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**Abstract**

Oro-facial impairment following stroke frequently involves reduced chewing performance, that is oral phase dysphagia. The aim was to investigate the sensitivity of oral tissues following stroke and its potential impact on masticatory function. Therefore, hospitalised post-stroke patients were recruited and compared to healthy controls. Outcome measures comprised masticatory performance employing a colour-mixing ability, that is a bolus-kneading test, maximum lip- and bite force and the one-point and two-point tactile thresholds. Food hoarding and prevalence of dry mouth were evaluated with ordinal scales. Twenty-seven stroke patients (age 64·3 ± 14·1 years) and 27 healthy controls (age 60·8 ± 14·3 years, P = 0·254) participated in this study. The groups had similar numbers of occluding units. Stroke patients reported more frequently dry mouth sensations and food hoarding. The intra-oral tactile sensitivity on the contra-lesional side was significantly lower in stroke patients compared to controls (0·0001 < P < 0·0002), and significant intra-group side differences were found only in the stroke group (0·0001 < P < [...]

Reference

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# Oral tactile sensitivity and masticatory performance are impaired in stroke patients

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**SUMMARY Oro-facial impairment following stroke frequently involves reduced chewing performance, that is oral phase dysphagia. The aim was to investigate the sensitivity of oral tissues following stroke and its potential impact on masticatory function. Therefore, hospitalised post-stroke patients were recruited and compared to healthy controls. Outcome measures comprised masticatory performance employing a colour-mixing ability, that is a bolus-kneading test, maximum lip- and bite force and the one-point and two-point tactile thresholds. Food hoarding and prevalence of dry mouth were evaluated with ordinal scales. Twenty-seven stroke patients (age 64·3 ± 14·1 years) and 27 healthy controls (age 60·8 ± 14·3 years, $P = 0{\cdot}254$) participated in this study. The groups had similar numbers of occluding units. Stroke patients reported more frequently dry mouth sensations and food hoarding. The intra-oral tactile sensitivity on the contra-lesional side was significantly lower in stroke patients compared to controls ($0{\cdot}0001 < P < 0{\cdot}0002$), and significant intra-group side differences were found only in the stroke group ($0{\cdot}0001 < P < 0{\cdot}0010$). For the lip, both sides were less sensitive in the stroke group compared with controls. The experiments confirmed lower masticatory performance and lip force in the stroke group, but the bite force was similar compared to healthy controls. Oral sensitivity was correlated with masticatory performance when a global correlation model was applied. A stroke may affect the sensitivity of the intra-oral tissues contra-lesionally, thus potentially affecting chewing function. Rehabilitation should therefore not only focus on motor impairment, but equally stimulate the sensitivity of the oral tissues, employing dry ice application or similar specific treatments.**

KEYWORDS: **mastication, stroke, symptom assessment, chewing gum, dysphagia, tactile perception**

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## Introduction

The mouth is densely populated with mechanoreceptors, and the lips and the tip of the tongue are among the most sensitive tissues of the body (1, 2). This high sensitivity is important to assure safe food intake, food texture perception, food comminution and swallowing (3).

Although the motor deficiencies following stroke are well documented for the limb muscles, the cerebral lesion may also lead to a large range of oro-facial motor impairment. Whereas facial muscle palsy following stroke often presents with a clear laterality, the impairment of the chewing muscles is less asymmetrical (4, 5), due to the presence of bilateral cortical projections to the motorical nuclei of the trigeminal

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nerve (6). Chewing movements are centrally generated by a central pattern generator located in the brain stem, with continuous integration of the afferent information from the oro-facial receptors (7, 8).

Depending on the location and the size of the cerebral lesion, stroke may or may not impair oral mechanosensation, and the effect of such a lack of peripheral input to the central nervous system (CNS) on masticatory performance has not yet been studied. In addition, up to half of stroke victims suffer from dysphagia during the acute period, and about one-fifth of the patients are still dysphagic more than 14 days post-stroke (9).

These neurological swallowing difficulties may equally be attributed to motor impairment of the oral and pharyngeal muscles, the tongue (10) or the larynx (11). Oral sensory deficits may also be directly related to silent aspiration, choking events and aspiration pneumonia (12), the latter being a major risk factor in stroke patients at highest risk of death (13).

