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Masticatory function evaluation methods: Critical analysis of selected literature

Métodos de avaliação da função mastigatória: Análise crítica da literatura selecionada

Métodos de evaluación de la función masticatoria: Análisis crítico de literatura seleccionada

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Abstract
*Objective***:** To identify the ideal and/or most suitable masticatory function assessment methodology or treatment for each group of patients. *Material and Methods***:** A survey was carried out in the MEDLINE, Science Direct, and Embase databases for articles published since 1990. The articles were initially selected by their titles and abstracts, and after application of inclusion and exclusion criteria, some were selected for full text reading. The studies were submitted to qualitative, quantitative, and bias analysis. *Results***:** Of the 1,514 studies retrieved in the initial search, 51 were selected for complete analysis. Advantages of the test foods Optocal and Optosil included reliability and standardization capacity, while their disadvantages included high processing time and hardness. Wax was mentioned for its ease of chewing and testing speed, with the disadvantages of handling and the influence of temperature, in addition to low palatability. Chewing gum exhibited a speedy and easy way of testing, low cost, and reliability, in addition to commercial availability. *Conclusion***:** Among the existing methodologies, those that were used in few studies or not validated require additional data, and for now, their indication is not recommended. Optocal and Optosil should be indicated for patients who do not have impaired chewing function. Chewing gum is a more suitable test food for patients with impaired chewing. Its practicality in being used in tests and evaluation of results makes it a more comprehensive indicator for different types of patients, treatments, or needs to assess masticatory function.
Keywords: Mixing ability; Oral function; Masticatory performance; Chewing; Test food.

Resumo
*Objetivo***:** Identificar o ideal ou o mais apropriado método de avaliação da função mastigatória para um determinado tipo de tratamento ou grupo de pacientes. *Metodologia***:** Uma pesquisa foi realizada nas bases de dados MEDLINE, Science Direct, e Embase para artigos publicados desde 1990. Os artigos foram incialmente selecionados baseados em seus títulos e resumos, e após a aplicação de critérios de inclusão ou exclusão, alguns deles foram selecionados para leitura completa. Os estudos foram submetidos a avaliação quantitativa, qualitativa e análise/risco de viés. *Resultados***:** Dos 1.514 estudos conduzidos na busca inicial, 51 foram selecionados para análise completa. As vantagens de alimentos testem como Optocal e Optosil incluíram confiabilidade e capacidade de padronização, enquanto as suas desvantagens foram um tempo de processamento de dados alto e a dureza do material. A cera foi mencionada por sua facilidade de mastigação, e velocidade na realização do teste, com as desvantagens de necessidade de manuseio do material e a influência da temperatura, além da baixa palatabilidade, ou gosto ruim. A goma de mascar exibiu uma rápida e fácil aplicação e manuseio no teste, com baixo custo e boa confiabilidade, além de ser comercialmente disponível. Outros como as balas de goma, cápsulas de fucsina e alimentos naturais, ainda precisam de maior padronização para utilização rotineira. *Conclusão***:** Dentre as existentes metodologias, aquelas que foram usadas em poucos estudos ou não foram validadas ou requerem dados adicionais, por enquanto não tem a sua indicação recomendada. Optocal e Optosil, devem ser indicados para pacientes que não tem limitação de sua função mastigatória, devido a dureza do material. A goma de mascar é um alimento teste mais apropriado para pacientes com a função mastigatória prejudicada ou limitada. A sua

praticidade em ser usada em testes e avaliação dos resultados a torna mais compreensível e reprodutível para diferentes tipos de pacientes e tratamentos que tenham a necessidade de avaliação da sua função mastigatória.
Palavras-chave: Habilidade de mistura; Função oral; Performance mastigatória; Mastigação; Alimento teste.

Resumen
*Objetivo***:** Identificar el método ideal o más adecuado de evaluación de la función masticatoria para un determinado tipo de tratamiento o grupo de pacientes. *Metodología***:** Se realizó una búsqueda en las bases de datos MEDLINE, Science Direct y Embase de artículos publicados desde 1990. Inicialmente se seleccionaron artículos en base a sus títulos y resúmenes, y luego de aplicar criterios de inclusión o exclusión, algunos de ellos fueron seleccionados para lectura completa. Los estudios fueron sometidos a evaluación cuantitativa y cualitativa y análisis/riesgo de sesgo. *Resultados***:** De los 1514 estudios realizados en la búsqueda inicial, 51 fueron seleccionados para un análisis completo. Las ventajas de los alimentos de prueba como Optocal y Optosil incluyeron la confiabilidad y la capacidad de estandarización, mientras que sus desventajas fueron el alto tiempo de procesamiento de datos y la dureza del material. La cera fue mencionada por su facilidad de masticación y rapidez en la realización de la prueba, con los inconvenientes de la necesidad de manipular el material y la influencia de la temperatura, además de la baja palatabilidad o mal sabor. La goma de mascar exhibió en la prueba una rápida y fácil aplicación y manejo, con bajo costo y buena confiabilidad, además de estar comercialmente disponible. Otros, como los ositos de goma, las cápsulas de fucsina y los alimentos naturales, aún necesitan una mayor estandarización para su uso rutinario. *Conclusión***:** Entre las metodologías existentes, aquellas que han sido utilizadas en pocos estudios o no han sido validadas o requieren datos adicionales, por el momento no tienen su indicación recomendada. Optocal y Optosil deben estar indicados para pacientes que no tienen limitación de su función masticatoria, debido a la dureza del material. La goma de mascar es un alimento de prueba más apropiado para pacientes con una función masticatoria deteriorada o limitada. Su practicidad para ser utilizado en pruebas y evaluación de resultados lo hace más comprensible y reproducible para diferentes tipos de pacientes y tratamientos que necesitan evaluar su función masticatoria.
Palabras clave: Capacidad de mezcla; Función oral; Rendimiento masticatorio; Masticación; Alimento de prueba.

1. Introduction

Mastication is a physiological process that involves food fragmentation. Its harmonious performance depends on various structures such as the tongue, teeth and muscles for its proper function [1-3]. Satisfactory masticatory function will influence the nutritional status and yield a better quality of life [1-5]. Propper masticatory function is so important, that recent studies point to its influence as an activity that protects cognitive function and prevents degenerative diseases of the patient's central nervous system [3-7].

