Devices for Tooth Mobility Measurement

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Evaluating tooth mobility is clinically significant, not only for diagnosing periodontal tissues but also in determining the overall periodontal treatment plan. Numerous studies related to tooth mobility have been conducted, including the proposal of various classifications as well as the development of electronic devices for objective measurement.

Keywords: tooth mobility ; displacement ; measurement

1. Introduction

Tooth mobility refers to how loose a tooth is from the alveolar socket. The factors that influence tooth mobility include the height of the supporting alveolar bone, the width of the periodontal ligament, the presence of inflammation, the shape of the root(s), and the number of roots [1][2][3][4][5][6].

Tooth mobility is divided into physiological and pathological categories. In the morning, physiological mobility is at its greatest in all teeth, but this diminishes throughout the day [7]. Individuals with healthy tissue conditions typically exhibit lower mobility compared to those with parafunctional habits [8][9]. Pregnancy primarily leads to physiological changes that are associated with increased mobility, and prolonged unilateral dental function can contribute towards heightened mobility [10]. Pathological mobility refers to a progressive increase in tooth mobility and can be caused by a variety of factors, such as the progression of periodontal disease, loss of the supporting alveolar bone, bruxism, occlusal trauma, root pathology, and pulp inflammation [11][12][13][14]. Pathological tooth mobility arises from quantitative and/or qualitative changes in the tooth's supporting structures. Tooth mobility can be categorized into two stages: the initial/intrasocket stage and the secondary stage. The initial/intrasocket stage takes place within the periodontal ligament and is attributed to viscoelastic distortion of the periodontal fluid, periodontal fibers, and interbundle content. This stage typically involves movement ranging from 50 to 100 µm under a 100 lb load. On the other hand, the secondary stage results from the elastic deformation of the alveolar bone in response to increased horizontal forces [15]. Tooth mobility is a useful clinical indicator of the biophysical state of the tooth-supporting structures. Therefore, it is essential for the diagnosis of a patient, and it plays a clinically significant role in various dental treatments, including prosthodontics, orthodontics, periodontics, and dental traumatology [16][17][18][19][20][21]. The most commonly used clinical method to assess tooth mobility involves applying pressure to the tooth using two metal instruments or one metal instrument and fingers [22]. The results are indicated by the range of horizontal or vertical displacement of the tooth [23]. Horizontal tooth mobility refers to the degree to which the tooth can move buccally or lingually within the alveolar socket. The evaluation is performed by placing the handles of the dental instruments on either side of the tooth's mesiodistal axis and applying moderate pressure alternately, assessing the handle of the other instrument [24]. Vertical tooth mobility refers to the degree to which the tooth can move downward within the alveolar socket. This is evaluated by applying pressure to the tooth's occlusal or incisal surface using the tip of the instrument handle [25]. This method is widely accepted in clinical routines due to its speed and ease of execution. However, it has the disadvantage of subjective interpretation influenced by the clinical sensitivity and perception of each individual, lacking objective confirmation of tooth mobility and reproducibility of results without addressing causal factors [10][26].

Various electronic devices have been developed over the years to objectively measure the degree of tooth mobility [25][26][27]. Although many techniques and devices exist, their reliability for measuring tooth mobility is still limited and ambiguous. This is because it is challenging to accurately replicate tooth displacement influenced by the viscoelastic properties of the periodontal ligament and the impact of the modulus of elasticity under load conditions in laboratory studies [27]. Additionally, both pathological and physiological factors can influence tooth mobility, and different types of teeth exhibit varying ranges of mobility in different individuals, making it difficult to establish precise criteria for tooth mobility measurement methods [28].

2. Devices for Tooth Mobility Measurement

Along with the classification methods for tooth mobility, various devices have been developed to evaluate tooth mobility in a more objective manner. In the early stages of device development, a static loading method was utilized to measure tooth mobility by applying force and visually assessing the displacement of the tooth. This method involved manually moving the tooth to evaluate its mobility, which was a common approach employed by dentists to assess tooth mobility. However, this method is subjective, has low reproducibility, and presents challenges in achieving precise numerical measurements [29]. Subsequently, a dynamic loading method was developed to measure tooth mobility. This method enabled the accurate measurement and quantification of tooth mobility [10]. With further technological advancements, electronic devices were introduced to measure tooth mobility. These devices apply forces and electronically measure the tooth's response, enabling precise quantification [30][31][32][33].