In qualitative studies, stroke victims stated that they experience difficulties with food comminution, hoarding of food in the oral vestibule, drooling from the corner of the mouth and/or reduced taste sensation (14, 15). Quantitative experiments showed that the masticatory performance in stroke patients might only be half of that in healthy controls of similar age, gender and dental state (5, 16). In-depth discussions with chronic stroke victims revealed that some ‘lose their food’ in the oral vestibule and experience persistent dysaesthesia or anaesthesia of certain areas of the intra-oral structures. Hence, the aim of this study was to investigate whether the impaired chewing function in stroke patients is related to intra-oral and perioral sensorial deficits. For safety in stroke patients, it would seem to be beneficial to assess tactile detection thresholds and two-point discrimination. The following two null hypotheses were tested:

1. Post-stroke patients with facial palsy do not show reduced intra-oral sensitivity compared to healthy controls.
2. Intra-oral sensitivity is not correlated to masticatory performance.

## Materials and methods

Ethical approval was granted (Psy11-259, Psy 11-032), and written informed consent was obtained from all participants.

Patients were screened and recruited from the Division of Neurorehabilitation, Department of Clinical Neurosciences, University Hospitals and University of Geneva, Geneva, Switzerland, between February 2012 and December 2015. Patients were included if they were hospitalised for stroke rehabilitation, were able to undergo psychophysical testing and presented with a facial impairment ≥2 according to the House–Brackmann criteria (17), because of central facial palsy. They were excluded if they presented with acute pain in the oro-facial sphere (nominal question) or an additional neuro-muscular disease. Furthermore, tube-fed patients or those with acute risk of aspiration because of oesophageal/pharyngeal dysphagia were excluded. The participants of the control group were recruited from staff and patient pool of the University Clinics of Dental Medicine, University of Geneva, Switzerland. There was one control per case. They were included to be similar in age, gender and dental state to the stroke patients. Controls were excluded if the presented with pain in the oro-facial region, a neuro-muscular disease, diabetes or oligosialia. The time point of experimentation in relation to stroke onset was noted as ‘days post-stroke’ (Table S1).

For the experiments, an in-depth oral examination was performed and the number of functional premolar units (OU) was noted. A premolar tooth with an occluding antagonist counted as one OU, whereas a molar was considered two OU (including third molars). Participants were asked with a simple dichotomic question if they perceived dry mouth.

### *Food hoarding*

Food hoarding was assessed with an ordinal Likert scale. Participants were asked if they ‘lost’ foodstuff in the oral vestibule on a scale of never (score 0), rarely (score 1), occasionally (score 2), frequently (score 3), very frequently (score 4) or always (score 5).

### *Maximum voluntary bite force*

Maximum voluntary bite force (MBF) was assessed by means of an Occlusal Force Meter GM 10® (Nagano Keiki*), which has an 8·6-mm-thick bite element. The gauge was placed in between the first molars, and the

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participants were asked to bite three times as hard as possible for about three-seconds. The MBF was tested independently on the right and left sides. For the analysis, the peak MBF of each side was noted and the mean of the two sides was used for further analysis. None of the patients had dental implants. If present, removable prostheses were worn during measurement. In case the first molar was not present, the first mesial adjacent tooth was used as site of assessment.

*Maximum restraining lip force*

For the lip force measurements, an oral screen (Dentaurum 'Ulmer Modell' maxi; Dentaurum GmbH†) was connected to a dynamometer (ZP50-N; IMADA‡). It was placed in the anterior oral vestibule and a horizontal pulling force was applied while the participant tried to withstand the force as long as possible. Three peak recordings were averaged for analysis.

*Tactile detection thresholds*

The tactile detection threshold (TDT) of mechanoreceptors was evaluated using psychophysical testing methods. A touch sensation was elicited using von Frey filaments (optihair, Marstock nerv test§) (18). This test kit consists of 11 monofilaments of varying stiffness, which are calibrated to apply defined forces of 0·25–512 mN (±10%). The filaments were pushed vertically for about 1 s to the different test sites on each side (ipsi- and contra-lesional in stroke patients and right and left sides in controls). The tests started with a supra-threshold stimulus, which was consecutively lowered until the patient did not feel the filament anymore. Following the filament with the lowest perceived pressure, the applied force was re-increased until the patient recognised the touch again. This procedure was repeated twice. The final threshold was calculated from the mean of the three infra- and three supra-thresholds. If the patient felt even the lowest stimulus available (0·25mN), the infra threshold was set at 0·125mN.

