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Title page

Title: Relationship between tongue pressure and hand-grip strength: A systematic review and meta-analysis

Running Title: A systematic review of tongue pressure and hand strength

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Author contribution

Itsuka Arakawa-Kaneko initiated the study together with Samir Abou-Ayash and Martin Schimmel, and conceptualized and designed the study, collected and analyzed data, drafted and

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revised the manuscript. Yuko Watarai contributed to data collection, and analysis during the systematic search. Martin Schimmel contributed to the conception and design of the study, and critically revised the manuscript. Samir Abou-Ayash contributed to the conception and design of the study, analyzing data, and critically revised the manuscript.

Conflict of interests
The authors have no conflict of interests to declare.

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Abstract

Objectives: Muscle strength decreases with age, causing a decline in physical and oro-facial function. However, the impact of physiological and pathophysiological factors on tongue pressure (TP) has not been clarified. The purpose of this systematic review and meta-analysis was to compare and analyze TP and hand-grip strength (HGS) between individuals aged <60 years and ≥60 years, gender, and need for care (independent older adults (IC) and older adults receiving nursing-care (NC)). Furthermore, the effect of HGS in physical function on TP was examined.

Methods: Human clinical studies reporting HGS and TP were searched systematically using PubMed and Ichushi-Web published from 1969 to Nov 2021. Random-effects meta-regressions were performed to compare between subgroups and to examine the association between HGS and TP ($\alpha<0.05$).

Results: Forty-four studies with a total of 10343 subjects were included. TP and HGS values were significantly higher in people aged <60 years relative to ≥60 years, and in IC relative to NC (all p<.001). Regarding gender, there was no significant difference in TP (p=.370). However, a significant gender-dependent difference in TP was observed in people aged <60 years (p<.001), but not in aged ≥60 years in IC group (p=.118) and aged ≥60 years in NC group (p=.895). There was a significant positive correlation of HGS and TP (p<.001).

Conclusions: Similar to decrease in HGS, age-related sarcopenia seems to have an effect on oro-facial muscles like the tongue. Research on rehabilitation measures for oro-facial muscle strength, similar to HGS might be beneficial to improve the personally acquired oro-facial potential.

(251 words)

Keywords: Tongue, Pressure, Hand Strength, Muscle Strength, Geriatric Dentistry, Frailty.

1. Introduction

As a result of the global trend of an aging population, nursing care needs will grow correspondingly.[1] In this situation, frailty adults are at risk for falls, hospitalization, disability, and death.[2] The most well-known model of the frailty phenotype was proposed by Fried et al, and their criteria for physical frailty are based on: unintentional weight loss, self-reported exhaustion, low physical activity, slow walking speed, and weakness (hand-grip strength (HGS)).[2] Falling into a frailty cycle leads to a vicious circle of sarcopenia and decreased general function.[2,3] Most frail older adults exhibit sarcopenia, and some older adults with sarcopenia are frail.[4] Primary sarcopenia is considered to be age-related loss of skeletal muscle mass or quantity, muscle strength and physical performance, while secondary sarcopenia is progressive generalized muscle weakness secondary to disease, malnutrition and inactivity.[5] Sarcopenia is often assessed with HGS for muscle strength, skeletal muscle mass index (SMI) for muscle mass and gait speed for physical performance.[5] As sarcopenia progresses, metabolism and consumed energy decrease, and then appetite (food intake) decreases, causing weight loss and malnutrition, further promoting sarcopenia. Several studies have reported that systemic sarcopenia and frailty are associated with decreased oro-facial function in older adults.[6-8].

The decline in oral function with aging is predicted to affect the decline in nutritional status and physical function.[6,9] A recent study has proposed that in line with the Meikirch model for health, that there is an age-related decline of the biologically given potential of the oro-facial system during physiological ageing processes.[10] The management of oral hypofunction is expected to delay the need for nursing care and contribute to the extension of healthy life expectancy. Diagnosis of oral hypofunction is necessary prior to management, which allows for a comprehensive assessment of oral function. There are seven criteria for diagnosis of oral hypofunction proposed by the Japanese Society of Gerodontology: oral cleanness, oral dryness, lip and tongue motor function, tongue pressure (TP), occlusal force, masticatory function and swallowing function.[11] Moreover, previous studies have examined the associations between oral health and sarcopenia[12], oral function and sarcopenia[13-16], swallowing muscles and sarcopenic dysphagia[17,18], oral function and physical performance[19-23], oral function and cognitive function[24] and oral function and polypharmacy[7]. Especially, TP and tongue thickness, which are sensitive markers for oral frailty, decrease with age.[25] However, the association between general physiology and pathophysiological factors on TP has not been clarified.

Hence, we focused on muscle strength, hypothesizing that age-related decline in physical muscle strength represented by HGS could equally be found in TP, and analyzed the effects of age, gender and the need for care. This systematic review and meta-analysis designed to evaluate the relationship between HGS and TP among aged <60 years and ≥60 years. The null-hypothesis was that there would be no correlation between HGS and TP in people older and younger than 60 years. Furthermore, the influence of gender, need for care (independent older adults (i.e., without need for care) (IC) vs. older adults receiving nursing care (NC)) and measuring device was analyzed as secondary outcomes.

2. Materials and Methods

2.1 Protocol and registration

This systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[26] The PRISMA checklist is provided in the Appendix S1. The focused question was designed based on the PICO format (P: population, I: intervention, C: comparison, O: outcome) as follows: P (general populations), I (physiology), C (pathophysiology), and O (TP). Accordingly, the PICO question was: ‘In patients younger or older than 60 years, is there an association between TP and general physiology and pathophysiology.' This study protocol for the systematic review and meta-analysis was registered in PROSPERO (registration number CRD42020187265).

2.2 Eligibility criteria

Studies were eligible if they met the following inclusion criteria: (a) human clinical studies (randomized controlled trials (RCTs), non-randomized controlled trials (non-RCTs), cross-sectional studies, cohort studies, case-control studies), (b) subjects over 18 years of age, (c) studies with more than 10 subjects in study arm or group, (d) studies with TP values assessed with the JMS tongue strength measurement device (JMS) (JM-TPM; JMS Co., Ltd., Hiroshima, Japan) or Iowa Oral Performance Instrument (IOPI) (IOPI; IOPI Medical LLC, WA, USA), (e) studies reporting HGS in kg or kgf, (f) publications in English, German, or Japanese.

Studies were excluded if they met the following criteria: (a) *in vitro* or animal studies, (b) subjects younger than 18 years old or age not reported (c) fewer than 10 subjects in each relevant study arm/group, (d) insufficient documentation of TP and HGS, (e) measurement of TP in units other than kPa, (f) TP during swallowing, (g) publications not written in English, German, or Japanese.

2.3 Search strategy

Two reviewers (SAA and IA) searched electronically in the PubMed/MEDLINE and the Japanese database Ichu Shi-Web for publications in English, German, and Japanese between 1969 and Nov 30th, 2021. In the initial search, the following search terms and combinations were applied: ((patient OR population OR subject OR people OR individuals) AND (condition OR muscle OR body OR capacity OR power OR performance OR physiology OR pathophysiology) AND ("tongue strength" OR "tongue pressure" OR "tongue force" OR "lingual pressure")). An additional hand search was carried out on the reference lists of related review articles dealing with similar topics in the following journals: Dysphagia, Journal of

Speech, Language, and Hearing Research, Journal of Medical Speech-language Pathology, Archives of otolaryngology-head & neck surgery, Seminars in Speech and Language, Perspectives on Swallowing and Swallowing Disorders (Dysphagia), Journal of Motor Behaviour, Journal of the American Geriatrics Society, Archives of Physical Medicine and Rehabilitation. Collecting references and eliminating duplicates were performed using a reference manager software (EndNote X8®).

2.4 Study selection and data extraction

Duplicate articles were removed, and the titles and abstracts of the remaining articles were screened independently by two reviewers (IA, YW) according to the eligibility criteria. Next, the full-text articles that met eligibility criteria were evaluated by the same reviewers and the reasons for exclusion were noted. Studies with insufficient data, unstable subjects, etc., were finally excluded for meta-analysis. Disagreements between two reviewers regarding included studies were discussed and resolved by a third reviewer (SAA).

After the full texts screening, a first reviewer (IA) collected the following extracted data from all applicable studies and recorded them in a spreadsheet software (Excel, Microsoft Office 2017): authors, year of publication, sample size, age, gender, TP and HGS values (mean, minimum, maximum), TP measuring device (JMS or IOPI), need for care (IC or NC), and study design. The second reviewer (YW) checked the extracted data. Discordance in data extraction between these two authors were discussed and decided in consultation with a third reviewer (SAA). Kappa score was calculated to identify the level of agreement between internal reviewers.

2.5 Risk of bias in individual studies

The methodological quality was evaluated individually by two authors (IA, YW) using the Newcastle-Ottawa-Scale (NOS)[27] for the included observational studies and the Cochrane risk of bias tool[28] for the included RCTs and non-RCTs. The NOS was used to assess the quality of observational studies, including case-control studies, cohort studies and cross-sectional studies, in three major domains: selection (four items), comparability (one item), and exposure (three items for case-control study) or outcome (three items for cohort study and cross-sectional study). Each item was given a certain number of stars if the study met the criteria. Studies with 7 to 10 stars corresponded to high quality, 4 to 6 stars to intermediate quality, and 1 to 3 stars to low quality. The Cochrane risk of bias tool is a domain-based assessment comprising the seven 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 "low risk of bias", "high risk of bias", or "unclear risk of bias".

2.6 Data synthesis and Statistical analysis

All statistical analysis was conducted using Stata/IC 16.0 for Unix (StataCorp LLC 4905 Lakeway Drive, College Station, TX 77845, USA), with two-sided at a significance level of 0.05. For the analysis, the results were sorted and processed into subgroups according to participant age, gender, TP measuring device type and need for care. Unweighted TP and HGS values from each included study were aggregated for each subgroup and calculated as mean, standard deviation (SD), median, minimum, and maximum values, respectively. A test of homogeneity was performed for this meta-analysis. A random-effects meta-regression was applied to TP and HGS, respectively, to estimate weighted mean (EWM) with a 95% confidence interval (95% CI) for the various subgroups as well as estimating weighted mean difference (WMD) between subgroups and inter-subgroup comparison, including age (<60 years vs. ≥60 years), device (JMS vs. IOPI), gender (men vs. women), and need for care (IC vs. NC). Additionally, the effect of HGS on TP was analyzed using a random- effects meta-regression with TP as dependent variable and HGS as independent variable. The results were presented as coefficients, 95% CIs, p-values and the adjusted R^2 (%), which indicates the proportion of between study variance of mean TP explained by mean HGS. Individual mean TPs and HGSs, estimated overall mean TPs and HGSs, their 95% CIs and the weights of each study were provided as forest plots.

3. Results

3.1 Study selection

The systematic electronic search found 1376 articles and the hand search found 47 articles, resulting in a total of 1423 articles identified. After removing 71 duplicate articles, 1352 titles were screened independently by two reviewers (IA and YW) to assess their suitability for the inclusion criteria, and 767 abstracts were assessed for further screening. The remaining 116 articles were assessed in full text, and 72 articles were excluded since they did not meet the eligibility criteria due to the following reasons: insufficient data (58 articles), incorrect unit (6 articles), no measuring device mentioned (3 articles), ineligible subjects (5 article). Finally, a total of 44 articles were eligible and included in the qualitative and quantitative synthesis in this systematic review and meta-analysis. The Kappa scores indicated high agreement, between the two reviewers (title: κ= 0.88, abstract: κ= 0.88, full-text: κ= 0.92). The flow diagram of the literature search and screening process is shown in Figure 1. The included and excluded studies during data extraction are listed in the Appendix S2.

