Clinical Nutrition (2005) **24**, 314–320

Clinical Nutrition

http://intl.elsevierhealth.com/journals/clnu

ORIGINAL ARTICLE

Clinical evaluation of mastication: validation of video versus electromyography

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Received 29 April 2004; accepted 26 November 2004

KEYWORDS
Mastication;
Evaluation;
Video;
Electromyography;
Validation

Summary *Backgrounds and Aims*: The ability to evaluate masticatory function in people with neurological disabilities is important as this function is often compromised in these groups. However, current standard techniques are often impossible in such groups due to cognitive difficulties. This study is a validation of several variables read from standardised video recordings of mastication as indicators of masticatory function.

Methods: Fifteen healthy, fully dentate male subjects were recorded using EMG and by video simultaneously. An evaluation was undertaken of the video parameters (i) to compare their validity against the electromyographic parameters, (ii) to test intra-rater and inter-rater reliability and (iii) to test the ability to discriminate between four model foods differing in hardness.

Results: Masticatory time and the number of masticatory cycles counted on video were found to be valid and reliable indicators. In addition, the number of active chewing cycles performed with an open mouth and identification of the chewing side, were found to have reasonable validity and reliability. The former may allow discrimination between food types.

Conclusion: As an alternative to the complex evaluation of masticatory function, observation of certain parameters from video recording could be an alternative for use in uncooperative patients.

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doi:10.1016/j.clnu.2004.11.010

Introduction

Masticatory function has been extensively evaluated using different methods developed with either clinical or fundamental physiological goals in mind. The physiological concerns imply the use of sophisticated techniques such as bite force measurement, electromyography, kinematics using magnetic fields or infra-red video recordings. Most of these methods need expensive equipment and specially qualified personnel, and are difficult to carry out in clinical studies or in clinical practice. Furthermore, they are inappropriate for those people whose cognitive status (e.g. those with Down syndrome, cerebral palsy, etc.) or anatomical status (e.g. post-trauma or post-cancer surgery patients) does not permit the use of such evaluations or makes them extremely difficult. This is unfortunate, as these groups have a great need for the assessment and treatment of their masticatory function by clinicians. Clinical indicators of masticatory function can be considered under three groups: (i) Methods based on anatomic criteria such as number of teeth, number of functional pairs of teeth, or number of occlusal contacts.[1–3] These methods are easily accessible for clinicians, but they are dentally focused, are only anatomical indicators of a functional construct and ignore the role of the other organs and systems involved in mastication, such as salivary glands, jaw and tongue muscles and neurological control. (ii) Methods of self-assessment of masticatory function by means of scales and questionnaires.[4–8] Although this method permits large samples, it gives very different results to a clinician's evaluation,[9] as the clinician and the subject/patient evaluate different things. (iii) Methods based on the analysis of retrieved and sieved expectorated foods after mastication.[2,5,6,10,11] These methods approach the natural conditions of bolus preparation, involving all the organs implicated in mastication, but masticatory function is probably incomplete because it is detached from deglutition. All these methods are indicators of different aspects of this complex function. The best overall evaluation of masticatory function should include several different types of complementary indicators.

A very large number of authors have proposed many techniques, and controversy concerning the reliability of particular methods are legion.[12] For clinicians interested in the consequences of either dental conditions or dental treatment, a sensitive and reliable test of mastication is needed which can be used in a routine way. Counting one or two indicators of mastication, such as the number of cycles or the time of chewing directly during a meal or on video recordings of a meal sequence seems a reasonable and feasible clinical approach. It has been used in children with and without disabilities [13,14] and it could be useful for the all groups for whom it is difficult to obtain assessment of masticatory function using more complex physiological-type evaluations. Despite its previous use, however, video evaluation had never been validated. With a view to the development of a research program to investigate and treat masticatory function in people with cognitive disabilities, we therefore undertook the validation of a number of indicators of masticatory function read from video recordings. To achieve this goal, a two-stage process was necessary: (i) to demonstrate the validity of video evaluation compared to standard techniques in healthy subjects; and then (ii) to compare video evaluation in healthy and cognitively impaired subjects. This was necessary because of the impossibility of using standard techniques (e.g. EMG) for the vast majority of people with cognitive disabilities, due to their inability to co-operate. The first stage of validation required a comparison of the test evaluation technique (video evaluation) against EMG in healthy individuals to demonstrate that, under normal circumstances, video evaluation of certain indicators of mastication is as valid as standard evaluation of the same indicators. The second stage of the validation process was to evaluate the validity of video evaluation in people with cognitive disabilities. This was done by comparing the results of video evaluation in healthy people with results in those with Down syndrome.[15]

This paper reports the results of the first stage validation process. It aims to validate certain indicators of the masticatory function of healthy people measured using video recordings.

