Application of masticatory control in dental treatment for elderly individuals

Ta-Chung Chen[a], Dong-Hui Cheng[a], Ming-Lun Hsu[b,*], Yen-Ping Lei[b]

[a]Division of Prosthodontics, Department of Stomatology, Taipei Veterans General Hospital, Taipei, Taiwan, ROC; [b]Department of Dentistry, School of Dentistry, National Yang-Ming University, Taipei, Taiwan, ROC

Abstract: Taiwan transitioned to an aged society in 2018. Appropriate dental treatment is important for elderly individuals. Previously, reconstruction of the dentition was thought to help regain chewing function. However, concerns of the elderly population, such as decline in learning ability and saliva secretion, complicate dental reconstruction. Overlooking the special needs of elderly individuals may lead to impaired chewing function, resulting in nutritional imbalances and increased burden on the digestive tract, causing more health disorders. For the elderly population, treatment must be aimed at restoring as much chewing function as possible with minimal changes. Additionally, regular oral hygiene care, proper design of fixed partial dentures, and implant placement greatly reduce the difficulty in adapting to a new prosthesis. These measures allow us to provide better quality of life for elderly individuals.

Keywords: Aged; Dental care; Dental prosthesis design; Mastication

1. INTRODUCTION

In 2018, Taiwan was officially recognized as an aged society, with more than 14% of the population being older than 65 years. According to the National Development Council of Taiwan, the nation may be identified as a super-aged society by 2026 because of the continual increase in the elderly population.[1] This transition has resulted in dental care for elderly people becoming highly important. To provide better quality of life for elderly individuals, treatment should be aimed at functional retention of the dentition to the greatest possible extent.

The most important functions of dentition are phonation, chewing, and esthetics, and most dental reconstruction treatments aim to fulfill these functions. Because of the high adaptability of the tongue and lips, phonation is usually not a major concern. Advancements in dental material and digital dentistry have enabled the precise design of prostheses. Moreover, prothesis with the right choice of shade that blends with the natural tooth color is esthetically favorable. However, during dental reconstruction, emphasis is placed on retaining chewing ability. Although dental functions are thought to be regained after structural reconstruction, this is not always true, and most clinicians often overlook the nuances of masticatory control.

Once the food is ingested into the oral cavity, the tongue conveys the food to the occlusal tables of the premolars and molars, initiating chewing. Assisted by the tongue, the food is broken into small pieces during mastication and combined with salivary mucin to form a slippery food bolus. The slippery bolus is formed as a part of the swallow phase, wherein the food particles are passed through the esophagus.[2] Thus, chewing helps reduce the size of food particles and softens them for an easier swallow and increases the surface area of the food to facilitate digestion.

Multiple factors, such as missing posterior teeth, decreased occlusal contact area, tooth malalignment, bite force, salivary flow, age, sex, sensory feedback, and oral motor function, seem to affect chewing efficiency.[3,4] Among these factors, pairs of functional tooth units and bite force are important determinants of chewing function.[3,4] Käyser considered a pair of occluding premolars as one "occlusal unit" and a pair of occluding molars as two occlusal units. According to his "shortened dental arches" theory,[5] chewing function is adequate when at there are at least four occlusal units, preferably in a symmetrical pattern. This concept, which has been supported by several studies,[6–9] provides us with the insight into the lower limit of functional tooth units for adequate chewing function when a full mouth reconstruction is performed. In this study, we will review the factors affecting bite force regulation and changes in the masticatory system during the aging process. We will also provide suggestions regarding prosthetic treatment for elderly individuals.