3.2 Study characteristics

A total of 10343 subjects' data in 44 studies published between 2013 and 2021 were analysed. Extracted data for subjects <60 years of age (young) were reported in seven studies included 829 subjects with a mean age of 31.4±11.9 [range 19.7-53.5] years, and those for subjects ≥60 years (older adults) were in 41 studies included 9514 subjects with a mean age of 76.9±5.2 [range 66.2-88.0] years. In regard to gender, a total of 5767 data were analysed: 2015 men (17 studies) and 3752 women (23 studies). In regard to the TP measuring device, 549 subjects (3 studies) were assessed with the IOPI, and 9794 subjects (41 studies) were assessed with the JMS. In regard to need for care, there were 28 studies included 8270 subjects with IC and 14 studies included 1244 subjects with NC. Table 1a summarize the characteristics of the included studies. An overview of the unweighted synthesis values, separated by age, gender, measuring device, need for care, and the combination of those parameters (JMS data only) is presented in Table 1b for TP and in Table 1c for HGS. The mean TP assessed with JMS of individual studies, their 95% CIs and their weights and the estimated overall mean TP for combinations of age and need for care are described as forest plots, HGS are drawn as well (Appendix S3).

3.3 Quality Assessment

In the quality assessment, 39 cross-sectional studies, two before and after studies, one prospective cohort study, one RCT and one non-RCT were evaluated. 42 analytical studies were assessed with NOS (Table 2a); 6 studies (14.3%) were considered low quality, 27 studies (64.3%) intermediate and 9 studies (21.4%) high quality. One RCT was rated as having a low risk of bias or unclear risk of bias and one non-RCT was rated as having a high risk. (Table 2b).

3.4 Synthesis of results

3.4.1 Tongue Pressure

Regarding analysis of age group, the WMD between young and older groups was 11.5 kPa (SE: 2.13 kPa), indicating that TP was significantly higher in subjects <60 years ($p < .001$). Regarding analysis of measuring device, the TP value assessed with the IOPI was significantly higher than those with the JMS, with a WMD of 15.9 kPa (SE: 2.36 kPa) ($p < .001$). Analyzing the TP values measured with the JMS only among IC for both genders, significantly higher TP values were found in the younger group than in the older adults' group for both men ($p < .001$) and women ($p = .001$).

In terms of TP, there was no difference between men and women (WMD: -1.8 kPa; SE: 1.97 kPa; $p = .370$). However, when the gender differences in TP values measured with the JMS were analyzed in combination with age and need for care, a significantly higher TP was found in men than in women in the younger IC ($p < .001$), whereas there was no significant gender difference in older adults' IC ($p = .118$) and in older adults' NC ($p = .895$).

Regarding analysis of need for care, TP was significantly higher in the IC compared to in the NC, with a WMD of -8.8 kPa (SE: 1.2 kPa) ($p < .001$). When analyzing the difference in TP values of older adults measured with JMS between IC and NC, TP was significantly higher in the IC than in the NC for both men and women (both $p < .001$). Table 3a provides a detailed overview on the EWM TP for each group and the WMD between groups.

3.4.2 Handgrip strength

Regarding age group, the WMD between young and older adults' groups was 8.7 kg (SE: 2.24 kg), indicating that HGS was significantly higher in subjects <60 years ($p < .001$). Furthermore, a significantly higher HGS values among IC were found in younger group than in older adults' group both for men ($p = .001$) and women ($p = .003$).

Regarding gender, the HGS was significantly higher in men than in women (WMD: -10.5 kg; SE: 1.54 kg; $p < .001$). Analyzing the gender differences in combination with age and need for care, a significantly higher HGS was shown in men than in women in the younger IC, in older adults IC and in older adults NC (all $p < .001$).

Regarding need for care, the HGS was significantly higher in the IC compared to the NC, with a WMD of -9.0 kg (SE: 1.41 kg) ($p < .001$). When analyzing the difference in HGS values between IC and NC in older adults, HGS was significantly higher in the IC than in the NC for both men and women (both $p < .001$). Table 3b provides a detailed overview on the EWM HGS for each group and the WMD between groups.

3.4.3 Effect of handgrip strength on tongue pressure

The null hypothesis of homogeneity of studies was rejected by statistical test ($p<0.05$ for each analysis) for all forest plots. Therefore, random effects models were used for the analysis in this study because this approach allows variation (heterogeneity) of study outcomes i.e heterogeneity of studies is incorporated in the analysis. The random effects meta-regression analysis to evaluate the effect of HGS on TP was performed separately for all studies and for different groups, including age, gender, device and need for care. There is a significant positive correlation between TP and HGS in older adults' group ($p < .001$), in men ($p = .006$), in women ($p = .002$), in the group with TP values measured with JMS ($p < .001$), in IC ($p = .001$) and in NC ($p = .024$), whereas no significant correlation in young group ($p = .053$) and in the group with TP values measured with IOPI ($p = .100$). (Table. 4a) (Figure 2) Subsequently, the multivariate analysis based on data from all studies ($n = 75$), adjusting for age, device and need for care, showed a significant positive effect of HGS and TP ($p < .001$). (Table. 4b).

4. Discussion

In this systematic review and meta-analysis, TP and HGS values were summarized by age groups, gender, need for care and measuring device, and the effect of HGS on TP was analyzed. TP and HGS were significantly higher in people <60 years than in those ≥60 years, in men than in women, and in people living independently than in people receiving nursing care. In addition, there was a significant difference in TP between measured with IOPI and JMS. A significant correlation between HGS and TP was observed. Therefore, the null-hypothesis was rejected.

TP increases with age during the growth stage of childhood[29]and decreases with aging. A previous study reported that TP and HGS values in healthy older adults were significantly higher than in older adults receiving nursing care.[30] Regarding the tongue pressure, it was suggested that it may conclude that healthy older people could maintain a value of 30 kPa.[31] In the present study, older adults' groups were classified into those with and without nursing care, and the EWM TP indicated that the independent older adults were 32.5 kPa for men and 31.0 kPa for women, while those requiring nursing care were 23.6 kPa for men and 23.3 kPa for women, supporting the tongue pressure reference value for oral hypofunction[11]. With regard to gender, previous studies found that TP was significantly higher in men than in women among healthy older adults[32,33], whereas no significant gender difference in older adults receiving nursing care[34,35] and in healthy older adults[36] as demonstrated in our previous systematic review[37]. The current results similarly indicated a significant gender difference in the healthy young group, while no significant gender difference was found in the older adults' group, either in IC or NC. The proportion of older adults requiring nursing care increases with age[38], and older adults requiring nursing care have lower potential, ADL and oral function than independent older adults. The first thing to consider is that individual difference might be more influential than gender difference in older adults. The second thing to consider is that there would be less change in tongue pressure with age in women. Among women, ageing-induced decreases in swallowing-related muscle strength tended to be more gradual than the corresponding decreases in whole-body strength.[39] In fact, the current study found that WMD between healthy older and younger people was smaller in women with a WMD of -6.6 kPa (SE: 1.93 kPa) than in men with a WMD of -13.1 kPa (SE: 2.95 kPa).

The HGS, one of the criteria for sarcopenia and frailty, is defined by the Asian Working Group for Sarcopenia (AWGS) as the threshold for low muscle strength in Asians: <28 kg for men and <18 kg for women. The EWM HGS values in this present meta-analysis were 33.1 kg for men and 21.3 kg for women in independent older adults, and 20.8 kg for men and 13.8 kg for women in older adults requiring care, which are very reasonable considering the AWGS reference values. HGS is used to assess physical function in the rehabilitation field.[40] One systematic review illustrated that HGS was associated with mobility and ADL in older people.[41] In this present review, adjusting for age, gender, need for care and tongue pressure measuring device, HGS and TP are significantly correlated.

Previous evidence on a correlation between HGS and TP is indecisive.[22,30,31,33,42-53] In the present meta-analysis, TP was used as dependent variable and HGS was used as an independent variable, i.e., the estimated coefficient shows the influence (effect) of handgrip strength on tongue pressure. Significant correlations between HGS and TP could be shown in independent group ($p = .001$), in requiring nursing care group ($p = .024$) and in older adults' group ($p < .001$), but not in young group ($p = .053$) as the p-value was just above the level of significance. This result might be due to the small number of young groups studies (n=7). Furthermore, the estimated coefficients of men and women are very similar (0.74[0.25-1.23], 0.83[0.34-1.33]). Since there was no hint that the effect of HGS on TP does depend on gender, it was estimated without adjusting for gender factors in Table 4b. The results of this present study suggested that HGS can be used to roughly analyze TP. Measuring HGS is an easier approach for non-dental health-care professionals, as they don't have to look in the patients' mouths. And if HGS is low, it may predict a decline in oro-facial function and help to collaborate with dentistry.

An accumulated poor oral status including low TP was reported to significantly predict future physical weakening (new onsets of physical frailty, sarcopenia, and disability)[7], and low TP would significantly hinder food bolus formation and propagation, thus leading to malnourishment following decreased oral intake[45,54]. A decrease in the food intake diversity is considered to be a risk to decrease the limb skeletal muscle mass.[55] TP is one of the muscle strength indicators of the swallowing muscles[56], or predictors of the risk of low nutrition[57]. The swallowing muscles are inevitably affected by malnutrition and disuse.[58] It has also been noted that although the swallowing muscles are strained, it receives constant input stimulation from the respiratory center and are different from other skeletal muscles, and there is no certainty as to whether the swallowing muscle and other skeletal muscles undergo functional decline in parallel.[58,59] TP and HGS have been correlated, but the direct mechanism is not yet clear. In the future, with increasing evidence that poor oral function can lead to a deterioration of general health, it may be effective and important to expand the opportunities for TP measurements as well as HGS measurements. Furthermore, a lot studies have suggested that low nutrition, sarcopenia and dysphagia are closely related.[60] Further research is needed to prevent the vicious circle of "sarcopenia - dysphagia - low nutrition"[59] from starting.

This systematic review has some limitations. The number of young people was less than that of older adults. In addition, there were only three study investigated TP and HGS in healthy young people, divided by gender. Data on TP values were taken from studies that measured tongue pressure using either JMS or IOPI. As a result, most of the studies used JMS, and most of the studies were performed in Japan. In the future, it will be necessary to analyze research data not only from Japan but also from around the world. It is expected to contribute to the further development of healthy longevity by examining the differences between countries and new perspectives on the characteristics of older people.

It was proposed that oro-facial fitness is a state in which the physiological, psychosocial and environmental requirements of life of an individual are met.[10] The loss of oro-facial function may or may not be restored through dental intervention, or training.[10] Reduced neuro-plastic capacity in older adults might preclude a positive outcome of these strategies that might need to be accompanied by functional training and nutritional counselling.[10] However, a few longitudinal studies reported physical and/or intervention and nutritional management for older adults could be effective to improve oral and physical function.[61-64] Additionally, another previous study suggested that decrease in overall muscle strength, which may result from bedrest during hospitalization, is more important as a factor than the actual performance of activities of daily living in the reduction of TP.[53] On the other hand, age-related decline in TP might be associated with high TP, reflecting decreased reserve.[31] Although many studies have shown that age-related changes result in a decrease in tongue pressure, a previous study was reported that age-related decline in tongue function might be different from decline in physical function[31], suggesting that further longitudinal studies are needed. Additionally analyzing the relationship between oral function and muscle mass, nutritional status, cognitive function, level of care and psychosocial function will be essential in examining the factors that influence it.

5. Conclusions

Based on the results of this systematic review and meta-analysis, it is concluded that when tongue pressure is measured using the JMS:

- tongue pressure and handgrip strength are higher in subjects younger than 60 years relative to subjects 60 years and older in both men and women.
- gender differences were found in tongue pressure and handgrip strength in the younger independent subjects. However, in older adults' group, there is significantly gender difference in handgrip strength, but not tongue pressure regardless of the presence or absence of receiving care.
- in older adults' group, subjects who live independently have significantly higher tongue pressure and handgrip strength compared to those who receive care.
- handgrip strength and tongue pressure are significantly correlated.

- It is suggested further study might be necessary to research on rehabilitation measures for muscle strength, similar to handgrip strength might be beneficial to improve the personally acquired oro-facial potential according to age-related sarcopenia.

