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Effect of side switch frequency on masticatory performance and rhythm in adults with natural dentition: A randomised crossover trial

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Abstract

Background: The relationships between the frequency of masticatory side switches (MSS) and other aspects of masticatory function are not clear.

Objectives: In this study, we determined the effect of MSS frequency on masticatory performance and rhythm in dentate adults and explored the between-subject relationships among side switch frequency, masticatory rhythm and laterality.

Methods: In this crossover study, subjects performed six masticatory patterns of five trials each, chewing bagged silicone for 20 cycles. The six patterns were freestyle, unilateral right, unilateral left, and switching sides one, three and five times. Masticatory performance and rhythm were determined for each style by median particle size (MPS) and chewing cycle duration, respectively. In the freestyle mastication pattern, masticatory laterality was assessed by the unilateral chewing index, and the frequency of MSS was assessed by the MSS Index. Data were analysed using Friedman's test and repeated measures analysis of variance.

Results: We included 29 participants (15 women; median age, 23 years). No significant between-subjects differences in the MPS were detected obtained by switching one, three or five times per trial. Chewing cycle duration increased with the MSS number per trial. During freestyle mastication, the MSS Index was inversely correlated with the unilateral chewing index (Rho −0.569; 95% CI −0.25 to −0.78; $p = .001$; Spearman test), but not with the MPS or chewing cycle duration.

Conclusion: Differences in MSS frequency do not affect masticatory performance, but they do alter the masticatory rhythm. Individuals with a higher MSS frequency also have a more symmetrical chewing pattern.

KEYWORDS
chewing rate, chewing side, masticatory performance, masticatory side switch, oral function

1 | INTRODUCTION

Mastication is the main function of the oral system and can be assessed subjectively by questionnaires and objectively by masticatory assays through direct or indirect methods.[1] Masticatory performance is a direct method which quantifies the degree of comminution of a test food after a certain number of chewing strokes.[2,3] Chewing rate, as an indirect method, seems to be remarkably stable within individuals and has a normal masticatory cycle duration of 0.6–0.8 s.[4–6] Masticatory laterality, which occurs when there is functional asymmetry due to a preference of one side over the other when chewing, can be objectively and quantitatively assessed with an asymmetry index and/or unilateral chewing index.[7–9] Good masticatory health can be assumed by high masticatory performance, lower degree of unilateral chewing and a normal and stable masticatory rhythm.[10–15]

An aspect of masticatory laterality that requires further exploration is the number and frequency of chewing side changes,[11,16] also known as chewing side alternation,[17] side-shift cycles,[10] chewing side continuity[18] or masticatory side switches (MSS).[19] When healthy people masticate natural food in unilateral cycles, keeping it on one side on the mouth only, most still occasionally change the side of mastication in an alternately unilateral chewing pattern.[10,20] The normal number of side switches is not well established, but several studies have approximated it to be between 1 and 6 per 20 masticatory cycles, corresponding to 5%–32% of the maximum switches possible.[10,16,18–21] Nonetheless, MSS frequency may vary both within and between individuals depending on the food type.[10,16,18–21] In fact, there is low relative reproducibility for determining the number of changes of chewing side while eating biscuits or bread compared with other aspects of the masticatory pattern.[16] Assessing the number of side switches with the aid of an artificial test food may be more reliable than with natural foods.

The pros and cons of frequently switching side while chewing remain unclear. It is possible that changing side benefits from increased taste appreciation, enhanced saliva production and reduced fatigue of the masticatory muscles, similar to that seen with bilateral mastication.[10,22] An observational cross-sectional study showed that individuals with lower MSS frequency or longer chewing side continuity during freestyle mastication exhibited better masticatory performance than those with higher MSS frequency or shorter chewing continuity.[18] However, that study assessed the MSS frequency with a different test food than that used for masticatory performance. Moreover, the study design did not allow for causal conclusions to be drawn between the high frequency of side switches and poorer masticatory performance. Clarifying the relationship between MSS frequency and other aspects of masticatory function might provide novel insights into the physiology of mastication. This knowledge would also be useful for dentists to advice their patients on how frequently they could switch while chewing and to design restorative strategies for partially edentulous patients.

