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The influence of training variables on lingual strength and swallowing in adults with and without dysphagia

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Abstract

Background Swallowing disorders (dysphagia) occur in a large proportion of individuals over the age of 60. The improvement of tongue strength by resistance exercise is postulated to be directly related to lingual-palatal pressure generation and bolus propulsion into the pharynx during swallowing. To the best of our knowledge, however, there is no evidence-based discussion evaluating the strength training variables of the tongue for improving tongue strength maximally.

Methods To solve this problem, we reviewed the relationships between different resistance training variables (i.e. training period, intensity, duration of muscle contraction, volume, and frequency) and the change in muscle strength in the lingual muscle.

Results Our findings show that tongue strength training may improve anterior and posterior tongue strength in both healthy adults and patients with dysphagia. Anterior and posterior tongue strength gradually increased and did not reach a plateau after at least 8 weeks of training. Data for other variables were insufficient to draw clear conclusions. Available data suggest that a training intensity of 60–100% of maximum tongue strength, a contraction time of 2–3 s, a total number of 90–120 repetitions per day, and a training frequency of three times per week appears to result in an improvement in maximal isometric tongue elevation strength in adults with and without dysphagia.

Conclusions Future studies are warranted to better determine if there are dose–response relationships in tongue strength training in healthy adults and patients with dysphagia.

Keywords Tongue strength; Isometric training; Dysphagia; Swallowing

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Introduction

It is estimated that swallowing disorders (dysphagia) occur in up to 40% of individuals over the age of 60.[1] Because the older population continues to grow, it is expected that age-related dysphagia will become clinically more prevalent. Treatment for dysphagia is usually rehabilitative (i.e. restoration of normal swallow function) or compensatory (i.e. modifications to diet consistency and patient behaviour) in approach. Over the past 20 years, there has been a growing interest in improving tongue (i.e. lingual) strength and function through progressive resistance exercise of the lingual muscles with the aim of improving swallowing performance in individuals with and without dysphagia.[2] The improvement of tongue elevation strength by resistance exercise is postulated to be directly related to lingual-palatal pressure generation and bolus propulsion into the pharynx during swallowing.[3] Some studies would suggest that increased lingual pressure during swallowing also occurs as a result of tongue strength training.[4,5] Changes in tongue strength and swallowing function may help improve nutritional intake and quality of life for individuals with dysphagia and may prevent the onset of dysphagia for older adults who are currently asymptomatic.

In the limb skeletal muscles, studies of progressive resistance training have demonstrated dose–response relationships between select training variables (e.g. training period, intensity, volume, and frequency) and the measurement outcome of muscular strength and morphology.[6,7] A recent meta-analysis using data from individuals aged 60 and older revealed that, for example, the largest training effects on measures of muscle strength were found for intensities (i.e. external load) of 70–79% of the one-repetition maximum (1RM).[8] Whether these same relationships with exercise variables exist in muscles of the tongue are less transparent. A recent randomized controlled trial investigating the effect of three different resistive loads (60%, 80%, and 100% of maximal tongue elevation strength) on tongue strength in healthy older adults showed that training-induced increases in the tongue strength were not different between the three groups.[9] However, it is unclear whether young adults will achieve the same results. In addition, given the biomechanical (e.g. three-dimensional changes in tongue shape), anatomical (e.g. no joints or rigid support structures within the tongue), and histological (e.g. complex muscle fibre arrangement) characteristics of the lingual muscle,[10,11] it is unknown whether the resistance exercise response is similar to that observed in limb skeletal muscle. Thus, the purpose of this paper is to review the relationships between different resistance training variables (i.e. training period, intensity, volume, and frequency) and the change in muscle strength in the lingual muscle.

Methods

Literature search

A literature search using PubMed and Google Scholar was performed with the following keywords and phrases to obtain relevant articles, without time limits until July 2019: ‘tongue or lingual’ AND ‘strength or resistance training’. References from pertinent articles and the names of the authors cited were cross-referenced to locate any further relevant articles not found with the initial search. To be included, a study needed to meet the following criteria: (a) intervention: the study needed to perform tongue resistance (strength) training, including isometric tongue elevation exercise, and include healthy adults or patients with dysphagia (over 18 years of age); (b) outcome measure: the study needed to measure maximal isometric tongue elevation strength (pressure) using a standardized instrument in the anterior and/or posterior position at baseline (pre-intervention) and after the last training session (post-intervention); (c) language: the search was limited to original research that was written in English. Studies were excluded if involved tongue strengthening exercise were combined with other movements (e.g. head flexion exercise or swallowing exercise). If a study did not report absolute and/or relative change in outcome measures between pre-intervention and post-intervention, then we calculated the variables using reported mean values. In addition, if methodological conditions or results of pre-measurements and post-measurements were not conclusively reported, the authors of the respective studies were contacted via email to obtain clarifications as to responses to the intervention.

Classification of training variables

The studies were classified for the following variables: (a) training period; (b) frequency; (c) volume (i.e. number of sessions per day, number of sets per session, number of repetitions per set); and (d) intensity. The training groups were subdivided according to the applied training intensity: 100% of maximal voluntary isometric tongue strength (MVC); 80% of MVC; and 60% of MVC. If the first week of training was 60% of MVC and 80% was maintained thereafter, it was classified as 80% of MVC. If it was stated that ‘subject pressed as hard as possible’, it was classified as 100% of MVC. Considering the specificities of training,[12] when performing multiple tongue movement exercise (i.e. lateralization, protrusion, and elevation), only anterior/posterior tongue elevation exercise was selected, and the total number of repetitions in the training day was calculated as the exercise volume. The exercise volume of the training groups was subdivided according to the performed total repetitions: low volume $\leq$ 60 repetitions; high volume $>$ 60 repetitions.