Masticatory function can be assessed by masticatory performance and by masticatory efficiency. These terms are also ambiguous and can cause some confusion in the literature, and that may lead to compare different test methods and lead to a misjudgment in the current literature [8,9]. Chewing performance refers to the chewing outcome after a determined number of chewing cycles [8-10]. Chewing efficiency is referred to the number fo chewing cycles needed to obtain a particular chewing outcome [8-10]. Simplifying those terms, chewing performance is an individual's ability to grind solid foods in a certain number of masticatory cycles, and/or masticatory efficiency, which is the number of cycles needed for the test food particles to reach a size suitable for swallowing [8-10]. The tests and the methods of evaluation for them are different and must be evaluated separately [9].

A person's masticatory function, more specifically, his masticatory performance, can be assessed using a wide variety of natural or artificial “test foods”, chewed through a number of predetermined masticatory cycles to observe the degree of food comminution or fragmentation. The evaluation of the average size of the chewed particles of a test food will determine the results, and it is often carried out using sieving methods (single or multiple) [8,9]. Test foods include those from natural sources, such as carrots, almonds, and coffee beans, and artificial sources, such as Optosil and Optocal [10-13].

Another way of evaluating masticatory function is the mixing ability test (chewing efficiency), which analyzes an individual's ability to form a cohesive and homogeneous bolus [8,14,15]. The mixing ability test index of masticatory function is based on the mixture of color and shape of a given food stuff [14-16]. This method was validated when compared to the sieving method [15,16]. For this type of test, some studies used commercial or specially developed chewing gums to analyze mixing ability; others used paraffin cubes, each citing specific advantages over other masticatory function assessment methods [17-20]. This type of evaluation employs several ways to obtain results, such as software to evaluate the pixels of the formed images, a visual scale, or a colorimetric analysis [11,18,21]. Other forms of evaluation using gummy jellies, fuchsin capsules, gelatin, and silicone are also cited [22-27].

In view of the several different methods and test foods used to evaluate masticatory/chewing performance and chewing efficiency, as well as their respective ways of obtaining or evaluating results. There is still no consensus in the literature on the best method to evaluate masticatory performance or which method should be indicated for a specific group of patients [9,28]. It is thus necessary to distinguish these tests from one another in relation to their main objective and the type of treatment instituted, in addition to the physiological characteristics of the patients under evaluation [9,28]. The objective of this study was to carry out a literature review to identify which masticatory function evaluation tests are currently available, their respective indications, advantages and disadvantages, and their availability and ease of use, with a view to suggest which test would be more suitable according to the dental condition under evaluation.

2. Methodology

Procedure

This work is a narrative review. The authors selected articles based on the inclusion and exclusion criteria. All potentially eligible studies were analyzed and included. All disagreements were analyzed between members and eliminated through discussion with the researchers, thus leading to a consensus. This research does not have the intent to be a systematic review of the literature, but some specific care so that the most rigorous methodological criteria could be applied to this literature review were taken.

Search strategy

Two independent reviewers (RZA and RSM) conducted an electronic survey of the PubMed/Medline, Science Direct, and Embase databases searching for articles published in English between January 1990 and June 2021. The keywords used were: “masticatory performance”, “masticatory efficiency”, and “masticatory cycle”. A manual search was performed in the following relevant journals in the field within the stipulated period: Clinical Implant Dentistry and Related Research; Clinical Oral Implants Research; International Journal of Oral and Maxillofacial Implants; International Journal of Oral and Maxillofacial Surgery; Journal of Oral and Maxillofacial Surgery; Journal of Periodontology; Journal of Prosthodontics; Journal of Craniofacial Surgery; Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology; and the Journal of Prosthetic Dentistry. All titles were analyzed, and the relevant ones were selected according to the inclusion criteria. Any disagreement between the authors was eliminated.

Study selection criteria

The initial study selection consisted of an analysis of the article title and abstract. Prospective and retrospective studies were both included, given the existence of few randomized controlled studies. Subsequently, eligible studies were analyzed and included or excluded from the total sample. Thus, the population, the intervention, the comparison and the outcome (PICO), as recommended by PRISMA, were determined as a questioning criterion for organization of a clear clinical question with an appropriate inclusion focus, and although this is not a systematic review of the literature, we tried to follow some of the PRISMA recommendations so that this review could extract reliable results from the included works and evaluated data [29].

Population or participants: Patients subjected to masticatory evaluation who had or had not undergone dental treatment rehabilitation.

Intervention: All methodologies that evaluated masticatory performance or efficiency.

Comparison: Two or more methods of evaluating masticatory performance or efficiency in the same study or in comparison to other studies.

Outcome: To analyze the advantages, disadvantages, reliability and availability/ease of each masticatory performance evaluation method.

Inclusion criteria

A. Studies published since 1990.

B. Studies in English.

C. Studies in humans.

D. Studies with at least five patients evaluated.

E. Studies that conducted the masticatory performance or efficiency test with any researched or available test food, with the masticatory evaluation being the main factor under study

Only studies that offered parameters for comparison between the included/evaluated studies were included.

Exclusion criteria

A. Duplicate studies.

B. Studies related to orthodontic therapy; for example, assessment of masticatory efficiency before and after orthodontic treatment or who underwent orthognatic surgery.

C. Studies related to advanced surgeries such as bone reconstruction and zygomatic implants.

D. Studies whose main focus was prosthetic and/or surgical rehabilitation treatments and not masticatory performance itself.

E. *In vitro* assays and biomechanical studies.

F. Studies that emphasized systemic aspects or pathologies, such as the use of bisphosphonates and osteoporosis, radiotherapy, chemotherapy, and cleft patients.

G. Articles that only focused on prosthesis reconstruction, without elucidating the characteristics of the evaluation of masticatory performance or efficiency.

H. Systematic reviews or reviews that addressed the topic. These studies were used only as theoretical parameters for discussion.

I.