*Two-point discrimination*

To determine the patients' tactile spatial resolution, the static two-point discrimination threshold (2PD) was investigated (19). The smallest distance between two simultaneously presented punctiform stimuli was evaluated using a medical calliper (Schieblehre Zürcher Modell, 125 mm, Hammacher Instrumente¶). The separation between the two tips ranged from 0 to 15 mm; the cut-off was set to 15 mm. A staircase method was used with descending distances. The participant was asked to indicate whether he/she sensed one or two points, and the corresponding distances were noted. The mean between those two distances was considered as the individual minimum 2PD.

*Test sites for sensory testing*

The 2PD test sites were the extraoral surface of the lip (approximately halfway between philtrum and oral commissure) and the dorsum of the tongue opposing the second premolar. For TDT, the mucosa of the cheek opposing the second premolar and on the linea alba was used as an additional test site. Whereas these test sites were evaluated on both sides, the 2PD test was additionally applied to the tip of the tongue without side discrimination. For one particular analysis, all TDT readings per participant were averaged (TDT. global).

*Masticatory performance*

Masticatory performance was assessed with a previously validated colour-mixing ability test, that is bolus-kneading test, using chewing gum (20). The gum (Lotte™**) was composed of two individually packed beads (pink and azure colour) that measured 18·8 × 14·2 × 3·9 mm; they were placed on the participant's tongue. The task was to chew the specimen for twenty cycles while being monitored by the operator. The bolus was then retrieved from the oral cavity, placed into a transparent bag, pressed to a 1-mm-thick wafer and both sides were scanned at 300dpi (Epson Perfection V750 Pro, Seiko Epson Corp.††).

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The compound images of both sides were then subjected to a colorimetric evaluation using the custom software ViewGum© (dhal Software‡‡). The software transposes the images to the HSI colour space and then calculates the hue value for each pixel in the pictures of the semi-automatically segmented gum wafers. If the colours are not mixed, two well-separated peaks on the hue axis are present which will gradually converge with increasing colour mixture. 'Hue' is an angle in the HSI colour space; thus, the circular variance of hue is defined as 1 minus the length of the average vector. ViewGum© displays the standard deviation between those colour peaks by taking the square root: s.d. = sqrt (Variance of Hue, VOH) (21). A low VOH indicates greater colour mixture and therefore better masticatory performance.

*Statistical analysis*

Normality of all numerical variables was rejected with empirical cumulative distribution function and QQ plots. Results are reported as median values ± standard deviation. The two groups (stroke and control) were compared with exact Wilcoxon and Mann–Whitney *U*-tests for numerical data and Fisher's exact tests for categorical data.

Numerical and linear regression models were computed to analyse the impact of the investigated parameters on VOH. The relationship between VOH and the investigated parameters was measured with a Spearman correlation coefficient. In the case of a binary variable, the end point was transformed into a categorical variable that separates the values below and above the median. Odds ratios (OR) and 95% confidence intervals (95% CI) were calculated to analyse the resulting 2 × 2 contingency table. All statistical tests were performed with R 3.2.2 (R Project for Statistical Computing§§).

## Results

*Study participants*

A total of 54 participants were included in the study, 27 in the stroke group (19 women, eight men, age 64·3 ± 14·1 years, median 31 days post-stroke) and 27 in the control group (17 women, 10 men, age 60·8 ± 14·3 years, $P = 0{\cdot}2535$). There was no difference between the groups with regard to functional OU on natural teeth (control group 7 ± 4·2, stroke group 7 ± 4·2, $P = 0{\cdot}8616$).

In the stroke group, 16 of the 27 participants affirmed the dichotomic question in relation to a dry mouth sensation positively, compared to two of the 27 members of the control group ($P < 0{\cdot}0001$). Food hoarding was reported more frequently in the stroke group ($n = 25$, score 3 ± 1·8) than in the control group ($n = 3$, score 0 ± 0·7, $P = 0{\cdot}0005$), and the facial paralysis as evaluated with the House–Brackmann Scale was significantly different between the groups (stroke: 2·0 ± 0·75, control: 1·0 ± 0, $P < 0{\cdot}0001$). In-depth details of the participants are listed in Table S1.

*Bite and lip force*

Maximum voluntary bite force was similar between sides in both the control group and the stroke group, and there was no significant difference between the groups (n.s.). No dental trauma occurred during the assessment of MBF. The lips, however, showed a lower force in the stroke group (Table 1).