Materials and methods

Procedure

Fifteen healthy, fully dentate male subjects (average age 22.6 ± 1.3years), were recorded using EMG and by video simultaneously. Test foods were jellied confectionery products presenting visco-elastic behaviour, predominantly elastic. Four series of products, differing in weight of gelatine to obtain a scale of hardness (22.5, 25, 33 and 41.5 g for H1, H2, H3 and H4, respectively), but identical in size and shape, were prepared from four grades of gelatine (Rousselot 100, 150, 200 and 250 blooms; Degussa Texturant Systems, Baupte, France).

Subjects were given three samples each of four confectionery products of differing hardness (increasing from H1 to H4) in a random order. Video recordings were all taken with a full-face camera view, placed at 1.2 m from the subject. The frame was delimited 10 cm beyond the shoulders and from the top of the head of the subject. The muscular activity was recorded during chewing by surface EMG for both left and right masseter and temporal muscles. The analysis of the EMG data, the dental status of the subjects, the model foods and the procedure for EMG recording have been published previously.[16] Description of the method of collection and analysis of the video data is described here.

Data collection techniques

The video variables were collected independently from 15 video recordings by two observers using a stopwatch for those involving time, and a manual counter for those involving a simple count. The evaluation of each variable, except the chewing side, implied an independent reading of each videotape by each observer. The videotapes were read in random order by each observer.

Variables collected by the means of the video included masticatory time (MT—the number of seconds between the moment food is placed in the mouth and swallowing, identified by the immediate swallow after the end of rhythmic rotary movements), number of masticatory cycles (MC—number of masticatory actions during the MT period, this includes all the rotary patterns, with and without lip closure), number of open masticatory cycles (OMC—number masticatory actions taken with separated lips during the MT period), cleaning time (CT—time between swallowing and completion of self-cleansing actions, identified by the end of the mouth movements), number of cleaning cycles (CC—number of movements of the mouth after deglutition, including movements of the lips, chin, tongue, mandible and swallowing) and chewing side (CS), right or left. The lip separation was determined when the teeth, the tongue or the food was seen during a masticatory cycle. With respect to the latter variable, research subjects involved in the criterion validity and reliability aspects of the study were asked to choose a side on which they would chew for each recording and to keep chewing on that side. Variables collected by means of EMG included MT, MC, CT and CS (*NB.* to differentiate between equivalent variables assessed by video and EMG, variables are described with a "v" or "e" prefix demarcating video and EMG variables, e.g. vMT, eCS). The mandibular movements recorded during mastication were also simultaneously examined using kinematics.[17] These results are not analysed in this paper, but the kinematic criteria (change in size and shape of the cycles) indicated the end of the masticatory sequence on EMG recordings.

Evaluation of criterion validity

This was evaluated through the comparison of vMT, vMC, vCT and vCS with eMT, eMC, eCT and eCS respectively for 15 subjects. Association between vMT, vMC and vCT and their EMG equivalents were evaluated through generation of Pearson correlation coefficients. In addition, with the MT, MC and CT variables, any difference between the video variable means and their EMG equivalents was evaluated using a paired Student's t-test, examining the hypothesis that there should be no difference between the mean values of equivalent video and EMG variables for each food. Finally, agreement between evaluations of vCS and eCS was evaluated through the generation of a Kappa coefficient. This statistic is an evaluation of the agreement of evaluations of a dichotomous variable (in this case left side vs. right side), with a range of −1 to +1, wherein −1 indicates perfect disagreement, 0 indicates no agreement and +1 indicates perfect agreement. Kappa values below 0.4 indicate poor agreement, between 0.4 and 0.75 fair agreement and above 0.75 excellent agreement.[18]

