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# How Passive Neck Immobilisation Influences Tongue Mobility and Strength: An Observational Study

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## ABSTRACT

**Background:** There is a physiological association of the neck movements and jaw and tongue movements. However, there are no previous data regarding the performance of the tongue when the neck is under a lack of movement condition.

**Objective:** To quantify the tongue's maximal strength and mobility under an experimental restriction of cervical mobility.

**Methods:** This cross-sectional study recruited 33 healthy volunteers. We measured the tongue's mobility and maximal strength reached at the posterior, middle and anterior parts of the tongue; all were performed with and without neck immobilisation. A neck collar was used for the experimental restriction of cervical mobility.

**Results:** ANOVA revealed no differences in tongue strength between cervical condition ($p = 0.84$), but differences were found among the three tongue areas' strength ($p < 0.001$), according to the post hoc results the posterior area of the tongue resulted significantly weaker compared to the anterior (with collar $p = 0.006$; without collar $p = 0.01$) and midparts (with collar $p = 0.03$; without collar $p = 0.006$). Significant differences were also found in the tongue's range of motion (ROM) between groups for the protraction ($p = 0.02$). A subclassification of the participants was made according to the greatest strength obtained with (CCI group) or without (WCI group) neck collar, or no difference (NC group). The analysis of variance showed significant changes in tongue strength between groups at the tongue's anterior area ($F = 5.28$; $p = 0.01$), middle area ($F = 9.83$; $p < 0.001$) and posterior area ($F = 4.05$; $p = 0.02$). The post hoc analyses showed strength in the middle area of the tongue changed between neck conditions, obtaining significantly greater results without the neck collar compared with those with the neck collar ($p = 0.01$; $d = 1.10$).

**Conclusion:** The results of this study indicate a trend suggesting that posture induced by experimental cervical fixation may influence tongue strength, with a possible greater effect in the middle area of the tongue compared to the anterior and posterior areas; however, it affects tongue range of motion. These findings suggest that cervical posture could be an important factor to consider in clinical assessments and interventions involving tongue function. Nonetheless, a larger sample size and further studies are needed to draw more definitive conclusions and understand these potential associations.

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## 1 | Introduction

The stomatognathic system is a single functional complex shaped by various musculoskeletal structures, such as the maxilla, the jaw, the dental arches, the tongue, other soft tissues, the temporomandibular joint and the associated muscles [1, 2]. The functions of this system are numerous, involved in actions such as speech, facial expression, breathing and chewing. Chewing is one of the main functions of the stomatognathic system, in which the components described above are organised and coordinated to crush and prepare food (food bolus), to facilitate swallowing and to aid digestion [3].

The tongue is one of the most relevant structures of this functional complex, and it fills part of the oral and pharyngeal cavity [4]. It is an organ shaped by a group of intrinsic and extrinsic muscles that work synergically to enable the functions of chewing, swallowing and speech [5]. All these muscles are innervated by the hypoglossal nerve, except for the palatoglossal muscles, whose innervation comes from the pharyngeal plexus [6]. The intrinsic muscles of the tongue, unlike the extrinsic muscles, do not present bony attachments. They form a muscle fibre network arranged in various directions, which originate and insert within the tongue, thus forming the tongue's body [4, 6, 7]. Its three-dimensional spatial conformation, its high-water content and its type II fibre (fast contraction) predominance allow the tongue great speed and agility; hence, its ability to effectively perform its main functions [5, 8, 9].

The biomechanical and neurophysiological characteristics of the tongue make it a vital organ during the oral and pharyngeal phase of swallowing. During the oral swallowing phase, the tongue performs an important task of distribution and preparation of the food bolus, in addition to presenting neurophysiological and biomechanical coordination with the mandibular movement performed during mastication [10–15]. Through the retraction and pushing movements performed mainly by the genioglossus muscle, together with the coordinated control of the other intrinsic and extrinsic muscles, the tongue executes a sequential elevation. The anterior region is raised first, followed by the middle and dorsal regions, moving the food bolus into the pharynx [16, 17].

Some authors hypothesise about a possible influence and coordination of the temporomandibular and craniocervical region with respect to the hyolingual system, working as a physiological and biomechanical unit [10]. These structures are supposed to functionally impact one another, even in the context of dysfunctional processes [7, 10, 11, 18–20].

The anatomical relationship between the craniocervical and mandibular regions has been described by many authors as a mutual dependence. This mechanical correlation is shown by the influence of the craniocervical spine on the temporomandibular joint, with its synergic mobility and concomitant disorders [21–24].

Scientific evidence establishes a neurophysiological link between the structures within the trigeminocervical complex, notably the anatomical convergence at the caudal trigemino-cervical complex where the caudalis nucleus of the trigeminal nerve intersects with the first cervical segments (C1–C3). This relationship involves the integration of cervical and cranial somatosensory afferents, facilitated by the arrangement of this nucleus at the brainstem level. Inputs from the masticatory muscles, teeth, temporomandibular joint, tongue, palate and rhinopharynx mucosa are processed together with information from superior cervical areas [11, 25]. This physiological interconnection supports the understanding of clinical symptoms in various craniofacial pain pathologies, including cervicogenic headaches and migraines [26].

