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A novel colourimetric technique to assess chewing function using two-coloured specimens: Validation and application

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ABSTRACT

Objectives: Chewing efficiency may be evaluated using cohesive specimen, especially in elderly or dysphagic patients. The aim of this study was to evaluate three two-coloured chewing gums for a colour-mixing ability test and to validate a new purpose built software (ViewGum©).

Methods: Dentate participants (dentate-group) and edentulous patients with mandibular two-implant overdentures (IOD-group) were recruited. First, the dentate-group chewed three different types of two-coloured gum (gum1–gum3) for 5, 10, 20, 30 and 50 chewing cycles. Subsequently the number of chewing cycles with the highest intra- and inter-rater agreement was determined visually by applying a scale (SA) and opto-electronically (ViewGum©, Bland–Altman analysis). The ViewGum© software determines semi-automatically the variance of hue (VOH); inadequate mixing presents with larger VOH than complete mixing. Secondly, the dentate-group and the IOD-group were compared.

Results: The dentate-group comprised 20 participants (10 female, 30.3 ± 6.7 years); the IOD-group 15 participants (10 female, 74.6 ± 8.3 years). Intra-rater and inter-rater agreement (SA) was very high at 20 chewing cycles (95.00–98.75%). Gums 1–3 showed different colour-mixing characteristics as a function of chewing cycles, gum1 showed a logarithmic association; gum2 and gum3 demonstrated more linear behaviours. However, the number of chewing cycles could be predicted in all specimens from VOH (all $p < 0.0001$, mixed linear regression models). Both analyses proved discriminative to the dental state.

Conclusion: ViewGum© proved to be a reliable and discriminative tool to opto-electronically assess chewing efficiency, given an elastic specimen is chewed for 20 cycles and could be recommended for the evaluation of chewing efficiency in a clinical and research setting.

Clinical Significance: Chewing is a complex function of the oro-facial structures and the central nervous system. The application of the proposed assessments of the chewing function in geriatrics or special care dentistry could help visualising oro-functional or dental comorbidities in dysphagic patients or those suffering from protein-energy malnutrition.

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1. Introduction

Mastication is a complex function of the oro-facial system and the central nervous system. It involves numerous structures like teeth, palate, tongue and cheeks as well as neural pathways and reflexes to guide the mandibular force and movement through muscle control.[1] The goals of mastication comprise fragmenting food stuffs to increase the surface area and mix the aliment with saliva in order to form a bolus that is safe to swallow.[2] Besides these functional aspects, the mastication plays an important psychosocial role especially late in life when enjoying meals becomes one of the principal pleasures.[3]

The chewing process might be compromised by several factors. Most commonly, the lack of teeth or saliva as well as reduced muscular forces is associated with an impaired chewing function.[4] This oral impairment might have considerable influence on the individual's well being. Furthermore, food choice and nutritional intake are closely related to the chewing efficiency.[5] Tooth loss contributes essentially to the impairment of chewing function, hence edentulous persons suffer from a well-documented significant oral handicap which cannot fully be compensated by dental interventions.[6]

In the context of geriatric and special care medicine and dentistry it seems to be imperative to have methods at hand which allow for easy, simple and quick evaluation of the chewing function. Impaired chewing and bolus formation might have a significant impact in this fragile population, because of poor motor control, reduced sensitivity and a high prevalence of dysphagia. Consequently, elderly persons are at risk for chewing related protein-energy malnutrition.[5] For the evaluation of the masticatory process one has to distinguish between chewing ability and chewing efficiency/performance. Chewing ability refers to the subjective perception,[7] yet very old persons tend to overestimate their performance.[8] Objectively assessed, the term "masticatory efficiency" is defined as the "effort required achieving a standard degree of comminution".[9] An approach firstly described by Gaudenz in 1902, the chewing efficiency relates to the particle size of a test food which is evaluated after a defined chewing sequence.[10] Nowadays test foods like silicon cubes or peanuts are used. The resulting fragments are analysed by sieving or opto-electronical methods to evaluate the particle size distribution *D50*.[11] Fragmenting tests are still regarded as the gold standard when it comes to assessing the masticatory efficiency; however they present some inherent inconveniences. The sieving method requires specialised equipment, which makes it expensive and cumbersome. Further, the comminuted specimen needs to be collected *in toto* after chewing, which can be challenging if the particles are very small and the mobility and sensitivity of the oral structures are reduced. Small particles may furthermore constitute an aspiration risk in dysphagic patients. Hence comminution tests are little suited for a clinical setting like a geriatric ward and alternative methods using cohesive specimen such as coloured chewing gums or wax have been proposed.[12–14] Here, a two-coloured sample is masticated for a given number of chewing cycles and the resulting bolus is evaluated either visually on a reference scale or opto-electronically. These techniques evaluate both the colour-mixing ability and the capacity to form a bolus. It was demonstrated that colour-mixing tests correlate significantly with the sieving method, especially in patients with impaired masticatory function,[15] yet the ideal specimen has not yet been identified.

The aim of this study was to evaluate three two-coloured chewing gums for a colour-mixing ability test and to validate a new purpose built software (ViewGum©). The following hypotheses H0 were tested:

i. The new opto-electronic colourimetric method cannot detect different degrees of colour mixture in three two-coloured chewing gums.
ii. A simple visual test cannot discriminate dental states.
iii. The new opto-electronic colourimetric method is not able to discriminate different oro-dental conditions and serves to evaluate chewing efficiency.
iv. The parameters gender, age and maximum voluntary bite force are no additional predictors of chewing efficiency when measured with two-coloured chewing gums.
v. A simple mathematical correlation does not exist between the chewing efficiency obtained with different types of specimen.