Statistical analysis

To determine the overall effect of resistance training on lingual strength, we performed qualitative and quantitative analyses of the studies included in this review. The within group meta-analysis was conducted using a weighted random-effects model (the DerSimonian-Laird approach) to see the overall effects of tongue strength training on anterior and/or posterior tongue strength in healthy adults and in patients with dysphagia. All within group analyses were conducted plotting mean difference (MD) and standard error of MD (SE_{MD}) into JASP open-source software (JASP, Version 10.1, University of Amsterdam, The Netherlands). The MD of each study was calculated as the post-value minus pre-value, and the SE_{MD} was calculated as the standard deviation (SD) of MD (SD_{MD}) divided by the square root of sample size ($SE_{MD} = SD_{MD}/\sqrt{N}$). Also, we conducted a between group meta-analyses using a weighted random-effects models (the DerSimonian–Laird approach) to compare the effects of tongue strength training (therapy plus tongue strength training) vs. control (therapy only) on anterior and posterior tongue strength in patients with dysphagia. All between group analyses were conducted plotting MD and SE_{MD} into JASP open-source software (JASP, Version 10.1, University of Amsterdam, The Netherlands). The MD of each study was calculated as follows: (post-value training group − pre-value training group) − (post-value control group − pre-value control group). Standard error of the MD was calculated using the following formula:

$$SE_{MD} = \sqrt{\left(SD_{MD\ traininggroup}{}^2/N_{traininggroup}\right) + \left(SD_{MD\ controlgroup}{}^2/N_{controlgroup}\right)}.$$

When SD_{MD} for each group was not provided, we first obtained the reliability coefficient from a previous study using the same tongue strength evaluation method. Thereafter, we used the following formula:

$$SD_{changescore} = \sqrt{\left(SD_{pre-test}{}^2 + SD_{post-test}{}^2\right) - \left(2r \times SD_{pre-test} \times SD_{post-test}\right)}$$

The statistical heterogeneity of the treatment effect among studies was assessed using Cochran's Q, Tau^2, and the inconsistency I^2 test, in which values above 30% and 50% were considered indicative of moderate and high heterogeneity, respectively.[13]

Findings

Included studies and participant characteristics

Eighteen studies[4,9,12,14–28] were included in our analysis, totalling 374 adults (*Table* 1). Ten of the 18 studies targeted healthy adults,[4,9,12,14–20] while the other eight studies[21–28] targeted patients with dysphagia. In studies involving healthy individuals, two studies compared tongue strength training vs. a non-exercise control group,[12,14] six studies were composed of only a tongue strength training group,[4,15,16,18–20] one study had two different tongue strength training interventions,[17] and one study compared three different tongue strength interventions and an exercise control group (lip compression).[9] Seven studies involving patients with dysphagia compared therapy interventions vs. tongue strength training plus therapy interventions.[22–28] Participants of six of the eight studies involving dysphagia were stroke survivors.[21,23,25–28] All studies[4,9,12,14–28] involved men and women; however, it was not possible to identify the number of men and women in each intervention group in three studies[12,17,22] (*Table* 1). In studies involving healthy individuals, five studies were composed of young adults,[12,14,16,18,19] four studies were composed of older individuals,[4,9,17,20] and one had both young and older adults.[15] Although all studies with dysphagic patients were composed of older patients (according to the mean patients age reported),[21–28] four studies were composed of young and older patients,[20–22,24] and the other four studies did not report the patients' age range.[24,26–28] *Table* 1 shows additional information about participants' characteristics from the included studies.

Tongue strength interventions

In relation to studies involving healthy individuals, the intervention durations were accounted for; three studies applied a tongue strength intervention for 4 weeks,[12,14,20] one study for 6 weeks,[4] five studies for 8 weeks,[9,16–19] and one study for 9 weeks.[15] For studies involving dysphagia, one study applied a tongue strength intervention for 3 weeks,[24] two studies for 4 weeks,[26,27] two studies for 6 weeks,[22,23] two studies for 8 weeks,[21,28] and one study for 8–12 weeks.[25] The most common training frequency for healthy individuals (seven studies) and patients with dysphagia (six studies) was three and five sessions per week, respectively (*Table* 2). The type of tongue strength training most applied for healthy individuals was composed of anterior tongue elevation,[4,12,17–19] followed by anterior and posterior tongue elevations.[9,16] For patients with dysphagia, six[21,23,25–28] of the eight included studies had tongue strength training composed of anterior and posterior tongue elevations (*Table* 1). The most common tongue training intensity was 80% of 1RM (six studies out of 10) for healthy individuals and patients with dysphagia (three studies out of eight). Two studies involving patients with dysphagia did not report tongue training intensity;[27,28] 9 of the 18 included studies (50%) did not report the duration of a single contraction time of the tongue elevation during an exercise session.[4,12,18,19,21,23,24,27,28] However, other studies reported the duration of contraction time (six studies in healthy adults[9,14–17,20] and three studies in patients with dysphagia[22,25,26]). The most common contraction time was 2–3 s in both healthy adults and patients with dysphagia. Tongue contraction time ranged from 1[15] to 10 s[20] in healthy individuals, and from 2 to 3 s[22,25,26] in patients with dysphagia. The most common daily exercise volume (repetitions per session multiplied by number of sessions per day) was 90–120 repetitions for healthy individuals[4,9,17–19] and 60 repetitions for patients with dysphagia.[21,25,27,28] *Table* 2 shows additional information about tongue strength interventions from the included studies.

Anterior and posterior tongue strength assessment

Fifteen studies (18 training groups) used the Iowa Oral Performance Instrument (IOPI) to measure tongue elevation strength,[4,9,12,14–19,21–23,25–28] while three studies (three

Table 1 Age, number of subjects, and type of lingual strength training in healthy adults and patients with dysphagia