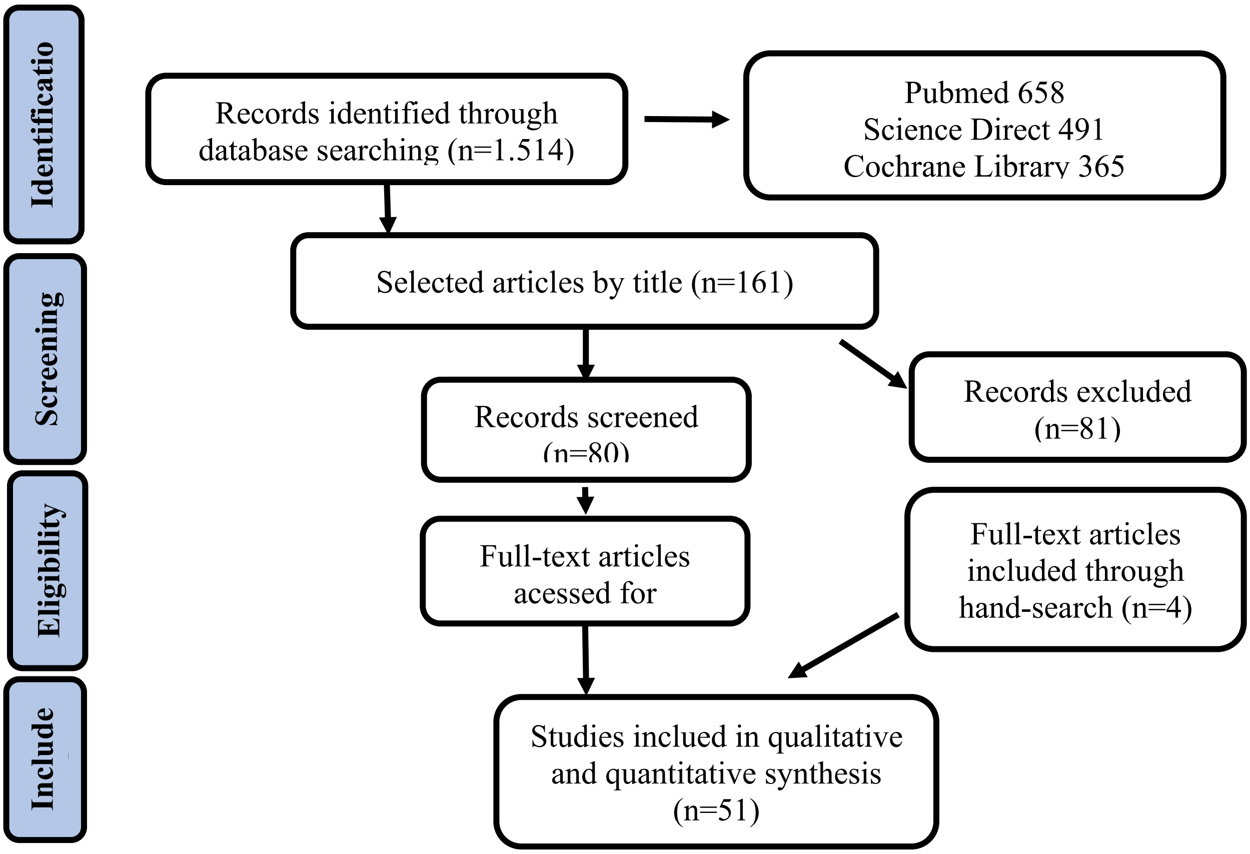
Evaluation of the quality of studies

The evaluation of the quality of the studies was performed using the scale and bias classification of the included studies of the National Health and Medical Research Council (NHMRC) (Commonwealth of Australia©, National Health and Medical Research Council, Melbourne, Australia, https://www.nhmrc.gov.au/sites/default/files/images/appendix-f-levels-of-evidence.pdf). The studies were classified as randomized controlled trial, prospective cohort, or retrospective cohort clinical studies.

Data analysis

Data were obtained following the order: first author, journal and year of publication; bias classification; test food used; number or time of masticatory cycles; type of instituted or compared treatment; dentulous or edentulous patients; number of patients and average age; and result assessment method. When present, information about the advantages and disadvantages of the test food and evaluation method was also collected.

Figure 1 - Flowchart of the article search strategy.



Fonte: Autores.

3. Results

Figure 1 shows the number of articles surveyed, from identification in the databases to quantitative and qualitative analyses. The database search yielded 1,514 articles. After analysis of the titles according to the inclusion and exclusion criteria for duplicate articles, 161 articles were selected for title and abstract reading, of which 81 were excluded. The remaining 80 articles were fully read. Of these 80 articles, 47 were included for the analysis, in addition to 4 other papers searched in specialized journals that were also included. After application of the inclusion and exclusion criteria, 51 articles were selected for complete quantitative and qualitative analysis.

Table 1 presents the detailed information from the analysis of collected data and methodology of selected articles and information described in the methodology used. Author, Year of publication, level of evidence/risk of bias, type of testing food, the number of masticatory cycles used to obtain the results, the type of instituted or compared treatment (and if dentate or edentulous), the number of patients and average age and the form of evaluating the results are all describe in Table 1.

Table 1 – Data and methodology of selected articles.