2. Material and methods

2.1. Inclusion and exclusion criteria

Participants were recruited to form two groups, a dentate-group representing "ideal chewers" as well as an edentulous-group (IOD-group) with a presumed impaired chewing function.[16] The inclusion criteria for the dentate-group comprised an age between 18 and 40 years, having at least 26 teeth, a maximum DMFT (decayed missing filled teeth) score of 4 and an Angle Class I occlusion. They all perceived their chewing ability as normal. The IOD-group had no age limit; here the participants had to have clinically acceptable conventional upper dentures and two-implant overdentures in the mandible. Exclusion criteria were the presence of oro-facial pain, signs of severe TMD dysfunction or neuromuscular disorders.

2.2. Specimens

As a control, the "Hubba-Bubba Tape Gum" (gum1, The Wrigley Company Ltd., England) was selected, because it is well documented and widely used since its introduction in 2007.[13] Unfortunately the company discontinued the production and now produces the gum without artificial colourings; hence it became unsuitable for colourimetric evaluation. For the current study, residual strips of the original gum were cut from pink and azure colours in the dimensions of 30 mm × 18 mm × 3 mm and prepared according to the original protocol.[13]

The second type of specimen was developed and produced specifically for assessing masticatory performance for research purposes (gum2, Lotte™, Tokyo).[17] It was developed for the *8020 Promotion Foundation (Japan)* to be similar to gum1.[13] It is composed of two individually packed gum beads, which are manually stuck together (18.8 mm × 14.2 mm × 3.9 mm).

The third gum was the Vivident Fruitswing "Karpuz/Asai Üzümü" (gum3, Perfetti van Melle, Turkey). It is a two-coloured gum comprising a green and dark violet layer with the dimensions 43 mm × 12 mm × 3 mm and is commercially available only in Turkey.

Hardness was evaluated for gum2 and gum3 with a Shore durometer (Shore Scale OO, Ø 2.4 mm, 1.11 N) in the dry material. Fourteen specimens of each gum (seven measurements for each colour) were evaluated by a specialist bioengineer.

2.3. *Protocol*

Ethical approval was granted (Psy06-038) and written informed consent was obtained from all participants. For all participants, the age, the gender, the number of teeth and the DMFT-index were noted. Furthermore the number of occluding posterior units (OU, 1 molar equals 2 premolar units) was counted.[18] For the IOD-group, the modified OU was applied which takes the number of replaced teeth into account.

Two series of experiments were performed. First dentate participants sat upright and chewed all three gum types for 5, 10, 20, 30 and 50 chewing cycles, respectively. The chewing cycles were counted by the operator. Between each chewing sequence a pause of 1 min was respected, after the 50 chewing cycles the pause was 2 min. The specimens were then retrieved from the oral cavity, placed in a transparent plastic bag and subsequently flattened to a 1 mm thick wafer by pressing on a custom-made polyvinyl chloride plate with a milled depression of 1 mm × 50 mm × 50 mm. Additionally, in order to complete the range of colour mixing, 10 unchewed gums of each specimen were analysed.

Based on the results of the first series of experiments, a second series comprised both the dentate- and IOD-groups, yet only gum2 and gum3 were used for 20 cycles each. Again, participants sat upright and a gum was placed on their tongue with the pink (gum2) or violet (gum3) side facing the palate.

2.4. *Visual assessment*

The specimens were visually evaluated in a random order and independently by two operators (MS, FM) using a previously described categorical scale (SA) (Fig. 1)[13]:

- SA 1 chewing gum not mixed, impressions of cusps or folded once
- SA 2 large parts of chewing gum unmixed
- SA 3 bolus slightly mixed, but bits of unmixed original colour
- SA 4 bolus well mixed, but colour not uniform
- SA 5 bolus perfectly mixed with uniform colour

2.5. *Colourimetry*

Both sides of the samples were scanned using a flatbed scanner (resolution 300 dpi, Epson Perfection V750 Pro, Seiko Epson Corp., Japan) and subsequently copied into one image. The compound images were then assessed with a purpose built programme, which is freely available (ViewGum© software, dHAL Software, Greece, www.dhal.com). The software first transforms the images into the HSI colour space. It then calculates the hue value for each pixel in the semi-automatically segmented images. If the colours of the specimen are not mixed, two well-separated peaks on the hue axis are present. With increasing degree of colour mixing, the two hue peaks of each colour group converge and will eventually fuse at an intermediate position into one peak when the colours are perfectly mixed. Hence, inadequate mixing presents with larger variance on the hue axis than complete mixing. The variance of the hue (VOH) is considered as the measure of mixing. The method used was originally described by Halezonetis et al.[19]

The images were analysed by two operators independently in a random order (MS, PC) to evaluate the inter-rater agreement. A single operator (MS) repeated the evaluation of all specimens for assessing repeatability.

2.6. *Maximum bite force*

The maximum voluntary bite force (MBF) was evaluated using a digital force gauge with an 8.6 mm thick bite element (Occlusal Force-Metre GM 10®, Nagano Keiki Co., Japan).[20] The sensor was placed between the first molars of each side separately and the participant was asked to exert a maximum clenching effort three times; the peak value was noted for each side. For analysis, the mean of both peak reading was calculated. In the IOD-group the contra-lateral side was stabilised with an equivalent bite block avoiding tilting of the dentures.