2. THE ROLE OF PERIODONTAL MECHANORECEPTORS IN REGULATING CHEWING FUNCTION

The jaw closing movement during chewing can be categorized into two phases: fast close and slow close.[2] The fast close phase begins when the mouth closes after food intake and ends when teeth bite the food, whereas the slow close phase begins when teeth bite the food and ends when the jaw closes against the resistance of the food to crush it. Control of fast close phase depends on proprioception of masticatory muscles; the velocity and path of the jaw may be influenced by chewing speed and expectation of food texture. The faster an individual chews or the harder the food is, the more vertical is the jaw

*Address correspondence. Dr. Ming-Lun Hsu, Department of Dentistry, School of Dentistry, National Yang-Ming University, 155, Section 2, Li-Nong Street, Taipei 112, Taiwan, ROC. E-mail address: mlhsu@ym.edu.tw (M.-L. Hsu).

Conflicts of interest: The authors declare that they have no conflicts of interest related to the subject matter or materials discussed in this article.

Journal of Chinese Medical Association. (2021) 84: 125-128.

Received April 16, 2020; accepted June 29, 2020.

doi: 10.1097/JCMA.0000000000000467.

Copyright © 2020, the Chinese Medical Association. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/)

trajectory.[10–12] Fine chewing regulation occurs in the slow close phase. The sensory feedback of food texture during chewing assists in adjusting the bite force and direction to chew safely and efficiently.[12]

In a study to evaluate the regulation of slow close phase, Svensson and Trulsson[13] instructed the participants to hold the food between the pair of opposing central incisors for 3 s and then split them. The test food included a soft food item (biscuit) and a hard food item (peanut). To clarify the role of periodontal mechanoreceptors (PMRs), local anesthesia was applied on the incisors of the participants to block the innervation. The force during the whole course was recorded. They concluded that holding helps sense and manipulate the food to facilitate splitting, which reduces the size of the food particle. Because there are multiple holding and splitting movements during chewing, any change in the regulation of these movements will affect chewing function.

In the aforementioned study, the authors also found that the holding force was the same for different foods, but the force increased after application of local anesthesia. The split force was considerably higher in the peanut group, but no significant difference was found on the split force for each food between before and after application of local anesthesia. The split force rate under anesthesia is lower than normal, thus it took more time to split the food under anesthesia. The findings revealed that PMRs play an important role in food perception and adaptation of the bite force rate to the hardness of the food.

Chewing regulation is highly important, and any factor that impairs the periodontal tissue may also impair chewing function. A periodontally compromised individual cannot regulate masticatory force remarkably well. The holding force is elevated and the bite strategy is also changed to a more defensive food-splitting behavior.[14] A long-span bridge splint, along with the abutment, may compromise the sensitivity of the PMRs of the abutments, leading to regulation dysfunction.[15,16] Although chewing ability is less efficient when PMRs are impaired, the function can be improved through practice. A hold-and-splint experiment in participants administered under local anesthesia revealed that both the accuracy and precision improved after repeated practice, although not as precise as natural dentition.[17]

In patients with implant-supported prosthesis, periodontal tissues are completely missing. In such patients, the total chewing cycle and chewing time are the same as those in individuals with normal dentition, but the electromyography showed that the power of masticatory muscles are not able to adjust to different hardness of food and different particle size. This condition leads to a less efficient chewing function, resulting heavier loading of the gastrointestinal tract.[15]

3. MAXIMAL BITE FORCE

Chewing regulation mainly relies on the sensory feedback of periodontal tissues and muscles, but whether or not the food can be crushed depends on the magnitude of the maximal bite force. This parameter is highly important to evaluate the chewing ability in individuals with dentures. The value of the maximal bite force varies from 234 to 1110 N, possibly because of the different measuring methods used in the studies.[18] Typically, the following factors appear to significantly influence the maximal bite force.