This study was motivated by the need to elucidate the functional correlation between the craniocervical region and the hiolingual system. Although significant mechanical and neurophysiological relationships have been identified within various components of the stomatognathic system, current knowledge primarily stems from the field of speech therapy. In this context, postural, structural and functional alterations are often linked with dysphagia processes [27–29]. Moreover, preliminary research has begun to shed light on the mechanical impact of craniocervical posture on tongue strength [10].

The current scientific knowledge base, as outlined previously, provides robust information on the coordination between the temporomandibular and craniocervical regions in relation to the hiolingual system, demonstrating their function as a physiological and biomechanical unit [10]. It is believed that these structures significantly influence each other, even in the presence of dysfunctional processes [7, 10, 11, 18–20].

Many authors have described the anatomical relationship between the craniocervical and mandibular regions as one of mutual dependence. This mechanical correlation is evident in the influence of the craniocervical spine on the temporomandibular joint, which manifests in synergistic mobility and associated disorders [21–24].

From the perspective of motor correlation among the components of the stomatognathic system, several clinical and physiological findings have been observed. These include rhythmic craniocervical flexion–extension movements during mastication [19, 30], preactivation of tongue protractor and retractor muscles during the mandible's opening and closing phases, respectively [12, 31], and variations in neuromuscular activation of the intrinsic and extrinsic lingual musculature depending on food consistency [13]. Additionally, there is an electromyographic increase in cervical musculature prior to mandibular clenching [32, 33], similar to changes in autonomic activation observed when the tongue is pressed against the palate [34].

These findings demonstrate a genuine physiological relationship from somatoperceptive, sensorimotor and somatotopic perspectives. Indeed, one study has sought to elucidate the actual neuroanatomical relationships, revealing topographic projections from the facial motor nucleus. This suggests that orofacial receptive fields contribute to directing automatic or semiautomated behaviours, such as eating and blinking [35]. These insights support the hypothesis that motor interactions among the stomatognathic system's components are synergistic, facilitating various activities.

This framework has led the scientific community to explore the potential neurophysiological and biomechanical relationships between the craniocervical system, the tongue and the swallowing process. Given the similar central processing and the close anatomical and mechanical relationships of these systems, a mutual coordination and influence are anticipated. Accordingly, this study aims to test the hypothesis that restricting or limiting the cervical region in healthy subjects could impair the movement and motor activity of the hyolingual complex, thereby reducing its maximal strength [36].

The primary objective was to quantify the tongue's maximal strength and mobility after experimental restriction of cervical mobility. The secondary objectives were to assess the percentage of subjects who improved their tongue strength with or without experimental cervical restriction and to evaluate the differences between these groups. Additionally, the study aimed to compare subjects who showed improvement with those who experienced no change.

## 2 | Methods

### 2.1 | Study Design

A cross-sectional observational study was performed with a non-probabilistic and convenience sample. The design followed the international recommendations of the Statement on Strengthening the Reporting of Observational Studies in Epidemiology [37]. All the participants involved in the study received an informed consent document and an explanation of the procedures. The study protocol was planned according to the ethical standards of the Declaration of Helsinki and was approved by the University Ethics Committee (CSEULS-PI 010/2020).

### 2.2 | Participants

The study sample was collected by an expert physiotherapist with 8 years of clinical experience between February and March of 2022 on the campus of La Salle University and from the Community of Madrid through direct verbal informative communication about the project, in which more information would be provided via email. Screening of potential participants was conducted through interviews, with all individuals not meeting the study's established criteria being excluded. The inclusion criteria were as follows: healthy individuals, men and women, between 18 and 65 years of age. The exclusion criteria were individuals with pain or dysfunction in the hyolingual, craniomandibular and cervical regions in the last 3 months; history of orthognathic, cervical or head–face surgical interventions; and those who presented systemic, cardiorespiratory, central nervous system or rheumatic diseases. All the included participants voluntarily signed an informed consent document after receiving the study information and before their inclusion. No functional or traumatological assessments were conducted, as the study only included asymptomatic subjects who met the inclusion and exclusion criteria and fell within a normogram of standard structural and functional behaviour.

### 2.3 | Variables and Instruments

#### 2.3.1 | Tongue Strength

The Iowa Oral Performance Instrument (IOPI) (IOPI Northwest Co. LLC, Carnation, WA, USA), was used to measure the lingual strength (Figure 1). This instrument measures and saves the data on the patient's maximum tongue peak force against the palate. The results obtained were expressed in kilopascals [38]. The maximum tongue strength was measured for each of the three tongue areas (anterior, middle and posterior) with the IOPI manometer. The maximum lingual voluntary contraction value of 3 s' duration was quantified. The assessor, who has several years of research experience using the IOPI, was specifically trained for this study.

**FIGURE 1** | IOPI device and neck collar. Procedure for the measurements with and without the neck collar, inserting the IOPI's probe in the mouth to place it onto the corresponding part of the tongue (anterior, middle or posterior).