Author Year	**Level of Evidence NHMRC**	**Testing food**	**Number of cycles**	**Type of treatment**	**Number of patients and average age**	**Form of evaluating the results**
Slagter[32], 1993	III – 2	Optocal; Optosil	10, 20, 40, 60 and 80 MC	ND; CD	n=14; m: 58 y	Sieving
Fontijn-Tekamp[53], 2000	III – 2	Optocal Plus	5,10,20,40 e 60 MC	ND; Partially dentate; OD; CD	n=40; m: 58,3 y	Sieving
Van der Bilt[8], 2004	III – 3	Optocal Plus	15 MC	ND (some presented posterior losses)	n=176: 123W / 53M; m: 42,1y and 44,9 y, respectively	Multiple and single sieve method (comparison)
Speksnijder[19], 2009	III – 2	Bi-colored wax cube; Optocal Plus	Wax 5, 10, 15, e 20 MC; Optocal 15 MC	ND; CD upper, OD lower; CD	n=60: 10W / 10M, m 58,2 y; 9W / 11M, m: 62,2 y; 10W / 10M, m: 60,5 y	Adobe Photoshop software for the wax; Sieving method for Optocal
Van der Bilt[31], 2010	III – 2	Optosil; Optocal; Chewing Gum	Optocal and Optosil: 15 MC; Chewing gum: 10, 20 MC	ND; PT	n=40: 15w/5M, m: 72,1 y (G elderly); 14W/ 6M, m: 24,0 y (G young)	Adobe Photoshop CS2 for gum; Sieving for Optocal/ Optosil
Neves[13], 2015	III - 2	Optocal	40 MC	ND; fixed implant upper and lower; fixed implant upper, CD lower; CD upper, OD lower; CD	n= 15 aged 20-28y; n= 8 aged 55-80y; n= 14 aged 55-80y; n= 16 aged 30-76y; n= 16 aged 30-76y	Sieving
Miranda[54], *2019*	III – 3	Optocal	Until they felt the desire to swallow	CD OD	n=40: 27W / 13M, m: 66,2 y	Multiple sieving
Eberhard[12], 2012	IV	Optosil Comfort	15 MC	ND	n=20: 10W / 10M, mean 24 y	Sieving; Analysis by scanning and processing (Image J software)
Rovira-Lastra[55], 2014	IV	Optosil	20 MC	ND	n=42: 23W / 19M, m: 26,8 y	Sieving
Khoury-Ribas[33], 2018	IV	Optosil Optozeta	20 MC	ND; RPD, CD; IPP	n=35: 23W / 12M, m:ean 37 y; Retest with n=15: 11W / 4M, m: 34 y	Sieving
Liu[56], 2018	IV	Optosil	3, 7, 14, 28 MC	ND	n=8: 4W / 4M, m: 23,6 y	Sieving
Liedberg[17], 1995	III – 2	Chewing gum developed from SOR-BITS®	GA: 10, 20, 40, 60, 80, 100 MC GB: 10 MC	ND; CD; RPD;	GA- n=25: 20W / 5M, aged 32-82 y; GB- n=20	Visual analysis of the mixing ability, with self scale score
Prinz[37], 1999	IV	Chewing gum Bubble YumTM®	5, 20, 30 MC	ND	n=10: 3W / 7M; Age is not cited.	Digital image analysis "Graphics Unbiased Measurement System"
Anastassiadou[34], 2001	III - 2	4 chewing gums: Freedent; Dentine-Ice; Elma-f; Pita	5, 10, 20, 30 MC	ND; CD	n=8: G CD: n=5 58-76 y; G ND: n=3 26-42 y	A formula is applied to check the weight loss of the gum in three moments
Schimmel[21], 2007	IV	Chewing gum Hubba-Bubba	5, 10, 20, 30 e 50 MC	ND	n=20: 11W / 9 M, m: 27,5 y	Visual analysis; Adobe Photoshop
Kamiyama[18], 2010	IV	Chewing gum xylitol	20, 40, 60, 80, 100, 120, 140,	ND	n=11 for calibration; n=18 to perform visual analysis of the gum	Colorimeter (CR-13; Konica-Minolta, Tokyo, Japan); Visual scale

			160, 180, 200 MC			
Komagamine [57], 2011	IV	Chewing gum xylitol	20, 40, 60, 80, 120, 160 MC	ND	n=45: 22W / 23M, m: 29,8 y	Colorimeter; Visual scale
Ohira[40], 2011	III – 2	Chewing gum xylitol that changes color when chewed	2 minutes of mastication	ND	n=70: 34W / 36M, m: 5,4y ; n=28: 14W / 14M, m: 5,3 y	Colorimeter (CR-13; Konica-Minolta, Tokyo, Japan)
Molenaar[30], 2012	IV	Chewing gum Hubba-Bubba	Anterior: 20 MC; Posterior: 20 MC	ND	n=10: 4W / 6M, m: 30,3y	Software Adobe Photoshop Elements 2.0
Halazonetis[52], 2013	III – 3	Chewing gum Hubba-Bubba	5, 10, 20, 30 e 50 MC	ND	n=20: 9W / 11M, m: 27,5y	Software ViewGum® (dHAL Greece)
Hama[41], 2014	III – 2	Chewing gum xylitol	100 MC	ND; CD	G ND - n=42, m: 26,8 y; G CD - n=47, m: 74,9 y	Colorimeter (Konica-Minolta, Tokyo, Japan)
Aimaijiang[42], 2015	III – 3	Chewing gum xylitol	100 MC	Removable dentures	n=38: 18W / 20M, m: 69y	Colorimeter
Schimmel[10], 2015	III – 2	3 gums: Hubba-Bubba; LotteTM; Vivident Fruitswing	5, 10, 20, 30, 50 MC	ND; CD upper, OD lower	n=20: 10W / 10M, m: 30,3 y n=15: 10W / 5M, m: 74,6y	Software ViewGum® (dHAL Greece) and Visual analysis with score from 1 to 5
Vaccaro[11], 2016	IV	Chewing gum Trident® of two colors and flavors united	3, 6, 9, 12, 15, 18, 21, 25 MC	ND	n=250: 130W / 20M, m: 25 y	Software MATLAB (MPAT V10, Spain)
Elmoula[58], 2017	IV	Chewing gum (does not cite brand)	20 MC	CD	n=58: 21W / 37M, m: 61,59 y	Software (Adobe Photoshop CS5)
Silva[51], *2018*	III – 3	Chewing gum Vivident Fruitswing	5, 10, 20, 30, 50 MC	CD	n=75: 51W / 24M, m: 67,1 y	Software ViewGum® (dHAL Greece) and Visual analysis with score from 1 to 5
Vaccaro[59], 2018	III – 2	Chewing gum Trident® of two colors and flavors united	G1: 0, 5, 10, 15, 20 MC; G2: 20 MC	ND (G1); CD (G2)	n=120: G1- 41W / 39M, m: 25 y; G2- 21W / 19M, m: 73 and 71 y respectively	S Formula-based system for the calculation of the index mix to gums
Nogueira[60], *2018*	III - 3	Chewing gum Vivident Fruitswing	20, 50 MC	ND; CD upper, OD lower above one implant	n=34 G OD: n=15; G CD: n=19; 23W / 11M, m: 63.9 y	Software ViewGum® (dHAL Greece)
Komagamine [47], *2018*	III – 1	Chewing gum xylitol	Chewing gum: 60 MC; Gummy jelly: 30 MC	OD lower immediate loading or OD conventional	n=19: G immediate: n=10; G conventional: n= 9; 10W / 9M, m: 68,4 y	Colorimeter (CR-13; Konica-Minolta, Japan); Visual analysis for gummy jelly
Iwaki[61], 2019	III – 3	Chewing gum xylitol	100 MC	Lower CD that started to use OD on two implants	n=19, m: 69.8 y	Colorimeter (CR-13; Konica-Minolta Sensing, Tokyo, Japan)
Leles[62], *2019*	IV	Chewing gum Vivident Fruitswing	20, 50 MC	CD	n=204: 138W / 66M, m: 65.6 y	Software ViewGum® (dHAL Greece)
Yousof[63], *2019*	IV	Chewing gum (Glee Gum)	3,6,9,15 e 25 MC three times	ND	n=20: 10W / 10M, m: 20,9 y	Software (ImageJ)
Sato[14], 2003	III – 2	Bicolored wax cube at 37°C	MC among 5 and 50 chews	RPD upper, ND lower; ND upper, RPD lower; RPD upper and lower;	n=37 G ND: 8W / 13M, m: 29,3 y; G rehabilitated: 9W / 7M, m: 58,8 y	Software (Luzex-FS)‡ to evaluate the photographed wax cube, dividing the groups in “good, medium or bad”