3.1. Craniofacial morphology

Compared with individuals with a low mandibular plane angle, those with a high mandibular plane angle exhibit lower muscle volume of the masseter and pterygoid muscles.[19] Moreover, a negative correlation was reported between the mandibular plane angle and bite force.[20]

3.2. Age

The maximal bite force increases up to 25 years of age, and then decreases slightly with increasing age, with a correlation coefficient between –0.22 and –0.31.[18,21,22] The maximal bite force may be affected by the effect of aging on muscle strength or by change in food type because of worsening dental condition.[4]

3.3. Gender

Although there is no difference in the maximal bite force between the sexes in adolescents,[22] a significant difference has been noted between the sexes in adults.[23] The bite force increases up to 25 years of age in both women and men but decreases gradually thereafter in women but remains constant in men up to 45 years of age.[21]

3.4. Periodontal support

The bite force decreases as more of the periodontal tissue attachment is lost, with a correlation coefficient of –0.42.[24] However, some studies reported no difference between patients with periodontal destruction and healthy individuals.[25]

3.5. Habitual biting side

No difference exists in bite force between both sides in most of the population; however, if preferred biting side exists, the maximal bite force is greater than the contralateral side. Importantly, better intercuspation was found in the preferred biting side.[26]

3.6. Temporomandibular disorder

The maximal bite force is reduced in individuals with temporomandibular disorders, irrespective of whether it is of muscular, articular, or mixed type.[19,27]

4. INFLUENCE OF AGING IN MASTICATION

Aging is always associated with natural tooth loss. The presence of at least four occlusal units is a basic requirement to achieve sufficient chewing function,[5–9] which means that a minimum of 20 teeth are necessary for normal functioning. A 2016 survey conducted in Taiwan revealed that only 60.3% individuals older than 65 years had more than 20 teeth, only 40.2% individuals older than 80 years had more than 20 teeth, and 12.7% of the study population had no teeth.[28] Essentially, the survey only focused on the number of all the remaining teeth, including residual roots, periodontally compromised teeth, and teeth without antagonists, but not on the remaining functional teeth. Chewing function degraded with age is more severe than this survey can revealed.

Although the ability to crush food is not affected by saliva, food cannot be swallowed without adequate moistening. The salivary flow rate and composition are affected by aging and disease.[29,30] Xerostomia can be caused by either systemic or local factors. Systemic factors include endocrinologic, autoimmune, infectious, granulomatous, and other factors, such as chronic graft-versus-host disease and amyloidosis. Local factors include medication use, head and neck radiation, and lifestyle factors, such as smoking, dehydration, and alcohol use.[31–33] The most common categories of medications that may cause xerostomia include antihistamines, decongestants, antidepressants, antipsychotics, antihypertensives, and anticholinergics.[31,34] Xerostomia is common in the elderly population and is mostly caused by loss of approximately 30% of the acinar salivary gland cells due to aging and higher prevalence of the aforementioned comorbidities.[35] Thus, food choices in elderly individuals tend to be soft and easy to chew due to reduced secretion of saliva and presence of only few functional teeth,[32,36] which may result in vitamin, iron, and fiber deficiencies.[37,38]

The chewing efficiency is additionally affected in denture wearers and is often associated with the severity of ridge resorption.[39–41] Although ridge resorption is not an age-related problem,[42] factors such as history of denture use, menopause-related hormonal change, cumulative effects of steroid intake, alveolar bone destruction due to periodontitis, and extraction procedure are all related to aging process.[42,43] In elderly individuals, it is not uncommon to find a patient with severely resorbed edentulous ridge.

Orofacial alterations such as tooth extraction, implant placement, and occlusal adjustment cause adaptational changes in the occlusal system.[44] This adaptation, or compensation, modifies the coupling of brain and behavior through neuroplasticity.[45] Maybe caused by a decreased automaticity in older people, it takes more time to complete the neuroplasticity process.[46] The clinical manifestation is that the elderly individual adapts to changes in the mouth much slower and that a fine force control of the tongue and lips is more difficult.[45,47] In healthy elderly individuals, this deficit may be compensated by the increased involvement of the brain. However, in patients with stroke, dementia, or other neurological disorders, the ability to compensate may be compromised.[45,47] Such individuals may find it difficult and take more time to adapt to the changes in the mouth, whether it is a new set of dentures or a fixed prosthesis.