### 2.3.2 | Tongue Range of Movement

The tongue's length was measured using a plastic depressor placed at the mentolabial sulcus in a horizontal plane. The patient was asked to 'stick your tongue straight out as far as you can'. The length was registered in centimetre with a tongue depressor placed vertically in contact with the tongue and the ruler [39]. The lateral reach of the tongue was measured in this case by placing the ruler in the left or right lateral region, depending on the movement to be measured, of the mentolabial sulcus. The patient was told, 'stick your tongue out to (the left or right) as far as you can'. The length was recorded using the same method as in the measurement of the anterior range (see Figure 2).

### 2.3.3 | Minerva Collar

It is an external support device that directly contacts the body with occipitomentonian supports and a headband or fronto-occipital fixation strap for enhanced stability (Figure 1). This splint was used to create stable craniocervical and lower cervical segments to study the impact of cervical immobilisation on lingual function. The decision to use a hard collar over a soft one was based on its proven effectiveness in restricting cervical movement [40, 41].

## 2.4 | Procedure

The selected participants were measured twice, with and without a cervical collar, in a randomised manner.

The Minerva collar was used to experimentally reduce movement in the cervical and craniocervical regions (Figure 1), thereby limiting the mechanical freedom essential for various functions of the stomatognathic system, such as the mastication processes that involve craniocervical flexion–extension movements [19].

Measurements were conducted under two different neck conditions: (1) craniocervical immobilisation using the Minerva collar (MC); and (2) without craniocervical immobilisation (WCI), where subjects were in an upright position. The verbal instruction used was to try to stay steady in an upright position, without limiting cervical movement but avoiding excessive cervical movement. During both conditions, the jaw was kept relaxed and closed, but without dental contact [42].

A 30-min rest time between measurements was established. The variables measured with each condition (with/without collar) were also randomised: maximum tongue strength and tongue range of motion (ROM).

The lingual strength variables were acquired by placing an IOPI pressure receptor in three specific areas of the tongue (anterior, middle and posterior). The areas were established by means of anatomical references, in addition to being explained to the patient through images and the descriptions indicated by the researcher. For the anterior area of the tongue, the IOPI probe was placed on the tip of the tongue, behind the lower incisors, so that during the pressure against the hard palate, it ends up behind the upper incisors; for the middle area, the premolars and first molars were referenced; and for the posterior area of the tongue, the last molars were used as a reference, as previously described [36]. After placing the probe on the tongue (at the corresponding area), the patient had to perform a maximal contraction, pushing the tongue against the hard palate, until the maximum peak was reached.

**FIGURE 2** | Measurement of the tongue's range of movement. Protrusion and lateral movement.

Another measurement performed was lingual mobility (Figure 2). It was performed before or after the tongue strength measures, according to the randomisation, employing a previously described protocol [39]. A ruler was placed at the mentolabial sulcus in a forward position (horizontal) as a reference starting point, after which the participant was asked for lingual protrusion. For the lateral range measurement, the ruler was placed in the left or right lateral region (depending on the movement to be measured) of the mentolabial sulcus. The participant was then asked to stick out their tongue following the direction of the ruler as far as possible. The length was registered in centimetre with a tongue depressor placed vertically in contact with the tongue and the ruler [39].

## 2.5 | Randomisation

The order of measurement was randomised using GraphPad software (version 8.00 for Windows, 2019; GraphPad Inc., CA, USA) to mitigate the effects of fatigue or learning on the study results. The first randomisation determined the sequence for collecting data with and without neck immobilisation, while the second randomisation established the order for assessing different tongue positions.

## 2.6 | Sample Size

A pilot study involving 11 participants was conducted to calculate the effect size, which was determined to be 0.62 using a repeated measures ANOVA for tongue strength. Sample size calculations were then performed with GPower 3.1.9.2 for Mac (GPower, University of Düsseldorf, Germany), setting an alpha error ($\alpha$) of 0.05 and a power ($1-\beta$) of 0.95 for one group across three measurements. These calculations indicated that a total of 33 participants would be required for the study.

## 2.7 | Statistical Analysis

We used the Statistical Package for Social Sciences (SPSS 22; SPSS Inc., Chicago, IL, USA) for the statistical analysis. The level of significance for all tests was $p < 0.05$. The Shapiro–Wilk test and visual inspections of $Q$–$Q$ and $P$–$P$ plots assessed the normality of distributions, indicating homogeneity of variances through plots of residuals versus fitted values. Continuous variables will be treated through mean ± standard deviation and categorical variables, through number and percentage.

Differences within and between strength measurements in the tongue's areas (anterior, middle and posterior) were analysed using repeated measures analysis of variance (ANOVA), focusing on interactions between cervical conditions (with and without cervical immobilisation) and tongue areas. The Bonferroni post hoc test was used to identify significant pairwise differences.

The effect size of the ANOVA test was estimated using partial eta square ($\eta p^2$), considering the range of 0.0–0.059 as a small effect size, 0.06–0.139 as a medium effect size and values above 0.14 as large effect sizes. On the other hand, Cohen's *d* was used as an estimator of effect size in post hoc comparisons. According to established values for interpreting Cohen's *d*, effect sizes below 0.49 were considered small, effect sizes between 0.50 and 0.79 were considered medium and effect sizes above 0.80 were considered large.