*Tactile sensitivity*

Intra-group comparisons between the left and right sides confirmed no differences in the control group for the TDT and the 2PD tests. Consequently, in the control group, the means of left and right TDT and 2PD were used for further analysis. In the stroke group, however, the TDT and 2PD were significantly higher on the contra-lesional compared to the ipsi-lesional sides (Table 2).

The intergroup assessment revealed higher thresholds and 2PDs on the contra-lesional side compared to the control group on all sites of measurement. However, for the lip, the ipsi-lesional sides were additionally less sensitive in the stroke group compared with controls (Table 3).

*Masticatory performance*

The participants in the stroke group exhibited significantly lower chewing efficiency than their controls ($P < 0{\cdot}0001$, Fig. 1). The OR for the categorical classification control/stroke was 7·69 (95% CI: 2·36–28·36,

‡‡Kifissia, Greece.

§§Vienna, Austria.

$P$ = 0·0009) and for xerostomia yes/no OR 2·72 (95% CI: 0·84–9·59, $P$ = 0·1480).

The linear regression model revealed stroke ($P$ = 0·0056), OU ($P$ = 0·0311) and MBF ($P$ = 0·0204) as significant predictors (adjusted R-squared: 0·5407, $F_{8,40}$ = 8·063, $P < 0·0001$), but no other factors (Table S2).

Taking all 54 study participants into account, chewing efficiency was correlated with age, MBF, OU, TDT.global and 2PD of the lip as well as TDT of the dorsum of the tongue. For this calculation, five observations were missing: four values from 2PD.cheek.contra and one value from 2PD.lip.contra (Table 4).

**Table 1.** Group comparisons for the number of occluding units, taking solely natural teeth into account (OU) or also counting tooth replacements (modOU)

| | Control group | | Stroke group | | |
|---|---|---|---|---|---|
| | Median | s.d. | Median | s.d. | *P* value |
| OU (*n*) | 7 | 4·21 | 7 | 4·18 | 0·8616 |
| modOU (*n*) | 8 | 3·6 | 10 | 3·05 | 0·2346 |
| House–Brackmann (1–5) | 1 | 0 | 2 | 0·75 | <0·0001 |
| MBF (*N*) | 334·5 | 279·76 | 165 | 174·95 | 0·1021 |
| MLF (*N*) | 19·92 | 5 | 15·07 | 5·74 | 0·0041 |
| Days post-stroke | n.a. | n.a. | 31·00 | 54·00 | n.a. |

MBF, maximum voluntary bite force (mean from both sides); MLF, maximum restraining lip force; s.d., standard deviation.
Facial asymmetry was assessed with the House–Brackmann Scale (17). Control group $n$ = 27, stroke group $n$ = 27.

**Table 3.** Intergroup comparison between the control group (mean values from right and left sides) and the stroke group (contra-lesional and ipsi-lesional sides)

| | Control group | | Stroke group | | |
|---|---|---|---|---|---|
| | Median | s.d. | Median | s.d. | *P* value |
| TDT.lip.contra (mN) | 0·19 | 0·04 | 0·38 | 2·63 | <0·0001 |
| TDT.lip.ipsi (mN) | 0·19 | 0·04 | 0·19 | 0·59 | 0·0475 |
| TDT.tongue.contra (mN) | 0·19 | 2·56 | 0·75 | 101·75 | <0·0001 |
| TDT.tongue.ipsi (mN) | 0·19 | 2·56 | 0·19 | 0·58 | 0·4826 |
| TDT.cheek.contra (mN) | 0·19 | 2·31 | 1·50 | 120·24 | <0·0001 |
| TDT.cheek.ipsi (mN) | 0·19 | 2·31 | 0·19 | 0·76 | 0·3323 |
| TDT.global (mN) | 0·19 | 1·62 | 1·21 | 36·73 | <0·0001 |
| 2PD.lip.contra (mm) | 2·30 | 1·60 | 8·00 | 4·78 | <0·0001 |
| 2PD.lip.ipsi (mm) | 2·30 | 1·60 | 3·50 | 1·95 | 0·0296 |
| 2PD.tongue.contra (mm) | 3·00 | 3·31 | 10·50 | 5·55 | 0·0002 |
| 2PD.tongue.ipsi (mm) | 3·00 | 3·31 | 4·50 | 3·61 | 0·2241 |
| 2PD.tongue.tip (mm) | 1·50 | 0·97 | 1·50 | 3·68 | 0·0646 |

s.d., standard deviation.
The activation threshold of mechanoreceptors (TDT) and two-point discrimination (2PD) were evaluated for lip, tongue, and tongue tip (no side discrimination). Additionally, TDT was evaluated on the inside of the cheek. 'TDT.global' averages all TDT readings per participant.