2.7. *Statistical analysis*

Sample size estimation was based on previous experiments.[13] Normal distribution was tested using Shapiro–Francia W′ tests. Intra- and inter-rater agreement were analysed using weighted kappa (κ) statistics (SA) to take into account the ordered categories or when some ratings are unobserved and Bland–Altman plots (VOH) along with Pitman's test of difference in variance. The findings for the SA scale is ordinal, thus the related findings are presented as median (interquartile range, iqr). The VOH was analysed using mixed linear regression models (STATA command "xtmixed") which takes the repeated nature of the measures into account. Group comparison was performed using two-sample *t*-tests with unequal variances (VOH) and Mann–Whitney tests (SA). Analysis was performed using STATA 13.1 (STATA Corporation, College Station, TX, USA) by a specialised biostatistician (FRH).

3. Results

3.1. *Description of participants and specimens*

The dentate-group comprised 20 participants (10 female, age 30.3 ± 6.7 years); the IOD-group 15 participants (10 female, age 74.6 ± 8.3 years) (Table 1). The pink beads of gum2 (mean depth of indentation 0.2 ± 0.01 mm, mean Durometer 93.7) and the azure beads showed similar hardness (mean depth of indentation 0.1 ± 0.02 mm, mean Durometer 95.1). The green side of gum3 (mean depth of indentation 0.8 ± 0.08 mm, mean

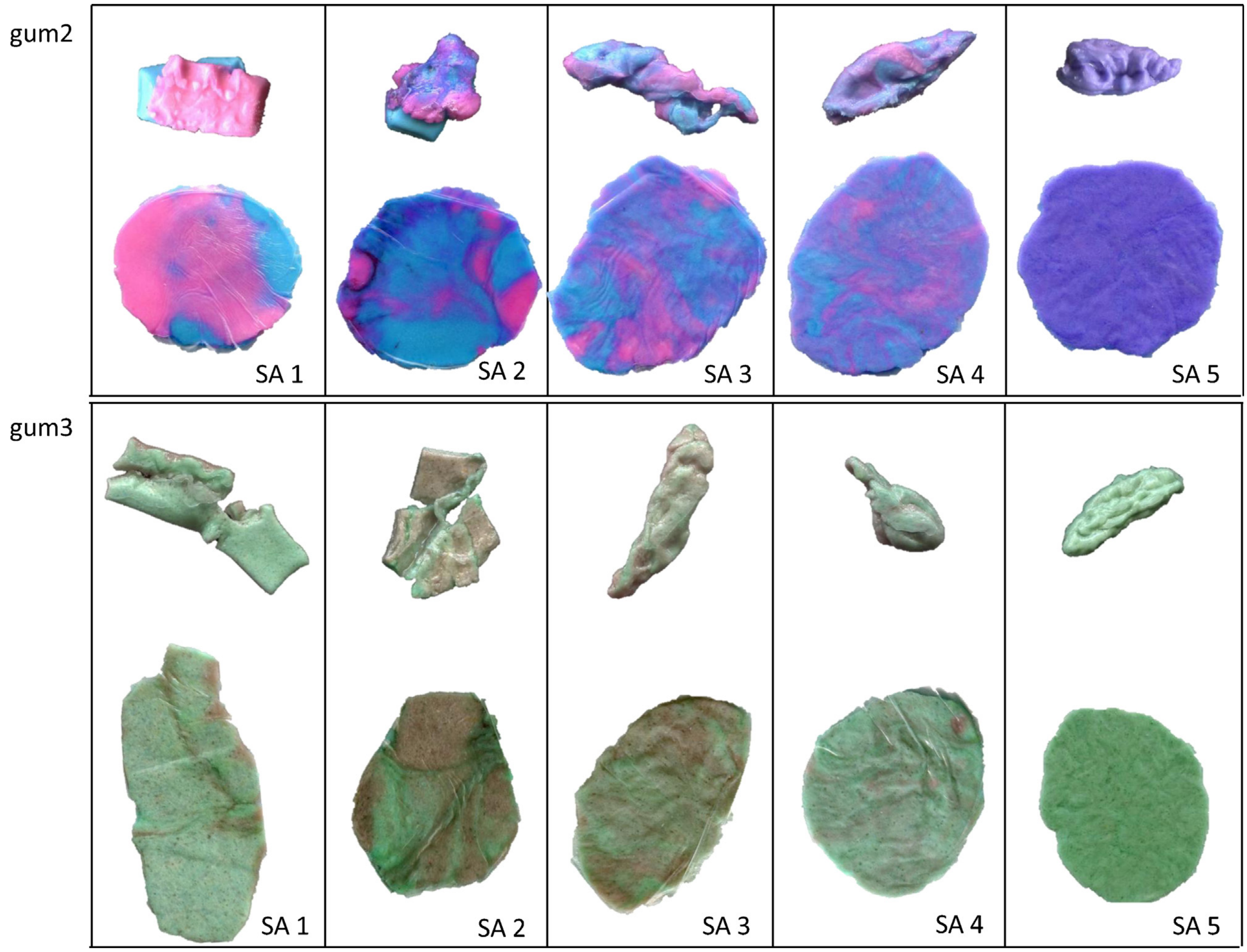

Fig. 1 – Examples of the different categories of SA as applied to the Lotte™ (gum2) and Perfetti van Melle (gum3) chewing gum. The columns from left to right represent the classes SA1 to SA5. The upper line depicts examples of the bolus; the lower line shows the wafers. Every depicted specimen was chewed for 20 chewing cycles, but by different study participants. A score of SA1 or SA2 would signify an impaired chewing function and was solely found in the IOD-group.