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Tables

Table 1. (1a) Study characteristics of included studies (n=44), (1b) Tongue pressure -descriptive analysis and (1c) Handgrip strength -descriptive analysis.

Table 1a

Author	Year	Subjects (n)	Men (n)	Women (n)	Mean age ± SD (years)	Median age (Q1, Q3) (years	Min age (years)	Max age (years)	Tongue pressure device	Mean tongue pressure ± SD (kPa)	Median tongue pressure (Q1, Q3) (kPa)	Mean handgrip strength ± SD (kg)	Median handgrip strength (Q1, Q3) (kg)
Sugiya	2021	24	20	4	77.5 ± 5.0	NA	65	NA	JMS	38.0 ± 5.3	NA	36.0 ± 8.4	NA
Ogawa	2021	45	22	23	84.3 ± 7.8	NA	65	NA	JMS	15.8 ± 8.1	NA	9.9 ± 6.5	NA
Miyoshi	2021	22	0	22	67.8 ± 1.4	NA	65	69	JMS	35.3 ± 5.9	NA	24.0 ± 2.8	NA
	2021	99	0	99	75.3 ± 2.6	NA	70	79	JMS	35.0 ± 7.9	NA	21.3 ± 3.7	NA
	2021	84	0	84	82.9 ± 2.5	NA	80	89	JMS	31.9 ± 7.5	NA	19.7 ± 3.3	NA
Kugimiya	2021	610	0	610	NA	78 (70, 86)	65	NA	JMS	NA	31.3, (25.8, 35.7)	NA	21.0 (17.0, 25.0)
	2021	268	268	0	NA	71 (68, 78.8)	65	NA	JMS	NA	33.4, (27.8, 39)	NA	35.0 (30.3, 40.0)
Kim	2021	51	25	26	32.1 ± 7.4	NA	20	45	JMS	38.92 ± 10.93	NA	31.14 ± 10.49	NA
	2021	54	26	28	53.5 ± 4.2	NA	46	60	JMS	38.28 ± 10.50	NA	28.22 ± 8.71	NA
	2021	45	21	24	66.2 ± 2.8	NA	61	70	JMS	31.68 ± 7.82	NA	27.56 ± 9.29	NA

	2021	61	23	38	77.4 ± 5.2	NA	71	NA	JMS	26.52 ± 9.74	NA	21.44 ± 8.03	NA
Kato	2021	107	0	107	74.37 ± 4.46	NA	66	84	JMS	32.89 ± 6.41	NA	23.66 ± 3.69	NA
Iyota	2021	42	23	19	73.1 ± 3.1	NA	68	79	JMS	33.8 ± 8.4	NA	31.2 ± 7.4	NA
Hirata	2021	90	55	35	77.2 ± 8.3	NA	65	NA	JMS	27.5 ± 9.9	NA	22.4 ± 7.8	NA
Chang	2021	26	9	17	73.53 ± 6.33	NA	65	NA	IOPI	34.84 ± 11.57	NA	22.88 ± 6.80	NA
	2021	336	140	196	71.61 ± 5.18	NA	65	NA	IOPI	38.20 ± 14.01	NA	26.52 ± 7.33	NA
Sakai	2020	30	15	15	NA	88 (79.75, 91.00)	65	NA	JMS	NA	26.75 (21.43, 31.78)	NA	17.4 (12.70, 23.00)
	2020	30	15	15	NA	89 (85.00, 90.00)	65	NA	JMS	NA	18.10 (14.20, 23.075)	NA	12.0 (8.40, 13.50)
Nakamori	2020	163	163	0	76.9 ± 5.8	NA	65	NA	JMS	37.4 ± 10.2	NA	28.8 ± 6.9	NA
	2020	91	0	91	79.5 ± 6.7	NA	65	NA	JMS	32.5 ± 10.5	NA	15.9 ± 4.5	NA
Nagano	2020	19	19	0	79.3± 7.2	NA	65	NA	JMS	27.5 ± 10.1	NA	17.9 ± 6.5	NA
	2020	76	0	76	84.3 ± 5.0	NA	65	NA	JMS	24.9 ± 8.5	NA	12.7 ± 3.4	NA
Miyoshi	2020	40	0	40	70.4 ± 2.8	NA	65	74	JMS	32.8 ± 7.4	NA	23.4 ± 5.0	NA
	2020	123	0	123	80.3 ± 4.1	NA	75	NA	JMS	31.4 ± 7.7	NA	20.2 ± 3.4	NA
Kunieda	2020	16	13	3	85.0 ± 6.6	NA	NA	NA	JMS	21.8 ± 5.1	NA	14.5 ± 6.3	NA

Kugimiya	2020	282	282	0	NA	75 (70,79)	65	NA	JMS	NA	30.2 (25.1,34.5)	NA	33 (28.8,38.0)
	2020	397	0	282	NA	76 (71,80)	65	NA	JMS	NA	28.4 (23.4,33.1)	NA	20 (17.0,23.2)
Kobuchi	2020	54	16	38	78.8 ± 7.1	NA	NA	NA	JMS	28.5 ± 7.7	NA	22.4 ± 7.1	NA
Hirano	2020	36	0	36	76.2 ± 5.0	NA	65	NA	JMS	25.1 ± 9.2	NA	21.9 ± 3.7	NA
Hirata	2020	66	37	29	NA	77.0 (70.0, 84.2)	65	NA	JMS	NA	28.9 (22.4, 33.5)	NA	23.3 (16.9, 27.0)
Higa	2020	42	42	0	72.4 ± 4.7	NA	65	NA	JMS	36.8 ± 8.9	NA	35.3 ± 7.2	NA
	2020	70	0	70	69.0 ± 4.5	NA	65	NA	JMS	34.6 ± 8.4	NA	22.7 ± 4.1	NA
Arakawa	2019	68	29	39	81.5 ± 7.3	NA	65	NA	JMS	22.1 ± 8.9	NA	15.8 ± 6.6	NA
	2019	99	35	64	79.4 ± 6.5	NA	65	NA	JMS	27.1 ± 11.2	NA	17.1 ± 6.9	NA
Wakabayashi	2019	108	72	36	76 ± 7	NA	65	NA	JMS	21.4 ± 9.4	NA	17.0 ± 8.0	NA
Morita	2019	52	52	0	77.0 ± 5.3	NA	65	NA	JMS	31.8 ± 6.4	NA	33.0 ± 5.6	NA
	2019	179	0	179	74.1 ± 4.8	NA	65	NA	JMS	30.7 ± 6.4	NA	21.5 ± 3.6	NA
Kugimiya	2019	445	445	0	77.0 ± 4.9	NA	70	NA	JMS	30.8 ± 9.0	NA	32.2 ± 6.3	NA
	2019	673	0	673	77.0 ± 4.5	NA	70	NA	JMS	29.8 ± 7.7	NA	21.5 ± 4.5	NA
Koyama	2019	24	0	24	19.7 ± 1.5	NA	18	NA	JMS	36.49 ± 6.29	NA	26.88 ± 3.87	NA

Kito	2019	86	6	80	75.6 ± 5.6	NA	65	NA	JMS	32.4 ± 8.0	NA	21.6 ± 4.8	NA
Kaji	2019	82	82	0	72.1 ± 7.2	NA	60	NA	JMS	31.6 ± 10.2	NA	30.9 ± 6.2	NA
	2019	62	0	62	70.5 ± 5.8	NA	60	NA	JMS	27.1 ± 8.5	NA	20.1 ± 3.7	NA
Hara	2019	497	208	289	37.7 ± 10.7	NA	20	59	JMS	37.3 ± 7.7	NA	32.5 ± 9.8	NA
	2019	288	97	191	70.6 ± 5.4	NA	60	89	JMS	31.4 ± 8.0	NA	27.2 ± 8.3	NA
Sakai	2018	25	25	0	82.4 ± 7.8	NA	65	NA	JMS	19.2 ± 9.7	NA	22.3 ± 6.3	NA
	2018	38	0	38	84.2 ± 6.1	NA	65	NA	JMS	20.1 ± 10.6	NA	14.3 ± 5.1	NA
Hiroshimaya	2018	18	18	0	84.4 ± 5.0	NA	NA	NA	JMS	21.2 ± 8.3	NA	NA	22.6 (19.3,24.4)
	2018	46	0	46	87.2 ± 5.6	NA	NA	NA	JMS	18.9 ± 10.4	NA	NA	13.4 (10.9,16.5)
Yoshimi	2018	37	37	0	NA	72.81 (69.00,77.00)	65	NA	JMS	29.63 ± 9.27	NA	NA	35.22 (28.88,41.25)
	2018	81	0	81	NA	69.57 (66.00,73.00)	65	NA	JMS	30.85 ± 7.74	NA	NA	23.50 (20.50,26.38)
Yamanashi	2018	1603	650	953	72.8 ± 7.4	NA	65	95	JMS	30.5 ± 10.1	NA	26.0 ± 8.8	NA
Suzuki	2018	245	0	245	NA	81.0 (75.0,85.0)	65	NA	JMS	28.4 ± 9.5	NA	NA	19.1 (15.7,22.0)
Morita	2018	262	56	206	74.2 ± 5.9	NA	60	89	JMS	30.9 ± 6.4	NA	25.0 ± 6.4	NA

Higashi	2018	241	241	0	NA	71.0 (64.0,78.0)	NA	NA	JMS	30.5 ± 10.6	NA	NA	31.4 (25.8,36.9)
	2018	397	0	397	NA	70.0 (62.0,77.0)	NA	NA	JMS	28.3 ± 9.9	NA	NA	20.5 (16.1,23.9)
Hashiguchi	2017	15	7	8	21.9 ± 4.0	NA	18	25	JMS	40.4 ± 8.6	NA	34.5 ± 8.5	NA
Sakai	2017	64	64	0	NA	84.5 (78,89)	NA	NA	JMS	NA	25.2 (21.4,32.3)	NA	17.4 (14.2-23.3)
	2017	110	0	110	NA	84.0 (80,88.3)	NA	NA	JMS	NA	26.7 (22.4,32.6)	NA	13.6 (10.6,17.3)
Sakai	2017	201	70	131	NA	84 (79,89)	65	NA	JMS	NA	26.8 (21.8,32.6)	NA	15.1 (11.7,19.5)
Yasuhara	2016	47	47	0	25.66 ± 6.43	NA	18	46	JMS	45.60 ± 9.23	NA	40.92 ± 6.49	NA
	2016	54	0	54	23.48 ± 4.23	NA	18	39	JMS	38.68 ± 7.37	NA	24.42 ± 4.33	NA
Furuya	2016	169	169	0	75.9 ± 6.1	NA	NA	NA	JMS	31.8 ± 7.8	NA	35.2 ± 6.7	NA
	2016	195	0	195	75.4 ± 5.6	NA	NA	NA	JMS	29.3 ± 7.1	NA	22.7 ± 4.2	NA
Saito	2015	27	9	18	20.7 ± 0.6	NA	20	22	JMS	32.3 ± 10.4	NA	28.8 ± 7.9	NA
	2015	17	11	6	74.1 ± 4.5	NA	65	84	JMS	27.1 ± 5.6	NA	27.8 ± 7.6	NA
Nakahigashi	2015	21	0	21	77.4 ± 6.6	NA	70	89	JMS	29.6 ± 10.3	NA	19.9 ± 3.2	NA
	2015	41	0	41	81.0 ± 7.2	NA	70	89	JMS	24.3 ± 9.3	NA	13.5 ± 4.6	NA

Mendes	2015	30	NA	NA	30.37 ± 6.75	31.5 (26.00,36.25)	18	39	IOPI	56.57 ± 14.85	NA	38.20 ± 12.05	NA
	2015	30	NA	NA	49.13 ± 5.07	50 (45.00,53.25)	40	58	IOPI	51.97 ± 10.81	NA	32.20 ± 11.05	NA
	2015	30	NA	NA	69.63 ± 8.06	67.00 (63.00,74.75)	60	86	IOPI	43.20 ± 13.58	NA	26.93 ± 10.15	NA
Shimada	2014	13	13	0	73.5 ± 5.7	NA	NA	NA	JMS	36.1 ± 8.1	NA	36.2 ± 7.2	NA
	2014	27	0	27	74.4 ± 5.0	NA	NA	NA	JMS	32.2 ± 7.0	NA	22.3 ± 4.4	NA
Buehring	2013	48	48	0	81.3 ± 6.3	NA	70	95	IOPI	50.6 ± 12.7	NA	32.4 ± 7.4	NA
	2013	49	0	49	80.0 ± 5.5	NA	70	95	IOPI	47.0 ± 10.2	NA	18.3 ± 4.8	NA