2.1. Displacement Measuring Devices

The first device, Elbrecht's Indicator, appeared in 1939 [34]. This device uses a static loading method to measure tooth mobility by measuring the labio-lingual displacement generated through digital pressure using a large-dial indicator. It is capable of measuring mobility only above 0.75 mm, and applied force cannot be separately measured. Furthermore, the execution of this technique necessitated a considerable magnitude of force to induce a displacement of 1/1000 inches, thus posing a formidable challenge [35].

Subsequent advancements led to the development of various types of periodontometers [18][34][35][36][37][38]. The utilization of periodontometers required customized clutches or trays, primarily limiting their use for research purposes. Moreover, the need for customized tools, as opposed to standardized ones, indicates the challenge of maintaining consistent and precise control over loading rates and applied loads [39]. Therefore, persistent endeavors have been dedicated to objectively controlling the variables that impact the outcomes [40][41][42][43][44].

Holographic interferometry, an application of laser technology, offered intricate and comprehensive insights through non-contact and non-destructive means. Nonetheless, the intricate nature of the procedure hindered its clinical implementation [44][45].

Both of the methods mentioned above, periodontometers and holographic interferometry, utilized static loading to measure tooth mobility. Periodontometers use a measuring probe that is inserted between the tooth and the periodontal ligament to apply a specific force and measure mobility. Holographic interferometry involves shining a laser beam on the tooth to capture its initial state and record the interference pattern to create an initial hologram. Then, a static load is applied to the tooth, and the laser beam is, again, directed onto the tooth to record the interference pattern and create a hologram of the deformed state after applying the load. By comparing the initial hologram with the deformed state hologram, the difference in tooth movement is analyzed.

Konermann's novel intraoral measuring device applies dynamic loading to measure tooth mobility. The dynamic loading is exerted on the teeth using the device's splint, which moves at a constant speed, applying dynamic force to the teeth. As a result, the teeth undergo displacement, and the amount of movement is measured using laser holographic technology. It was introduced to overcome the difficulties associated with the complex configuration and handling of laser holographic technology [46] or manually driven equipment [47][48] in clinical use. The goal of this technology was to reveal characteristic changes in the periodontal ligament during the maintenance period after orthodontic treatment and record the mobility of teeth within the oral cavity. This device has demonstrated high accuracy and effectiveness in practical use. The precise, fine grading of deflection durations has become an indicator of tooth movement. However, a drawback is that the measurement results can vary depending on unwanted movements by the patient and how the investigator applies the splint [32].

The most recent method used for tooth mobility measurement also utilizes the static loading method. Intraoral scanner measurements aim to provide three-dimensional quantitative results regarding tooth movement using an intraoral scanner within the oral cavity. This is a user-friendly, non-invasive technique that eliminates the need for separate devices such as splints, resulting in less variability due to investigator-dependent results. The intraoral scanner is then used to obtain 3D files of tooth positions, which are then analyzed using measurement software. Tooth mobility is then measured by calculating the linear deviations along three axes (x, y, and z) based on three reference points (cervical (C), middle (M), and occlusal (O)) in the interproximal areas [33].

2.2. Strain-Measuring Devices

Picton's Gauge [40] uses resistance wire strain gauges to measure tooth mobility. Strain gauges detect the vertical movement of teeth, measuring displacement or mobility. One end of the gauge is attached to a single tooth, while the other end is connected to adjacent teeth through a spring. The displacement of the test tooth relative to adjacent teeth is detected by two strain gauges. The measurement of each tooth requires the insertion of a custom assembly. Using these custom assemblies, tooth stress and displacement are measured, and this information is recorded through a Wheatstone bridge circuit.

In Persson and Svensson's transformer [49], strain gauges and a differential transformer are employed to sense force and displacement. Tooth mobility is recorded at the same location and direction as the loading force, and the signals are documented using a two-channel potentiometric recorder.

They utilize strain analysis using sensors distributed on the tooth surface to measure the deformation caused by the forces applied to the tooth. This technique can provide quantitative information about stress distribution and tooth mobility.

2.3. Modal Measuring Devices

Modal analysis has emerged as the predominant approach within electronic devices employed for assessing tooth mobility [50]. Modal analysis measures a system's dynamic characteristics in the frequency domain. In the industrial field, it is used in the design of structures such as automobiles, aircraft, spacecraft, and computers [51]. In the dental field, non-invasive techniques such as damping capacity assessment (DCA) and resonance frequency analysis (RFA) are utilized. Both methods involve the use of controlled force to detect lateral movement and measure stability, but they differ significantly regarding their technical aspects [52]. RFA utilizes the piezoelectric effect to generate deflection in implants, requiring a transducer such as an implant or abutment, making it an unsuitable method for natural teeth [53].