The main purpose of this study was to establish the effect of different MSS frequencies on masticatory performance in adults with natural dentitions. The secondary aims were to assess how these variations affect masticatory rhythm and to explore the interindividual relationship between the MSS frequency and other aspects of the masticatory function during freestyle mastication. The null hypothesis was that the frequency of MSS would not affect masticatory performance.

2 | MATERIAL AND METHODS

2.1 | Study design

This study was a randomised crossover trial of six sequences to compare three MSS frequencies: A1 (side switching once), A3 (side switching three times) and A5 (side switching five times). Each 1-min period involved chewing using a specific test food for 20 masticatory cycles. Although carry-over effect was not expected in masticatory assays,

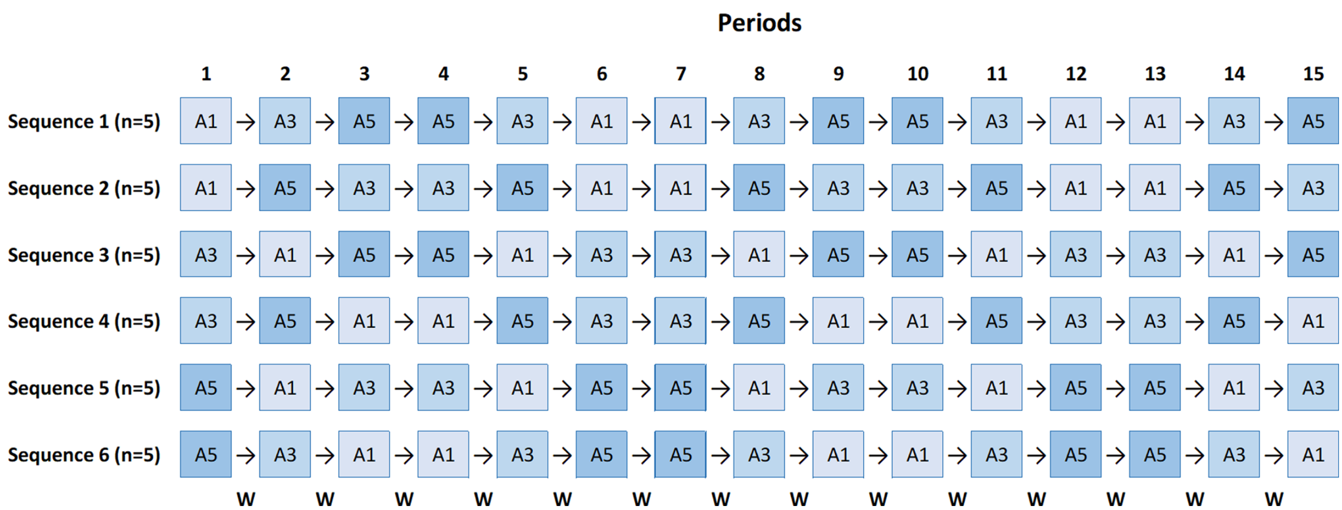

FIGURE 1 Study design. A1 = side switching once, A3 = side switching three times, A5 = side switching five times per masticatory trial of 20 cycles, W = Washout period of 2–5 min

2–5-min washout periods were employed between periods to avoid muscle fatigue. The crossover design was chosen because it requires fewer participants, with each participant serving as his or her own control. The participants were assigned to one of six intervention arms by a researcher (I-M, T) (Figure 1), following a 1:1:1:1:1:1 allocation ratio. Permuted blocks were used to ensure equal assignment to each arm, using 'Research Randomizer' (https://www.randomizer.org). No blinding techniques were applied to the intervention sequence, allocation or outcome assessment. The only change in the study design after it started was an increase in sample size from 28 to 30.