Participants were categorised into three groups: those who showed improvements in the strength of more than two points (2 kPa) without using the collar (better_WCI), those who showed improvements while using a collar (better_CCI) and those who did not show improvements < 2 points in either condition (NC). A one-way repeated measures ANOVA was used to calculate and compare the mean differences among the three groups. The mean differences and standard deviation were calculated for each one of the three groups, subtracting the data obtained by those participants who obtained more than two points using collar to the data obtained by them in the other condition. And this same approach was used for the noncollar group. The mean difference for the NC group was calculated using the data of the participants that did not achieve the two points of change in each neck condition.

The differences between the ranges of tongue movement (anterior ROM, left ROM, right ROM) were analysed using a repeated measures ANOVA. Additionally, a fundamental analysis evaluated the interaction between the tongue movement ranges and cervical conditions. The Bonferroni post hoc test was used to identify significant pairwise differences.

## 3 | Results

The total sample was 33 participants, with a mean age of 35.06 ± 15.43 years. All the variables analysed had a normal distribution ($p > 0.05$). None of the asymptomatic participants had pain or adverse symptoms during the procedure. The demographic data are shown in Table 1.

### 3.1 | Maximal Tongue Strength

The ANOVA showed statistically significant differences in the strength factor across different areas of the tongue ($F = 12.67$; $p < 0.001$; $\eta p^2 = 0.16$). However, the interaction between cervical conditions and the areas of the tongue did not present statistically significant differences ($F = 0.17$; $p = 0.84$; $\eta p^2 = 0.003$). The Bonferroni-adjusted post hoc analysis did not find statistically significant differences in the comparison between cervical fixation (CCI group) and nonfixation conditions (WCI group) in any of the tongue area measurements ($p > 0.05$). Statistically significant differences were found between the strength measurements of the anterior area of the tongue compared to the posterior area (with collar [CCI] mean difference = 6.27 kPa; $p = 0.006$; without collar [WCI] mean difference = 5.78 kPa; $p = 0.01$) and between the mid-area and the posterior area (with collar [CCI] mean difference 4.39 kPa;

**TABLE 1** | Demographic data.

| | (*N* = 33) | |
|---|---|---|
| **Measurement** | **Mean ± SD** | ***N* (%)** |
| Age | 35.06 ± 15.43 | |
| Gender | | |
| Female | | 19 (39.6%) |
| Male | | 14 (29.2%) |
| Marital status | | |
| Single | | 9 (18.8%) |
| Married | | 9 (18.8%) |
| Stable couple | | 14 (29.2%) |
| Divorced | | 1 (2.1%) |
| Studies | | |
| Primary | | 1 (2.1%) |
| Secondary | | 7 (14.6%) |
| Higher education | | 25 (52.1%) |
| Laboral situation | | |
| Worker | | 16 (33.3%) |
| Not worker | | 4 (8.3%) |
| Student | | 13 (27.1%) |

$p = 0.03$; without collar [WCI] 5.36 kPa; $p = 0.006$) in both groups (Table 2). The results indicate that the strength exerted in the anterior area under both fixation and nonfixation conditions is greater compared to the other two measurements (Table 2).

A second analysis was performed to evaluate the changes in tongue strength between the two neck conditions (with/without neck immobilisation), having categorised the participants into three groups according to an improvement greater of two points in tongue's strength: better_CCI, better_WCI and NC. Figure 3 illustrates the percentage distribution of subjects across these three groups for the anterior, middle and posterior areas of the tongue.

In the anterior area of the tongue, 45.5% (15 participants) showed greater tongue strength without the collar, 30.3% (10 participants) with the collar and 24.2% (8 participants) had no change in strength between the neck conditions.

For the middle area of the tongue, 48.5% (16 participants) showed greater tongue strength without the collar, 30.3% (10 participants) with the collar and 15.2% (5 participants) had no difference.

In the posterior area of the tongue, 48.5% (16 participants) showed greater tongue strength without the collar, 33.3% (11 participants) with the collar and 18.2% (6 participants) had no difference.

ANOVA was used to calculate and compare the mean differences among the three groups (Table 3). Significant changes were observed in the mean differences in tongue strength between groups in the anterior ($F = 5.28$; $p = 0.01$), middle ($F = 9.83$; $p < 0.001$) and posterior areas of the tongue ($F = 4.05$; $p = 0.02$) (Figure 4).

Post hoc analysis (Table 3 and Figure 4) revealed significant differences in the anterior area of the tongue between the NC group and both the CCI (mean difference = 8.63 kPa; $p = 0.01$; $d = 1.93$) and WCI groups (mean difference = 10.70 kPa; $p = 0.03$; $d = 1.39$), both of which showed greater strength under each neck condition. No significant difference was observed between the CCI and WCI groups ($p = 1$; $d = 0.25$). For the middle area, a significant change in tongue strength was noted, with the WCI group showing greater strength compared to the CCI group (mean difference = 3.87 kPa; $p = 0.01$; $d = 1.10$). In the posterior area, significant differences were found between the WCI group and the NC group (mean difference = 7.97 kPa; $p = 0.03$; $d = 1.59$) and between the CCI group and the NC group (mean difference = 7.71 kPa; $p = 0.05$; $d = 2.13$).