**Table 2.** Intra-group comparison in the control group between the right and left sides, as well as in the stroke group between the contra-lesional and ipsi-lesional sides

| Control group (right side) | Median | s.d. | Control group (left side) | Median | s.d. | *P* value |
|---|---|---|---|---|---|---|
| TDT.lip (mN) | 0·19 | 0·04 | TDT.lip (mN) | 0·19 | 0·04 | 1·0000 |
| TDT.tongue (mN) | 0·19 | 4·50 | TDT.tongue (mN) | 0·19 | 0·55 | 1·0000 |
| TDT.cheek (mN) | 0·19 | 2·31 | TDT.cheek (mN) | 0·19 | 2·31 | 1·0000 |
| 2PD.lip (mm) | 1·50 | 1·57 | 2PD.lip (mm) | 2·50 | 1·76 | 0·1373 |
| 2PD.tongue (mm) | 2·50 | 3·67 | 2PD.tongue (mm) | 3·50 | 3·33 | 0·3084 |
| MBFmax (*N*) | 319·00 | 279·50 | MBFmax (*N*) | 319·00 | 296·72 | 0·6282 |
| **Stroke group (contra-lesional side)** | **Median** | **s.d.** | **Stroke group (ipsi-lesional side)** | **Median** | **s.d.** | ***P* value** |
| TDT.lip (mN) | 0·38 | 2·63 | TDT.lip (mN) | 0·19 | 0·59 | 0·0010 |
| TDT.tongue (mN) | 0·75 | 101·75 | TDT.tongue (mN) | 0·19 | 0·58 | 0·0001 |
| TDT.cheek (mN) | 1·50 | 120·24 | TDT.cheek (mN) | 0·19 | 0·76 | <0·0001 |
| 2PD.lip (mm) | 8·00 | 4·78 | 2PD.lip (mm) | 3·50 | 1·95 | 0·0001 |
| 2PD.tongue (mm) | 10·50 | 5·55 | 2PD.tongue (mm) | 4·50 | 3·61 | 0·0003 |
| MBF (*N*) | 163·00 | 162·70 | MBF (*N*) | 180·00 | 198·36 | 0·7221 |

MBF, maximum voluntary bite force; s.d., standard deviation.
The activation thresholds of mechanoreceptors (TDT) and two-point discrimination (2PD) were evaluated for lip, tongue, tongue tip and TDT only for the inner surface of the cheek.

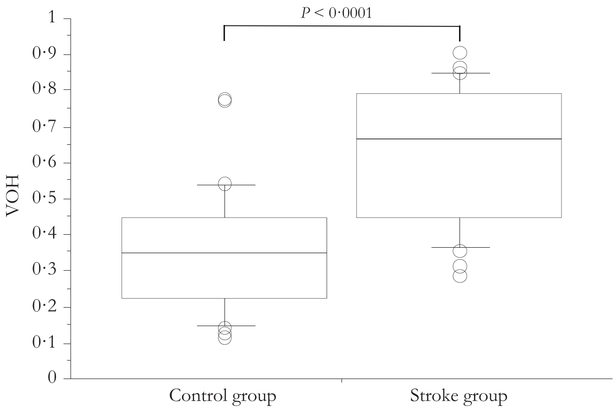


**Fig. 1.** Box plot of variance of hue (VOH), a measure of masticatory performance. The higher the VOH, the lower is the masticatory performance and vice versa (17). The groups were similar in dental state.