Sato[16], 2003	III – 2	Bicolored wax cube; Grains of a mixed test food	5, 7, 10, 15, 20 and 30 MC,	ND (A); RPD, ND (B); RPD upper and lower (C)	n=44 GA: 4W / 7M, m: 26,0 y; GB: 18W / 2M, m:62,6 y; GC: 8W / 5M, m: 66,6 y	Digital analysis, Photo of the chewed wax; Digital analysis of sieving food
Asakawa[15], 2005	III – 3	Bicolored wax cube	10 MC	RPD	n=32: 25W / 7M, m: 65 y	Software (Luzex-FS)[§]
Yoshida[64], 2007	IV	Bicolored wax cube at 37°C	10 MC	ND	n=26: 13W / 13M, m: 25,3 y	Software (Luzex-FS)[§]
Fueki[20], 2008	IV	Bicolored wax cube at 37°C	10 MC	ND	n=20: 10W / 10M, m: 24,1 y	Scanned image and software
Fueki[65], 2009	IV	Bicolored wax cube ; Peanut	Wax: 10 MC; Peanut: 20 MC	ND	n=20: 10W / 10M, m: 24,1 y	Unable to clearly identify how the author processed the results
Iwashita[35], 2014	III – 2	Gummy jelly	20 seconds on each side and free mastication	ND; Unilateral or bilateral posterior edentuism	n=83: 15W / 15M, m: 26,9 y; 19W / 11M, m: 63,8 y; 18W / 5M, m: 69,2 y	Glucosensor GS-1, GC Corporation, Tokyo, Japan)
Uesugi[48], 2017	IV	Gummy Jelly	20 seconds	ND	n=30M, mean 27,4 years	Glucose measuring sensor
Tanaka[22], 2018	III – 3	Gummy jelly	20 seconds	No posterior; Until 1st pre; Until 2nd pre; Until 1st molar; Until 2nd molar	n=149 W; m: 72,3 y G1 n=29, m: 76 y; G2 n=21 m: 71.6 y; G3 n=24 m: 72.4 y; G4 n=28 m: 70,4 y; G5 n=47 m: 70,9 y	Glucose measuring sensor (GS-2; GC, Tokyo, Japan)
Yamamoto[23], 2018	IV	Gummy Jelly	20 seconds	CD	n=30: 15W / 15M, m: 74,7 y	Glucose measuring sensor
Igarashi[39], *2018*	IV	Gummy Jelly	30 MC	CD	n=1248: 742W / 506M Age not specified	Visual analysis; Photoreceptor analysis
Kapur[28], 2006	IV	Carrots and peanuts	Carrot: 40 MC; Peanut: 20 MC	CD	n=140 Age and gender not specified	Sieving
Sugimoto[36], 2012	IV	Carrot, peanut and beef	Until they felt the desire to swallow	ND	n=20W, m: 23,4 y	Software digital image analysis and then sieving
Cazal[43], 2015	IV	Gum, Fuchsin capsules; Peanut;	For 15 seconds in each side separately	ND	n=30: 15W / 15M, m: 23,46 y	Spectrophotometer (Beckman Inc., Palo Alto, CA, USA).
Buschang[27], 1997	IV	CutterSil® Silicone	20 MC; 40 cycles/ min., 100 cycles/ min.	ND	n=20M (“young”) Age not specified	Sieving
Santos[25], 2006	IV	Fuchsin capsules	20 seconds of mastication	ND	N=10: 5W /5M, m: 25-30y ;	Spectrophotometer (Beckman, CA, USA)
Felício[24], 2008	IV	Fuchsin capsules	20 seconds on each side	ND	N=19: 10W / 9M, m: 22,9 y	Spectrophotometer (Beckman, CA, USA)
Reitemeier[26], 2012	III - 2	Gelatin based cylinder	30 MC	ND; CD; Maxillofacial prosthesis	N=60: 18W / 2M, m: 27 y; 9W / 11M, m: 72 y; 11W / 9M, m: 62 y	Sieving

MC: Masticatory Cicle; G: group; N: number of patients; m: mean (age); y: years (age); CD: Complete denture; ND: Natural dentition; RPD: removable partial denture; RCD: removable complete denture; OD: overdenture; IFP: Implant Fixed Prosthesis; TFP: Tooth Fixed Prosthesis.
Source: Authors.

Table 2 presents information about each test food used in the selected articles, specifically in relation to their respective advantages and disadvantages. The evaluation method and data on the type of instituted treatment or evaluated patient and the test food evaluation form are also presented therein.

Table 2 – Collected data about test foods.