Durometer 67.4) was harder than the violet side (mean depth of indentation 1.1 ± 0.08 mm, mean Durometer 58.4).

3.2. *Colourimetry*

The number of chewing cycles could be predicted with the new colourimetric method VOH (all $p < 0.0001$; Table 2). However, the various gums showed different colour-mixing characteristics, depending on the number of chewing cycles. Gum1 showed a strong negative logarithmic association with the number of chewing cycles; gum2 and gum3 revealed a more linear negative association. Gum3 showed the smallest ΔVOH with increasing number of chewing cycles (Fig. 2).

Table 1 – Descriptive of the participants: OU – occlusal units, mod-OU – modified occlusal units taking replaced teeth into account, MBF – maximum voluntary bite force.

	Dentate-group ($n = 20$)	IOD-group ($n = 15$)	p-value
Age [years]	30.3 ± 6.7	74.6 ± 8.3	<0.0001
Number of teeth [n]	28.7 ± 1.9	0	<0.0001
OU [n]	12.6 ± 1.9	0	<0.0001
Mod-OU [n]	12.6 ± 1.9	11.2 ± 1.3	0.012
MBF [N]	674.3 ± 276.8	162.5 ± 107.2	<0.0001

3.3. *Intra-and inter-rater agreement*

3.3.1. *Subjective assessment*

Intra-rater and inter-rater agreement with the visual assessment scale was moderate to almost perfect at 20 chewing cycles for gum2 according to the weighted kappa statistics. For gum3, the intra-rater agreement was lower, whereas for this gum the inter-rater agreement was as good.[21] At 50 chewing cycles, all specimens were mixed to SA5 (Table 3).

Gum2 showed better intra- and inter-individual agreement than gum3 at 20 cycles and this number of chewing cycles was used for the second series of experiments.

The mean and range of VOH corresponding to SA for 20 chewing cycles were for gum2: dentate-group SA median 4.0 (iqr 0.50) – VOH 0.254 ± 0.088 (min: 0.135, max: 0.470) and for