The study protocol, including the informed consent form, was approved by the Ethics Committee of the Barcelona University Dental Hospital (Code 2020/036, 28/10/2020) and was registered in the US Clinical Trials Registry (NCT04714437, 19/01/2021). All procedures were carried out in accordance with the principles of the Helsinki Declaration. The Consolidated Standards of Reporting Trials (CONSORT) statement and the extension to randomised crossover trials were followed in reporting the study results.[23]

2.2 | Participants

Thirty healthy adults with natural dentition were recruited from volunteer students at the University of Barcelona Dental School (Catalonia, Spain) from February to April 2021 and participated in this study. The participants were young adults with a minimum of 24 natural teeth. The sample size was determined by considering a type I error of 0.05, a power of 0.8, an estimated within-subject standard deviation of 0.5 mm[13] and an estimated dropout rate of 25% to find an intra-subject difference of 0.3 mm in the median particle size (MPS). We excluded individuals with large dental restorations, dental prosthesis, severe malocclusions, ongoing orthodontic treatment and oro-facial pain.

2.3 | Data collection

Age, sex, number of teeth, Angle's classification and the presence of a crossbite were recorded through clinical history and examination. Vertical facial height, overjet and overbite were measured using a digital caliper (Absolute; Vogel).[24]

Each volunteer performed a series of six different masticatory patterns in different chewing styles. Each pattern consisted of five trials chewing a latex bag containing 2 g of Optozeta silicone particles (Optosil P Plus, Heraeus Kulze; Zetalabor, Zhermack) for 20 masticatory cycles.[13,25] These particles were prepared from silicone tablets measuring 20 mm in diameter and 5 mm thick, according to the instructions of Albert et al. and Khoury-Ribas et al.[25–27] These were then divided into quarters and three quarters to give a weight of 2 g per latex bag.

The first pattern involved five trials of freestyle mastication in which the participant was asked to chew the latex bag naturally, without imposing a side preference. For the second and third patterns, of five trials each, subjects were asked to chew the bagged silicon unilaterally, using only the right-hand side in one pattern and only the left-hand side in the other, alternating the order of trials between right and left sides.[12,14] In the last three patterns, they performed 15 trials of 20 cycles each (patterns A1, A3 and A5) in one of the following six sequences (Figure 1). For pattern A1, the masticatory side was changed only in the 11th cycle; for A3, it was changed in the 6th, 11th and 16th cycles; and for A5, it was changed in the 3rd, 7th, 11th, 15th and 19th cycles. The chewing side preference recorded in the freestyle pattern was used for the 1st cycle. Patterns A1, A3 and A5 corresponded to MSS Indexes of 0.053 (5.3%), 0.158 (15.8%) and 0.263 (26.3%), respectively.

2.4 | Outcome variables

To determine the masticatory performance for each pattern, the degree of comminution of the silicone was evaluated. The silicone particles of each of the five trials (10 g) were dried for 24 h and then vibrated for 6 min through a series of eight sieves (0.25–5.6 mm), and the cumulative weight distribution of the sieve contents was determined. Then, the median particle size (MPS) for each participant was estimated by the Rosin-Rammler equation [$Qw(X) = 1{-}2E{-}(X/X_{50})^{b}$], where Qw (X) represents the fraction of particles by weight presenting a diameter lower than X, the MPS (or X_{50}) is the dimension of a theoretic sieve which could allow 50% of the weight to cross, and b corresponds to the breadth of the particle size distribution.[28] A higher MPS indicated poorer masticatory performance.

The time spent to complete 20 masticatory cycles per trial was recorded, and the time for the average masticatory cycle per trial was calculated and expressed as ms/cycle.[29]

A single operator observed the menton during the five freestyle masticatory trials and noted the side of mandible lateralisation while closing, considering right as '+1', left as '−1' and neither as '0'. These trials were also recorded on video and watched in slow-speed playback to revise these records and determine the asymmetry index as follows: [(number of right strokes)−(number of left strokes)]/[(number of right strokes) + (number of left strokes)].[9] The unilateral chewing index was established as the absolute asymmetry index value and expressed the degree of unilateral mastication, regardless of the side.[14]

In order to calculate MSS Index, the cycle counts for each of the five freestyle mastication trials were performed using slow-speed playbacks of their recordings. A masticatory switch from right to left or from left to right was scored as 1 point. A masticatory switch from right or left to center or from center to left or right was scored as 0.5 point. To obtain the MSS Index, the total number of points was divided by the maximum number of switches, which was 19 in this study.[21]