NA: not applicable

Table 1b

		studies	subgroups	subjects	unweighted mean tongue pressure (kPa)			
					mean	sd	median	min-max
Gender	men	17 (42.5%)	17 (38.6%)	2015 (34.9%)	32.4	7.7	31.6	19.2-50.6
	women	23 (57.5%)	27 (61.4%)	3752 (65.1%)	30.6	5.7	30.9	18.9-47.0
Device	JMS	41 (93.2%)	68 (90.7%)	9794 (94.7%)	30.0	5.7	30.6	15.8-45.6
	IOPI	3 (6.8%)	7 (9.3%)	549 (5.3%)	46.1	7.8	47.0	34.8-56.6
Need for care	independent (ic)	28 (66.7%)	45 (69.2%)	8270 (86.9%)	32.7	4.9	31.7	25.1-50.6
	nursing care (nc)	14 (33.3%)	20 (30.8%)	1244 (13.1%)	23.7	3.9	24.6	15.8-28.5
Age	older adults (o)	41 (85.4%)	65 (86.7%)	9514 (92.0%)	30.0	6.2	30.5	15.8-50.6
	young adults (y)	7 (14.6%)	10 (13.3%)	829 (8.0%)	41.7	7.5	38.8	32.3-56.6

o: older adults, y: young adults, ic: independent group, nc: nursing care group

Table 1c

		studies	subgroups	subjects	unweighted mean handgrip strength (kg)			
					mean	sd	median	min-max
Gender	men	17 (42.5%)	17 (38.6%)	2015 (34.9%)	30.6	6.6	32.4	17.9-40.9
	women	23 (57.5%)	27 (61.4%)	3752 (65.1%)	20.1	3.8	21.0	12.7-26.9
Device	JMS	41 (93.2%)	68 (90.7%)	9794 (94.7%)	23.8	7.1	22.4	9.9-40.9
	IOPI	3 (6.8%)	7 (9.3%)	549 (5.3%)	28.2	6.6	26.9	18.3-38.2
Need for care	independent (ic)	28 (66.7%)	45 (69.2%)	8270 (86.9%)	25.8	5.8	23.7	15.9-36.2
	nursing care (nc)	14 (33.3%)	20 (30.8%)	1244 (13.1%)	16.7	3.9	16.4	9.9-22.4
Age	older adults (o)	41 (85.4%)	65 (86.7%)	9514 (92.0%)	23.0	6.7	22.3	9.9-36.2
	young adults (y)	7 (14.6%)	10 (13.3%)	829 (8.0%)	31.8	5.1	31.7	24.4-40.9

o: older adults, y: young adults, ic: independent group, nc: nursing care group

Table 2. Results of quality assessment for (2a) analytical study according to NOS, and for (2b) included randomized clinical trials (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
Sugiya	2021	Cross-sectional	3	0	1	4	Intermediate
Ogawa	2021	Cross-sectional	3	2	2	7	High
Miyoshi	2021	Cross-sectional	1	2	1	4	Intermediate
Kugimiya	2021	Cross-sectional	5	2	2	9	High
Kim	2021	Cross-sectional	2	2	2	6	Intermediate
Kato	2021	Cross-sectional	3	1	2	6	Intermediate
Hirata	2021	Cross-sectional	1	2	2	5	Intermediate
Chang	2021	Cross-sectional	4	2	2	8	High
Sakai	2020	Cross-sectional	4	0	2	6	Intermediate
Nakamori	2020	Cross-sectional	1	2	2	5	Intermediate
Nagano	2020	Before and after	1	2	2	5	Intermediate
Miyoshi	2020	Cross sectional	2	2	2	6	Intermediate
Kunieda	2020	Cross sectional	3	0	1	4	Intermediate
Kugimiya	2020	Cross sectional	5	2	1	8	High
Kobuchi	2020	Cross sectional	3	2	2	7	High
Hirano	2020	Cross sectional	1	0	1	2	Low
Hirata	2020	Cross sectional	1	1	2	4	Intermediate
Higa	2020	Before and after	1	1	2	4	Intermediate
Arakawa	2019	Cross sectional	2	1	2	5	Intermediate
Wakabayashi	2019	Prospective cohort	3	2	0	5	Intermediate
Morita	2019	Cross sectional	3	1	1	5	Intermediate
Kugimiya	2019	Cross sectional	4	2	1	7	High
Koyama	2019	Cross sectional	1	0	1	2	Low
Kaji	2019	Cross sectional	3	2	2	7	High
Hara	2019	Cross sectional	3	2	2	7	High
Sakai	2018	Cross sectional	3	2	1	6	Intermediate
Hiroshimaya	2018	Cross sectional	3	1	2	6	Intermediate
Yoshimi	2018	Cross sectional	3	1	2	6	Intermediate
Yamanashi	2018	Cross sectional	2	1	2	5	Intermediate
Suzuki	2018	Cross sectional	2	1	1	4	Intermediate
Morita	2018	Cross sectional	1	2	1	4	Intermediate
Higashi	2018	Cross sectional	3	1	3	7	High
Hashiguchi	2017	Cross sectional	1	1	1	3	Low
Sakai(Tongue)	2017	Cross sectional	2	1	2	5	Intermediate
Sakai(Relationship)	2017	Cross sectional	3	1	2	6	Intermediate
Yasuhara	2016	Cross sectional	1	1	1	3	Low
Furuya	2016	Cross sectional	2	2	1	5	Intermediate
Saito	2015	Cross sectional	0	1	1	2	Low
Nakahigashi	2015	Cross sectional	0	1	1	2	Low
Mendes	2015	Cross sectional	2	1	1	4	Intermediate
Shimada	2014	Cross sectional	2	2	1	5	Intermediate
Buehring	2013	Cross sectional	3	2	1	6	Intermediate

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
Iyota	2021	non-RCT	high risk	high risk	low risk	low risk	low risk	low risk	high risk
Kito	2019	RCT	unclear	low risk	low risk	low risk	low risk	low risk	low risk

Table 3. (3a) Tongue pressure and gender, device, need for care, age (estimation by random effects meta-regression*), (3b) Handgrip strength and gender, device, need of care, age (estimation by random effects meta-regression*)

Table 3a

		# studies	# subgroups (rows)	# subjects	EWM / WMD	SE	95%-CI	p-value
Gender	men	17	17	2015	32.4	1.83	28.8 - 36.0	
	women	23	27	3752	30.6	1.06	28.5 - 32.7	.370
	women vs men			WMD:	-1.8	1.97	-5.6 - 2.1	
Device	JMS	41	68	9794	30.0	0.68	28.7 - 31.4	
	IOPI	3	7	549	46.0	2.90	40.3 - 51.7	<.001
	IOPI vs JMS			WMD:	15.9	2.36	11.2 - 20.5	
Need for care	ic	28	45	8270	32.6	0.69	31.3 - 34.0	
	nc	14	20	1244	23.8	0.87	22.1 - 25.5	<.001
	ic vs nc			WMD:	-8.8	1.20	-11.2 - -6.5	
Age	o	41	65	9514	29.9	0.75	28.5 - 31.4	
	y	7	10	829	41.5	2.28	37.0 - 46.0	<.001
	y vs o			WMD:	11.5	2.13	7.3 - 15.7	
JMS only:								
men / women	men y ic	1	1	47	45.6	1.35	43.0 - 48.2	
	women y ic	2	2	78	37.7	1.09	35.6 - 39.9	<.001
	women y ic vs men y ic			WMD:	-7.9	2.02	-11.8 - -3.9	
	men o ic	11	11	1794	32.5	0.81	31.0 - 34.1	
	women o ic	16	19	3314	31.0	0.59	29.8 - 32.1	.118
	women o ic vs men o ic			WMD:	-1.5	0.99	-3.5 - 0.4	
	men o nc	4	4	126	23.6	1.95	19.8 - 27.4	
	women o nc	5	5	311	23.3	1.56	20.2 - 26.4	.895
	women o nc vs men o nc			WMD:	-0.3	2.48	-5.2 - 4.5	
young adults/ older adults	men y ic	1	1	47	45.6	1.35	43.0 - 48.2	
	men o ic	11	11	1794	32.5	0.81	31.0 - 34.1	<.001
	men o ic vs men y ic			WMD:	-13.1	2.95	-18.8 - -7.3	
	women y ic	2	2	78	37.7	1.09	35.6 - 39.9	
	women o ic	16	19	3314	31.0	0.59	29.8 - 32.1	.001
	women o ic vs women y ic			WMD:	-6.6	1.93	-10.4 - -2.9	
independent / nursing care	men o ic	11	11	1794	32.5	0.81	31.0 - 34.1	
	men o nc	4	4	126	23.6	1.95	19.8 - 27.4	<.001
	men o nc vs men o ic			WMD:	-8.9	1.83	-12.5 - -5.3	
	women o ic	16	19	3314	31.0	0.59	29.8 - 32.1	
	women o nc	5	5	311	23.3	1.56	20.2 - 26.4	<.001
	women o nc vs women o ic			WMD:	-7.6	1.42	-10.4 - -4.8	

o: older adults, y: young adults, ic: independent group, nc: nursing care group

EWM: estimated weighted mean

WMD:: estimated weighted mean difference between groups

* except for JMS only, women e nc vs men e nc (t-Test for independent group)

Table3b

		# studies	# subgroups (rows)	# patients	EWM / WMD	SE	95%-CI	p-value
Gender	men	17	17	2015	30.6	1.59	27.5 - 33.7	
	women	23	27	3752	20.1	0.73	18.7 - 21.5	<.001
	women vs men			WMD:	-10.5	1.54	-13.5 - -7.5	
Device	JMS	41	68	9794	23.7	0.86	22.0 - 25.4	
	IOPI	3	7	549	28.0	2.50	23.2 - 32.9	.125
	IOPI vs JMS			WMD:	4.3	2.83	-1.2 - 9.9	
Need for care	ic	28	45	8270	25.7	0.85	24.1 - 27.4	
	nc	14	20	1244	16.7	0.88	14.9 - 18.4	<.001
	nc vs ic			WMD:	-9.0	1.41	-11.8 - -6.3	
Age	o	41	65	9514	23.0	0.83	21.4 - 24.6	
	y	7	10	829	31.7	1.64	28.4 - 34.9	<.001
	y vs o			WMD:	8.7	2.24	4.3 - 13.1	
JMS only:								
men / women	men y ic	1	1	47	40.9	0.95	39.1 - 42.8	
	women y ic	2	2	78	25.6	1.23	23.2 - 28.0	<.001
	women y ic vs men y ic			WMD:	-15.3	2.22	-19.7 - -11.0	
	men o ic	11	11	1794	33.1	0.69	31.8 - 34.5	
	women o ic	16	19	3314	21.3	0.44	20.5 - 22.2	<.001
	women o ic vs men o ic			WMD:	-11.8	0.78	-13.3 - -10.2	
	men o nc	4	4	126	20.2	1.18	17.9 - 22.5	
	women o nc	5	5	311	13.4	0.31	12.8 - 14.1	<.001
	women o nc vs men o nc			WMD:	-6.7	0.90	-8.4 - -4.9	
young adults/ older adults	men y ic	1	1	47	40.9	0.95	39.1 - 42.8	
	men o ic	11	11	1794	33.1	0.69	31.8 - 34.5	.001
	men o ic vs men y ic			WMD:	-7.8	2.43	-12.6 - -3.1	
	women y ic	2	2	78	25.6	1.23	23.2 - 28.0	
	women o ic	16	19	3314	21.3	0.44	20.5 - 22.2	.003
	women o ic vs women y ic			WMD:	-4.3	1.46	-7.1 - -1.4	
independent / nursing care	men o ic	11	11	1794	33.1	0.69	31.8 - 34.5	
	men o nc	4	4	126	20.2	1.18	17.9 - 22.5	<.001
	men o nc vs men o ic			WMD:	-12.9	1.38	-15.6 - -10.2	
	women o ic	16	19	3314	21.3	0.44	20.5 - 22.2	
	women o nc	5	5	311	13.4	0.31	12.8 - 14.1	<.001
	women o nc vs women o ic			WMD:	-7.7	0.90	-9.5 - -6.0	

o: older adults, y: young adults, ic: independent group, nc: nursing care group

EWM: estimated weighted mean

WMD:: estimated weighted mean difference between groups

* except for JMS only, women e nc vs men e nc (t-Test for independent group)