Study (reference #)	Condition	Group	Mean age & range (years)	# of subject (sex)	Type of training
Healthy adults					
Lazarus et al.[14]	_	Training	26 (20–29)	21 (18 W, 3 M)	Lateralization/Protrusion/ Elevation
		Control		10 (5 W, 5 M)	No exercise
Robbins et al.[4]	_	Training	NR (70–89)	10 (6 W, 4 M)	Anterior elevation
Clark et al.[15]	_	Training	37.8 (18–67)	39 (22 W, 17 M)	Lateralization/Protrusion/ Elevation
Clark[12]	_	Training	29.8 (19–57)	5 (NR)	Anterior elevation
		Control		5 (NR)	No exercise
Oh[16]	_	Training	25.8 (21–35)	10 (7 W, 3 M)	Anterior and posterior elevation
Van den Steen et al.[17]	_	Training Anterior	84 (70–95)	7	Anterior elevation
		Training Posterior		9	Posterior elevation
Van den Steen et al.[9]	_	Training 100%	NR (~70)	15	Anterior and posterior elevation
		Training 80%		16	Anterior and posterior elevation
		Training 60%		16	Anterior and posterior elevation
		Control		13	Lip compression
Yano et al.[18]	_	Training	21.0 (20–21)	7 (4 W, 3 M)	Anterior elevation
Yano et al.[19]	_	Training	20.6 (20–21)	11 (8 W, 3 M)	Anterior elevation
Namiki et al.[20]	_	Training	76.8 (>65)	18 (7 W, 11 M)	Entire tongue elevation
Patients with dysphagia					
Robbins et al.[21]	Stroke	Training	69.7 (51–90)	10 (5 W, 5 M)	Anterior and posterior elevation
Lazarus et al.[22]	Cancer	Training	61.7 (21–79)	8 (NR)	Lateralization/Protrusion/ Elevation
		Control	62.3 (21–79)	10 (NR)	Range of motion exercises
Park et al.[23]	Stroke	Training	67.3 (51–82)	15 (9 W, 6 M)	Anterior and posterior elevation
		Control	65.8 (52–80)	14 (7 W, 7 M)	Therapy only
Aoki et al.[24]	Dysphagic patients	Training	69.9 (NR)	17 (7 W, 10 M)	Two types of tongue elevation
		Control	74.7 (NR)	14 (4 W, 10 M)	Conventional rehabilitation only
Steele et al.[25]	Stroke	Training	67.1 (49–89)	7 (2 W, 5 M)	Anterior and posterior elevation
Moon et al.[26]	Stroke	Training	64.7 (NR)	8 (3 W, 5 M)	Anterior and posterior elevation
		Control	65.2 (NR)	8 (2 W, 6 M)	Therapy only
Kim et al.[27]	Stroke	Training	62.17 (NR)	18 (7 W, 11 M)	Anterior and posterior elevation
		Control	59.29 (NR)	17 (9 W, 8 M)	Therapy only
Moon et al.[28]	Stroke	Training	62.0 (NR)	8 (3 W, 5 M)	Anterior and posterior elevation
		Control	63.5 (NR)	8 (4 W, 4 M)	Therapy only

M, men; NR, not reported; W, women; #, number.

training groups) used the JMS device.[18,20,24] Nine studies (50%) measured only anterior tongue strength,[4,12,14,15,18,20,22,24,26] and nine studies (50%) measured both anterior and posterior tongue strength.[9,16,17,19,21,23,25,27,28]

Overall effect of tongue strength training (within-group analysis)

As mentioned above, the IOPI is the main instrument to evaluate tongue strength. All of the following analysis was conducted only in studies used the IOPI, taking into account differences in measurement error between the devices. Seven studies with healthy individuals[9,14–17,19] and six studies with patients with dysphagia[22,23,25–28] allowed us to perform a within-group meta-analysis to examine the effects of tongue strength training on anterior and posterior tongue strength in healthy adults and in patients with dysphagia (*Table* 3). We found that tongue strength training resulted in significant improvements on anterior [MD: 16.01 kilopascal (kPa)] [95% confidence interval (CI): 95% CI: 10.85; 21.17], $P < 0.001$) and posterior (MD: 17.52 kPa [95% CI: 15.17; 19.87], $P < 0.001$) tongue strength in healthy adults, with evidence of significant heterogeneity (I^2 = 96.3%; Tau^2 = 64.7; $P < 0.001$ and I^2 = 62.9%; Tau^2 = 5.9; P = 0.013, respectively) (*Figure* 1). Furthermore, tongue strength training resulted in significant improvements on anterior [MD: 7.33 kPa (95% CI: 2.12; 12.54), P = 0.006] and posterior [MD: 11.88 kPa (95% CI: 1.38; 22.38), p = 0.027] tongue strength in patients with dysphagia, with evidence of significant heterogeneity (I^2 = 96.3%; Tau^2 = 32.6; $P < 0.001$ and I^2 = 99.1%; Tau^2 = 109.1; $P < 0.001$, respectively) (*Figure* 2).

Overall effect of tongue strength training (between-group analysis)

Six studies involving patients with dysphagia[22,23,25–28] allowed us to perform a between-group meta-analysis to

Table 2 Intensity, exercise volume, frequency, and training period of lingual strength training programs

Study (reference #)	Period (week)	Frequency (times per week)	Intensity (%MVC)	Exercise volume			
				Time	RPS	SPD	Total repetition
Healthy adults							
Lazarus *et al.*[14]	4	5	100	2 s	10	5	50
Robbins *et al.*[4]	6	3	80 (60 first week)	NR	30	3	90
Clark *et al.*[15]	9	7	100	1 s	30	1	30
Clark[12]	4	3	100	NR	25	1	25
Oh[16]	8	3	80 (60 first week)	2 s	NR	1	NR (30 min)
Van den Steen *et al.*[17]	8	3	80	3 s	120	1	120
Van den Steen *et al.*[9]	8	3	100	3 s	120	1	120
	8	3	80	3 s	120	1	120
	8	3	60	3 s	120	1	120
Yano *et al.*[18]	8	3	80 (60 first week)	NR	30	3	90
Yano *et al.*[19]	8	3	80 (60 first week)	NR	30	3	90
Namiki *et al.*[20]	4	7	100	10s	5	2	10
Patients with dysphagia							
Robbins *et al.*[21]	8	3	80 (60 first week)	NR	20	3	60
Lazarus *et al.*[22]	6	5	100	2 s	10	5	50
Park *et al.*[23]	6	5	80	NR	50 for A/P	1	100
Aoki *et al.*[24]	3	5	80	NR	>50	1	>50
Steele *et al.*[25]	8–12	2–3	25–85	2–3 s	60	1	60
Moon *et al.*[26]	4	5	100	2 s	30	1	30
Kim *et al.*[27]	4	5	NR	NR	30 for A/P	1	60
Moon *et al.*[28]	8	5	NR	NR	30 for A/P	1	60

A/P, anterior and posterior sides; NR, not reported; RPS, number of repetitions per sessions; SPD, number of sessions per day; Time, contraction time; % MVC, percentage of maximum voluntary contraction; #, number.

compare the effects of therapy interventions vs. therapy plus tongue strength training on anterior and posterior tongue strength (evaluated by IOPI) (*Table* 3). The therapy plus tongue strength training resulted in superior improvements compared with only therapy on anterior [MD: 5.33 kPa (95% CI: 1.07; 9.58), P = 0.014] but not on posterior [MD: 6.85 kPa (95% CI: −2.60; 16.30), P = 0.155] tongue strength in patients with dysphagia. There was, however, evidence of significant heterogeneity (I^2 = 91.1%; Tau^2 = 20.0; $P < 0.001$ and I^2 = 96.8%; Tau^2 = 85.3; $P < 0.001$, respectively) (*Figure* 3).