2.5 | Data analysis

To evaluate the reproducibility of the main study parameters, masticatory assays were repeated in all participants 2–4 weeks after

TABLE 1 Test-retest reliability and the smallest detectable differences in masticatory parameters by mastication style

	ICC (CI 95%)	*p*-value	SDD
Masticatory side switch index	0.68 (0.31–0.85)	.002	0.03
Median particle size, mm			
Freestyle	0.86 (0.67–0.93)	<.001	0.42
Unilateral	0.87 (0.71–0.94)	<.001	0.44
Side switching 1 time	0.93 (0.85–0.97)	<.001	0.27
Side switching 3 times	0.86 (0.69–0.93)	<.001	0.39
Side switching 5 times	0.83 (0.64–0.92)	<.001	0.36
Chewing cycle duration, ms			
Freestyle	0.80 (0.15–0.93)	<.001	49.7
Unilateral	0.85 (0.23–0.95)	<.001	35.9
Side switching 1 time	0.86 (0.16–0.96)	<.001	31.3
Side switching 3 times	0.82 (0.19–0.94)	<.001	39.0
Side switching 5 times	0.85 (0.20–0.95)	<.001	36.7

Abbreviations: ICC, Intra-class correlation coefficient (2-way random, absolute agreement for average measurements); SDD, the smallest detectable difference.

the first measurements were taken. Reliability was assessed by the intra-class correlation coefficient (ICC) for average measurements, using a two-way random effects model and absolute agreement (Table 1). The smallest detectable difference (SDD) was determined as the measure of agreement between sessions, calculated as $1.96 \times (\sqrt{2}) \times$ standard error of the measurement.[30] Data obtained from the two sessions (test and retest) were averaged to determine the relationship between the MSS frequency and other aspects of the masticatory function. Data from unilateral mastication on the right and left were averaged and grouped as unilateral mastication. Normality and homogeneity of variances were confirmed using the Shapiro-Wilk and Levene tests, respectively. Data for the MSS Index and chewing cycle duration were normally distributed during freestyle mastication, but data for the MPS and unilateral masticatory index were not. Therefore, masticatory parameters were compared between genders using Mann-Whitney *U* tests, and the relationship between different masticatory parameters during freestyle mastication was assessed with Spearman Rank correlation coefficients. Friedman's test and repeated measures analysis of variance (ANOVA) were performed to assess the effect of MSS frequency on MPS and chewing cycle duration, respectively. All analysis was performed using the IBM SPSS, Version 27 (IBM Corp.) ($p < .05$).