### 3.2 | Range of Movement of the Tongue

The ANOVA showed statistically significant differences in the ranges of tongue movement ($F = 40.66$; $p < 0.001$; $\eta p^2 = 0.39$). However, the interaction between cervical conditions and the ranges of tongue movement did not present statistically significant differences ($F = 0.18$; $p = 0.83$; $\eta p^2 = 0.003$). The Bonferroni-adjusted post hoc analysis found statistically significant differences in the comparison between cervical fixation and nonfixation conditions concerning the anterior range of tongue movement (mean difference: −0.29; $p = 0.02$). No statistically significant differences were found in the other ranges of tongue movement ($p > 0.05$). Statistically significant differences were found between the measurements of the anterior tongue movement ranges compared to the left and right movement ranges (Table 2). The results indicate that the anterior movement ranges are greater than the left and right lateral movement ranges (Table 2).

## 4 | Discussion

This line of research will help explain the effects that restriction or dysfunction of cervical mobility can have on the lingual function of patients with craniocervical disorders, promoting the study of new therapeutic approaches in this type of patient. The main objective of the present study was to identify the differences in tongue strength (maximum voluntary contraction against the palate) and tongue mobility (anterior and lateral range of movement) performed with cervical experimental immobilisation (with a cervical collar) compared with a nonimmobilised neutral cervical and craniocervical position.

The results identified herein showed no significant changes between measurements with and without the collar for the tongue's maximum force in any of the measured tongue's areas; however, a trend in the results was found regarding a greater force obtained when the participant did not have cervical experimental immobilisation. When the specific comparisons were made, the results for both groups indicated that the strength the participants could develop with the posterior area of the tongue was significantly smaller than the strength developed with the mid and anterior areas, with a difference of 4.39 and 6.27 kpa respectively. Regarding the tongue's range of movement, the results obtained for the anterior movement indicate significant differences being greater than the result without the cervical immobilisation with a moderate effect size.

This study segmented patients into three groups based on their tongue strength outcomes when using a cervical collar. This innovative approach divides participants as follows: those who showed more than a two-point increase in tongue strength with the collar were placed in the Better_CCI group; those who demonstrated similar strength gains without the collar were categorised into the Better_WCI group and those with less than a 2-point difference between conditions were classified as NC (No Change).

The results were notable, with a significant proportion of participants achieving higher tongue strength without neck immobilisation. In contrast, only a few participants exhibited increased tongue strength with immobilisation, and a small percentage showed no performance variation due to neck condition.

Furthermore, we observed differences in tongue strength across the three groups, with measurements ranging from 3.4

**TABLE 2** | Results of maximum tongue strength at the three portions, and lingual range of movement.

| Measurement | | Mean ± SD CCI | Mean ± SD WCI | Difference of means | Confidence interval (95% CI) | Effect size ($d$) |
|---|---|---|---|---|---|---|
| Maximum tongue strength (kPa) | Anterior | 53.24 ± 11.22 | 54.18 ± 11.94 | −0.94 | (−6.63–4.76) | −0.08 |
| | Middle | 51.36 ± 11.86 | 53.75 ± 12.30 | −2.39 | (−8.33–3.55) | 0.19 |
| | Posterior | 46.97 ± 13.59 | 48.39 ± 12.99 | −1.42 | (−7.96–5.11) | 0.11 |
| Difference of means (95% CI); Effect size ($d$) | Anterior versus Middle | 1.87 (−2.53–6.29); $d = 0.16$ | 0.42 (−3.98–4.83); $d = 0.03$ | | | |
| | Anterior versus Posterior | 6.27 (1.51–11.03)*; $d = 0.50$ | 5.78 (1.02–10.55)*; $d = 0.46$ | | | |
| | Middle versus Posterior | 4.39 (0.32–8.46)*; $d = 0.34$ | 5.36 (1.29–9.42)*; $d = 0.42$ | | | |
| Range of movement of the Tongue (cm) | ROM Ant | 2.80 ± 0.58 | 3.10 ± 0.44 | −0.29 | (−0.55––0.03)* | 0.58 |
| | ROM L | 2.45 ± 0.55 | 2.69 ± 0.44 | −0.23 | (−0.48–0.01) | 0.48 |
| | ROM R | 2.42 ± 0.55 | 2.67 ± 0.51 | −0.25 | (−0.51–0.009) | 0.47 |
| Difference of means (95% CI); Effect size ($d$) | ROM Ant versus Left | 0.35 (0.16–0.53)*; $d = 0.62$ | 0.41 (0.22–0.51)*; $d = 0.93$ | | | |
| | ROM Ant versus Right | 0.38 (0.18–0.57)*; $d = 0.67$ | 0.42 (0.22–0.61)*; $d = 0.90$ | | | |
| | ROM Left versus Right | 0.03 (−0.9–0.16); $d = 0.05$ | 0.02 (−0.11–0.14); $d = 0.04$ | | | |

Abbreviations: Ant, Protrusion of the tongue to anterior; CCI, Cervical immobilisation with Minerva collar; L, Tongue protrusion to the left; R, Tongue protrusion to the right; ROM, Lingual Range of Motion; WCI, without cervical immobilisation group.
*$p < 0.05$.

to 10.70 kPa across all tongue regions. Specifically, each group showed distinct performance compared to the NC group across all tongue parts. Notably, in the middle tongue region, differences were also evident between the Better_CCI and Better_WCI groups.