TEST FOOD	ADVANTAGE	DISADVANTAGE	PATIENT INDICATION	FORM OF EVALUATION
Optocal	Reliable, has standardized proprieties and it is not affected by the saliva	It must be manufactured (time consuming), hard texture, perishable, hard-working (compared to other test-foods)	CD; ND; FP; TFP; OD	Sieving
Optosil	Comfortable to chew, reliable, does not suffer from saliva action	Manufactured, hard texture, more expensive and hard-working (compared to other test-foods), perishable.	CD; ND; FP; TFP; OD	Sieving or scanning
Optozeta	More stable than Optocal in the first seven days	Manufactured, hard texture, more expensive and hard-working (compared to other test-foods), perishable.	CD; ND; FP; TFP; OD	Sieving
Chewing-gum	Fast, does not stick to the prosthesis, easy to apply and handle, inexpensive, easy to store, non-toxic if swallowed, reliable, pleasant flavor	Need to repeat some scans, suffers from saliva action, may be too soft for dentate patients, may undergo constant reformulations, commercial availability	CD; RPD; RCD; OD;	Colorimeter, Viewgum, software, Visual evaluation, Sugar extraction
Wax	Fast, easy to chew, forms a bolus,	Temperature may influence. May be too soft for dentade patients (more suitable for mixing ability)	CD; RPD; RCD; OD	Software that evaluates pixel
Gummy Jelly	Inexpensive, objective results, easy and fast	Suffers from action of saliva	CD; RPD; RCD; OD;	Glucose extraction (glucose sensor)
Natural Foods	The patient is familiar with the food	Suffer from saliva action, may be retained or swallowed, lack of standardization	ND; RDP; RCD; OD; IFP; TFP	Sieving or photography
Others (Silicones, gelatines, fuchsin capsules)	Does not absorb saliva, non-toxic, neutral taste, easy to produce, fast, inexpensive	Difficult market availability. Fuchsin capsules are not available anymore	ND; RDP; RCD; OD; IFP; TFP	Sieving, colorimeter or spectrophotometer

CD: Complete denture; ND: Natural dentition; RPD: removable partial denture; RCD: removable complete denture; OD: overdenture; IFP: Implant Fixed Prosthesis; TFP: Tooth Fixed Prosthesis. Source: Authors.

The main advantages described for the Optocal test food were good reliability and the standardization of its properties[19]. Nevertheless, this test food still presented some reported disadvantages, such as high time-consuming processing to evaluate the results and difficulty experienced for some participants in chewing, due to its hardness [19,30]. The Optosil test food presents the same advantages and disadvantages as Optocal, but Optosil has even greater hardness in chewing specially for patients with impaired masticatory function or tooth loss [31,32].

The only selected article that used Optozeta reported that this test food is both more mechanically stable in the first 7 days and harder compared to Optocal [33].

Regarding chewing gum, the main advantages described were related to the ease of being used in evaluation and processing, in addition to being a fast, low-cost, and reliable method [10,31,34]. Some chewing gums are no longer commercialized or have undergone reformulations [10].

Paraffin-based wax was used either in cube or two-colored tablet forms, with the literature reporting its quickness, ease of chewing, and bolus formation as advantages, whereas unpalatability, adherence to prostheses, and the influence of temperature were reported as disadvantages [14,15,19].

Test methods involving gummy jelly were described as cheap, fast, and easy to perform [35]. In the selected articles, no disadvantage was described.

The main advantage for the group of natural foods was the participants' familiarity and taste with chewing a test food. Its main disadvantage was that standardization of the mechanical properties , making the comparison of results between studies difficult or even impossible [36].

The “others” group included different test foods used in only one study or which are no longer available. In addition to these foods having different physical properties, their main disadvantage is difficulty of access.

Table 3 presents the overall information on the methods of assessing masticatory function using a given test food. The form of evaluation, with their specific advantage or disadvantage, according to the studies reviewed is described. The description of the evaluation method and how it is managed is also described. Based on the literature reviewed, some comments and notes of the authors were also included.

Table 3. Overall information on a method used to evaluate a test foods

Evaluation Method	**Reported advantages**	**Reported disadvantages**	**Type of food analysed**	**How does it work**
Single sieve method	Simpler and faster than multiple sieves (only one mass measurement)	Time consuming, little detailing, difficult inter-individual comparison, depends on specific device (sieves and balance)	Optocal	The chewed food are dried and sieved, followed by weighing of the sieved particles
Multiple sieve method	Some authors report to be the “Gold standard”. Reliable, it is possible to determine the average size of the particles, provides detailed information, and to compare inter and intra-individuals results.	Time consuming, too many steps, high costs (depends on the specific device - sieves and balance).	Optocal, Optosil, CutterSil Silicone, Optozeta, gelatin based cylinder, natural foods	Sieves of different diameters of the chewed and dried particles to assess the weight and distribution of the particles in the sieves
Viewgum	Good clinical applicability, fast, easy to perform, efficient, inexpensive (software is free). Possible to compare inter-individuals and intra-individuals	It is more appropriate to evaluate mixing ability. May not perform well to healthy dentate patients.	Different types and brands of Chewing-gum	The software evaluates the “HSI” parameters (hue, saturation, intensity), focusing mainly on the “hue” factor. The higher the variation of the hue axis, the greater the presence of two different colors.
Photoshop digital analysis, CS3 extended (Adobe, USA)	No specific advantages described	No specific disadvantages described	Bicolored wax tablet	The software analyzes the RGB (“red, green, blue”) of the chewed wax and assess the pixels in the intensity of the red and blue colors
MATLAB digital analysis (MPAT V10, Spain)	No specific advantages described	No specific disadvantages described	Trident® chewing-gum of two flavors and colors (red and white)	Image analysis by the intensity of the colors using the “HSI” and the number of pixels of the colors in the RGB