Impact of training variables on anterior tongue strength

Training period

Five of the 10 studies (a total of seven training groups) reported time-course change in anterior tongue strength during the intervention in healthy adults.[4,9,16,17,19] Tongue strength increased gradually from the baseline to the final testing for all studies (*Figure* 4A). For example, a study by Yano *et al.*[19] measured maximal tongue strength every week during an 8-week intervention and found that increased strength during the first 4 weeks was higher than the following 4 weeks. Meanwhile, a study by Van den Steen *et al.*[17] reported a constant rate of the increment in tongue strength during the intervention. Tongue strength did not reach a plateau after at least 8 weeks of training. The results for the posterior tongue strength were identical.

Training frequency

The mean training frequency was four times a week in healthy adults and 4.4 times a week in patients with dysphagia. No studies were found that involved training at frequencies of less than three times per week. From the results of IOPI studies, the absolute and relative increases in anterior tongue pressure at frequencies of three times a week were, respectively, 19 kPa(SD 6) and 47% (SD 19) on average (eight training groups), which appears greater than that observed with other training frequencies such as five times a week [7 kPa (SD 6) and 23% (SD 20), respectively] (*Figure* 4B).

Exercise volume

The mean number of sessions a day was 2.2 and 1.8 in healthy adults and patients with dysphagia, respectively. Likewise, the mean total number of repetitions a day was 69 and 59, respectively, in healthy adults and patients with dysphagia. The study of Oh[16] did not report the number of repetitions in the training session. In the daily total repetitions (repetitions per session multiplied by number of sessions per day), eight data points (eight studies) were found in the range of 10–60 repetitions (low volume) and seven data points (five studies) in the range 90–120 repetitions (high volume). Using the results of IOPI studies, the average increases

Table 3 Lingual strength training-induced changes in lingual elevation strength in healthy adults and patients with dysphagia

Study (reference #)	Instrument/ position	Group	*n*	Lingual elevation strength (kPa) Pre-mean	Pre-SD	Post-mean	Post-SD	Mean change (% change)	Change SD	*P*-value
Healthy adults										
Lazarus *et al.*[14]	IOPI/Ant	Training	21	64.4	8.7‡	73.1	7.3‡	8.7 (13.5%)	8.7‡	<0.001
	IOPI/Ant	Control	10	69.8	17.7‡	71.2	17.1‡	1.4 (2.0%)	8.9‡	0.62
Robbins *et al.*[4]	IOPI/Ant	Training	10	41.0	NR	49.0	NR	7 (17%)	NR	0.001
Clark *et al.*[15]	IOPI/Ant	Training	39	61.9†	10.77†	65.6†	12.77†	3.7 (6%)	6.73	<0.001
Clark[12]	IOPI/Ant	Training	5	65.8	14.97	82.6	13.39	16.8 (25.5%)	7.91	NR
	IOPI/Ant	Control	5	66.8	13.18	73.6	10.06	6.8 (10.2%)	7.04	NR
Oh[16]	IOPI/Ant	Training	10	64.5	13.05	80.5	12.23	16 (24.8%)	6.97	<0.001
	IOPI/Post	Training	10	60.8	11.85	76.4	11.11	15.6 (25.7%)	7.11	<0.001
Van den Steen *et al.*[17]	IOPI/Ant	Training Ant	7	35.9	6.0	61.9	10.2	26.0 (72.4%)	6.0	<0.001
	IOPI/Post	Training Ant	7	32.3	3.7	51.6	8.7	19.3 (59.9%)	6.10	
	IOPI/Ant	Training Pos	9	33.8	7.9	38.9	9.9	5.1 (15.1%)	5.8	0.063
	IOPI/Post	Training Pos	9	28.3	6.1	41.0	8.7	12.7 (44.9%)	5.20	
Van den Steen *et al.*[9]	IOPI/Ant	Training 100	15	36.9	9.1	59.4	12.6	22.5 (61.0%)	6.83	<0.001
	IOPI/Ant	Training 80	16	34.1	8.0	54.7	7.7	20.6 (60.4%)	4.31	<0.001
	IOPI/Ant	Training 60	16	35.3	6.8	53.6	7.3	18.3 (51.8%)	3.85	<0.001
	IOPI/Ant	Control	13	39.2	9.9	44.5	11.7	5.3 (13.5%)	6.16	0.015
	IOPI/Post	Training 100	15	30.2	8.3	52.7	12.3	22.5 (74.5%)	7.40	<0.001
	IOPI/Post	Training 80	16	34.0	7.6	51.1	9.9	17.1 (50.3%)	5.82	<0.001
	IOPI/Post	Training 60	16	32.8	4.4	50.3	8.1	17.5 (53.4%)	5.22	<0.001
	IOPI/Post	Control	13	34.6	8.7	38.9	12.3	4.3 (12.4%)	7.32	0.073
Yano *et al.*[18]	JMS/Ant	Training	7	44.9	5.4	61.6	4.3	16.7 (37.2%)	1.33	<0.05
Yano *et al.*[19]	IOPI/Ant	Training	11	55.5§	10.1§	79.4§	10.1§	23.9§ (43.1%)	5.53§	0.027
	IOPI/Post	Training	11	42.4§	11.9§	61.7§	13.0§	19.3§ (45.5%)	7.75§	0.047
Namiki *et al.*[20]	JMS/Ant	Training	18	31.5	8.9	34.3	8.4	2.8 (8.9%)	1.43	0.002
Patients with dysphagia										
Robbins *et al.*[21]	IOPI/Ant	Training	10	35.6	NR	51.8	NR	16.2 (45.5%)	NR	<0.001
	IOPI/Post	Training	10	30.2	NR	54.6	NR	24.4 (80.8%)	NR	<0.001
Lazarus *et al.*[22]	IOPI/Ant	Control	10	49.3	10.53	52.4	10.78	3.1 (6.3%)	5.85	0.335
	IOPI/Ant	Training	8	44.63	13.39	46.5	16.5	1.87 (4.2%)	8.72	0.571
Park *et al.*[23]	IOPI/Ant	Control	14	22.0	5.74	22.86	5.36	0.86 (3.9%)	3.06	<0.05
	IOPI/Post	Control	14	17.29	4.3	17.71	4.36	0.42 (2.4%)	2.67	NS
	IOPI/Ant	Training	15	18.93	6.75	20.73	6.61	1.8 (9.5%)	3.66	<0.01
	IOPI/Post	Training	15	16.2	4.69	18.47	4.09	2.3 (14.2%)	2.77	<0.01
Aoki *et al.*[24]	JMS/Ant	Training	17	18.4	11.5	23.5	12.5	5.0 (27.2%)	3.4	<0.001
	JMS/Ant	Control	14	26.1	10.7	27.7	11.9	1.6 (6.1%)	5.1	0.25
Steele *et al.*[25]	IOPI/Post	Training	7	31.84†	8.59†	46.04†	13.81†	14.2 (44.6%)	95%CI: 8–29	<0.01
Moon *et al.*[26]	IOPI/Ant	Training	8	21.7	2.3	26.5	2.7	4.8 (22.1%)	1.49	<0.05
	IOPI/Ant	Control	8	21.2	4.4	21.8	4.4	0.6 (2.8%)	0.92	NS
Kim *et al.*[27]	IOPI/Ant	Training	18	32.67	10.78	41.89	9.54	9.22 (28.2%)	6.73	<0.001
	IOPI/Post	Training	18	28.06	7.56	39.11	7.8	11.06 (39.4%)	4.37	<0.001
	IOPI/Ant	Control	17	29.65	10.41	32.53	10.17	2.88 (9.7%)	3.38	0.003
	IOPI/Post	Control	17	26.59	9.13	31.41	9.74	4.82 (18.1%)	5.97	0.004
Moon *et al.*[28]	IOPI/Ant	Training	8	31.38	5.68	49.75	5.26	18.37 (58.5%)	4	0.012
	IOPI/Post	Training	8	28.5	4.75	50.13	4.32	21.63 (75.9%)	2.33	0.011
	IOPI/Ant	Control	8	32.25	5.37	35.5	6.35	3.25 (10.1%)	3.41	0.041
	IOPI/Post	Control	8	29.75	4.37	32.13	4.09	2.38 (8.0%)	3.66	0.127