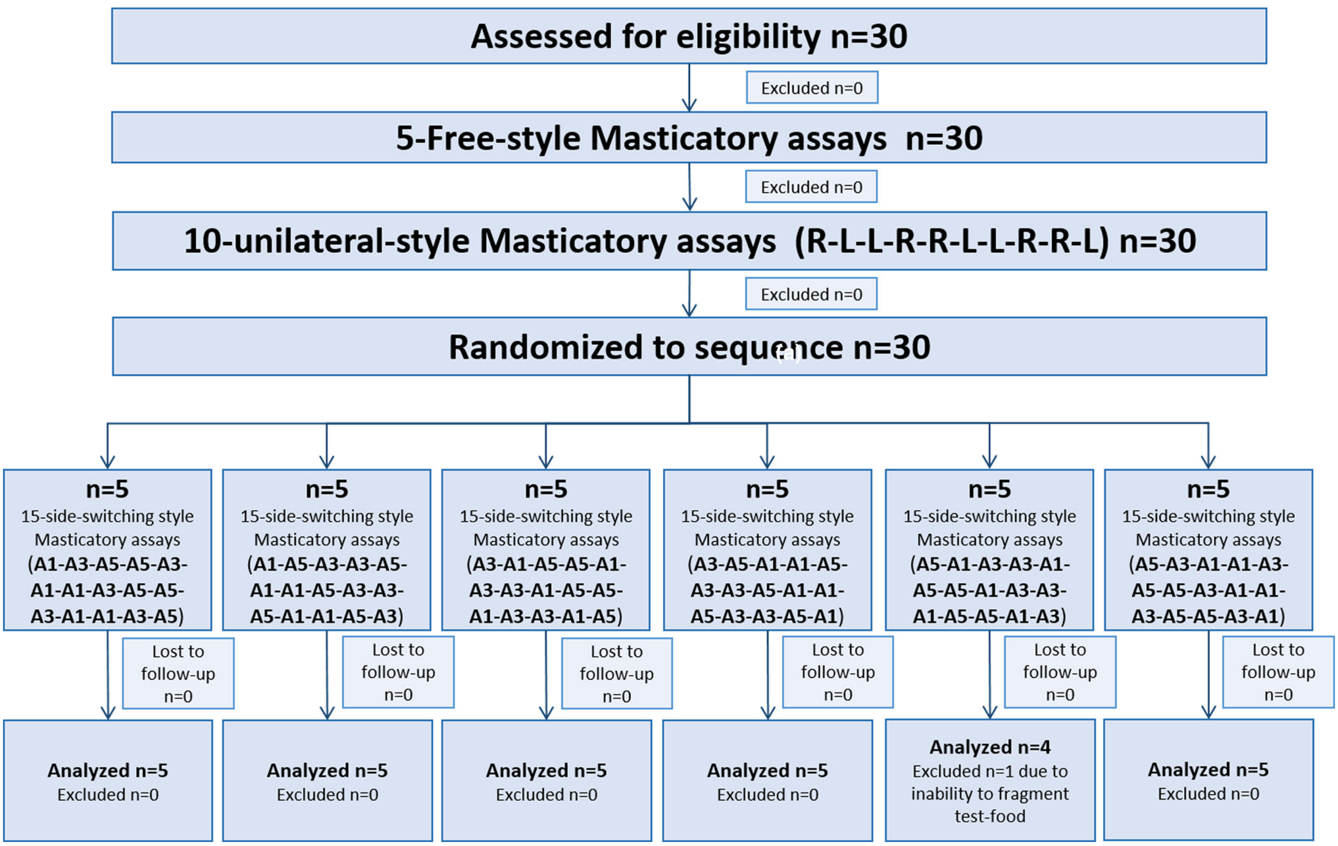

FIGURE 2 CONSORT flow diagram of the study

3 | RESULTS

The CONSORT study flow diagram is shown in Figure 2. Of the 30 volunteers, one was excluded from analysis because they failed to crush the silicone particles in both the test and the retest sessions. No side effects or adverse events were reported by any participant due to the masticatory assays. The 29 remaining participants (15 women) had a median age of 22.9 years (interquartile range, 21.4–26.9), and they presented a mean of 28.7 teeth (standard deviation [SD], 1.4; range, 26–32). Bilateral Angle class I was predominant among the participants ($n = 24$), the mean overbite was 2.8 mm (SD 1.5 mm) and the mean overjet was 3.4 mm (SD 1.6 mm). Four subjects had at least one tooth in crossbite (Three participants = one tooth; one participant = two teeth), but none presented severe malocclusion. The mean MSS Index during freestyle mastication was 0.087 (SD = 0.05; 95% CI 0.067–0.107). There were no differences between genders in each aspect of masticatory function for each mastication style (Table 2).

In the freestyle masticatory patterns, no significant correlation was observed between the MSS Index and either the MPS (Rho −0.166; $p = .389$; Spearman test) or chewing cycle duration (Rho 0.080; $p = .680$; Spearman test). However, a significant and negative correlation was observed between the MSS Index and the unilateral chewing index (Rho −0.569; 95% CI −0.25 to −0.78; $p = .001$; Spearman test).

Friedman's test revealed that MPS was different depending on the mastication style ($p < .001$). Pairwise comparison revealed no significant differences in the MPS between switching one, three or five times. However, the MPS obtained when the participants switched five times per trial was significantly lower than that obtained with unilateral or freestyle mastication ($p = .002$ and $p < .001$, respectively; adjusted by the Bonferroni correction for multiple tests) (Table 3).