Table 4. (4a) Effect of handgrip strength on tongue pressure – analysis of all studies and subgroups (multivariate random effects meta-regression) and (4b) Effect of handgrip strength on tongue pressure (multivariate random effects meta-regression adjusted for device, need for care and age) (n=75)

Table 4a

		no. of subgroups	Coeff. [95%-CI]	p-value	adj. R^2 *
total		75	0.69 [0.51 - 0.86]	<.001	46.9%
Gender	men	17	0.74 [0.25 - 1.23]	.006	38.9%
	women	27	0.83 [0.34 - 1.33]	.002	32.2%
Device	JMS	68	0.58 [0.45 - 0.71]	<.001	56.2%
	IOPI	7	0.79 [-0.22 - 1.79]	.100	34.7%
Need for care	independent	55	0.46 [0.20 - 0.71]	.001	19.5%
	nursing care	20	0.50 [0.07 - 0.92]	.024	26.1%
age	older adults	65	0.53 [0.35 - 0.72]	<.001	36.1%
	young adults	10	0.90 [-0.01 - 1.80]	.053	34.5%

Estimation by random-effects meta-regression

Table 4b

Coeff. [95%-CI]	p-value
0.28 [0.14 - 0.42]	<.001

Estimation by random-effects meta-regression adjusted for device, need for care and age

Figure legends

Figure 1.

Flow diagram of screening and selection of publications for systematic review and meta-analysis.

Figure 2

Linear relationship between mean tongue pressure and mean hand grip strength estimated by random-effects meta-regression (straight line) and the scatter plot of mean tongue pressure and mean hand grip strength (circles) for (2a) men, (2b) women, (2c) independent subjects, (2d) subjects with nursing care, (2e) older adults, (2f) young people, (2g) subjects who were measured for tongue pressure with JMS, (2h) subjects who were measured for tongue pressure with IOPI.

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.

Appendix S3 Forest plot with their 95% confidence intervals (95%CI) in studies of tongue pressure measured with JMS.

(S3a) mean tongue pressure for independent subjects <60 y (young).

(S3b) mean tongue pressure for independent subjects ≥ 60 y (older adults).

(S3c) mean tongue pressure for subjects ≥ 60 y (older adults) with nursing care need.

(S3d) mean handgrip strength for independent subjects <60 y (young).

(S3e) mean handgrip strength for independent subjects ≥ 60 y (older adults).

(S3f) mean handgrip strength for subjects ≥ 60 y (older adults) with nursing care need.

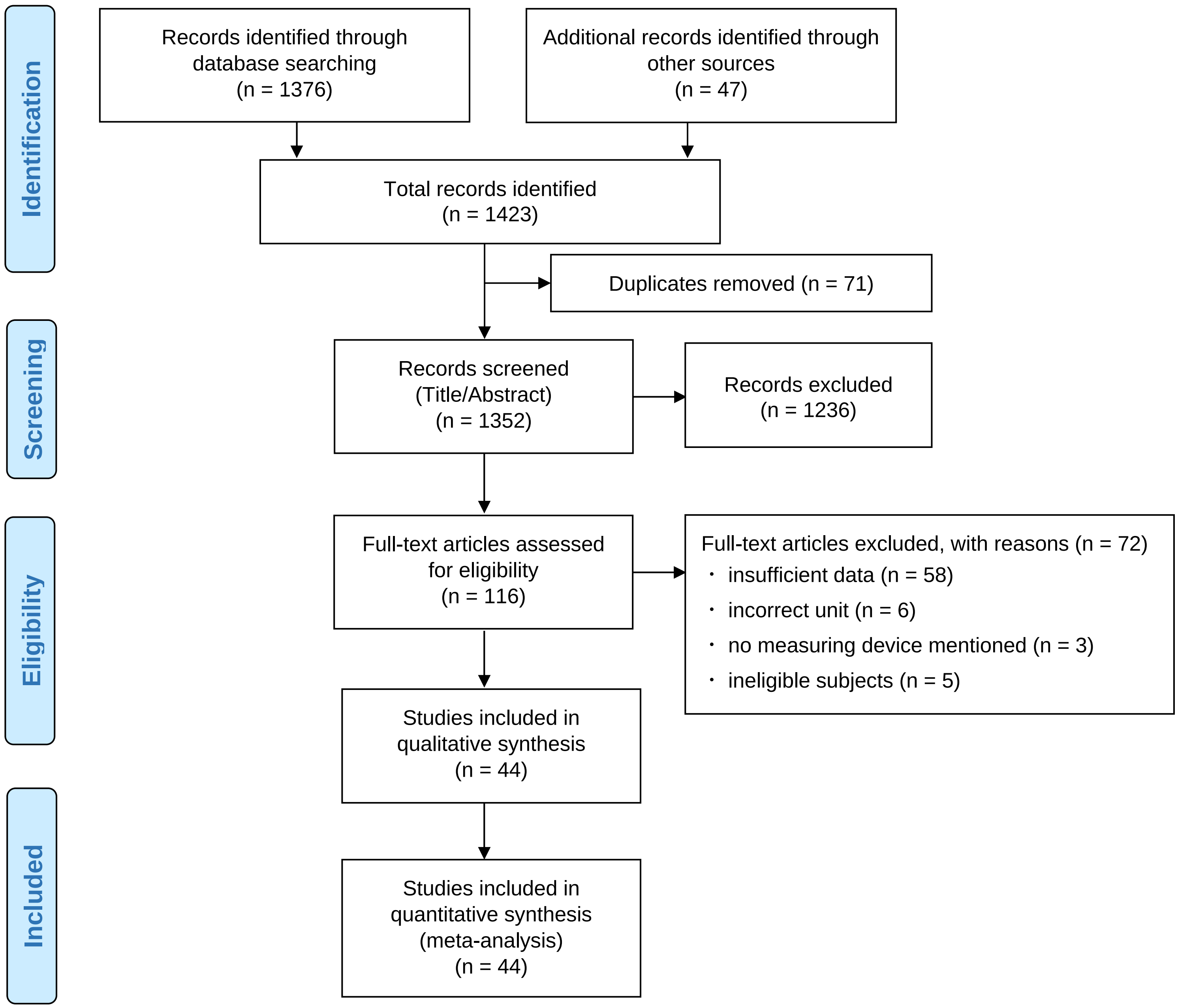
References

1. World report on ageing and health *Geneva, Switzerland : World Health Organization.* 2015
2. Fried LP, Tangen CM, Walston J, et al. Frailty in older adults: evidence for a phenotype. *J Gerontol A Biol Sci Med Sci.* 2001;56(3):M146-156.doi:10.1093/gerona/56.3.m146
3. Xue QL, Bandeen-Roche K, Varadhan R, Zhou J, Fried LP. Initial manifestations of frailty criteria and the development of frailty phenotype in the Women's Health and Aging Study II. *J Gerontol A Biol Sci Med Sci.* 2008;63(9):984-990.doi:10.1093/gerona/63.9.984
4. Cruz-Jentoft AJ, Baeyens JP, Bauer JM, et al. Sarcopenia: European consensus on definition and diagnosis: Report of the European Working Group on Sarcopenia in Older People. *Age Ageing.* 2010;39(4):412-423.doi:10.1093/ageing/afq034
5. Cruz-Jentoft AJ, Bahat G, Bauer J, et al. Sarcopenia: revised European consensus on definition and diagnosis. *Age Ageing.* 2019;48(1):16-31.doi:10.1093/ageing/afy169
6. Maeda K, Akagi J. Decreased tongue pressure is associated with sarcopenia and sarcopenic dysphagia in the elderly. *Dysphagia.* 2015;30(1):80-87.doi:10.1007/s00455-014-9577-y
7. Tanaka T, Takahashi K, Hirano H, et al. Oral Frailty as a Risk Factor for Physical Frailty and Mortality in Community-Dwelling Elderly. *J Gerontol A Biol Sci Med Sci.* 2018;73(12):1661-1667.doi:10.1093/gerona/glx225
8. Yamanashi H, Shimizu Y, Higashi M, et al. Validity of maximum isometric tongue pressure as a screening test for physical frailty: Cross-sectional study of Japanese community-dwelling older adults. *Geriatr Gerontol Int.* 2018;18(2):240-249.doi:10.1111/ggi.13166
9. Iwasaki M, Motokawa K, Watanabe Y, et al. Association between Oral Frailty and Nutritional Status among Community-Dwelling Older Adults: the Takashimadaira Study. *J Nutr Health Aging.* 2020;24(9):1003-1010.doi:10.1007/s12603-020-1433-1
10. Schimmel M, Aarab G, Baad-Hansen L, Lobbezoo F, Svensson P. A Conceptual Model of Orofacial Health with an Emphasis on Function. *J Oral Rehabil.* 2021;48(11):1283-1294.doi:10.1111/joor.13250
11. Minakuchi S, Tsuga K, Ikebe K, et al. Oral hypofunction in the older population: Position paper of the Japanese Society of Gerodontology in 2016. *Gerodontology.* 2018;35(4):317-324.doi:10.1111/ger.12347
12. Hatta K, Ikebe K. Association between oral health and sarcopenia: A literature review. *J Prosthodont Res.* 2020.doi:10.2186/jpr.JPOR_2019_567
13. Kobuchi R, Okuno K, Kusunoki T, Inoue T, Takahashi K. The relationship between sarcopenia and oral sarcopenia in elderly people. *J Oral Rehabil.* 2020;47(5):636-642.doi:10.1111/joor.12948
14. Hirata A, Ishizaka M, Sawaya Y, Shiba T, Urano T. Relationship between the swallowing function, nutritional status, and sarcopenia in elderly outpatients. *Nihon Ronen Igakkai Zasshi.* 2021;58(1):134-142 (in Japanese).doi:10.3143/geriatrics.58.134
15. Kugimiya Y, Iwasaki M, Ohara Y, et al. Relationship between Oral Hypofunction and Sarcopenia in Community-Dwelling Older Adults: The Otassha Study. *Int J Environ Res Public Health.* 2021;18(12):6666.doi:10.3390/ijerph18126666
16. Suzuki M, Koyama S, Kimura Y, et al. Relationship between characteristics of skeletal muscle and oral function in community-dwelling older women. *Arch Gerontol Geriatr.* 2018;79:171-175.doi:10.1016/j.archger.2018.09.003
17. Ogawa N, Wakabayashi H, Mori T, et al. Digastric muscle mass and intensity in older patients with sarcopenic dysphagia by ultrasonography. *Geriatrics & Gerontology International.* 2021;21(1):14-19.