Evaluation of inter-rater reliability

Two observers independently evaluated vMT, vMC, vOMC, vCT, vCC and vCS for the same 15 videos. Reliability for vMT, vMC, vOMC, vCT and vCC was then evaluated through the generation of an intraclass coefficient (ICC).[19] This involves examination of the contribution of rater variation as a proportion of the total variance for each variable (controlling for food type) in an ANOVA with subject and rater as independent variables. The smaller the proportion of the variance due to the raters is, the higher the ICC and the better the reliability. Finally, the reliability of vCS was evaluated through the generation of a Kappa coefficient to demonstrate the level of agreement between the two raters.

Evaluation of intra-rater reliability

One observer evaluated vMT, vMC, vOMC, vCT, vCC and vCS in the same videos on two separate occasions, 6 months apart. Intra-rater reliability was evaluated for the same variables as for inter-rater reliability, using the same statistical analyses, except that the independent variables in the ANOVA were subject and rating (first or second).

Evaluation of discriminatory ability

This test involved an examination of the hypothesis that vMT and vMC would increase with hardness from food H1 to food H4, as it has been shown with other methods.[20–22] This hypothesis was examined through ANOVA with food as the independent variable and the expectation of a correlation between increasing food hardness and increasing vMT and vMC.

Results

Criterion validity

Pearson correlation coefficients for vMT vs. eMT, vMC vs. eMC and vCT vs. eCT were $r = 0.89$ ($P<0.0001$), $r = 0.87$ ($P<0.0001$) and $r = 0.14$ ($P = 0.0089$) respectively, (number of observations upon which correlation coefficients based $n = 334$) indicating very good correlations for the masticatory time and masticatory cycles variables and a poor correlation for the cleaning time variables. Table 1 shows mean vMT, vMC, vCT, eMT, eMC and eCT scores for each of the four food products. There was no statistical difference between the video and EMG variable means as evaluated by t-test. Finally, the Kappa coefficient for the level of agreement between vCS and eCS was 0.85, indicating a good level of agreement between the two variables.

Table 1 Mean MT (s), MC and CT (s) scores for video and EMG evaluations.

Food type	Variable	Mean score (SD)
H1	vMT	15.6 s (±5.3)
	eMT	12.5 s (±5.2)
	vMC	20.2 (±6.9)
	eMC	19.0 (±7.5)
	vCT	3.5 s (±1.9)
	eCT	5.4 s (±3.1)
H2	vMT	19.0 s (±6.6)
	eMT	15.3 s (±5.4)
	vMC	24.5 (±8.2)
	eMC	23.3 (±8.2)
	vCT	3.5 s (±1.6)
	eCT	4.8 s (±2.3)
H3	vMT	21.5 (±6.5)
	eMT	19.3 (±4.9)
	vMC	28.5 s (±8.4)
	eMC	29.4 s (±7.4)
	vCT	3.3 s(±1.7)
	eCT	4.8 s (±2.8)
H4	vMT	26.0 s (±8.9)
	eMT	22.6 s (±6.8)
	vMC	33.3 (±11.6)
	eMC	32.2 (±9.4)
	vCT	3.5 s (±1.8)
	eCT	4.9 s (±2.4)

The "v" or "e" prefix demarcating respectively video and EMG variables.

Reliability

The results of the inter-rater reliability analyses are shown in Table 2. These figures demonstrate an extremely high level of reliability for vMT, vMC and vOMC for all foods, a reasonably good level of agreement for vCS with all foods but a relatively poor level of reliability for the vCT and vCC variables. These results were very similar to those concerning the intra-rater reliability, where vMT, vMC and vOMC were very reliable, vCS was reliable and vCT and vCC were relatively poorly reliable. The only remarkable observation concerning the intra-class coefficients for the latter variables was that there was a correlation between food hardness and reliability coefficient, with the harder foods having a worse reliability.

Discriminatory ability

The discriminatory ability of the video variables is demonstrated by the results shown in Table 3, wherein we see a very good relationship between food hardness (increasing from foods H1–H4) and vMT and vMC, with food type being significantly associated with differences in both variables as analysed by ANOVA ($P<0.0001$). There is a significant association between food type and vOMC ($P<0.0001$), although the relationship is not as strong. Finally, there was no relationship between food type and vCT and vCC.