Repeated measures ANOVA revealed that chewing cycle duration differed with the MSS frequency ($p < .001$). Pairwise comparisons adjusted by the Bonferroni correction for multiple tests revealed three differentiated groups, switching side once per trial, and unilateral mastication associated with the shortest chewing cycle durations. Side switching three times or chewing in freestyle produced moderate durations, and side switching five times per trial produced the longest cycle durations. The mean differences between one and three side switches and between three and five side switches were 59 ms (95% CI, 45–73) and 67 ms (95% CI, 46–89), respectively (Table 3).

4 | DISCUSSION

The results of the present study suggest that increases in MSS frequency do not impair masticatory performance in individuals with natural dentition during the mastication of an artificial test food. Moreover, those who showed high MSS frequency while masticating freely without any side imposition showed similar performance to those with low MSS frequency. In a previous study of partially edentulous patients, those missing three unilateral posterior teeth showed an increased frequency of chewing side switches 3 months after treatment with implant-supported fixed partial prostheses, achieving comparable to those for natural dentitions. However, this increased frequency of MSS was not associated with the degree of improvement in performance after the implant treatment.[21] Therefore, low MSS frequency does not appear to be related to higher masticatory performance, in contrast to what has been

TABLE 2 Gender comparison for masticatory parameters by mastication style

	Female ($n = 15$)	Male ($n = 14$)	Total ($n = 29$)	p-value[a]
Masticatory side switch index	0.084 (0.09)	0.074 (0.07)	0.084 (0.08)	.914
Unilateral chewing index	0.10 (0.09)	0.12 (0.14)	0.11 (0.11)	.400
Median particle size, mm				
Freestyle	3.26 (1.59)	2.91 (1.19)	3.18 (1.52)	.158
Unilateral	3.17 (1.37)	2.83 (1.14)	3.15 (1.41)	.123
Side switching 1 time	3.17 (1.24)	2.84 (0.94)	3.13 (1.43)	.252
Side switching 3 times	3.12 (1.31)	2.84 (1.59)	3.08 (1.46)	.354
Side switching 5 times	3.23 (1.13)	2.71 (3.15)	3.09 (1.25)	.270
Chewing cycle duration, ms				
Freestyle	833 (190)	784 (151)	809 (589)	.252
Unilateral	785 (147)	769 (158)	774 (480)	.354
Side switching 1 time	769 (138)	741 (133)	754 (123)	.290
Side switching 3 times	808 (204)	779 (107)	803 (130)	.331
Side switching 5 times	907 (199)	851 (139)	899 (144)	.186

Note: Data are shown as Median (IQR).

Abbreviations: CCD, chewing cycle duration; IQR, Interquartile range; MPS, median particle size.

[a]Independent-Samples Mann-Whitney U Test.

TABLE 3 Median particle size and chewing cycle duration by mastication style

Masticatory style	Median particle size, mm Median (IQR)	Chewing cycle duration, ms Mean (SD)
Freestyle	3.18 (1.5)[a]	818 (140)[y]
Unilateral	3.15 (1.4)[a]	770 (121)[x]
Switching 1 time (A1)	3.13 (1.4)[ab]	756 (116)[x]
Switching 3 times (A3)	3.08 (1.5)[ab]	816 (119)[y]
Switching 5 times (A5)	3.09 (1.3)[b]	883 (127)[z]

Note: Different superscript letters indicate significant differences. Median particle size analysed by Friedman's test and chewing cycle duration by repeated measures analysis of variance, both pairwise comparisons adjusted by the Bonferroni correction for multiple tests.

reported in a cross-sectional study.[18] The observed discrepancies may be explained by differences in masticatory characteristics of the study populations and the test foods employed.

We used Optozeta, an artificial test food sealed in a latex bag that benefits from being comfortable for participants, facilitating a consistent or alternate unilateral pattern, and being standardised.[25,27,31] However, chewing a bagged silicone as test food might not reflect actual chewing and might reduce the number of side switches. Natural foods such as carrot pieces, almonds or peanuts could offer other advantages. First, all side-shift cycles (balancing, segregation and aggregation shifts) could be analysed in all phases of mastication.[10] Second, the individuals would experience smell and flavour, better reflecting real-life conditions for the experiment. Therefore, future investigations with natural test foods would complement the results of the present study.