5. CONSIDERATION FOR DENTAL TREATMENT

Considering the importance of PMR in mastication, a dental treatment plan should be carefully designed with the primary goal to preserve the remaining healthy periodontal tissue. This is because adequate numbers of PMRs are required to chew food precisely. Treatment should be designed depending on the conditions of remaining dentition, maximal bite force, condition of remaining ridge, and especially the adaptation ability of elderly patients.

Because periodontal destruction is cumulative over years, an oral hygiene program should be started as early as possible.[48] Oral hygiene instructions must include toothbrush type, interdental brushing method, and use of dental floss to stop progression of periodontitis.[49–51] Regular professional periodontal cleaning is suggested. These practices may not reconstruct the lost tissue but will possibly help increase chewing function in patients with periodontal destruction.[52]

When treating a tooth with extensive structural loss, root canal treatment followed by crown protection is a better option than extraction and replacement with a dental implant. The remaining periodontal tissue will enable the patient to chew precisely.[13] Implant-supported prosthesis reduces not only the perception of the periodontal tissue but also the maximal bite force.[53]

In patients without PMRs, although masticatory function improves with practice,[17] teeth splinting must be performed only when absolutely necessary, especially in elderly individuals. Because the splinting procedure may desensitize the PMRs of abutments, elderly individuals need more time to adapt to their new dentition.[45,47] Single implants with a set of short-span fixed partial denture instead of a long-span bridge may be a better choice to preserve the sensation of PMRs. Preserving a relatively healthy tooth adjacent to the implant helps the patient distinguish different food textures.

It is necessary to evaluate the maximal bite force before planning reconstruction. An underestimated bite force may cause prothesis-related biological and mechanical complications. Higher maximal bite force is expected among the groups like male, age under 45 years old, with low mandibular plane angle, and the people without periodontal destruction.[18–24] The reconstruction plan should be more conservative in these patients. Adequate posterior support is crucial and less durable materials such as resin should be used carefully. Even if PMRs are compromised, splinting is a safer method to prevent fracture or trauma from occlusion of the compromised abutment tooth.[54]

For a patient with a complete denture, the placement of two or more implants is highly recommended to improve stability and retention of the denture.[55–57] Moreover, the sensor inputs for a denture is inadequate, and the bite force of a complete denture wearer is 5–6 times lesser than that of an individual with normal dentition.[58] This reduced bite force is not even adequate to penetrate some food such as raw carrot and boiled meat.[59] Most complete denture wearers perceive that their chewing ability is good enough, but the reduced bite force leads to longer chewing time and swallowing coarser food.[60] This concern can be overcome by placing an implant-retained overdenture, which despite still missing the sensory input, improves the bite force and masticatory performance, leading to better patient satisfaction.[55–57]

For patients with a declined neurological condition, the treatment strategy is to reduce the aspects they need to adapt. When setting the vertical dimension and centric relation of the new prosthesis, it is better to refer to the old position. The guidance in eccentric movement should also follow the original condition, or the interim prosthesis. Compared with reconstructing to full 28 teeth, the concept of shortened dental arches can be introduced to simplify both the treatment and adaptation processes.

Because the retention and stability of denture are improved with the assisted of dental implants, implant-retained overdenture has a lower learning threshold than conventional denture. Patients with declined neurological condition also have more opportunities to restore chewing function.[45,47]

In conclusion, with Taiwan being recognized as an aging society in 2018, dental treatment needs to be more attentive to the special needs of the elderly population. Reconstruction plans must be designed with an aim to reduce large-scale changes in the mouth and the aspects to which the patients need to adapt. Preserving periodontal tissue helps maintain fine regulation during chewing, which is important in elderly individuals with reduced adaptability. Better retention and resistance of implant-retained overdentures make them more elderly friendly.

Future studies must further explore the relationship between aging and changes in masticatory function. Differences in race, diet, and culture between Taiwan and the Western countries may influence the study results. Therefore, further studies focusing on the Taiwan's elderly population are required to appropriately manage chewing problems faced by these individuals.