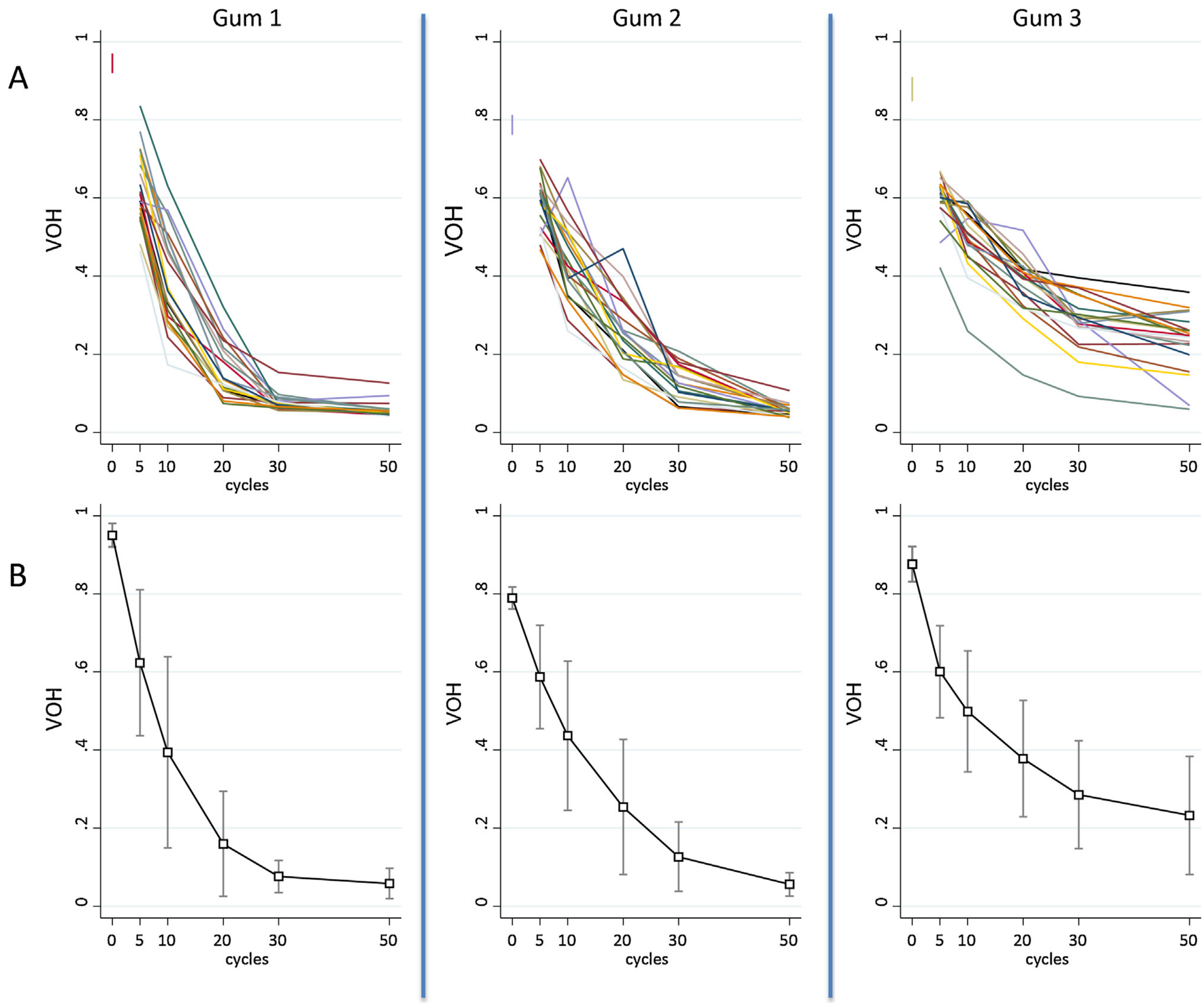

Fig. 2 – Colour-mixing characteristics of gums1–3 in the dentate-group. The variance of hue (VOH) decreases with increasing number of chewing cycles. (A) Scatter plot for all 20 dentate study participants; (B) mean graphs with standard deviation.

gum3: dentate-group SA median 4.0 (iqr 0.00) – VOH dentate-group VOH 0.378 ± 0.0761 (min: 0.147, max: 0.517).

3.3.2. *Colourimetry*

The Bland–Altman plots identified only few VOH measurements outside the limits of intra- and inter-individual agreement (Figs. 3 and 4). Separate plots for $n = 20$ chewing cycles revealed 2/20 (intra) and 1/20 (inter) of the measurements outside of the limits of agreement (Supplementary Table 1).

3.4. *Discriminate ability to dental state*

The number of chewing cycles for the second series of experiments was set to $n = 20$. By applying the visual assessment the different dental states could be discriminated (gum2: dentate-group SA median 4.0 (iqr 0.50), IOD-group SA median 3.0 (iqr 2.75), $p = 0.0029$; gum3: dentate-group SA median 4.0 (iqr 0.00), IOD-group SA median 3.0 (iqr 2.00), $p = 0.0006$).

The new colourimetric method revealed equally significant differences in the colour-mixing ability for the two groups of dental state. With gum3, this difference was smaller, but still significant (gum2: dentate-group VOH 0.254 ± 0.088, IOD-group VOH 0.485 ± 0.234, $p = 0.0021$; gum3: dentate-group VOH 0.378 ± 0.0761, IOD-group VOH 0.483 ± 0.176, $p = 0.0452$).

3.5. *Predictors of chewing efficiency*

The multiple linear regression models revealed that VOH (gum2 and gum3) could not be predicted from sex, age or MBF in the dentate-group (all n.s.). In the IOD-group however, VOH could be predicted from age ($p = 0.002$) and MBF ($p = 0.020$), for gum2, but not for gum3 (all n.s.).

3.6. *Mathematical association between chewing gums*

No suitable equation could be identified for the conversion of the degree of colour mixing (VOH) between gum1 to gum2 and gum3.

Table 2 – Prediction of VOH for each gum using mixed effect linear regression models with number of chewing cycles as the independent ordinal variable ($n = 20$ chewing cycles served as the reference). $P < 0.0001$ for all; β: coefficient, 95%CI: 95% confidence intervals.

	Cycles	β	95% CI
Gum1 (r^2: 0.8909)	5	0.463	0.426; 0.501
	10	0.235	0.197; 0.273
	30	−0.084	−0.121; −0.0462
	50	−0.101	−0.139; −0.064
	Constant	0.160	0.127; 0.193
Gum2 (r^2: 0.8938)	5	0.333	0.299; 0.367
	10	0.183	0.149; 0.217
	30	−0.127	−0.161; −0.093
	50	−0.198	−0.232; −0.164
	Constant	0.254	0.224; 0.284
Gum3 (r^2: 0.8909)	5	0.223	0.193; 0.252
	10	0.121	0.092; 0.150
	30	−0.092	−0.122; −0.063
	50	−0.145	−0.174; −0.116
	Constant	0.378	0.347; 0.409

Table 3 – Inter- and intra-rater agreement (percentage %) as well as weighted κ for the visual assessment (SA, Fig. 1).

	Agreement (%); weighted κ Lotte (gum2)	Agreement (%); weighted κ van Melle (gum3)
$n = 5$ cycles		
Intra	92.50%; 0.7479	95.00%; 0.6512
Inter	87.50%; 0.5935	91.67%; 0.4186
$n = 10$ cycles		
Intra	91.67%; 0.5902	86.67%; 0.3496
Inter	95.00%; 0.7521	95.00%; 0.7500
$n = 20$ cycles		
Intra	95.00%; 0.6250	93.75%; −0.1364
Inter	98.33%; 0.8750	98.75%; 0.6429
$n = 30$ cycles		
Intra	98.75%; 0.8571	97.50%; 0.4595
Inter	98.75%; 0.8571	98.75%; 0.7727
$n = 50$ cycles		
Intra	100%[a]	100%[a]
Inter	100%[a]	100%[a]
Cumulative over all cycles		
Intra	97.00%; 0.9018	95.50%; 0.8206
Inter	97.25%; 0.9123	97.50%; 0.9009
Patients $n = 20$, cycles $n = 20$		
Intra	100.00%; 1.0000	95.00%; 0.8505
Inter	100.00%; 1.0000	98.33%; 0.9430

[a] No statistics were computed because parameters were constants.