Discussion

The aim of this study was to validate certain indicators of masticatory function of healthy people measured using video recordings. This was the first stage of an overall evaluation of these indicators in groups for whom standard evaluations are very difficult or impossible. The results suggest very good validity for vMT and vMC, reasonable validity for OMC, but poor validity for vCT and vCC.

Table 2 Inter-rater and intra-rater reliability evaluations for given variables.

Variable	Food	ER* ICC/κ	RA† ICC/κ
vMT (ICC)	H1	0.92	0.98
	H2	0.93	0.97
	H3	0.95	0.98
	H4	0.93	0.97
vMC (ICC)	H1	0.93	0.96
	H2	0.89	1.0
	H3	0.95	0.97
	H4	0.95	0.97
vOMC (ICC)	H1	0.95	0.92
	H2	0.92	0.96
	H3	0.95	0.95
	H4	0.93	0.96
vCT (ICC)	H1	0.77	0.92
	H2	0.55	0.86
	H3	0.78	0.76
	H4	0.58	0.69
vCC (ICC)	H1	0.89	0.93
	H2	0.71	0.85
	H3	0.78	0.76
	H4	0.23	0.42
vCS (κ)	H1	0.81	0.92
	H2	0.85	0.86
	H3	0.86	0.87
	H4	0.89	0.83

κ = kappa
*ER = inter-rater reliability.
†RA = intra-rater reliability.

The correlations between vMT and vMC and their EMG equivalents are very strong. Actual scores for these variables differ non-statistically due to recording errors inherent in both methods (EMG equivalent variables also have an element of error due to the subject effect).[16] It is interesting to note that of the eight comparisons between vMT and vMC and their EMG equivalents for all foods, seven show consistent difference with the video variables being greater than the EMG ones for all except vMC vs. eMC for food H3. This suggests a systematic but consistent measurement error mainly due to the EMG data collection procedure that avoids the last burst before swallowing when cycle shape, measured by kinematics, is very different from other cycles. This variance in methodology is sufficient to explain the non-significant differences in means between vMC and eMC. The differences between vCT and eCT were not statistically significant and were again consistent with the EMG variables, which were always greater than their video equivalents. The correlation between vCT and eCT, however, was statistically significant but the low correlation ($r = 0.14$) indicated that minimal amounts of the variance in each variable was explained by the relationship. The evaluation of reliability tended to support the validity of vMT and vMC and confirm the poor validity of vCT and vCS. The former were consistently good for both forms of reliability and across all food types, while the latter had differing reliability scores across the different foods. The reliability of the vOMC variable was also highly consistent across food type and that of the vCS variable was good, although not as good as the reliability of the vMT, vMC and vOMC variables.

Variability between subjects and foods constitutes a major characteristic of the physiology of human mastication. This variability was observed, for example in cycle shape, amplitude of muscular contraction, masticatory time, number of

Table 3 Variation in video variable mean scores by food type.

Food type	vMT (s) (mean/SD)	vMC (*n*) (mean/SD)	vOMC (*n*) (mean/SD)	vCT (s) (mean/SD)	vCC (*n*) (mean/SD)
H1	15.6 (5.3)	20.2 (6.9)	2.6 (3.8)	3.5 (1.9)	2.2 (1.5)
H2	19.0 (6.6)	24.5 (8.2)	2.7 (3.7)	3.5 (1.6)	2.2 (1.4)
H3	21.5 (6.5)	28.5 (8.4)	4.2 (6.0)	3.3 (1.7)	2.0 (1.2)
H4	26.0 (8.9)	33.3 (11.6)	4.2 (5.6)	3.5 (1.8)	2.1 (1.4)
F values	105.44	96.91	8.27	1.16	1.07
P values	0.0001	0.0001	0.0001	0.3250	0.3592

masticatory cycles. These parameters are direct indicators of the masticatory process. However, there are not directly linked to masticatory efficiency.[16,23] Measurements with sieving and laser diffraction methods of the preswallowing bolus have shown no inter-individual variability in the distribution of particle size for different foods.[24] This contrasted with observations of the physiological parameters of mastication, that are representative of the ability to adapt the process of mastication to food texture. Among the physiological parameters of mastication, the number of cycles is one of the more affected by the food texture.[17]