REFERENCES

1. Directorate General of Health Services. *2017-2021 National Oral Health Promotion Program*. : Ministry of Health and Welfare; 2017.
2. Hiiemae K. Mechanisms of food reduction, transport and deglutition: how the texture of food affects feeding behavior. *J Texture Stud* 2004;**35**:171–200.
3. Julien KC, Buschang PH, Throckmorton GS, Dechow PC. Normal masticatory performance in young adults and children. *Arch Oral Biol* 1996;**41**:69–75.
4. Hatch JP, Shinkai RS, Sakai S, Rugh JD, Paunovich ED. Determinants of masticatory performance in dentate adults. *Arch Oral Biol* 2001;**46**:641–8.
5. Käyser AF. Shortened dental arches and oral function. *J Oral Rehabil* 1981;**8**:457–62.
6. Aukes JN, Käyser AF, Felling AJ. The subjective experience of mastication in subjects with shortened dental arches. *J Oral Rehabil* 1988;**15**:321–4.
7. Witter DJ, van Elteren P, Käyser AF, van Rossum MJ. The effect of removable partial dentures on the oral function in shortened dental arches. *J Oral Rehabil* 1989;**16**:27–33.
8. Sarita PT, Witter DJ, Kreulen CM, Van't Hof MA, Creugers NH. Chewing ability of subjects with shortened dental arches. *Community Dent Oral Epidemiol* 2003;**31**:328–34.