A slight improvement in masticatory performance (2%), switching the masticatory side once every four cycles compared to unilateral chewing or freestyle, was observed. This may have resulted from instructions causing a conscious alteration of masticatory function, and therefore, a reduction in the semi-automated character of chewing.[32] Another factor that may have contributed to these differences is that freestyle or unilateral masticatory patterns were not randomised with the A5 pattern, which may have resulted in some bias. Overall, we think that this slight improvement in masticatory performance, achieved by switching masticatory side every four cycles, is clinically irrelevant.

As expected, when the masticatory side was changed every four or five cycles, each participant required 6%–15% more time per cycle compared with unilateral mastication. Mandibular and lingual movements that accommodate the bolus on the other masticatory side require additional time when keeping the bolus on the same side. Moreover, most study participants exhibited a large cycle duration (>850 ms) when they changed their chewing side every four cycles. Slow masticatory rhythm reduces the chance of accidentally biting hard on a foreign object.[33] Moreover, eating slowly and with a large cycle duration may be a help with weight loss in the treatment of obesity and diabetes.[34–37] Although simple advice to change side more often while chewing and to eat more slowly could offer a simple intervention for these groups, a direct relationship should be demonstrated in appropriately controlled prospective studies.

The mean frequency of side switches while chewing natural food ranges from 5% to 32%, corresponding to 1–6 side switches for an assay of 20 cycles.[10,16,18–21] In the present study, individuals showed a mean side switch frequency of 6.7%–10.7%, corresponding to 1.3–2.0 side switches per 20 cycles. These values are consistent with those in studies mentioned previously after considering the test food characteristics, such as the lack of flavour, impossibility of segregation or aggregation shifts and absence of swallowing.

Among the features of mastication, MSS frequency had the lowest reproducibility, showing an intra-class coefficient of 0.68. This is consistent with the research by Remijn et al,[16] who also found the lowest ICC values for the variable 'change of chewing side', when using biscuit (0.71) and bread (0.72) test foods.[16] This finding may be explained by the fact that changing sides depends more on peripheral inputs than the central chewing pattern generator.[38–40] The quarter-tablet shape of the artificial test food, with an unequal radius and height, together with the position and orientation of the silicone pieces in the latex bag at the closing phase of each cycle, could influence the MSS frequency. It might be that using spheres or cubes as silicon pieces in a latex bag could improve the reproducibility of these data.

Our results indicate that clinicians may want to counsel their patients to change the eating sides every four or five cycles to slow their masticatory rhythm and produce a more symmetrical pattern without affecting performance. This could benefit the patient by reducing muscle fatigue and increasing saliva secretion, which may in turn improve flavour release and efficient bolus formation.[10] Further research designed with natural test foods is required to confirm these possible benefits.

This study has some limitations. First, the chewing side was assessed as the mandibular side during the closing phase of the masticatory cycle instead of the bolus location. However, as a non-disintegrable bolus, Optozeta use in a latex bag keeps the bolus at the side of the jaw during the closing phase of the masticatory cycle, as confirmed in all video recordings. Second, because only one test food was used, the results are only applicable to this food type. Finally, the absence of adverse events and the non-alteration of masticatory performance with increasing MSS frequency cannot be extrapolated to chewing at side switch frequencies exceeding 26%.

5 | CONCLUSIONS

In individuals with natural dentitions, variation in the MSS frequency does not affect masticatory performance when chewing an artificial test food. The higher the MSS frequency, the slower the masticatory rhythm. Individuals who show a high frequency of side switching during freestyle mastication also show a more bilateral chewing pattern.

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CONFLICT OF INTEREST

The authors declare that they have no competing interests.

AUTHOR CONTRIBUTIONS

T. Ignatova-Mishutina contributed to the conception, design, data acquisition, analysis and interpretation, and drafted and critically revised the manuscript; B. Rovira-Lastra and J. Martinez-Gomis contributed to the conception, design, data analysis and interpretation, and drafted and critically revised the manuscript; L. Khoury-Ribas and E.I. Flores-Orozco contributed to the design, data interpretation and critical revision of the manuscript. All authors approved this version of the manuscript.

PEER REVIEW

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DATA AVAILABILITY STATEMENT

The data sets used and/or analysed during the current study are available from the corresponding author on reasonable request.

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