Ant, anterior tongue pressure; IOPI, Iowa Oral Performance Instrument; JMS, JMS Tongue Pressure Measurement Device; kPa, kilopascal; NR, not reported; NS, non-significant; Post, posterior tongue pressure; SD, standard deviation; 95%CI, 95% confidence interval.

†Extrapolated from graph.

§Data were sent by the corresponding author.

Standard deviation (SD) of the change score was not provided, so we calculated it by first obtaining the reliability coefficient from previous studies[29,30] using the same tongue strength evaluation method. We calculated the SD of the posterior thong strength change from the mean value of the three reliability coefficients (r = 0.81) reported in a previous study[29] which used the IOPI to evaluated tongue strength. For all other studies which measured anterior thong strength with IOPI and did not reported the SD of the change, we used the mean value of the three reliability coefficients (r = 0.85) reported in a previous study.[29] As only two studies[18,20] (from those which did not reported the SD of the change) used a different anterior tongue strength evaluation method (JMS Tongue Pressure Measurement Device) other than the IOPI, we used it respective reliability coefficient (r = 0.988) from a previous study[30] to calculated the SD of the tongue strength change. When the change score SD was not reported, it was calculated using the following formula[31]:

$$SD_{change\ score} = \sqrt{\left(SD_{pre-test}^{2} + SD_{post-test}^{2}\right) - \left(2r \times SD_{pre-test} \times SD_{post-test}\right)}$$

Figure 1 Effect of tongue strength training on *(A)* anterior and *(B)* posterior tongue strength in healthy adults. MD, mean difference; CI, confidence interval; %1RM, percentage of one repetition maximum.

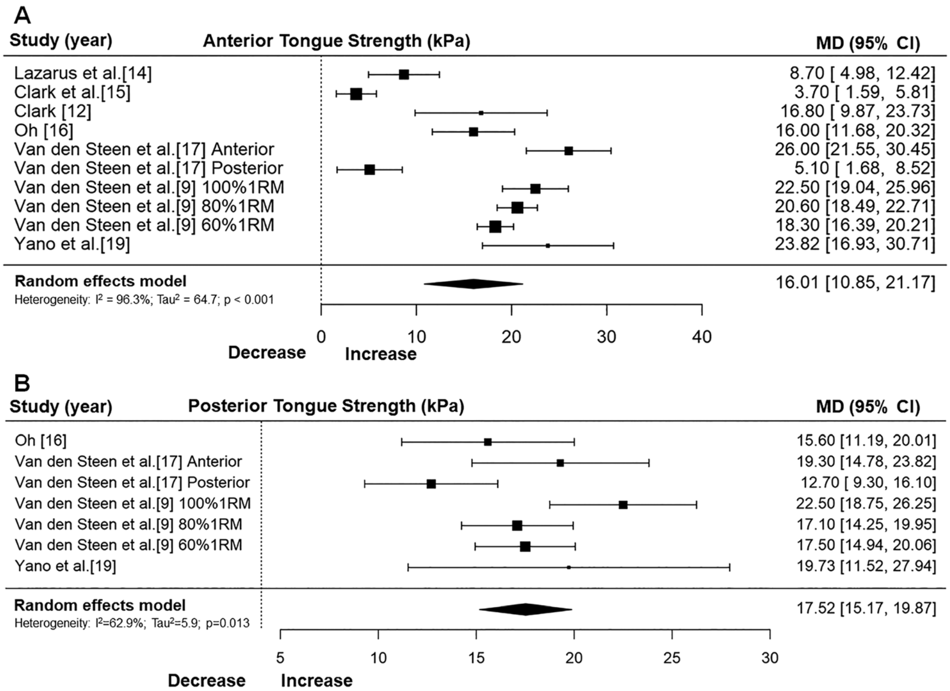


Figure 2 Effect of tongue strength training on *(A)* anterior and *(B)* posterior tongue strength in patients with dysphagia. MD, mean difference; CI, confidence interval.