9. McKenna G, Allen PF, O'Mahony D, Cronin M, DaMata C, Woods N. Impact of tooth replacement on the nutritional status of partially dentate elders. *Clin Oral Investig* 2015;**19**:1991–8.
10. Abbink JH, van der Bilt A, Bosman F, van der Glas HW. Speed-dependent control of cyclic open-close movements of the human jaw with an external force counteracting closing. *J Dent Res* 1999;**78**:878–86.
11. Dellow PG, Lund JP. Evidence for central timing of rhythmical mastication. *J Physiol* 1971;**215**:1–13.
12. Lund JP, Kolta A. Generation of the central masticatory pattern and its modification by sensory feedback. *Dysphagia* 2006;**21**:167–74.
13. Svensson KG, Trulsson M. Regulation of bite force increase during splitting of food. *Eur J Oral Sci* 2009;**117**:704–10.
14. Johansson AS, Svensson KG, Trulsson M. Impaired masticatory behavior in subjects with reduced periodontal tissue support. *J Periodontol* 2006;**77**:1491–7.
15. Grigoriadis A, Johansson RS, Trulsson M. Adaptability of mastication in people with implant-supported bridges. *J Clin Periodontol* 2011;**38**:395–404.
16. Grigoriadis J, Trulsson M, Svensson KG. Motor behavior during the first chewing cycle in subjects with fixed tooth- or implant-supported prostheses. *Clin Oral Implants Res* 2016;**27**:473–80.
17. Kumar A, Castrillon E, Trulsson M, Svensson KG, Svensson P. Fine motor control of the jaw following alteration of orofacial afferent inputs. *Clin Oral Investig* 2017;**21**:613–26.
18. van der Bilt A. Assessment of mastication with implications for oral rehabilitation: a review. *J Oral Rehabil* 2011;**38**:754–80.
19. Pereira LJ, Gavião MB, Bonjardim LR, Castelo PM, van der Bilt A. Muscle thickness, bite force, and craniofacial dimensions in adolescents with signs and symptoms of temporomandibular dysfunction. *Eur J Orthod* 2007;**29**:72–8.
20. Weijs WA, Hillen B. Relationships between masticatory muscle cross-section and skull shape. *J Dent Res* 1984;**63**:1154–7.
21. Bakke M, Holm B, Jensen BL, Michler L, Möller E. Unilateral, isometric bite force in 8-68-year-old women and men related to occlusal factors. *Scand J Dent Res* 1990;**98**:149–58.
22. Braun S, Hnat WP, Freudenthaler JW, Marcotte MR, Hönigle K, Johnson BE. A study of maximum bite force during growth and development. *Angle Orthod* 1996;**66**:261–4.
23. Ferrario VF, Sforza C, Serrao G, Dellavia C, Tartaglia GM. Single tooth bite forces in healthy young adults. *J Oral Rehabil* 2004;**31**:18–22.
24. Takeuchi N, Yamamoto T. Correlation between periodontal status and biting force in patients with chronic periodontitis during the maintenance phase of therapy. *J Clin Periodontol* 2008;**35**:215–20.
25. Kleinfelder JW, Ludwigt K. Maximal bite force in patients with reduced periodontal tissue support with and without splinting. *J Periodontol* 2002;**73**:1184–7.
26. Takahashi M, Takahashi F, Morita O. Evaluation of the masticatory part and the habitual chewing side by wax cube and bite force measuring system (dental prescale). *Nihon Hotetsu Shika Gakkai Zasshi* 2008;**52**:513–20.
27. Kogawa EM, Calderon PS, Lauris JR, Araujo CR, Conti PC. Evaluation of maximal bite force in temporomandibular disorders patients. *J Oral Rehabil* 2006;**33**:559–65.
28. Chen Y, Chen C, Wu J, Huang M. *2015-2016 Adult and Elderly Oral Health Survey Project Report*. Ministry of Health and Welfare; 2018 2018/9/17. Report No.: M04B3281, M05B4128.
29. Yeh CK, Johnson DA, Dodds MW. Impact of aging on human salivary gland function: a community-based study. *Aging (Milano)* 1998;**10**:421–8.
30. Finkelstein MS, Tanner M, Freedman ML. Salivary and serum IgA levels in a geriatric outpatient population. *J Clin Immunol* 1984;**4**:85–91.
31. Neville BW, Damm DD, Allen CM, Chi AC. *Oral and Maxillofacial Pathology*. 4th ed. Elsevier; 2016, p. 432.
32. Tanasiewicz M, Hildebrandt T, Obersztyn I. Xerostomia of various etiologies: a review of the literature. *Adv Clin Exp Med* 2016;**25**:199–206.
33. Millsop JW, Wang EA, Fazel N. Etiology, evaluation, and management of xerostomia. *Clin Dermatol* 2017;**35**:468–76.
34. Wolff A, Zuk-Paz L, Kaplan I. Major salivary gland output differs between users and non-users of specific medication categories. *Gerodontology* 2008;**25**:210–6.
35. Tylenda CA, Ship JA, Fox PC, Baum BJ. Evaluation of submandibular salivary flow rate in different age groups. *J Dent Res* 1988;**67**:1225–8.