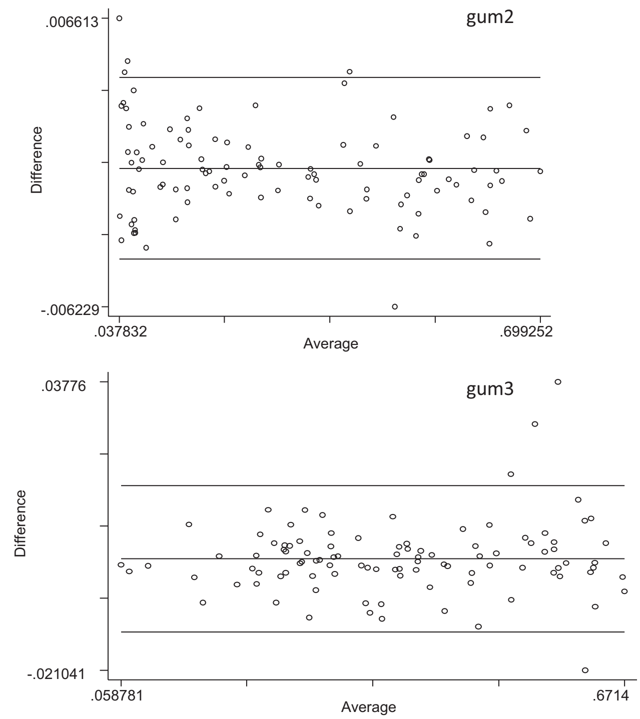

Fig. 3 – Bland–Altman plots for the intra-rater agreement for the operator MS for gum2 (mean difference: 0.000 (95% CI −0.0001 to 0.0001); Pitman's test of difference in variance: $n = 100$, $p = 0.131$) and gum3 (mean difference: 0.002 (95% CI 0.000 to 0.003); Pitman's test of difference in variance: $n = 100$, $p = 0.307$) over the full range of chewing cycles 0–50 ($n = 2 \times 110$ measurements). The x-axis represents the averages of all obtained values; the y-axis represents the differences between the two measurements.

4. Discussion

The study demonstrated that an objective assessment of the chewing function is feasible by applying the described analysis of the individual colour-mixing ability and bolus handling. Both with simple eyeballing of the specimens as well as with the utilisation of a purpose-built software the distinction between different dental states is possible.

In the first series of experiments, the colour-mixing characteristics of three different types of two-coloured chewing gums were tested in 20 healthy dentate volunteers. These experiments aimed to proof that the degree of colour mixture depends on the number of chewing cycles applied. The categories of chewing cycle numbers ($n = 0, 5, 10, 20, 30, 50$) were chosen to cover the entire range of possible degrees of colour mixture which will be presented from individuals with severely impaired to a fully functional chewing function. The present data therefore establish a nomogram to quantify the masticatory handicap of a patient in relation to healthy chewers. The analysis of the inter- and intra-individual reproducibility suggested that for the application of the test a fixed number of 20 chewing cycles should be applied. This number of chewing cycles was found to be useful in most mixing-ability tests.[12,22–25] Furthermore, it was demonstrated by Speksnijder et al. that the highest correlation coefficient ($r = 0.86$, $p < 0.001$) between a mixing-ability test and a comminution test for masticatory efficiency is also at 20 chewing cycles.[26] Twenty chewing cycles can therefore be regarded as the number of reference for mixing ability tests.

The new purpose-built free software ViewGum© evaluates the colour mixture, thus the colour entropy in the scanned gum wafers in the HSI colour space.[19] The analysis of only one

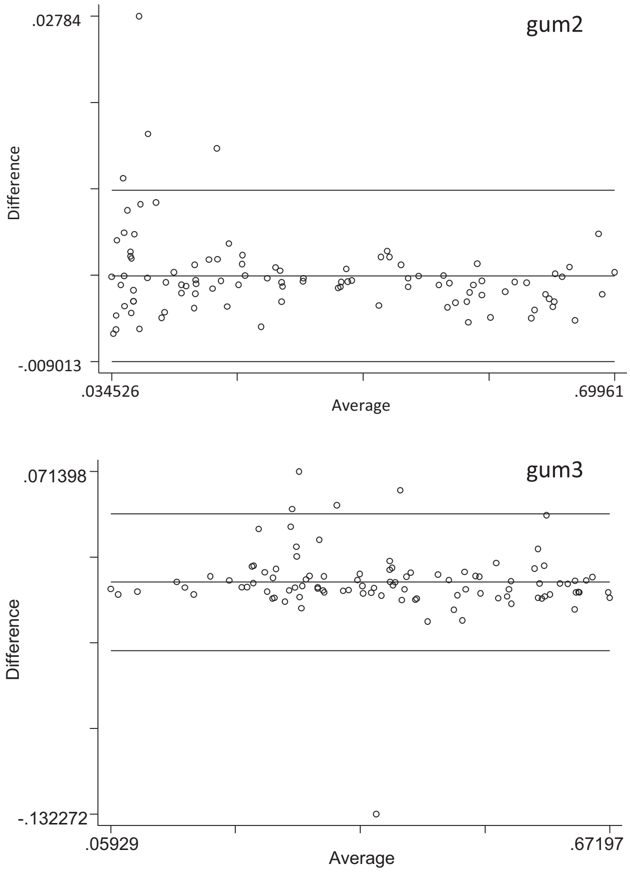

Fig. 4 – Bland–Altman plots for the inter-rater agreement for the operators MS and PC for gum2 (mean difference: 0.000 (95% CI −0.001 to 0.001); Pitman's test of difference in variance: $n = 100$, $p = 0.023$) and gum3 (mean difference: 0.006 (95% CI 0.002 to 0.010); Pitman's test of difference in variance: $n = 100$, $p = 0.390$) over the full range of chewing cycles 0–50 ($n = 2 \times 110$ measurements). The *x*-axis represents the averages of all obtained values; the *y*-axis represents the differences between the two measurements.