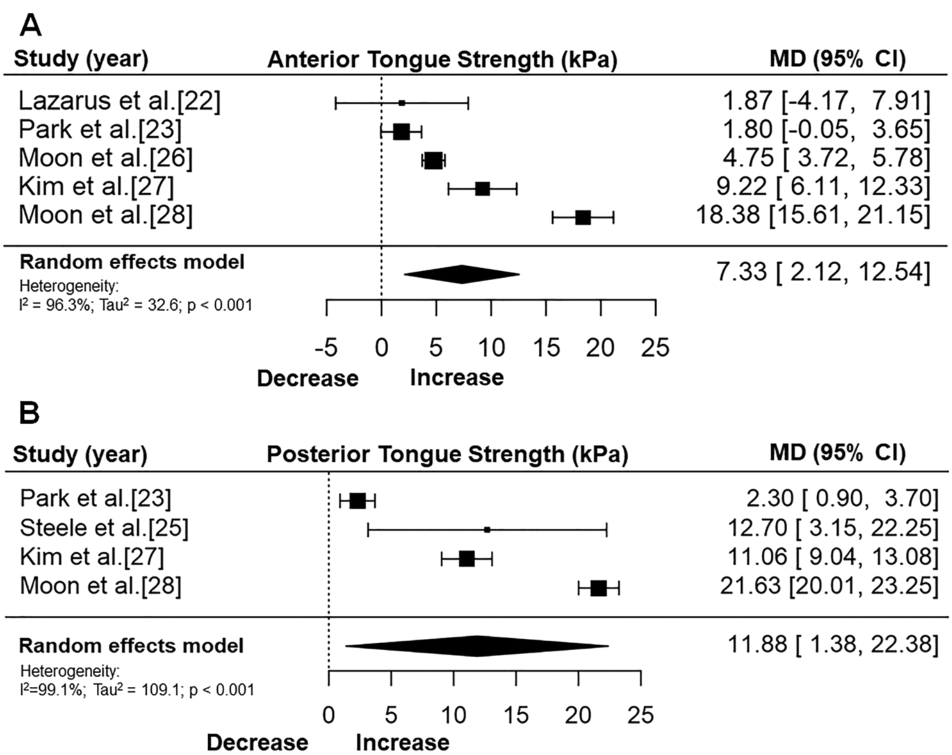
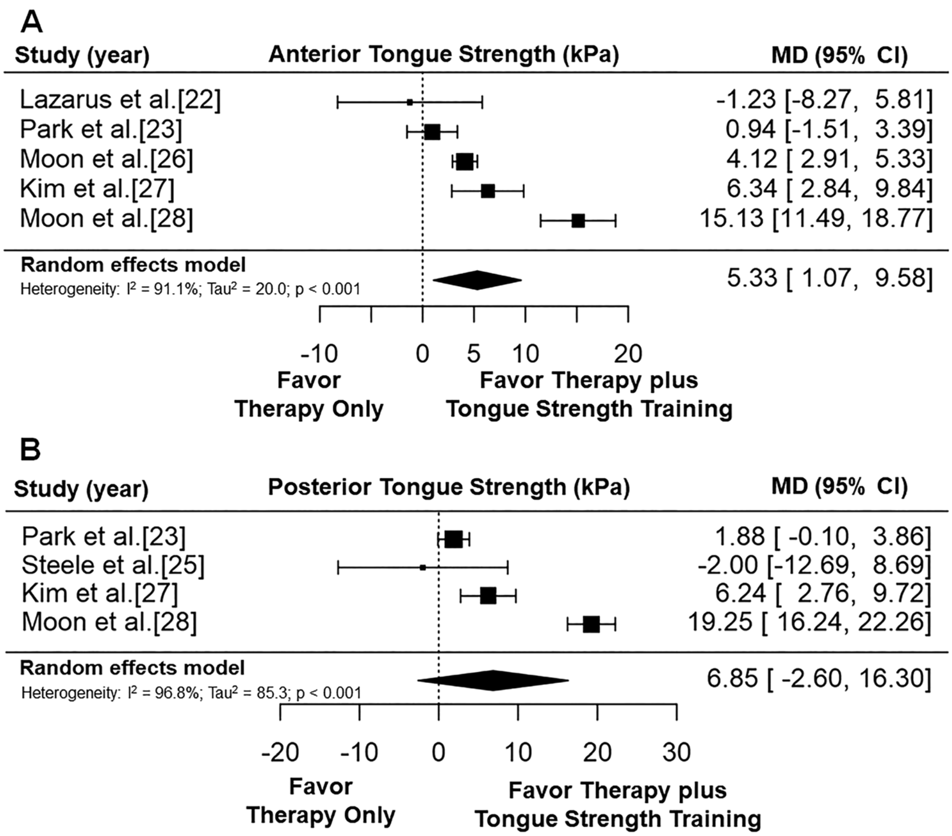


Figure 3 Comparison of only therapy interventions vs. therapy plus tongue strength training on *(A)* anterior and *(B)* posterior tongue strength in patients with dysphagia. MD, mean difference; CI, confidence interval.



in absolute and relative anterior tongue strength were 10 kPa (SD 6) and 25% (SD 19) in the low volume and 17 kPa (SD 9) and 45% (SD 24) in the high volume (*Figure* 4C).

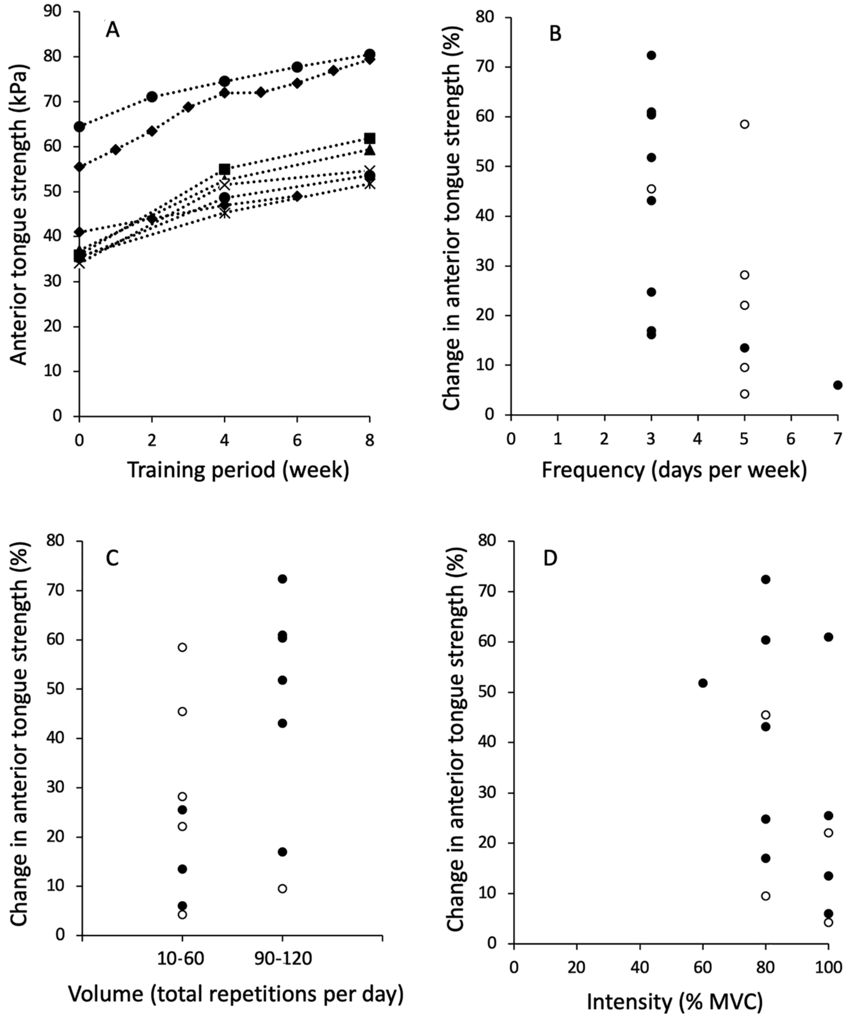
Exercise intensity (load)