These findings are significant from a neurophysiological perspective, underscoring the neck's potential impact on tongue functionality. This study introduces a novel approach, suggesting that individuals may respond differently to the same cervical condition.

The results obtained in the present study are in accordance with the data obtained in a previous study [36], in which it was found that the cervical segment could influence the tongue's strength. Differences were found in the anterior and middle areas of the tongue while maintaining a forward head posture or neutral cervical postures compared with a retracted head posture. But also, for the neutral craniocervical posture the results showed that the posterior part of the tongue is the weakest, obtaining significant greater values for the anterior and mid areas, those results are completely aligned with the ones obtained in the present study.

Interestingly, data from other relevant studies suggest that under normal conditions the anterior and middle areas show the highest levels of force and are the ones that generate submaximal forces during normal swallowing patterns [43–45]. The posterior tongue's region might be more effective in isometric work tasks, as it is more effective in terms of endurance variables [44].

Another key point in explaining the significant data on the anterior and middle areas of the tongue and the trend in the results towards greater tongue function with respect to tongue strength and mobility without the collar is the natural biomechanical advantage of specific muscles. Certain anatomical positions provide optimal lever arms to execute force with the lowest possible energy expenditure [46, 47].

Some studies have detailed the influence of craniocervical posture on swallowing ability due to biomechanical changes in the position of the hyoid, as well as the modification of the lever arms of the suprahyoid and infrahyoid muscles [39, 40]. We have found that postural changes in the craniocervical region directly affect the activity of the muscles involved in the resting position of the mandible and its function. In addition, the suprahyoid muscles are directly involved in the stabilisation of the mandible during food grinding, as well as in the active elevation of the hyoid bone and the larynx during swallowing, having a close association between functions involving jaw posture and the action of the supra- and infra-hyoid muscles [48–50].

Examples of these phenomena are found in biomechanical studies on the influence of chin posture on swallowing facilitation. These studies show how cervical extension positions with the chin up generate a delay in maximum hyoid elevation

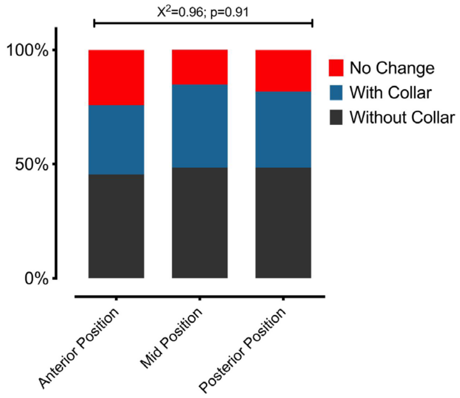

**FIGURE 3** | Graph representing the percentage of participants who achieved greater tongue strength at each tongue area when measured with (blue/light grey) or without (dark grey) neck fixation by the neck collar. Also shown is the percentage of participants who demonstrated no strength change between both neck conditions (medium grey/red).

due to an increase in passive tension in the supra-hyoid muscles, in addition to decreasing the number of fibres available for the contraction that allows hyoid ascent [50]. For the ascending and anteriorising action of the hyoid to be possible during the swallowing phase, a fixed position of the mandible must be established (by the intercuspation of the occlusal surfaces). This stable position allows the tongue and the rest of the suprahyoid muscles to perform adequately for a healthy swallow [50, 51].

That is why, in some cases, this compensatory method of swallowing facilitation can be useful in alterations of the posterior oral swallowing phase, and in no case for alterations of the oesophageal phases.

This alteration of the craniocervical posture (cervical extension and elevated chin) can facilitate the fall of the bolus [52]; however, it can also alter the capacity of muscles, such as the sternohyoid and omohyoid, to stabilise the hyoid and thus to

**TABLE 3** | Secondary analysis: Adjustment based on changes greater than two points in tongue strength across different cervical conditions—Post hoc analyses.