18. Sakai K, Nakayama E, Rogus-Pulia N, et al. Submental Muscle Activity and Its Role in Diagnosing Sarcopenic Dysphagia. *Clin Interv Aging.* 2020;15:1991-1999.doi:10.2147/cia.S278793
19. Miyoshi S, Saito A, Shigeishi H, Sugiyama M. Association of physical performance with oral function in older women participating in community-based health exercise programs. *Clin Exp Dent Res.* 2020;6(3):311-317.doi:10.1002/cre2.277
20. Kato Y, Kikutani T, Sagawa K, Tamura F. Association between masticatory movement and oral and physical function in healthy older women. *J Prosthodont Res.* 2021.doi:10.2186/jpr.JPR_D_20_00285
21. Morita K, Tsuka H, Kimura H, et al. Oral function and vertical jump height among healthy older people in Japan. *Community Dent Health.* 2019;36(4):275-279.doi:10.1922/CDH_4515Morita05
22. Koyama M, Ikeda R. Correlation between maximum tongue pressure and motor function in female college students. *Journal of Nippon Oral Health Sciences.* 2019;9(1):2-9 (in Japanese)
23. Morita K, Tsuka H, Kato K, et al. Factors related to masticatory performance in healthy elderly individuals. *J Prosthodont Res.* 2018;62(4):432-435.doi:10.1016/j.jpor.2018.03.007
24. Kugimiya Y, Ueda T, Watanabe Y, et al. Relationship between mild cognitive decline and oral motor functions in metropolitan community-dwelling older Japanese: The Takashimadaira study. *Arch Gerontol Geriatr.* 2019;81:53-58.doi:10.1016/j.archger.2018.11.008
25. Nakamori M, Imamura E, Fukuta M, et al. Tongue thickness measured by ultrasonography is associated with tongue pressure in the Japanese elderly. *PLoS One.* 2020;15(8):e0230224.doi:10.1371/journal.pone.0230224
26. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *Int J Surg.* 2010;8(5):336-341.doi:10.1016/j.ijsu.2010.02.007
27. Wells G. SB, O'Connell D., et al. . The Newcastle-Ottawa Scale (NOS) for Assessing the Quality of Nonrandomised Studies in Meta-analyses. 2013:http://www.ohri.ca/programs/clinical_epidemiology/oxford.asp. Accessed September 28, 2021
28. Higgins J.P. GS. Cochrane Handbook for Systematic Reviews of Interventions. Version 5.1.0. The Cochrane Collaboration; [updated March 2011]. 2011:http://www.cochrane-handbook.org. Accessed September 28, 2021
29. Hashiguchi C, Shiono Y, Morikawa K, Fujita Y, Kai H, Maki K. Relationship of Lip Closing Force with Oral Cavity Function. *The Japanese journal of pedodontics.* 2017;55(1):1-10. (in Japanese)
30. Nakahigashi N, Yamagata Y, Kayashita J. Influence of tongue pressure in elderly people on grip strength and food modification. *Journal of the Japan Dietetic Association.* 2015;58(4):289-293. (in Japanese)
31. Higa C, Mori T, Hiraoka A, et al. Five-year change in maximum tongue pressure and physical function in community-dwelling elderly adults. *J Dent Sci.* 2020;15(3):265-269.doi:10.1016/j.jds.2020.05.027
32. Kugimiya Y, Watanabe Y, Ueda T, et al. Rate of oral frailty and oral hypofunction in rural community-dwelling older Japanese individuals. *Gerodontology.* 2020;37(4):342-352.doi:10.1111/ger.12468
33. Higashi M, Tsuneoka M, Orita M, et al. Tongue pressure is associated with aging, sex, handgrip strength, and lean body mass in community-dwelling middle- and old-aged people: a cross sectional study. *Acta Medica Nagasakiensia.* 2018;61(4):145-149.
34. Sakai R, Hamasaki T, Kakuta S, al e. Associations among Oral Function, Nutritional Status, and Nutrient Intake in Elderly Individuals Living at Home and Receiving Nursing Care. *J Dent Hlth.* 2018;68(4):207-218. (in Japanese)

35. Hiroshimaya T, Iwasaki M, Sakai R, al e. A Pilot Study of the Relationship between Whole-body Skeletal Muscle Mass and Tongue Pressure in ≧75-year-old Individuals Requiring Home-based Care Support. *J Dent Hlth.* 2018;68(3):145-152. (in Japanese)
36. Shimada M, Hosaka M, Asaga T, al e. Relationship between oral function and physical fitness in the elderly. *J Educ Conf All Japan Colleges Dental Hygiene.* 2014(3):21-27. (in Japanese)
37. Arakawa I, Igarashi K, Imamura Y, Müller F, Abou-Ayash S, Schimmel M. Variability in tongue pressure among elderly and young healthy cohorts: A systematic review and meta-analysis. *J Oral Rehabil.* 2021;48(4):430-448.doi:10.1111/joor.13076
38. Cabinet office J. Annual Report on the Aging Society 2021. 2021;Accessed February 14, 2022:P31. https://www38.cao.go.jp/kourei/whitepaper/w-2021/zenbun/pdf/2021s2022s_2002.pdf
39. Wakasugi Y, Tohara H, Machida N, Nakane A, Minakuchi S. Can grip strength and/or walking speed be simple indicators of the deterioration in tongue pressure and jaw opening force in older individuals? *Gerodontology.* 2017;34(4):455-459.doi:10.1111/ger.12292
40. Bohannon RW. Grip Strength: An Indispensable Biomarker For Older Adults. *Clin Interv Aging.* 2019;14:1681-1691.doi:10.2147/cia.S194543
41. Lunt E, Ong T, Gordon AL, Greenhaff PL, Gladman JRF. The clinical usefulness of muscle mass and strength measures in older people: a systematic review. *Age Ageing.* 2021;50(1):88-95.doi:10.1093/ageing/afaa123
42. Sugiya R, Higashimoto Y, Shiraishi M, et al. Decreased Tongue Strength is Related to Skeletal Muscle Mass in COPD Patients. *Dysphagia.* 2021.doi:10.1007/s00455-021-10314-3
43. Yoshimi K, Hara K, Tohara H, et al. Relationship between swallowing muscles and trunk muscle mass in healthy elderly individuals: A cross-sectional study. *Arch Gerontol Geriatr.* 2018;79:21-26.doi:10.1016/j.archger.2018.07.018
44. Furuya H, Tamura F, Yoshida M, Hirano H, Iijima K, Kikutani T. Tongue Muscle Mass and Strength Relate to Whole-Body Muscle in the Community-Dwelling Elderly. *JAOR.* 2016;29(1):1-9.
45. Chang KV, Wu WT, Chen LR, Wang HI, Wang TG, Han DS. Suboptimal Tongue Pressure Is Associated with Risk of Malnutrition in Community-Dwelling Older Individuals. *Nutrients.* 2021;13(6):1821.doi:10.3390/nu13061821
46. Yasuhara Y. The Characteristics of the healthy adults who are high in a value of the Maximal Lingual-Palatal Pressure. *J Hiroshima Univ Dent Soc.* 2016;48(1):44-55. (in Japanese)
47. Buehring B, Hind J, Fidler E, Krueger D, Binkley N, Robbins J. Tongue strength is associated with jumping mechanography performance and handgrip strength but not with classic functional tests in older adults. *J Am Geriatr Soc.* 2013;61(3):418-422.doi:10.1111/jgs.12124
48. Kaji A, Hashimoto Y, Kobayashi Y, et al. Sarcopenia is associated with tongue pressure in older patients with type 2 diabetes: A cross-sectional study of the KAMOGAWA-DM cohort study. *Geriatr Gerontol Int.* 2019;19(2):153-158.doi:10.1111/ggi.13577
49. Hara K, Tohara H, Kenichiro K, et al. Association between tongue muscle strength and masticatory muscle strength. *J Oral Rehabil.* 2019;46(2):134-139.doi:10.1111/joor.12737
50. Saito K, Saito A, Shibamoto I. The relationship of maximum tongue pressure and grip strength of young and elderly healthy subjects. *Journal of the International University of Health and Welfare.* 2015;20(1):23-26. (in Japanese)
51. Mendes AE, Nascimento L, Mansur LL, Callegaro D, Jacob Filho W. Tongue forces and handgrip strength in normal individuals: association with swallowing. *Clinics (Sao Paulo).* 2015;70(1):41-45.doi:10.6061/clinics/2015(01)08

52. Kim S, Doh RM, Yoo L, Jeong SA, Jung BY. Assessment of Age-Related Changes on Masticatory Function in a Population with Normal Dentition. *Int J Environ Res Public Health.* 2021;18(13):6899.doi:10.3390/ijerph18136899
53. Sakai K, Nakayama E, Tohara H, et al. Tongue Strength is Associated with Grip Strength and Nutritional Status in Older Adult Inpatients of a Rehabilitation Hospital. *Dysphagia.* 2017;32(2):241-249.doi:10.1007/s00455-016-9751-5
54. Sakai K, Nakayama E, Tohara H, et al. Relationship between tongue strength, lip strength, and nutrition-related sarcopenia in older rehabilitation inpatients: a cross-sectional study. *Clin Interv Aging.* 2017;12:1207-1214.doi:10.2147/cia.S141148
55. Hirano S, Takemasa M. Nutrition Status of Community-dwelling Elderly Who Belong to a Geriatric Club. *Kawasaki Medical Welfare Journal* 2020;30(1-1):181-188. (in Japanese)
56. Kunieda K, Fujishima I, Wakabayashi H, et al. Relationship Between Tongue Pressure and Pharyngeal Function Assessed Using High-Resolution Manometry in Older Dysphagia Patients with Sarcopenia: A Pilot Study. *Dysphagia.* 2021;36:33-40.doi:10.1007/s00455-020-10095-1
57. Arakawa T, Kemuriyama S, Okamura Y, al e. An Examination of Actual Condition and Relevant Factors of Nutritional Condition at Admission to Rehabilitation Hospital. *The Journal of Japanese Physical Therapy Association.* 2019;46(5):360-365. (in Japanese)
58. Fujishima I, Fujiu-Kurachi M, Arai H, et al. Sarcopenia and dysphagia: Position paper by four professional organizations. *Geriatrics & Gerontology International.* 2019;19(2):91-97.doi: 10.1111/ggi.13591
59. Hirata A, Ishizaka M, Sawaya Y, Shiba T. Relationship between nutritional status and the number of masticable foods in elderly outpatients. *Journal of the International University of Health and Welfare.* 2020;25(2):8-15. (in Japanese)
60. Wakabayashi H, Takahashi R, Murakami T. The Prevalence and Prognosis of Sarcopenic Dysphagia in Patients Who Require Dysphagia Rehabilitation. *J Nutr Health Aging.* 2019;23(1):84-88.doi:10.1007/s12603-018-1117-2
61. Nagano A, Maeda K, Koike M, et al. Effects of Physical Rehabilitation and Nutritional Intake Management on Improvement in Tongue Strength in Sarcopenic Patients. *Nutrients.* 2020;12(10):3104.doi:10.3390/nu12103104
62. Iyota K, Mizutani S, Kishimoto H, et al. Effect of Isometric Tongue Lifting Exercise on Oral Function, Physical Function, and Body Composition in Community-Dwelling Older Individuals: A Pilot Study. *Gerontology.* 2021:1-11.doi:10.1159/000518270
63. Miyoshi S, Saito A, Shigeishi H, Ohta K, Sugiyama M. Relationship between oral and physical function and length of participation in long-term care prevention programs in community-dwelling older Japanese women. *Eur Geriatr Med.* 2021;12(2):387-395.doi:10.1007/s41999-020-00424-w
64. Kito N, Matsuo K, Ogawa K, et al. Positive Effects of "Textured Lunches" Gatherings and Oral Exercises Combined with Physical Exercises on Oral and Physical Function in Older Individuals: A Cluster Randomized Controlled Trial. *J Nutr Health Aging.* 2019;23(7):669-676.doi:10.1007/s12603-019-1216-8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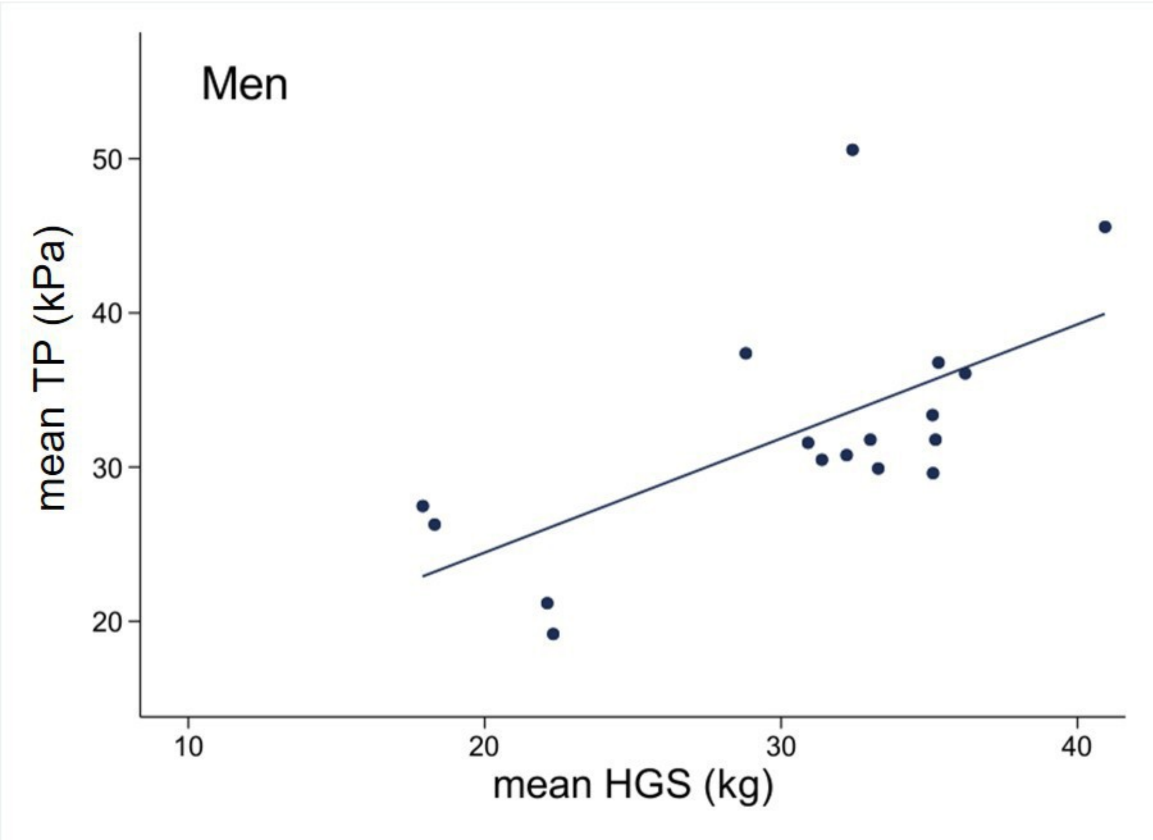