**Table 4.** Oral sensitivity and chewing efficiency: numerical predictors of chewing efficiency (VOH) were analysed with correlation coefficients, indicating significant correlations to the chewing efficiency (VOH)

| | Correlation coefficient $n$ = 54 | $P$ value |
|---|---|---|
| Age | 0·32 | 0·0196 |
| TDT.lip.contra (mN) | 0·40 | 0·0030 |
| TDT.lip.ipsi (mN) | 0·26 | 0·0611 |
| TDT.tongue.contra (mN) | 0·46 | 0·0005 |
| TDT.tongue.ipsi (mN) | 0·17 | 0·2306 |
| TDT.cheek.contra (mN) | 0·44 | 0·0010 |
| TDT.cheek.ipsi (mN) | 0·09 | 0·5128 |
| TDT.global (mN) | 0·47 | 0·0003 |
| 2PD.lip.contra (mm) | 0·54 | <0·0001 |
| 2PD.lip.ipsi (mm) | 0·44 | 0·0010 |
| 2PD.tongue.contra (mm) | 0·26 | 0·0606 |
| 2PD.tongue.ipsi (mm) | 0·05 | 0·7039 |
| 2PD.tongue.tip (mm) | 0·20 | 0·1612 |
| MBF | −0·52 | 0·0001 |
| OU | −0·40 | 0·0028 |
| modOU | −0·17 | 0·2270 |

The activation threshold of mechanoreceptors (TDT) and two-point discrimination (2PD) were evaluated for lip, tongue and tongue tip (no side discrimination). Additionally, TDT was evaluated for the mucosa of the cheek. TDT.global averages all tdts from all measured sites per participant ($n$ = 54).

## Discussion

In humans, mastication is a highly coordinated function that integrates sensory input, central control and muscle function. Food is ingested in bite-sized fragments, positioned on the occlusal surfaces of teeth for further breakdown, processed through chewing and accumulated in the oropharynx to form a bolus, which then can be swallowed (22). Food comminution and bolus formation not only depend on jaw movements but also on the bolus control through cheek, lips and tongue. The buccinator muscle, originating from the pterygomandibular raphe and running anteriorly to interdigitate with fibres of the orbicularis oris muscle, forms the lateral wall of the oral cavity and maintains the food bolus between occlusal tooth surfaces by compressing the cheeks (23). There is little evidence, however, of the influence of the sensory function of the oral structures on masticatory performance. Aktar *et al.* (24) did not find a correlation between 2PD of the tongue and food texture discrimination ability, but Kapur *et al.* (25) described impaired masticatory performance after anaesthesia of oral structures.

Woda *et al.* (26) stated that forming a bolus that is safe to swallow might be the ultimate driving command for mastication, because of the life-threatening risk of swallowing an unprepared bolus. This argument might especially be true for dysphagic stroke patients, who have a high aspiration risk.

Surprisingly, little is known about stroke-related impairment of the masticatory function. Jacobson *et al.* (14) reported on a possible interrelationship between eating difficulties and poor nutritional status in chronic stroke patients. Kim *et al.* (27) found that stroke patients needed more chewing cycles and showed a longer oral phase while eating thick rice gruel when compared to a healthy control group. Our own previous studies have identified impaired colour-mixing, that is bolus-kneading, ability following stroke, which does not improve in the absence of a specific rehabilitation programme (5, 16). Although the current experiments use the same methodology, both the viscoelastic specimens as well as the opto-electronical assessment method of testing the colour-mixing ability underwent significant refinement (20). Bite force in stroke patients is usually not affected contra-lesionally, as there are bilateral projections to the motor nuclei of the trigeminal nerves, but also because the mandible is a solid bone that acts as a lever. Therefore, bite forces cannot be assessed unilaterally. Nevertheless, the present results confirm that chewing is significantly impaired in stroke patients compared to healthy peers who are similar in age, gender and occlusal state. Hence, the current study aimed to identify in further detail physiological or pathophysiological factors, which are correlated with chewing efficiency. As a result of long discussions with stroke victims, the focus was placed on intra-oral sensitivity.

Little is known about intra-oral sensitivity in healthy humans and in particular about TDT or 2PD in stroke patients. Rath *et al.* (28) reported on a similar range of sensitivity thresholds in healthy participants (Table 5). The current study demonstrates clear evidence that intra-oral sensitivity is significantly impaired in stroke patients, at least on the contra-lesional side. Additionally, on the lip both ipsi- and contra-lesional sensitivity was reduced compared to healthy peers. Therefore, hypothesis 1 must be rejected.

Kim *et al.* (29) described a frequent occurrence of bilateral sensory disturbance of the hand in patients with unilateral stroke and bilateral sensory impairment was also observed in the current study for the lip, where both contra- and ipsi-lateral sides showed significantly lower TDT compared to the healthy controls. This effect seems to support the theory that this sensation might be branched, with bilaterally travelling pathways like the anterolateral system, rather than the strictly crossing medial lemniscal (29, 30). Also, it could be hypothesised if the innervation of the lip is organised as a whole without lateralisation.