No studies were found that involved training at intensities of less than 60% of MVC. A study by Van den Steen *et al.*[9] compared the effect of tongue resistance training using three different exercise intensities (60%, 80%, and 100% of MVC). Eight studies (five studies in healthy adults and three studies in patients with dysphagia) used an exercise intensity of 80% of MVC,[4,16–19,21,23,24] and six studies (four studies in healthy adults and two studies in patients with dysphagia) used 100% of exercise intensity.[12,14,15,20,22,26] From the results of IOPI studies, the average increases in absolute and relative anterior tongue strength were 10 kPa(SD 8) and 22% (SD 21) in 100% of MVC (six studies), 16 kPa (SD 9) and 39% (SD 23) in 80% of MVC (seven studies), and 18 kPa and 52% in 60% of MVC (one study) (*Figure* 4D).

Changes in swallowing function following tongue strength training

Eleven (four studies in healthy adults[4,16,18,20] and seven studies in patients in dysphagia[21–25,27,28]) of the 18 studies evaluated the changes in swallowing pressure and/or swallowing function following isometric tongue elevation strength training. Oral pressure generated during swallowing increased after tongue strength training in healthy adults[4,16] and patients with dysphagia.[21,24] Videofluoroscopic imaging has been used to assess the training-induced changes in swallowing function including pharyngeal transition time, penetration-aspiration scale (PAS) score, normalized residue ratio scale (NRRS), and Mann Assessment of Swallowing Ability (MASA). In asymptomatic older adults, one study[4] reported no significant changes in swallowing function (i.e. pharyngeal transition time, PAS score, and NRRS) after 8 weeks of tongue strength training. However, that study observed a relatively small increase in anterior tongue strength (pre-41 kPa and post-49 kPa). Meanwhile, a recent study[20] found tongue training-induced improvements of pharyngeal transition time

Figure 4 Relationships between different strength training variables (i.e. training period, intensity, volume, and frequency) and the change in anterior tongue elevation strength. Time-course change in anterior tongue strength during experimental period in each training group *(A)*. Percentage changes in anterior tongue strength because of differences in training frequency *(B)*, exercise volume *(C)*, and intensity *(D)*. Filled circles indicate healthy adults and open circles indicate patents with dysphagia (B, C, and D). %MVC, percentage of maximum voluntary contraction.



and PAS score. Neither study included a control group. In studies involving patients with dysphagia, the training group received standard care plus tongue strength training whereas the control group received standard care only. Therefore, improvement of swallowing function was observed in both training and control groups. However, a few studies showed that those improvements of the training group were higher than the control group.[24,27]

Discussion

To the best of our knowledge the current review is the first to provide information about the impact of resistance training variables (i.e. training period, intensity, volume, and frequency) on the change in tongue strength following tongue resistance training in adults with and without dysphagia. Our findings demonstrated that (i) tongue strength training in healthy adults improved anterior and posterior tongue strength; (ii) tongue strength training also improved anterior and posterior tongue strength in patients with dysphagia; (iii) only anterior tongue strength increased following tongue strength training when compared with the control group in patients with dysphagia; and (iv) although there is a lack of studies to determine the impact of training variables on the effects of tongue strength training, dose–response relationships did not appear in training frequency and intensity, but tongue strength gradually increased according to the training period of at least 8 weeks.

Task specificity

A study reported by Clark[12] demonstrated task specificity for tongue strength training in comparison with endurance, speed, and power targeted exercise training. Interestingly, a recent study[17] observed that although anterior or posterior targeted tongue strength training improved maximal tongue strength, targeted anterior training results in a much larger gain than that of targeted posterior training when measured strength in both target places. In this review, all but one study (only targeted anterior movement)[19] utilized a training program that involved targeted anterior and posterior tongue elevation movements in healthy adults and patients with dysphagia. Our findings indicated that both anterior and posterior strength were improved by tongue strength training in healthy adults and patients with dysphagia. However, as the number of studies is limited and the number of patients is low in those with dysphagia, additional research is needed to reconfirm the results.

Training variables

A crucial stimulus for maintaining and/or increasing muscular strength is the types of resistance exercise training. To potentiate the muscular strength response, resistance training guidelines advise the appropriate training conditions involving variables such as the type of muscle contraction (i.e. isometric, concentric, or eccentric contractions), exercise load, training volume, inter-set rest interval, and training frequency.[32,33] The training conditions of these guidelines are based on dynamic repetitive exercise of the limb and trunk muscles, and exercise load is based on percentage of 1RM and repetitions up to, or close to, failure. In this review, we selected the studies which used isometric contraction for tongue strength training. Although a few studies investigated the effect of dynamic tongue movement training (e.g. tongue rotation and gum chewing),[34,35] these studies were excluded because the main training variables (e.g. intensity and number of repetitions) were not reported. Therefore, when comparing training effects between tongue muscle and limb skeletal muscle, it is necessary to discuss with consideration of the contraction mode.

Intensity and duration of isometric contraction

A classical study investigating the effect of isometric training in the limb muscles revealed that the maximum training effect was achieved by over 40–50% of MVC (discussed in the following book[36] on p. 29). This is echoed in a recent review which suggests that isometric strength training of the limb musculature should be performed at 80–100% of MVC to produce maximal changes in strength.[37] Although there are currently no studies that included training at intensities less than 60% of MVC, tongue strength training-induced enhancement of tongue elevation strength was similar among 60%, 80%, and 100% of MVC.[9] There was also only a single study that included 60% of MVC. At this time, it cannot be determined what intensity is most effective for increasing tongue muscle strength. Future research is needed on minimal threshold values that can provide training effects on tongue strength, and whether there is a dose–response relationship.