Image J digital analysis (National Institutes of Health, USA.)	Can be used in a standardized food; results like sieving; can be employed in dentate and prosthetic patients; faster than sieving, it is more inexpensive than the sieves	It has questionable clinical applicability because it needs the sieving method to provide the sample reference	Optosil	The chewed Optosil is flattened and scanned. The software uses some parameters to generate values that are exported to excel and from the size reference, the estimated weight is obtained
Adobe Photoshop Elements 2.0 digital analysis	Easy to learn, well-suited for research, reliable, accurate, easy to standardize	Schimmel[21] reports that even though it is easy to learn, it is not clinically viable	Chewing-gum Hubba-Bubba Tape	The software analyzes the number of blue pixels and a formula was applied to determine the mixing ability from the comparison of the chewed with non-chewed gums.
Visual analysis (color chart)	Inexpensive, simple, test can be performed by the patient himself. Can be performed on a large scale, reliable and viable in clinical analysis	Access to the gum, may stick to the prosthesis, not recommended for individuals with salivary flow disturbance. Need calibration between the observers.	Chewing-gum XYLITOL, Lotte Co., Ltd., Tokyo, Japan	After chewing the gum was flattened and compared with a visual scale that provides the reference of 5 colors and their performance levels
Visual analysis (Standardized score)	Good clinical applicability, fast, efficient, simple	Despite the good correlation, the digital analysis is more accurate	Chewing-gum Lotte TM, (Tokyo); Vivident Fruitswing (Karpuz/Asai Uzumu,Turkey)	Chewed gum is analyzed visually by observers. It can be evaluated before and / or after being flattened
Spectrophotometer (Beckman Inc., USA)	Reliable, fast, effective, good sensitivity	The Fuchsin capsules test food is no longer available	Fuchsin capsules	The peak of Fuchsin is identified by the device at a wavelength of 546 nm, and the higher the reading (μg / mL), the better the masticatory efficiency
Sugar Extraction (by mass)	No loose particles, can be performed at home or home institutions for the elderly, easy to perform	Affected by saliva, high early mass loss, compromised method in individuals with altered salivary flow	Freedent (UK), Dentine-Ice (Warner Lambert, Belgium), Elma-f (Chios, Greece)	The gum is weighed in three moments: before and after the test with and without saliva. A formula is used to determine the level of weight loss.
Sugar Extraction (by sensor)	Low cost, easy, fast	No specific disadvantages described	Gummy Jelly (LOTTE Co., Ltd., Japan)	The glucose sensor measures the level of glucose present in the filter, and the greater the extraction of glucose, the better the masticatory efficiency

HSI: hue, saturation, intensity; RGB: Red, green, blue; Source: Authors.

The term "gold standard" was used by some authors when applying multiple sieving as a test food evaluation method [10,12,16,30]. Its advantages include reliability and the possibility of both determining the average particle size and comparing inter- and intra-individual results [10,12,16,30]. Also, comminuted particles of the test food selected can be analysed by optical scanning, and the results converted to a particle size distribution [8,9]. Its disadvantages include the time necessary for multiple screening, the need for several steps, and the dependence on specific devices such as screens and scales [8]. The cost of this equipment can also be a limiting factor for this type of analysis.

The single sieve method differs from the previous method in that it uses only one sieve with a diameter determined by the average particle size. In general, its advantages and disadvantages are similar to those of multiple sieving, but it is simpler and requires no further statistical analysis, making it more fast and easier than multiple sieves. The main disadvantages when compared to multiples sieves is that it is less detailed, which renders comparisons among individuals more difficult and less reliable [8,9].

On the other hand, digital analysis of images of test foods mixed after chewing can occur through Variance of Hue (VOH), special heterogeneity and optical scanning. The most commom method is with a software that identifies pixels within the image, corresponding to the portions of the test food that were mixed or not [10,19,21, 31,37]. Software used for this purpose was not developed specifically for but rather adapted to this type of evaluation, such as those derived from Adobe Photoshop [19,21]. The Viewgum software (ViewGum© software, dHAL Software, Greece, www.dhal.com) was specifically developed to evaluate mixing ability from the digital image obtained through photographing or scanning two-colored chewing gums. Evaluation using such software presents ease, reliability, speed, and low cost as advantages; the need to repeat the acquisition of the image or the reading by the software may pose as disadvantages for this method [10,19,21,31,37]. The analysis of the mixture of two-colored food stuff or of jelly candies can be performed visually using scales or scores as pre-established parameters , with the advantage of low cost, good reliability, simplicity, and speed [10,17,21,38,39]. Another method described to analyze color changes in test foods was the use of a colorimeter [18,38,40-42].

There are other devices such as glycosensors (glucose sensor) that can measure the sugar content decrease in the test food used, correlating it with the chewing capacity [22,23,35], or spectrophotometers to quantify fuchsin granules, which are currently no longer commercially available [24,25,43].

4. Discussion

Over the last decade, the relationship between masticatory function, its systemic benefits, and quality of life has been widely discussed and studied. Some studies have indicated that masticatory performance is one of the most important parameters in relation to the nutritional level and quality of life of elderly patients, while some have reported on the importance of increasing or maintaining masticatory capacity as a favorable factor to healthy aging and preservation of some cognitive functions [44,45].

This literature review did not include studies that applied only masticatory function evaluation as a way to obtain data after instituting specific dental, prosthesis and/or implant treatments. Only studies that presented a complete, detailed description of the relationship between the results of proposed treatments or specific groups of patients, based on the different methodologies for assessing masticatory function (regardless of which methodology was used) were considered. The use of a judicious methodology for the selection and evaluation of the articles included in this review allowed us to compare the test foods and their respective forms of evaluation to evaluate the results from the literature published over the last 32 years.

Test foods/materials published in few studies that have clear disadvantages regarding their use, evaluation or standardization or that are not commercially available (such as fuchsin capsules, beads or artificial foods) have not been fully discussed in this review [24,25,27]. Although they might have had good results in their previous studies published, the impossibility of continuous use or comparison does not have clear benefits for the purpose of this literature review [24,25,27].

Natural foods were used as the first test foods in earlier publications, and were gradually replaced by artificial foods, which have standardized properties [12,36,46]. The advantage that natural foods present regarding the pleasant taste and the participants' familiarity when chewing does not overcome the disadvantage of non-standardized samples, rendering a comparison of results unfeasible [12].

Paraffin-based wax cubes have been used in few studies, and although they have advantagens such as low cost and availability; their disadvantages, including the relationship between temperature and hardness of this food stuff, the need to handle samples before they are used, its unpalatability, and its adherence to patients' prostheses, do not justify their use [14,15,19].