Another observation from our study is that MT and MC were highly correlated, thereby raising the question of the need to evaluate both. Firstly, it is entirely to be expected that, depending on the food, MC and MT are highly correlated as time to chew something is very likely to be related to the number of chewing cycles required to complete the masticatory process. Nevertheless, it is important, at least at this stage in the validation process, to keep measuring both for two reasons: (i) it is feasible that the MT and MC of groups with various chewing problems (e.g. those with neurological problems, post-trauma patients, post-cancer patients etc.) may not be so well correlated; and (ii) MT and MC are required to generate the variable chewing frequency (MC/MT) and chewing frequency may be an important variable to demonstrate differences between food types and different groups of people. For example, the chewing frequency differed significantly for hard foods between people with or without Down syndrome, while MT and MC increased simultaneously with the food hardness.[15]

Discrimination of food hardness by a tool for the evaluation of mastication is of great interest in studies of adaptation of the masticatory process.[17,25,26] Evaluation of discriminatory validity across differing food types of known texture and hardness, again confirms the validity of the vMT and vMC variables, which demonstrate an excellent dose-response relationship in the expected direction with the different food types. vOMC is a variable that could be associated with a more or less important tongue protrusion pattern. The tongue position is affected in children with disabilities when the food is presented near the lips and during swallowing.[14,27] In the healthy group of adults of this study, the vOMC variable demonstrated an increase from H1 to H4, despite similar values for H1 and H2, and H3 and H4, respectively. It is difficult to predict how OMC should vary with food hardness, although, if there is any variation, it would logically be expected that OMC increases with harder foods as individuals put a greater conscious effort into chewing something that is difficult to chew. This theory is born out by the observations in our study. With respect to the vCT and vCC variables, they had no association with hardness for this type of food. It can be expected that other rheological characteristics of the food such as viscosity or stickiness would be better linked to these variables. Moreover, the cleaning cycles are movements with multiple components and the criteria of judgements used to identify them are not accurate. This again confirms that these two variables are invalid and not useful in evaluating videos of subjects chewing.

The use of the video evaluation of mastication could be extremely interesting for the study of impaired populations. The chewing time, the number of chewing cycles and the chewing frequency are good direct descriptors of mastication. The number of masticatory cycles performed with an open mouth characterises varying degrees of tongue protrusion. Open-mouth chewing patterns are found in neonates and it is hypothesised that lingual protrusion might be progressively inhibited in the young infant on the development of mature masticatory and respiratory function, by mechanisms that involve the cortex and the dental proprioceptive system. These mechanisms of inhibition may be absent or diminished in populations with neurological disorders (e.g. cerebral palsy, Down syndrome, Alzheimer disease) or may disappear with the loss of periodontal proprioception (edentulous elderly). Most of these groups are also characterized by a lack of cooperation during the procedures of EMG measurement. The video evaluation of mastication is not a method that can substitute all the indications for EMG. This method is specifically indicated in two conditions: (1) for uncooperative patients and (2) in clinical conditions, when more sophisticated methods cannot be used, either for time or economic reasons. The development of this simple, non-invasive method of evaluation of masticatory capacity will certainly help the development of clinical research initiatives aimed at improving the masticatory function of such groups.

In conclusion, this study suggests that masticatory time and the number of closing masticatory cycles used during that time, as observed from videos of people chewing various foods, are valid and reliable indicators that can discriminate between different foods of known hardness. As an alternative to the complex and highly costly evaluation of masticatory function through EMG, observation of certain parameters from video recording is shown to be valid in healthy subjects and could be an alternative for use in groups of people for whom EMG is not possible. The next stage is to validate these video evaluated indicators of mastication amongst target groups such as those with cognitive and/or physical disabilities.

Acknowledgements

The authors thank Dr. Jocelyne Feine for her kind participation in elaborating the methodology of this study. This investigation was supported by a research Grant no. 4M411D from "Institut National de la Santé et de la Recherche Médicale (INSERM) and Institut National de la Recherche Agronomique (INRA) in France.

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