defining variable of colour, or rather its variance seems to be much more practical than working in the RGB colour space. There, three colour peaks from a histogram have to be interpreted separately using expensive software, thus widespread use in clinic or research is unlikely.[14]

The inherent biological variation between the participants accounted for large standard deviations in the colour-mixing curves. Standardised conditions might have been only possibly by performing bench experiments in a chewing simulator.[27] Repeating the chewing sequence several times per patient would have not necessarily reduced the standard deviation, as biological variation occurs even in the same patient between one sequence to the other. Still, the applied statistical model could predict the number of chewing cycles from the variance of hue VOH; therefore the first study hypothesis is rejected.

For this study, the colour-mixing test was not compared to any of the previously described fragmentation tests, which are to date still considered the gold standard for testing chewing efficiency. Fragments may widely spread over the oral cavity, get stuck in the vestibule, between the teeth and the floor of the mouth. However, Speksnijder, van der Bilt and collaborators showed that there is a statistical correlation between mixing ability tests and D50.[15,26] Still it seems questionable if the same oral function is evaluated by both testing methods. Fragmentation tests may judge purely the comminution capacity and may rather depend on maximum available bite force whereas the use of bi-coloured cohesive specimens provides information on the ability to manipulate foodstuff, form and knead a bolus. Also, the mixing-ability tests for masticatory efficiency are less depended on the saliva flow rate, which is of particular importance when administering the test in geriatric patients who frequently suffer from xerostomia.[28]

Finding specimens for mixing ability tests is not trivial (Table 4). Some research groups prefer to produce custom made wax or gelatine cubes. However, a central aim of the study was to present an easy and widely available method for screening for chewing impairment, thus convenient available gums were selected for this study. Unfortunately, most companies prefer nowadays to not add artificial colourings to their gums which makes most of them unsuitable for such tests. The "ideal" chewing gum still needs to be located and validated. Using gum instead of wax or gelatine has some important advantages. Firstly, many people are accustomed to use chewing gums, thus a more unconscious chewing act is likely to occur. Furthermore, coloured paraffin waxes are not per se produced as foodstuff, thus colours could be harmful. Taste of paraffin is neutral, but the texture and oily surface makes it an unusual chewing experience.

The gums should be consistent in their colour-mixing behaviour and be discriminative to clinically relevant differences in chewing performance. The latter may be influenced by dental state, but also neuro-muscular disease and motor co-ordination, stroke, xerostomia, muscle atrophy or even cognitive impairment.[3,29–32] Whereas a patient's dental state can easily be determined by clinical examination, such colour-mixing test may be particularly useful to evaluate the function of the involved structures and motor control from the CNS. In this capacity the colour-mixing test may be a useful diagnostic tool for the early detection of disease and allow early referral to a specialist examination. But even when no disease is present, chewing function may contribute essentially to a patient's Oral Health Related Quality of Life and social well being, as enjoying meals is one of the main pleasures in late life.[33] Chewing performance is also decisive on the preparation of a patient's meal, when he/she is hospitalized or lives in a long-term care facility. All too easy carers prescribe mixed meals when dentures are present or they presume chewing impairment. However, chewing activity is beneficial to the elderly person in terms of muscle training, salivation, digestion and possibly even cognitive functioning.[3,34,35] Often physicians or nurses are not sufficiently trained to perform an oral examination and to detect functional impairment. The described colour-mixing test allows any health professional a fast and efficient, yet objective estimation of a patient's chewing efficiency. The test samples can be stored several weeks, are ready available, not costly and are available in standardised quality. The test procedures are safe and take

Table 4 – Specifications for specimens aimed to use for a two-colour-mixing ability test.

	Gum1	Gum2	Gum3
1. The specimen should have two colours, ideally already combined in one piece.	–/+	–/+	+
2. The colour-combination should represent a large spread in hue values in the HIS colour space (e.g. green/red or red/azure).	+	+	+/–
3. The colours should not include white, as its hue value is not defined.	+	+	+
4. The colours should both be visible in the un-chewed gum, ideally one side-one colour (a coloured "core" is unsuitable).	+	+	+
5. The specimen should not stick to denture-resin (PMMA).	–	+/–	+
6. The specimen should not be too big or too hard, thus relatively easy to chew.	+	+/–	+
7. The specimen should be storable and be widely available.	–	–	–
8. The specimen should be separately packed for handling and hygienic reasons.	–	+	+
9. The colours should be relatively stable over time, even when the specimen was already chewed.	–	+	+/–
10. The taste should be enjoyable for most people.	–	+	+/–
11. The gum should be sugar free.	–	+	+

less than 1 min of clinical time. Furthermore, chewing a gum is widely accepted by patients, even amongst elderly patients who are not usually accustomed to chewing gum at leisure.