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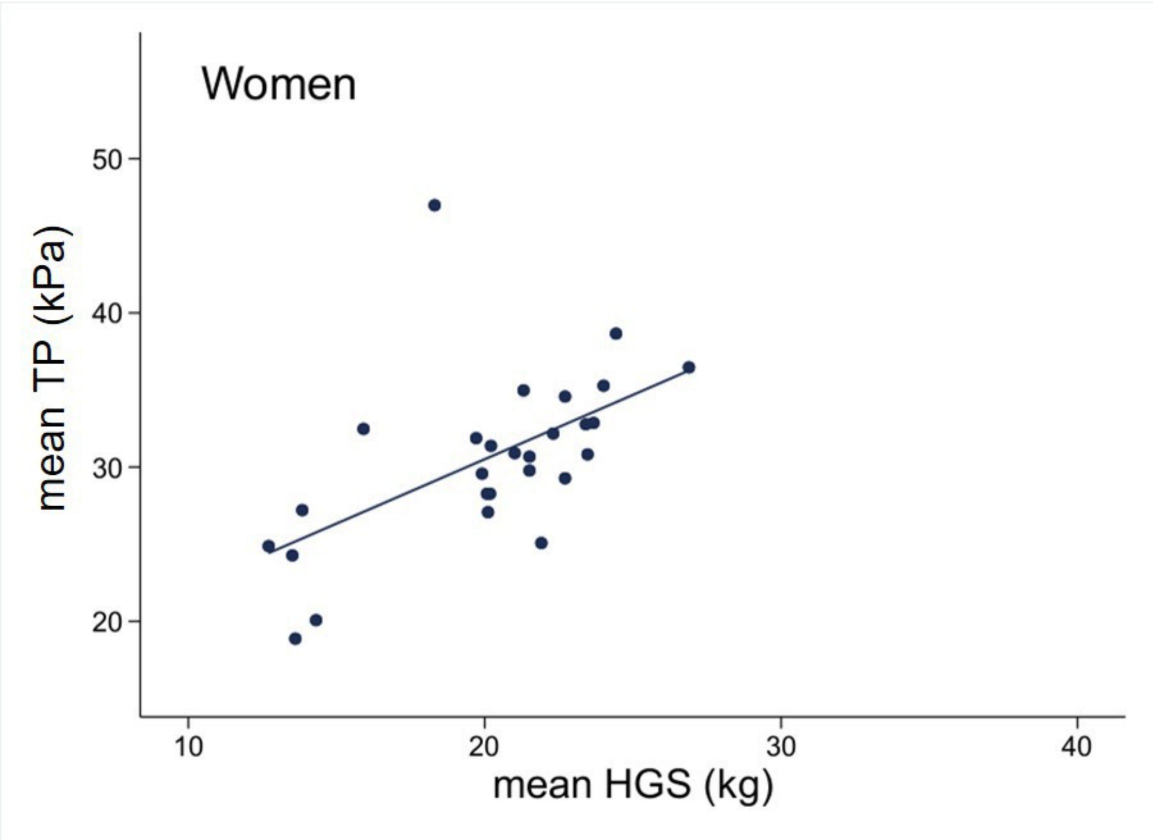

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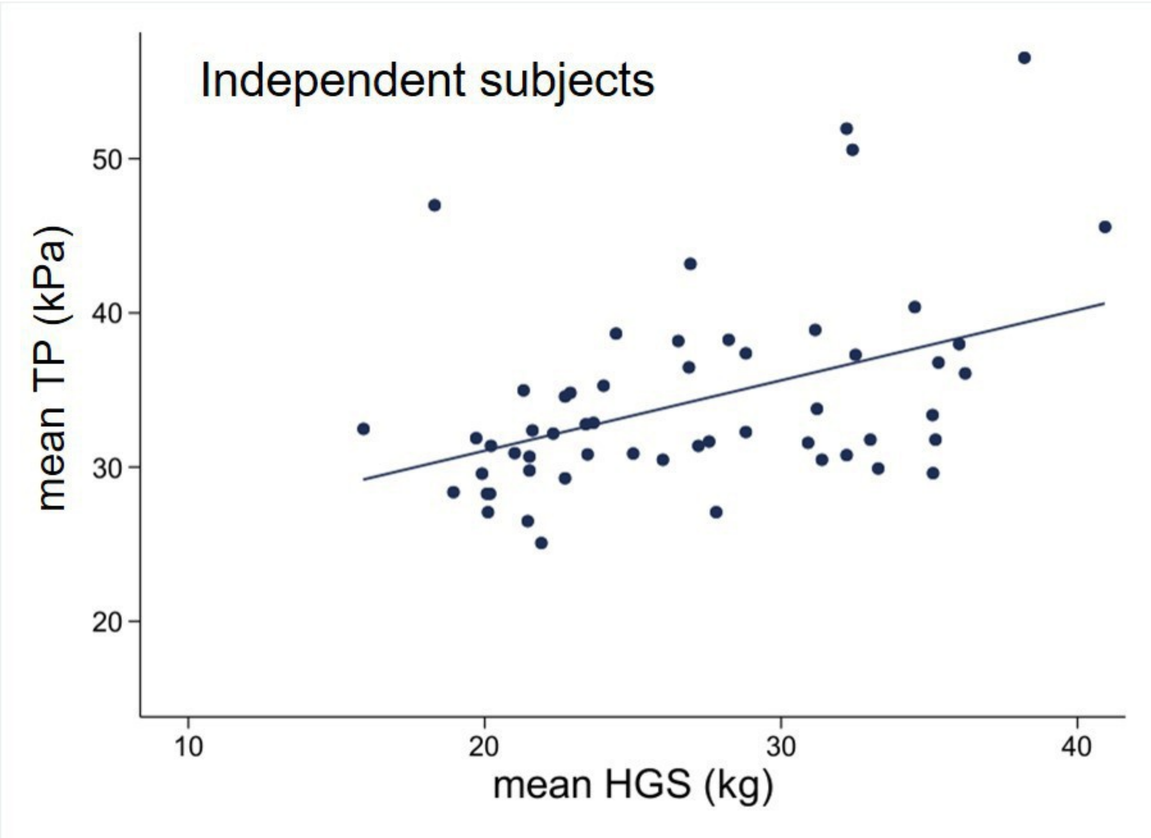

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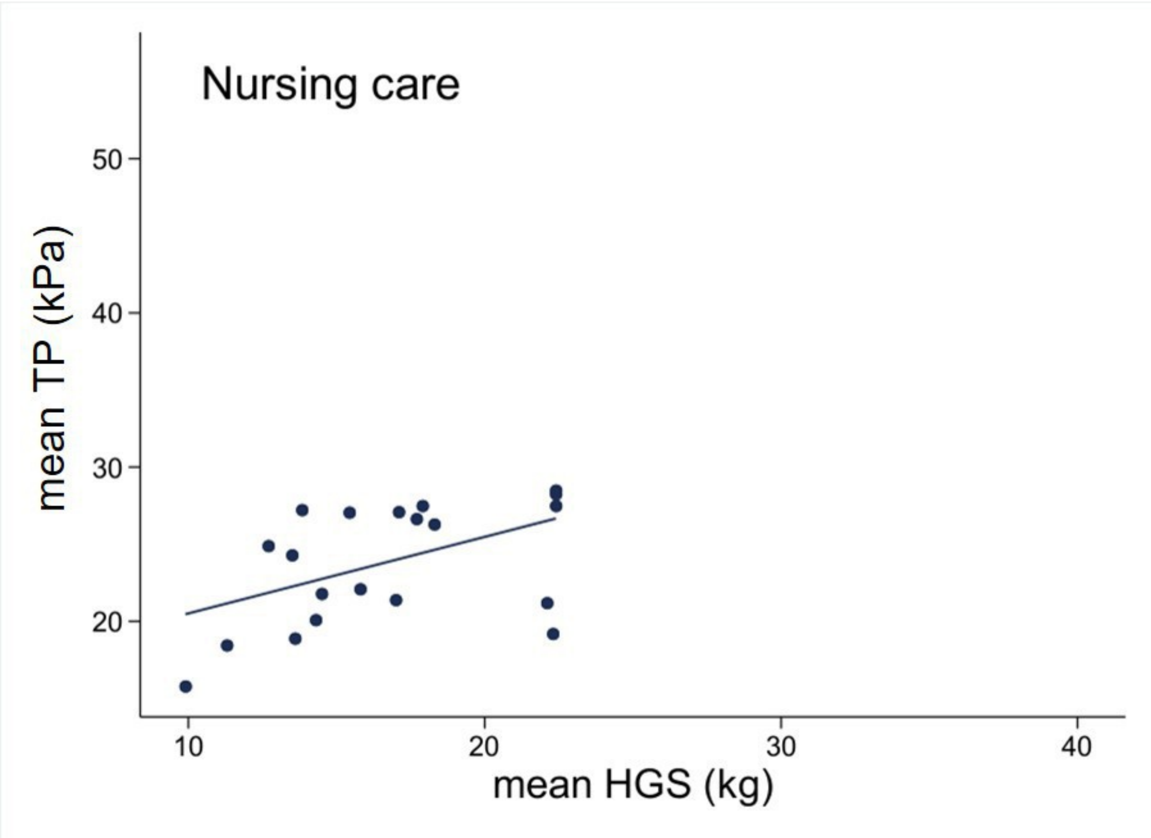