Early anatomical studies revealed bilateral and symmetrical projections to the trigeminal nuclei which innervate the jaw closing muscles (31). Later studies employing transcranial magnetic stimulation (TMS) evinced a bilateral corticobulbar projection to human digastric motor neuron (32). The rhythmic movement of the mandible observed during chewing is generated by a neuron population located in the brain stem, known as the central pattern generator (CPG). It is supplemented by the cortical masticatory area (8) for voluntary control of mastication and providing pre-programmed movement patterns. These are based on experience and sensory feedback of the visual, olfactory and gustatory systems but also from periodontal mechanoreceptors, receptors from oral mucosa, temporomandibular joint and muscle spindles. It has been suggested that peripheral inputs are integrated with the rhythmic activities of the CPG and sent to the cranial motor neurons innervating jaw, tongue and facial muscles (7). The current study confirms this theory demonstrating that chewing efficiency is correlated with TDT and 2PD, at least when all participants were pooled to increase the statistical sample size. Therefore, hypothesis 2 must be rejected. The applied correlation test does not account for possible confounders, but the current study provides valuable first insights into a possible interrelationship between oral sensory function and masticatory performance.

It might have been worthwhile to include an oral stereognosis test in the current study, as those tests were described to be impaired in stroke patients and oral stereognosis seems important for normal oral function (33). However, stroke patients show a high prevalence of dysphagia; hence, it was deemed too dangerous for the stroke victims in this study to undergo experiments in which small test pieces have to be manipulated freely in the mouth.

Engelen *et al.* (19) suggested in their classic article that deep mechanical sensors might be important to detect the size of a bolus and therefore be important for chewing efficiency. Two-point discrimination was not significantly correlated with chewing efficiency in their experiments, which used topical anaesthetic agents to block peripheral input in otherwise healthy subjects. Stroke has a distinctly different effect and can therefore only partly be compared to Engelen's results.

Few rehabilitation programmes have addressed orofacial impairment in stroke patients. Hägg and

**Table 5.** Comparison of the tactile detection threshold (TDT) and two-point discrimination thresholds (2PD) obtained in the control group with average thresholds reported in the literature (28)

| | TDT (mN) | | 2 PD (mm) | | |
|---|---|---|---|---|---|
| | Lip | Tongue | Lip | Tongue | |
| | | | | Dorsum | Tip |
| Control group | 0·24 ± 0·17 | 0·23 ± 0·09 | 2·87 ± 1·86 | 2·42 ± 1·78 | 1·28 ± 0·54 |
| Reference thresholds (28) | 0·24 | 1·14 | 2–4 | 4·00 | 1·70 |

collaborators proposed a training programme with oral screens to strengthen the lip muscles in stroke patients with oropharyngeal dysphagia (34). The median lip force increased significantly from 7 to 18·5 N. Likewise a significant improvement was noted in the swallowing capacity test and some improvement in 2PD. They reported distances comparable to patients' ipsi-lesional side in the current study. Rehabilitative motor training seems to promote oro-facial motor function after focal brain injury, but no specific programme has been proposed so far to improve poor masticatory performance.

For the rehabilitation of dysphagic stroke patients, the application of dry ice on the pharyngeal pillars was proposed to improve tactile sensation. This treatment is useful to trigger the swallow reflex in stroke patients (35).

## Conclusions

A stroke may affect the sensitivity of the intra-oral tissues contra-lesionally, thus potentially affecting chewing function. Rehabilitation should therefore not only focus on motor impairment, but equally stimulate the sensitivity of the oral tissues, like dry ice application or similar specific treatments.

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## Author contributions

Martin Schimmel developed the study hypothesis, planned the design and instruments, performed the literature search, data interpretation and writing of final manuscript. Garance Voegeli took part in data acquisition and first draft of the manuscript. Elena Duvernay performed data acquisition and critical review of final manuscript. Beatrice Leemann participated in recruitment of study participants, development of study design, data acquisition, neurological assessment and critical review of final manuscript. Frauke Müller was involved in development of study design, literature search, data interpretation and critical review of final manuscript.

## Disclosures

The authors have stated explicitly that there is no conflict of interest in connection with this article.

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## Supporting Information

Additional Supporting Information may be found in the online version of this article:

**Table S1** Detailed lesion location and characteristics of participating stroke patients.

**Table S2** Regression table for masticatory performance (VOH) as depended variable.