Gummy jellies have been published in several studies, but they have not yet been validated in comparison to other masticatory performance evaluation methods or food tests. Also, their use with defined protocols has not yet been established, making it difficult to interpret results, apply intergroup comparisons, and appraise the factors that may influence outcomes [22,23,47,48]. The evaluation methods to obtain the results for the gummy jelly's have not been fully validated and/or compared to other stablished and validated masticatory performance methods. The collection and rinsing, the preparation of the dissolution of the ingredients to evaluate results, make necessary trained personel, making it more difficult to reproduce, to measure and to compare results [9]. For these reasons, the aforementioned materials should not constitute, nowadays, the first choice in the assessment of masticatory performance.

The most frequently used food test material in the literature are Optosil® (a condensation silicone used in dental moldings), Optocal (the first test food developed exclusively for assessing chewing performance among the included articles), and chewing gums (reported in the largest number of articles to date). The use of Optosil was justified by some authors due to the possibility of determining the sample format and size (not feasible with natural foods), and the ease in standardizing its physical properties, in addition to it not being degraded by saliva [31,32,49,50]. Optocal was developed to be a softer test food than Optosil [31,32]. The hardness of Optosil makes it difficult to use it as a test food to assess masticatory performance in individuals with impaired masticatory function, such as patients with full and/or removable dentures, and patients with neuromuscular disorders [9,31,32]. Optocal is composed of Optosil itself incorporated with other components such as petroleum jelly, alginate powder, plaster powder, and toothpaste, rendering it softer than Optosil. The components used in its preparation need to be carefully dosed in order not to change its mechanical properties. Maybe this might be the biggest limitation among the comminution tests. The importance of choosing the correct population and the food test will directly impact the results of the masticatory performance, specially when trying to compare results from patients with different oral conditions or submitted to different dental reahabilitation [9].

Due to the need for preparation and adequate handling of Optocal/Optosil, and the fact that chewing gums are commercially available and therefore readily disponible for use, they are currently used in a greater number of studies to evaluate masticatory performance [10,17,31,51]. It is important to emphasize that this methods are mixing ability tests, and some of the studies published tend to quote or compare them with chewing performance methods, and this comparison may lead to bias or misjudgment of results. In general, the use of chewing gums to evaluate mixing ability is justified by the ease of obtaining the test food, the speed and simplicity of the test application, and the reliability and cost of the evaluation method employed [10,31]. The texture and flavor of the gums, as well as the non-adherence to prostheses, are other advantages of this method, thus presenting the same advantages as natural food stuffs [51]. Their quick and simple assessment make them available for different professional environments such as dental offices, hospitals, psychiatric and geriatric wards. In regard to the number of cycles needed, most of the studies published have different chewing cycles employed in their methodologies. The literature tends to suggest that 20 chewing strokes have the vest discriminatory characteristics to compared patients and treatments [9].

The form of processing and obtaining the results of the selected test food to evaluate masticatory performance is a key factor and must be carefully considered when determining the choice of test material. It is thus important to know how the chosen processing takes place, its advantages, and its possible limitations. In fragmentation tests, which is the case with Optosil and Optocal, the most commonly used result processing form is multiple sieving as it constitutes a very reliable method [8]. However, the number of studies employing screening methods as an initial choice decreased mainly due to the large number of steps necessary for its processing and the need to have a specific scale and sieves. The time consuming and the costs of the sieving methods are high when compared to some of the other available methods. Also, comminution tests are sensitive to changes in bite force, dental state and other possible oro-facial system changes, making it not suitable for all types of patients[9]. All these advantages and disadvantages and comparison are listed in Table 3. The analysis of mixing ability can occur in several different ways, with digital or visual methods [10,31,51,52]. The method of processing chewing gums (currently, software specific to this purpose) has been one of the greatest advantages of using this material [10,52]. Such software programs have been validated in the literature and present reliable, easy, and quickly measurable results [10,51]. Due to their practicality, low cost, and fast results, chewing gums are presently the most used test food to evaluate masticatory performance, and have been suggested for research on large populations [17,21]. It is worth mentioning that the limits of this test are not yet known in relation to different types of dentition.

The articles selected in this literature review varied between satisfactory or poor after assessment of the risk of bias according to the NHMRC scale, so their results should be interpreted with caution. In view of the various test foods and forms of processing available to assess masticatory function, each with its specific advantages and disadvantages, it is suggested that the ideal evaluation method has yet to be fully developed or standardized, especially when we thing in a universal method of evaluation that might be suitable to perform to individual groups of patients or treatments, and possibly to compare them. The standardization or adequacy of masticatory function evaluation will allow great evolution in understanding the importance of mastication and its impact on a patient's systemic health. It is imperative to understand the differences and indications among the evaluation methods of chewing performance and chewing efficiency.

5. Final Considerations

Our results showed Optocal and Optosil) were used more in studies with participants who present high chewing performance (patients with implants or patients with complete normal dentition). We suggest after this extensive and critical review of the literature that comminution tests (with Optosil and Optacal and evaluated through multiple sieving methods) may be used only for this "group" of patients and should no be indicated to patients with impaired oral conditions or diminished masticatory function. They are very reliable and can be used to compared treatments outcomes (before and after). Chewing ability, evaluated mostly by mixing ability tests, and in this case, with commercially gums evaluated by open and free software's, are more suitable and should be the first choice for patients with total or partial removable prostheses, elderly patients (with reduced masticatory muscle strength), children, geriatric patients, patients with neurological disturbances or any other oral disfunction, such as after ressective oral surgeries. In an attempt to standardize masticatory performance evaluation methods, especially in clinical, hospital and research settings that evaluate patients with age-deficient chewing, edentulism or systemic changes, the use of chewing gum seems to be the most indicated procedure for its practicality, low cost, reproducibility, and easy results. Also, to obtain epidemiological data and evaluate large samples of population they are more suitable. It should be noted that the protocols for using chewing gum for each patient profile still need to be further explored, and that additional studies are needed to identify which factors can influence the physical properties of commercially available chewing gums and consequently alter their results.

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