The next training variable to be considered is the duration of isometric muscle tension. In the study of limb muscles, Schott *et al*.[38] compared the effects of two different contraction times of isometric knee extension training using continuous (4 × 30 s) and intermittent (4 × 10 × 3 s) contractions with 70% of MVC. The authors found that both protocols increased isometric strength, but the change was greater in the continuous (54.7%) than that of intermittent (31.5%) protocol. In the previous studies of tongue strength training, the most common contraction time was 2–3 s in both healthy adults and patients with dysphagia. Tongue contraction time ranged from 1[15] to 10 s[20] in healthy individuals, and from 2 to 3 s[22,25,26] in patients with dysphagia. Therefore, there is no study comparing the effects of continuous and intermittent tongue contractions on tongue elevation strength with maximum or submaximal intensity (e.g. 70–80% of MVC). The study investigating the limb muscles found that it is unnecessary to maintain muscle tension up to muscle fatigue in order to stimulate increased muscle strength.[36,37] However, it is necessary to confirm whether a contraction time of 2–3 s is sufficient to elicit maximal changes in tongue strength.

Number of sessions per day and exercise volume

Traditional resistance training for the limbs and trunk does not typically involve multiple training sessions during a 24-h period.[32,33] In regard to tongue strength training, seven studies[4,14,18–22] used a training program with multiple sessions a day (2–5 sessions). For this reason, exercise volume in this review was calculated as a total number of repetitions (repetitions per session multiplied by the number of sessions) during the training day. We found that when compared between high volume and low volume, the higher exercise volume may be an advantage to improve tongue strength following training. However, because of the small number of studies available, it was not possible to determine if a dose–response relationship existed. In addition, when the total number of repetitions was the same, it was unclear as to whether the number of repetitions within the session or the number of sessions specifically should be increased to improve tongue strength.

Frequency and duration of training

The current guidelines for the American College of Sports Medicine on resistance training recommend that novice and moderately trained individuals train two to three times per week for each muscle group.[33] A recent meta-analysis showed a significant effect of training frequency on muscle strength gains. However, when using volume-equated studies, there was no significant effect of frequency on strength gains.[39] On the other hand, a classical study investigating isometric strength training in the limb muscles suggests that the maximum increase in muscle strength was obtained with seven training sessions per week.[36] In this review, our findings indicated that a frequency of three times per week produced greater changes in tongue strength compared with training frequencies such as five times a week. However, the most common frequency was three times a week in healthy adults and five times a week in patients with dysphagia. This observation related to frequency could be greatly impacted by the results of patients with dysphagia, which only found small changes. Future studies may wish to consider the most effective training frequencies between healthy adults and patients with dysphagia specifically.

Our findings demonstrated that tongue strength gradually increased from baseline to the end of the study and without reaching a plateau after at least 8 weeks of continued training. Similar results were observed in short-term[40–42] and long-term[43,44] resistance training studies. For example, a study investigating the effects of whole-body resistance training on muscle strength of the upper body, trunk, and lower body and found that increased strength during the first 10 weeks was higher than subsequent changes, but strength continued to increase during a 52-week training period.[42] These results would suggest that tongue strength is expected to increase after 8 weeks of tongue strength training, but questions remain on temporal points to where a plateau might appear.

Training-induced changes in tongue strength and swallowing function

During the oral phase of liquid and/or food swallowing, the tongue holds the bolus in place on its dorsal surface and produces a squeezing pressure, moving the bolus backward towards the pharynx.[45] The swallowing mechanism is a submaximal strength activity, and the pressure generated by the tongue during swallowing is similar between healthy young and older adults.[46,47] Therefore, when isometric tongue strength decreases with age, older adults with asymptomatic conditions have a lower functional reserve of swallowing.[46] In this review, we found that tongue strength training improved not only the tongue muscle strength but also effortful swallowing pressure in healthy adults[4,16] or swallowing functions assessed by videofluoroscopy in patients with dysphagia.[24,27] The relationship between change in tongue strength and change in swallowing function associated with tongue strength training has not been fully investigated. Only two studies reported the correlations between tongue strength and index of swallowing function using at baseline and follow-up.[20,22] A related study by Clark and Shelton[48] investigated the effects of training programs of effortful swallow combined with high-effort sips from straws or tongue elevation exercise on linguaparatal pressure in healthy adults. The reported correlation coefficients between the training-induced change in linguapalatal pressure during effortful swallowing and training-induced changes in anterior and posterior tongue strength were $r = 0.247$ ($P = 0.062$) and $r = 0.298$ ($P = 0.031$), respectively. Therefore, no strong correlation was found between the two variables. The magnitude of the correlations may relate to factors such as the change among the participants (large or small variations) and the degree of measurement error.

Tongue elevation strength (pressure) is detected as a force that presses the tongue against the upper jaw. This action is caused by the elevation of the hyoid which acts as a contraction of the suprahyoid muscles.[49] The suprahyoid involves four muscles with different actions including widening the oesophagus during swallowing (*m*. geniohyoid).[50] A study investigated the relationship between tongue elevation pressure and electromyographic measured muscle activity in the suprahyoid muscles using bipolar hooked wire electrodes and found that the tongue pressure was correlated with the activity of the suprahyoid muscles include the geniohyoid.[51] These results suggest that it is reasonable that tongue strength training could enhance suprahyoid muscles, resulting in improved swallowing mechanisms. In addition, a few studies measured the training-induced change in tongue muscle size.[4,52] In limb muscle studies, when discussing changes in muscle strength, muscle size is also traditionally measured. However, we have recently proposed that training-induced changes in muscle size do not contribute to the changes in muscle strength in the limb muscles.[53,54] Thus, even if the size of the tongue muscle does not change, the muscle strength of the tongue may change sufficiently.

Conclusion

In this review, we evaluated the relationships between strength training variables for the tongue (i.e. training period, intensity, volume, and frequency) and the change in tongue elevation strength (pressure). Our findings showed that tongue strength training improved anterior and posterior tongue strength in both healthy adults and patients with dysphagia. Anterior and posterior tongue strength gradually increased and did not reach a plateau after at least 8 weeks of training. Data for other variables were insufficient to draw clear conclusions. Available data suggest that a training intensity of 60–100% of maximum tongue strength, a contraction time of 2–3 s, a total number of 90–120 repetitions per day, and a training frequency of three times per week appears to result in an improvement in maximal isometric tongue elevation strength in adults with and without dysphagia. Future studies are needed to better determine if there are dose–response relationships in tongue strength training in healthy adults and patients with dysphagia.

Ethical standards

All authors certify that they comply with the ethical guidelines for authorship and publishing as laid down by the *Journal of Cachexia, Sarcopenia and Muscle*.[55]

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Conflict of interest

Takashi Abe, Ricardo B. Viana, Vickie Wong, Zachary W. Bell, Robert W. Spitz, Yujiro Yamada, Robert S. Thiebaud, and Jeremy P. Loenneke have no conflicts of interest relevant to the content of this review.

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