| | ***N*** | **Mean difference ± SD** | | **Mean Difference** | **Confidence interval (95% CI)** | **Error estándar** | ***p*** |
|---|---|---|---|---|---|---|---|
| Tongue's anterior strength (kPa) | | | | | | | |
| Better_WCI | 15 | 9.13 ± 8.71 | Better_CCI | −2.06 | (−9.65–5.52) | 2.99 | 1.00 |
| | | | NC | 8.63 | (0.49–16.77) | 3.21 | 0.03* |
| Better_CCI | 10 | 11.20 ± 7.80 | Better_WCI | 2.06 | (−5.52–9.65) | 2.99 | 1.00 |
| | | | NC | 10.70 | (1.87–19.52) | 3.47 | 0.01* |
| NC | 8 | 0.50 ± 0.53 | Better_WCI | −8.63 | (−16.7–−0.49) | 3.21 | 0.03* |
| | | | Better_CCI | −10.70 | (−19.52–−1.87) | 3.47 | 0.01* |
| Tongue's middle-position strength (kPa) | | | | | | | |
| Better_WCI | 16 | 7.87 ± 4.68 | Better_CCI | 3.87 | (0.51–7.23) | 1.32 | 0.01* |
| | | | NC | 7.27 | (2.76–11.78) | 1.77 | 0.001** |
| Better_CCI | 12 | 4.00 ± 1.65 | Better_WCI | −3.87 | (−7.23–−0.51) | 1.32 | 0.01* |
| | | | NC | 3.4 | (−1.28–8.08) | 1.84 | 0.22 |
| NC | 5 | 0.60 ± 0.54 | Better_WCI | −7.27 | (−11.78–−2.76) | 1.77 | 0.001** |
| | | | Better_CCI | −3.4 | (−8.08–1.28) | 1.84 | 0.22 |
| Tongue's posterior strength (kPa) | | | | | | | |
| Better_WCI | 16 | 9.81 ± 7.06 | Better_CCI | 0.26 | (−5.81–6.35) | 2.39 | 1.00 |
| | | | NC | 7.97 | (0.54–15.41) | 2.93 | 0.03* |
| Better_CCI | 11 | 9.54 ± 5.08 | Better_WCI | −0.26 | (−6.35–5.81) | 2.39 | 1.00 |
| | | | NC | 7.71 | (−0.17–15.59) | 3.10 | 0.05* |
| NC | 6 | 1.83 ± 0.40 | Better_WCI | −7.97 | (−15.41–−0.54) | 2.93 | 0.03* |
| | | | Better_CCI | −7.71 | (−15.59–0.17) | 3.10 | 0.05* |

Abbreviations: Better_CCI, Improved maximum lingual strength with cervical immobilisation; Better_WCI, Improved maximum lingual strength without cervical immobilisation; NC, No changes found between the results with and without cervical immobilisation.
*$p < 0.05$.
**$p < 0.01$.

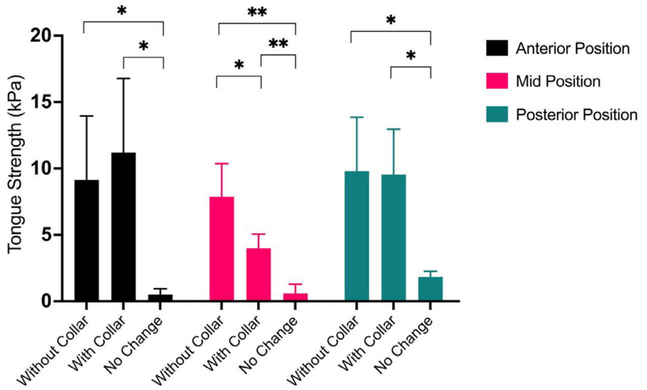

**FIGURE 4** | Influence of the cervical fixation. Comparisons of tongue strength in the various tongue areas performed with or without neck immobilisation. The largest differences were found for the middle part of the tongue; neck immobilisation was associated with lower strength compared with the strength achieved without immobilisation. $^{*}p < 0.05$; $^{**}p < 0.001$.

allow swinging and propulsion actions by the tongue. On the other hand, it can also alter the muscular lever arms by maintaining a pretension during the stabilisation phase of the mandible through occlusal intercuspation. This causes the suprahyoid muscles (digastric, geniohyoid, stylohyoid and thyrohyoid) to perform an upward and forward movement of the hyoid and larynx, leading to the correct opening of the upper oesophageal sphincter [51, 52].

Some studies have also revealed the compensatory influence of other craniocervical positions, so as to improve swallowing processes. Apart from the physiological and lingual biomechanical relationship, to contrast with the current study, some data have revealed that a chin tuck position reduces the anteroposterior distance of the oropharynx and the entrance of laryngeal substances (aspirations) at rest because it reduces the airway entrance [53]. Moreover, it restricts the maximum horizontal mobility of the hyoid, the base of the epiglottis and the larynx, in addition to notably reducing the maximum excursion velocity of these structures. This may be due to possible compression of the tongue and submental muscles by the mandible when performing the chin tuck position. In addition, the excursion distance is lessened with respect to the resting positions, reducing the contractile force, which is greater in neutral anatomical positions [54]. Lastly, it should be noted that this position can also reduce the opening of the upper oesophageal sphincter [53, 55].

The above data did not support the initial hypotheses of the present study regarding the significant decrease of tongue's strength in an immobilised neck. They only demonstrate trends of increased physiological responses of the tongue's maximum strength, and significantly greater anterior mobility in the results measured without a collar. Thus, we see that cervical immobilisation might lead to a different performance of the tongue in most cases. Along these lines, several studies have described problems related to the dysfunction of the tongue and oropharynx, such as dysphagia after the surgical fixation of the craniocervical segment [56–58]. Those are some of the main scientific findings that from a mechanical point of view can support part of the hypotheses of the present study, since part of their findings align with the results found in this work.