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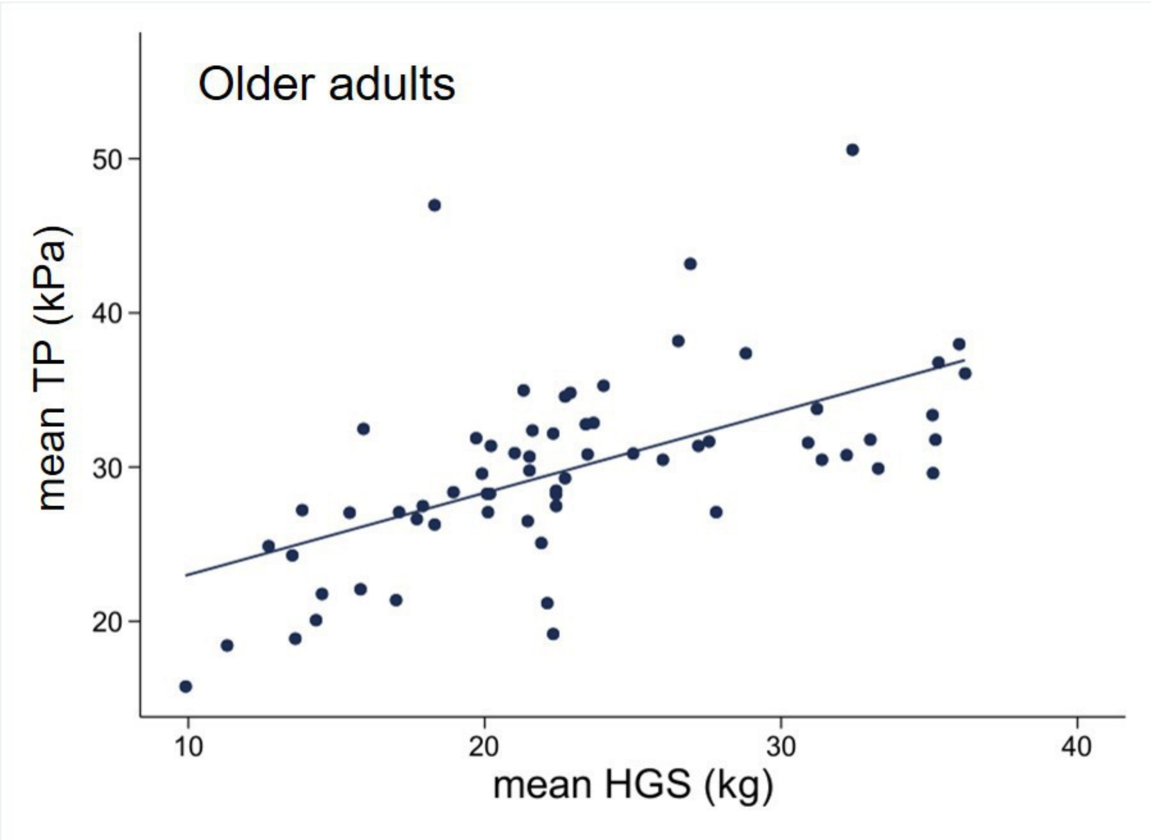

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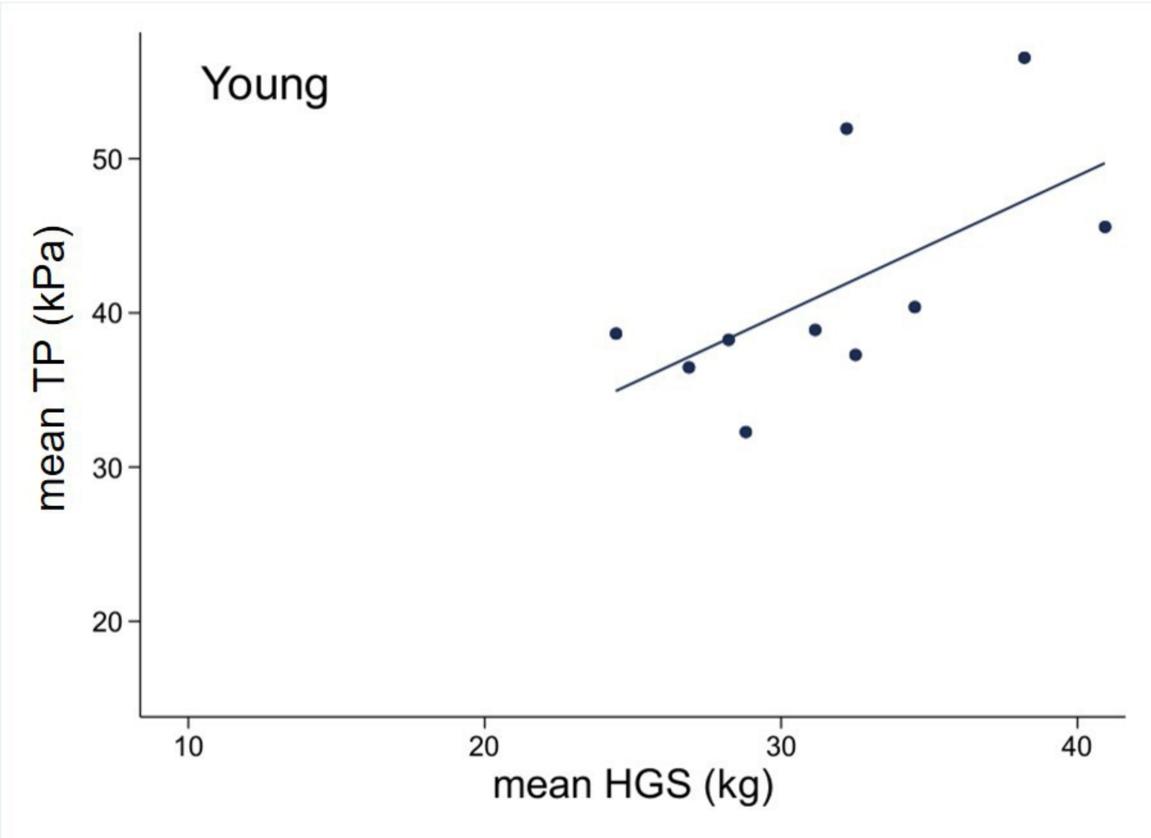

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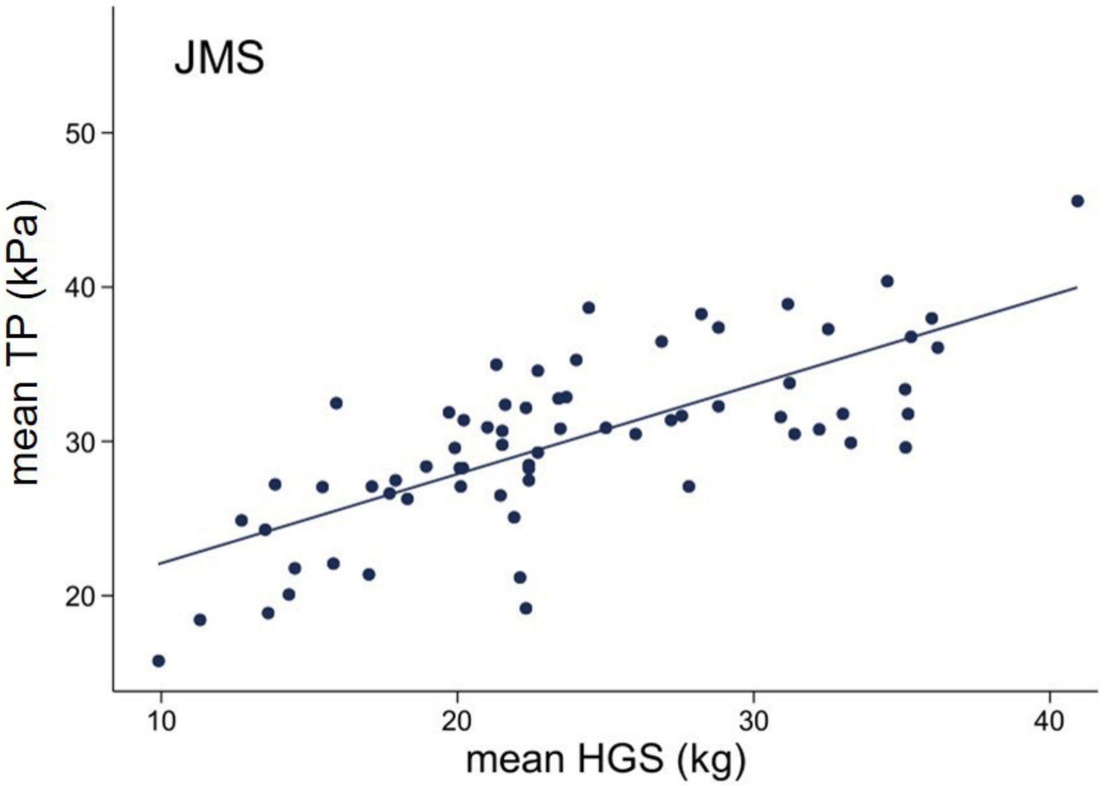

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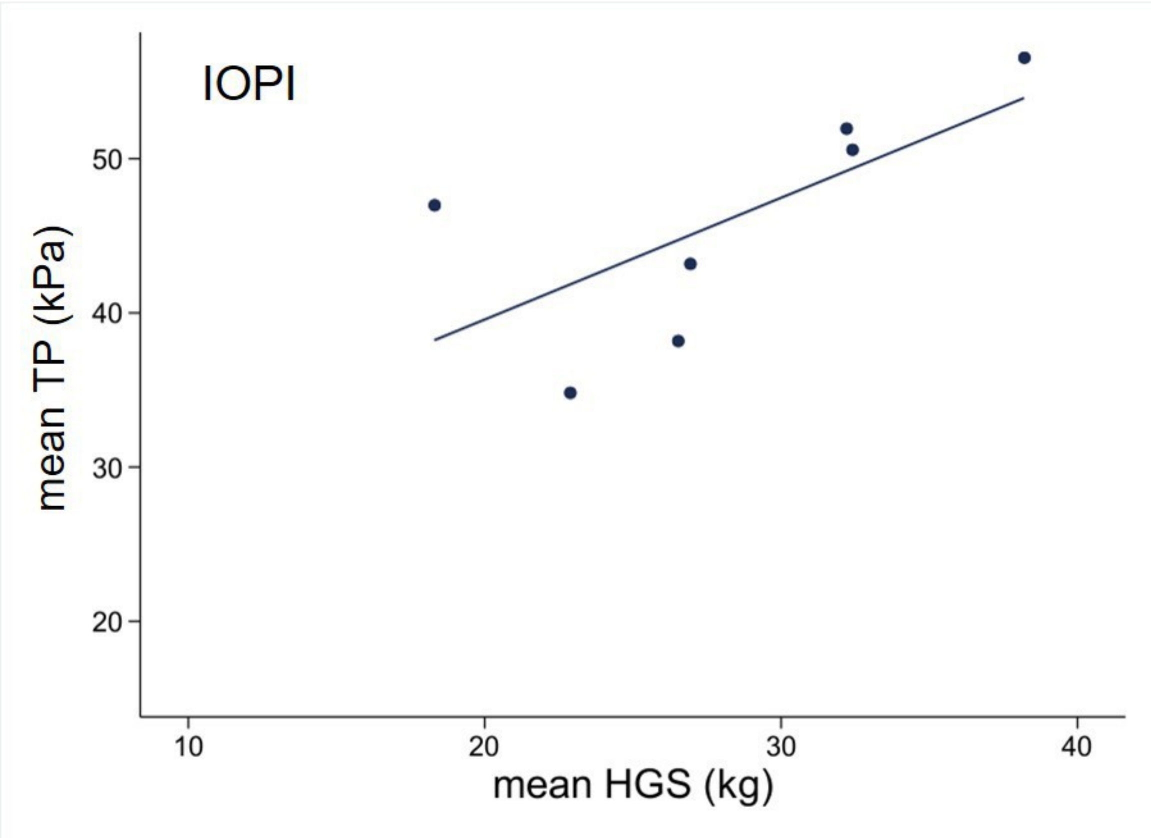

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