-64.6
Device	IOPI	30 (43.5%)	93 (52.2%)	2433 (17.7%)	51.9	12.9	52.9	21.2-75.7
	JMS	39 (56.5%)	85 (47.8%)	11340 (82.3%)	33.6	5.9	32.2	23.2-51.2
Age, Gender	<60 years old Men	15 (23.4%)	23 (26.4%)	748 (12.3%)	54.8	11.6	52.1	37.8-74.1
	<60 years old Women	14 (21.9%)	22 (25.3%)	838 (13.8%)	45.3	10.7	46.5	31.9-64.6
	>60 years old Men	17 (26.6%)	21 (24.1%)	1714 (28.3%)	36.5	9.0	31.8	24.1-56.1
	>60 years old Women	18 (28.1%)	21 (24.1%)	2765 (45.6%)	33.5	8.5	30.7	23.2-52.9
Age, Device	<60 years old IOPI	26 (29.5%)	54 (30.3%)	1447 (10.5%)	59.6	7.4	59.2	45.1-75.7
	<60 years old JMS	13 (14.8%)	31 (17.4%)	1818 (13.2%)	39.3	5.3	39.1	31.9-51.2
	>60 years old IOPI	17 (19.3%)	39 (21.9%)	986 (7.2%)	41.3	11.3	39.9	21.2-69.5
	>60 years old JMS	32 (36.4%)	54 (30.3%)	9522 (69.1%)	30.3	3.2	30.8	23.2-37.6

Gender, Device	Men IOPI	9 (16.4%)	20 (23.0%)	515 (8.5%)	57.7	10.5	57.5	36.7-74.1
	Men JMS	18 (32.7%)	24 (27.6%)	1947 (32.1%)	36.5	7.4	34.3	24.1-51.2
	Women IOPI	8 (14.5%)	17 (19.5%)	507 (8.4%)	51.7	7.2	52.2	33.1-64.6
	Women JMS	20 (36.4%)	26 (29.9%)	3096 (51.0%)	31.6	3.6	31.0	23.2-38.7

Table 2. Results of quality assessment for (2a) analytical study according to NOS, and for (2b) included randomized clinical trials (RCTs) and non-RCTs according to Cochrane Collaboration's tool for assessing risk of bias.

Table 2a

Author	Year	Study design	Selection	Comparability	Outcome	Ottawa total	
						Stars	Quality
Kobuchi	2020	Cross sectional	3	2	2	7	High
Satake	2019	Cross sectional	2	2	2	6	Intermediate
Sagawa	2019	Cross sectional	5	2	1	8	High
Oh J C	2019	before and after	0	0	2	2	Low
Namiki	2019	before and after	0	0	2	2	Low
Morita	2019	Cross sectional	3	1	1	5	Intermediate
Miyoshi	2019	Cross sectional	3	1	1	5	Intermediate
Liu	2019	Cross sectional	2	2	1	5	Intermediate
Kugimiya	2019	Cross sectional	4	2	1	7	High
Hasegawa	2019	Cross sectional	2	2	2	6	Intermediate
Chantaramanee	2019	Cross sectional	3	0	1	4	Intermediate
Ohta	2018	Cross sectional	2	0	1	3	Low
Yoshimi	2018	Cross sectional	3	1	2	6	Intermediate
Yamanashi	2018	Cross sectional	2	1	2	5	Intermediate
Tanaka	2018	prospective cohort	3	2	2	7	High
Steele	2018	Cross sectional	2	1	2	5	Intermediate
Oh J C	2018	before and after	0	0	2	2	Low
Morita	2018	Cross sectional	1	2	1	4	Intermediate
Hara	2018	Cross sectional	3	2	1	6	Intermediate
Yokoyama	2017	Cross sectional	0	1	1	2	Low
VanRavenhorst-Bell	2017	Cross sectional	1	2	1	4	Intermediate
Oh Dong-Hwan	2017	Cross sectional	0	0	1	1	Low
Machida	2017	Cross sectional	1	2	2	5	Intermediate
Yasuhara	2016	Cross sectional	1	1	1	3	Low
Takahashi	2016	Cohort	2	0	2	4	Intermediate
Satake	2016	Cross sectional	0	2	1	3	Low
Park JI-SU	2016	Cross sectional	1	2	1	4	Intermediate
Oh Dong-Hwan	2016	Cross sectional	1	1	1	3	Low
Kobayashi	2016	Cross sectional	1	1	1	3	Low
Izuno	2016	Cross sectional	2	2	2	6	Intermediate
Furuya	2016	Cross sectional	2	2	1	5	Intermediate
Shintani	2015	Cross sectional	0	1	1	2	Low
Saito	2015	Cross sectional	0	1	1	2	Low
Prandini	2015	Cross sectional	1	1	1	3	Low