From a neurophysiological perspective, we must remember the relationship between the upper cervical nerves and the trigeminal nerve within the trigemino-cervical complex [59]. It is crucial to consider that the anatomical and functional overlap between these systems suggests an integrated mechanism that could explain the observed variations in lingual strength in response to cervical immobilisation. Previous studies have shown that the innervation of the superficial cervical plexus, which affects mandibular areas and extends to the orofacial region, has connections with the branches of the trigeminal nerve that regulate facial sensations and masticatory movements [60].

The connection between the trigeminal sensory system and the hypoglossal motor system, especially in terms of their roles in lingual and cervical functions, presents an intriguing paradigm. The hypoglossal nerve, which primarily facilitates tongue movement, could be influenced by trigeminal signals passing through the cervical spine, thus altering lingual function depending on the cervical position. This is consistent with observations of exacerbations in atypical trigeminal neuralgia following interventions on the hypoglossal nerve, suggesting a functional interaction between the systems [61].

Expanding on this, the complex relationship between these neural interactions and clinical manifestations such as neck–tongue syndrome suggests a deeper, multifaceted neurophysiological framework [62–64]. This is highlighted by the symptomatic correlations attributed to neurophysiological interactions among brainstem processing nuclei and the somatotopic projections between cranial pairs that govern these regions [65]. Such a framework helps explain the often complex symptomatology observed in clinical settings, indicating a broader spectrum of influence than was previously understood.

Our study, by showing that some individuals experience changes in lingual strength in response to cervical immobilisation while others do not, might be observing individual variability in these neurophysiological connections. This hypothesis is supported by the variability in neuronal distributions and individual differences in neurophysiological responses to similar stimuli [66]. Ultimately, this interaction between cervical innervation and the trigeminal and hypoglossal systems underscores the complexity of the mechanisms that regulate neurosensory and motor functions, and justifies a deeper exploration of how these links may influence clinical practice and the management of related disorders.

From a clinical and research point of view, the most important concept that can be extracted from this study is the relevance of controlling neck posture when assessing the tongue's performance, thereby ensuring that changes from one assessment to another are not only due to the differences in neck posture invalidating the results. On the other hand, it is of special interest when treating patients with tongue dysfunctions to consider the neck posture. For future research, it could be of importance to test the possibility of training the tongue with a neck collar or neck immobilisation to generate an artificial advantage or disadvantage depending on the case and the patient status.

Lastly, it would be interesting to assess the influence of the neck status on the tongue performance of patients with temporomandibular disorders and oral parafunctions.

### 4.1 | Limitations

The present research provides new findings for the anatomical and physiological correlations of the so-called stomatognathic system and its function, and the possible influence of the subsystems that comprise it. However, there are some limitations that need to be discussed, therefore the results should be interpreted with caution. First, there was no physical screening for cervical impairments, since we relayed in the subjective perception of being healthy and having a healthy neck.

Second, a semirigid collar with mandibular fixation was utilised, potentially offering a biomechanical advantage for tongue clenching in specific tongue regions, as reported by some participants. However, this collar did not provide complete stability of the craniocervical region; instead, it induced a biomechanical modification. Third, it is important to note that the cervical neutral position was not quantified, and minor neck movements were allowed during the tongue assessments without collar. Nevertheless, these cervical movements were neither controlled nor measured.

Forth, although the IOPI device currently lacks reliability data, the tongue strength measurements obtained were similar to those reported in a previous study [36], suggesting some consistency in the findings despite the device's limitations. However, it is important to note challenges associated with the IOPI probe (small balloon). Specifically, its placement at the targeted tongue position to isolate it from other parts often proves difficult, despite detailed patient instructions before measurements. To address this issue, future research could benefit from adopting the method used by Gingrich et al. which evaluates lingual function by differentiating between antero-medial and posteromedial regions (38). This approach uses a simplified protocol that focuses on just two areas of the tongue.

Fifth, significant differences in strength showed small effect sizes, with the exception of the anterior versus posterior comparison. The relatively minor differences observed in the measured data (middle vs. posterior 4.39, anterior vs. posterior 6.27 kPa, with strength values between 46 and 54 kPa) make it challenging to draw meaningful conclusions.

Finally, the present study did not pretend to draw clinical conclusions. It is necessary to contrast these data with patients with craniomandibular disorders, dysphagia or other tongue disfunctions. Given that those results could be different, our data should be taken with caution in their translation to clinical practice.

## 5 | Conclusion

The results of this study indicate a trend suggesting that cervical and craniocervical posture induced by experimental fixation may influence tongue strength, with a potentially greater effect on the middle area of the tongue compared to the anterior and posterior areas. Additionally, we found the tongue length being greater without cervical fixation than with it. While these findings suggest that cervical and craniocervical posture could play a role when measuring tongue strength and tongue ROM, caution is needed in interpretation, as further research is required to establish these effects. Expanding the sample size and including populations with chewing, swallowing or speech disorders will be necessary to draw more definitive conclusions.

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### Conflicts of Interest

The authors declare no conflicts of interest.

### Data Availability Statement

The data generated and analysed during the current study are available from the corresponding author upon reasonable request.

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