36. Muñoz-González C, Vandenberghe-Descamps M, Feron G, Canon F, Labouré H, Sulmont-Rossé C. Association between salivary hypofunction and food consumption in the elderlies. a systematic literature review. *J Nutr Health Aging* 2018;**22**:407–19.
37. Iwasaki M, Yoshihara A, Ito K, Sato M, Minagawa K, Muramatsu K, et al. Hyposalivation and dietary nutrient intake among community-based older Japanese. *Geriatr Gerontol Int* 2016;**16**:500–7.
38. Walls AW, Steele JG. The relationship between oral health and nutrition in older people. *Mech Ageing Dev* 2004;**125**:853–7.
39. Huumonen S, Haikola B, Oikarinen K, Söderholm AL, Remes-Lyly T, Sipilä K. Residual ridge resorption, lower denture stability and subjective complaints among edentulous individuals. *J Oral Rehabil* 2012;**39**:384–90.
40. Koshino H, Hirai T, Ishijima T, Ohtomo K. Influence of mandibular residual ridge shape on masticatory efficiency in complete denture wearers. *Int J Prosthodont* 2002;**15**:295–8.
41. Gonçalves TM, Vilanova LS, Gonçalves LM, Garcia RC. Kinesiographic study of masticatory movements in denture wearers with normal and resorbed denture-bearing areas. *J Prosthet Dent* 2014;**112**:1343–8.
42. Xie Q, Närhi TO, Nevalainen JM, Wolf J, Ainamo A. Oral status and prosthetic factors related to residual ridge resorption in elderly subjects. *Acta Odontol Scand* 1997;**55**:306–13.
43. Xie Q, Ainamo A, Tilvis R. Association of residual ridge resorption with systemic factors in home-living elderly subjects. *Acta Odontol Scand* 1997;**55**:299–305.
44. Avivi-Arber L, Sessle BJ. Jaw sensorimotor control in healthy adults and effects of ageing. *J Oral Rehabil* 2018;**45**:50–80.
45. Sessle BJ. Can you be too old for oral implants? An update on ageing and plasticity in the oro-facial sensorimotor system. *J Oral Rehabil* 2019;**46**:936–51.
46. Holtrop JL, Loucks TM, Sosnoff JJ, Sutton BP. Investigating Age-related changes in fine motor control across different effectors and the impact of white matter integrity. *Neuroimage* 2014;**96**:81–7.
47. Lin CS. Functional adaptation of oromotor functions and aging: a focused review of the evidence from brain neuroimaging research. *Front Aging Neurosci* 2019;**11**:354.
48. Kressin NR, Boehmer U, Nunn ME, Spiro A 3rd. Increased preventive practices lead to greater tooth retention. *J Dent Res* 2003;**82**:223–7.
49. Slot DE, Dörfer CE, Van der Weijden GA. The efficacy of interdental brushes on plaque and parameters of periodontal inflammation: a systematic review. *Int J Dent Hyg* 2008;**6**:253–64.
50. Sälzer S, Slot DE, Van der Weijden FA, Dörfer CE. Efficacy of inter-dental mechanical plaque control in managing gingivitis–a meta-review. *J Clin Periodontol* 2015;**42**(Suppl 16):S92–105.
51. Waerhaug J. Healing of the dento-epithelial junction following the use of dental floss. *J Clin Periodontol* 1981;**8**:144–50.
52. Pereira LJ, Gazolla CM, Magalhães IB, Dominguete MH, Vilela GR, Castelo PM, et al. Influence of periodontal treatment on objective measurement of masticatory performance. *J Oral Sci* 2012;**54**:151–7.
53. Woodmansey KF, Ayik M, Buschang PH, White CA, He J. Differences in masticatory function in patients with endodontically treated teeth and single-implant-supported prostheses: a pilot study. *J Endod* 2009;**35**:10–4.
54. Lang NP, Lindhe J. *Clinical Periodontology and Implant Dentistry*. 6th ed. Wiley Blackwell, 2015. p. 1146–54.
55. van der Bilt A, Burgers M, van Kampen FM, Cune MS. Mandibular implant-supported overdentures and oral function. *Clin Oral Implants Res* 2010;**21**:1209–13.
56. Boven GC, Raghoebar GM, Vissink A, Meijer HJ. Improving masticatory performance, bite force, nutritional state and patient's satisfaction with implant overdentures: a systematic review of the literature. *J Oral Rehabil* 2015;**42**:220–33.
57. Maniewicz S, Duvernay E, Srinivasan M, Perneger T, Schimmel M, Müller F. Effect of implant-supported mandibular overdentures versus reline on masticatory performance and salivary flow rates in very old adults-a randomized clinical trial. *Clin Oral Implants Res* 2019;**30**:59–67.
58. Zarb G, Hobkirk JA, Eckert SE, Jacob RF. *Prosthodontic Treatment for Edentulous Patients: Complete Dentures and Implant-Supported Prostheses*. 13th ed. Elsevier, 2013, p. 8–9.
59. Eerikäinen E, Könönen M. Forces required by complete dentures for penetrating food in simulated function. *J Oral Rehabil* 1987;**14**:607–13.
60. Johansson A, Unell L, Johansson AK, Carlsson GE. A 10-year longitudinal study of self-assessed chewing ability and dental status in 50-year-old subjects. *Int J Prosthodont* 2007;**20**:643–5.