An important advantage of the described method is that there are two levels of analysis. In a clinical setting, for example in a geriatric ward, simple eyeballing the bolus may already be of diagnostic value. By applying the visual scale in the current study, a high intra- and inter-rater agreement was observed and the two groups of different dental state could be clearly distinguished, rejecting the second hypothesis. However, a precise and more objective continuous assessment can be achieved by complementing this first estimation by the described opto-electronical analysis. Thus, the third study hypothesis is also rejected. The use of the ViewGum© freeware is likely to be limited to research purposes, until further simplifications of scanning and software are available. Already now the purpose built software provides a built-in nomogram for each of the described gums, thus the individual chewing efficiency can be quickly compared to the one in ideal, young and healthy volunteers. The high repeatability allows for follow-up evaluations, for example during a dental treatment or neuro-muscular rehabilitation programmes. Comparing to previously described analysis methods using relative pixel counts of unmixed colour with Adobe Photoshop™ "magic wand tool", the new software seems much more robust in terms of inter- and intra-rater reliability, so follow-up examinations could even be performed by different operators and still provide sound information. Another advantage applies to multi-centre or large-scale epidemiological studies where different operators perform the test, although a calibration meeting is still recommended. Another advantage compared to the previously described method using Adobe Photoshop™ is that the analysis is strictly based on the degree of colour-mixture, thus the amount of sugar extraction, expressed as the total bolus size seems less important, as no reference to the total pixels in the scanned frame is used.[13]

Shortcomings of the study comprise that the dentate and IDO groups were not matched for age, yet recruiting would have been substantially more difficult had this been an inclusion criteria. A crucial shortcoming is also that gum1 and gum2 tended to adhere to the denture resin.

Although the described colour-mixing test allows for a simple and robust measurement of the chewing efficiency, the "ideal" chewing specimen remains to be found. Eleven criteria for an ideal test food are listed in Table 4. Most importantly it has to be noted that sugar and flavour are extracted from the gum during chewing; hence the specimen have to be considered a nutrient. Taste, health condition (e.g. diabetes) or even the cultural context may play a role in the applicability of the test.

The chewing efficiency expressed as VOH could be predicted in implant-overdenture wearers by the maximum bite force, whereas this was not the case in the dentate volunteers with gum2. Therefore, the fourth hypothesis is partly rejected. These findings are relevant as it indicates that gum2 is particularly suitable to detect impaired chewing efficiency in elderly patients with impaired dental state. Van der Bilt et al. stated that the mixing ability tests are particularly useful in denture wearers.[15] In contrast, dentate persons seem to have an excess muscle force available due to the physiological spare capacity available for almost all physiological functions before ageing leads to functional decline. Already in a previous study the colour-mixing test did not reveal a correlation between chewing efficiency and maximum bite force in dentate individuals.[13] As this colour-mixing test is destined to aged and fragile individuals, gum2 seems more suited than gum3 because the latter seems too soft and the two colours are too similar. Gum1 was not even tested for detecting dental state, as it was withdrawn from the market and could therefore no longer be recommended. However, it was used as reference to the newly available types of gum. The hypothesis that there was a mathematical formula which would allow to translate a given VOH from the nomogram of one gum to another is confirmed, as all three gums showed a distinct colour-mixing characteristic due to hardness, texture and rheological characteristics. Even if, the formula would be impractically complicated. In addition the colours of gum3 seemed less saturated, thus the difference VOH is lower compared to gum2. However, the IOD group does not represent the lowest possible chewing efficiency, as experimental studies prove that the stabilisation of a complete denture with two interforaminal implants doubles the chewing efficiency. Van Kampen et al. showed that only half of the chewing cycles were needed to achieve the same fragmentation as with conventional complete dentures.[36] Hence gum3 may be indicated for persons with complete dentures or a very weak chewing efficiency, for example in palliative care. In favour of gum3 it also needs to be mentioned that this gum does not stick to the denture resin. A limiting factor is that this gum is only available in Turkey, and that it cannot even be obtained elsewhere, even by mail order.

Last but not least, any purely technical test to assess chewing efficiency only reveals various aspects of the complex chewing behaviour. A complete evaluation of the masticatory process should ideally be complemented by a subjective evaluation or qualitative information on possible physiological compensation mechanisms like the increase in chewing time or the number of chewing cycles before swallow or even the occurrence of food avoidance.[2,37] Impaired chewing efficiency must be considered as a symptom of oral phase dysphagia, thus swallowing disorders may equally be associated with the results.[32]

5. Summary and conclusions

The proposed tests proved reliable and able to measure differences in chewing efficiency visually and opto-electronically, given an elastic specimen is chewed for 20 cycles.

The tested types of specimens show distinct colour-mixing characteristics, but can be recommended to assess chewing efficiency in a clinical and research setting, by simple visual inspection or using the purpose built software ViewGum©. The ideal test specimen still needs to be located, but if most of the presented specifications are respected, the colour-mixing ability tests are most likely to produce clinical relevant information on chewing impairment and can be applied in geriatric or special care patients.

Further simplification of the opto-electronical assessment could help establishing widespread screening for chewing deficiencies. Thus, the application in geriatrics or special care could help to visualise oro-functional or dental comorbidities in dysphagic patients or those suffering from protein-energy malnutrition. However, a holistic approach to assess the chewing function should also take individual compensation strategies into account.

Conflict of interest

None.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.jdent.2015.06.003.

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