Park	2015	Cross sectional	3	2	1	6	Intermediate
Nakahigashi	2015	Cross sectional	0	1	1	2	Low
Mendes	2015	Cross sectional	2	1	1	4	Intermediate
Laguna	2015	Cross sectional	2	1	1	4	Intermediate
Hiramatsu	2015	Cross sectional	2	1	1	4	Intermediate
Ezaki	2015	Cross sectional	0	0	1	1	Low
Shimada	2014	Cross sectional	2	2	1	5	Intermediate
Adams	2014	Cohort	2	1	2	5	Intermediate
Takahashi	2013	Cross sectional	0	1	1	2	Low
Okuno	2013	Cross sectional	2	2	1	5	Intermediate
Buehring	2013	Cross sectional	3	2	1	6	Intermediate
Neel	2012	Cross sectional	1	2	1	4	Intermediate
Gingrich	2012	Cross sectional	0	1	1	2	Low
Clark H M	2012	Cross sectional	1	2	1	4	Intermediate
Yoshikawa	2011	Cross sectional	0	1	1	2	Low
Vitorino	2010	Cross sectional	1	2	1	4	Intermediate
Kikutani	2009	Cross sectional	1	1	1	3	Low
Utanohara	2008	Cross sectional	2	2	1	5	Intermediate
Stierwalt	2007	Cross sectional	3	2	1	6	Intermediate
Ono	2007	Cross sectional	0	2	1	3	Low
Youmans	2006	Cross sectional	1	2	1	4	Intermediate
Crow	1996	Cross sectional	1	2	1	4	Intermediate
Robbins	1995	Cross sectional	0	2	1	3	Low
Robin	1992	Cross sectional	2	0	1	3	Low

Table 2b

Author	Year	Study design	Random sequence generation	Allocation concealment	Blinding of participants and personnel	Blinding of outcome assessment	Incomplete outcome data	Selective reporting	Other bias
Park	2020	RCT	low risk	low risk	low risk	low risk	low risk	low risk	unclear
Hwang	2020	RCT	unclear	unclear	low risk	low risk	low risk	low risk	unclear
Van den Steen	2019	RCT	unclear	unclear	low risk	low risk	low risk	low risk	low risk
Park J S	2019	RCT	unclear	unclear	low risk	low risk	low risk	low risk	unclear
Kito	2019	RCT	unclear	low risk	low risk	low risk	low risk	low risk	low risk
Ito	2017	non-RCT	high risk	high risk	low risk	low risk	low risk	low risk	low risk
Endoh	2017	RCT	unclear	unclear	low risk	low risk	low risk	low risk	low risk

Oh Jong-Chi	2015	non-RCT	high risk	high risk	low risk	low risk	low risk	low risk	high risk
Arakawa	2015	non-RCT	high risk	high risk	low risk	low risk	low risk	low risk	low risk
Lazarus	2003	RCT	unclear	unclear	low risk	low risk	low risk	low risk	low risk

Table 3. Tongue pressure and age, device, gender (estimation by random effects meta-regression)

		# studies	# subgroups	# subjects	EWM / WMD	SE	95%-CI	p-value*
Age	<60 years old	38	85	3265	51.9	1.28	49.4 - 54.4	<0.001
	>60 years old	50	95	10530	34.7	0.94	32.8 - 36.5	
	>60 years old -			WMD:	-17.2	1.57	-20.2 - -14.1	
	<60 years old							
Device	IOPI	30	93	2433	51.9	1.32	49.3 - 54.5	<0.001
	JMS	40	87	11362	33.5	0.63	32.2 - 34.7	
	JMS - IOPI			WMD:	-18.4	1.46	-21.3 - -15.6	
Gender	Men	27	44	2462	45.9	2.09	41.8 - 50.0	0.015
	Women	28	43	3603	39.3	1.68	36.0 - 42.6	
	Women - Men			WMD:	-6.5	2.69	-11.8 - -1.3	
>60 years old - <60 years old in subgroups:								
Men	<60 years old	15	23	748	54.7	2.42	49.9 - 59.4	<0.001
	>60 years old	17	21	1714	36.2	1.94	32.4 - 40.0	
	>60 years old -			WMD:	-18.3	3.14	-24.4 - -12.2	
	<60 years old							
Women	<60 years old	14	22	838	45.0	2.25	40.6 - 49.4	<0.001
	>60 years old	18	21	2765	33.4	1.79	29.9 - 36.9	
	>60 years old -			WMD:	-11.5	2.89	-17.2 - -5.9	
	<60 years old							
IOPI	<60 years old	26	54	1447	59.3	0.98	57.4 - 61.2	<0.001
	>60 years old	17	39	986	41.4	1.81	37.9 - 45.0	
	>60 years old -			WMD:	-17.9	1.93	-21.7 - -14.1	
	<60 years old							
JMS	<60 years old	13	31	1818	39.3	0.92	37.5 - 41.1	<0.001
	>60 years old	33	56	9544	30.3	0.42	29.4 - 31.1	
	>60 years old -			WMD:	-9.0	0.87	-10.7 - -7.3	
	<60 years old							
JMS - IOPI in subgroups:								
<60 years old	IOPI	26	54	1447	59.3	0.98	57.4 - 61.2	<0.001
	JMS	13	31	1818	39.3	0.92	37.5 - 41.1	
	JMS - IOPI			WMD:	-19.9	1.42	-22.7 - -17.1	

>60 years old	IOPI	17	39	986	41.4	1.81	37.9 - 45.0	
	JMS	33	56	9544	30.3	0.42	29.4 - 31.1	<0.001
	JMS - IOPI				WMD:	-11.3	1.52	-14.3 - -8.3
Men	IOPI	9	20	515	57.7	2.34	53.2 - 62.3	
	JMS	18	24	1947	36.4	1.49	33.4 - 39.3	<0.001
	JMS - IOPI				WMD:	-21.4	2.67	-26.6 - -16.1
Women	IOPI	8	17	507	51.5	1.74	48.0 - 54.9	
	JMS	20	26	3096	31.5	0.70	30.1 - 32.9	<0.001
	JMS - IOPI				WMD:	-19.7	1.60	-22.9 - -16.6
Women - men in subgroups:								
<60 years old	Men	15	23	748	54.7	2.42	49.9 - 59.4	
	Women	14	22	838	45.0	2.25	40.6 - 49.4	0.004
	Women - Men				WMD:	-9.6	3.31	-16.1 - -3.1
>60 years old	Men	17	21	1714	36.2	1.94	32.4 - 40.0	
	Women	18	21	2765	33.4	1.79	29.9 - 36.9	0.282
	Women - Men				WMD:	-2.8	2.64	-8.0 - 2.3
IOPI	Men	9	20	515	57.7	2.34	53.2 - 62.3	
	Women	8	17	507	51.5	1.74	48.0 - 54.9	0.038
	Women - Men				WMD:	-6.2	2.99	-12.1 - -0.4
JMS	Men	18	24	1947	36.4	1.49	33.4 - 39.3	
	Women	20	26	3096	31.5	0.70	30.1 - 32.9	0.003
	Women - Men				WMD:	-4.8	1.60	-7.9 - -1.6

EWM: estimated weighted mean

WMD:: estimated weighted mean difference between groups

Table 4. Influence of age, device and gender on mean tongue pressure (multivariate random effects meta-regression)

		estimation	SE	95%-CI	p-value
all subjects	>60 years old vs <60 years old	-13.41	1.11	-15.58 - -11.24	<0.001
subgroups: n=178	JMS vs IOPI	-15.38	1.11	-17.54 - -13.21	<0.001
	constant	57.51	0.90	55.75 - 59.26	<0.001
subgroups: n=87	>60 years old vs <60 years old	-10.05	1.11	-12.21 - -7.88	<0.001
	JMS vs IOPI	-17.92	1.14	-20.15 - -15.68	<0.001
	Women vs Men	-5.34	1.07	-7.43 - -3.24	<0.001
	constant	60.61	1.07	58.52 - 62.71	<0.001

SE: standard error

Figure legends

Figure 1.

Flow diagram of study screening and selection.

Figure 2a.

Forest plot of mean tongue pressure with their 95 % confidence intervals (95 % CI) for subjects < 60 years (young) with IOPI.

Figure 2b.

Forest plot of mean tongue pressure with their 95 % confidence intervals (95 % CI) for subjects > 60 years (old) with IOPI.

Figure 2c.

Forest plot of mean tongue pressure with their 95 % confidence intervals (95 % CI) for subjects <60 years (young) with JMS.

Figure 2d.

Forest plot of mean tongue pressure with their 95 % confidence intervals (95 % CI) for subjects > 60 years (old) with JMS.

Supporting Information

Additional supporting information may be found in the online version of this article:

Appendix S1 The PRISMA checklist.

Appendix S2 List of the included, and excluded studies during the full-text screening.

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