The Periotest value (PTV) is a biophysical parameter that represents the reaction to impact on periodontal tissues [31]. Periotest (Siemens AG, Bensheim, Germany) involves tapping the tooth with a handheld device that applies a tapping load of 8 g at a velocity of 0.2 m/s. The contact time between the tapping load and the tooth is measured by software and converted into PTV. Periotest is suitable for measuring tooth mobility due to its ease of application, ability to measure both horizontal and vertical dimensions, and reproducibility [18][54][55][56][57]. Originally, Periotest was developed to measure the damping characteristics of the periodontal ligament around natural teeth [58][59]. When using Periotest for research, operators have tried to standardize the condition of assessment with several types of positioning jigs [60][61]. However, there are many parameters that could influence mobility and are difficult to control, leading to unstable results. PTV changes linearly with contact time between the tapping head of Periotest and the tooth surface in the lower range (PTV $\leq$ 13), while it changes quadratically in the upper range (PTV > 13) [62]. It has been suggested that the difference in the change in PTV based on the range might be affected by the resistance change in interstitial or vascular fluids against loading in the early stages of periodontitis [49][63]. Therefore, it is currently primarily used for measuring the mobility of implants [64][65].

A recently developed modified DCA device (Anycheck, Neobiotech Co., Ltd., Seoul, Republic of Korea) has been improved compared to conventional DCA devices by reducing the amount of impact and discontinuing the tapping action when stability is low, thus reducing the impact on teeth and implants [50][66][67].

The DCA method applies repetitive impact to the tooth surface, measuring the tooth's rebound velocity and direction. Depending on the mobility of the tooth, the rebound velocity and direction will vary. By analyzing the measured rebound information obtained using dynamic loading, the device provides an immediate numerical representation of the tooth's mobility.

References

1. Anitha Balaji, D.S.S. Tooth mobility. Eur. J. Mol. Clin. Med. 2020, 7, 6713–6716.
2. Lang, N.P.; Bartold, P.M. Periodontal health. J. Periodontol. 2018, 89, S9–S16.
3. Verna, C.; Melsen, B. Tissue reaction to orthodontic tooth movement in different bone turnover conditions. Orthod. Craniofac. Res. 2003, 6, 155–163.
4. Oyama, K.; Motoyoshi, M.; Hirabayashi, M.; Hosoi, K.; Shimizu, N. Effects of root morphology on stress distribution at the root apex. Eur. J. Orthod. 2007, 29, 113–117.

5. Huang, R.-Y.; Lin, C.-D.; Lee, M.-S.; Yeh, C.-L.; Shen, E.-C.; Chiang, C.-Y.; Chiu, H.-C.; Fu, E. Mandibular disto-lingual root: A consideration in periodontal therapy. J. Periodontol. 2007, 78, 1485–1490.
6. Polson, A.M. Interrelationship of inflammation and tooth mobility (trauma) in pathogenesis of periodontal disease. J. Clin. Periodontol. 1980, 7, 351–360.
7. Raitapuro-Murray, T.; Molleson, T.; Hughes, F. The prevalence of periodontal disease in a romano-british population c. 200–400 ad. Br. Dent. J. 2014, 217, 459–466.
8. Mishra, P.S.; Marawar, P.P.; Mishra, S.S. A cross-sectional, clinical study to evaluate mobility of teeth during pregnancy using periotest. Indian J. Dent. Res. 2017, 28, 10.
9. Littlewood, S.J.; Mitchell, L. An Introduction to Orthodontics; Oxford University Press: Oxford, UK, 2019.
10. Varadhan, K.B.; Parween, S.; Bhavsar, A.K.; Prabhuji, M.L.V. Tooth mobility measurements-realities and limitations. J. Evolution. Med. Dent. Sci. 2019, 8, 1342–1350.
11. Matthews, D.C. Prevention and treatment of periodontal diseases in primary care. Evid. Based Dent. 2014, 15, 68–69.
12. Ella, B.; Ghorayeb, I.; Burbaud, P.; Guehl, D. Bruxism in movement disorders: A comprehensive review. J. Prosthodont. 2017, 26, 599–605.
13. Bastone, E.B.; Freer, T.J.; McNamara, J.R. Epidemiology of dental trauma: A review of the literature. Aust. Dent. J. 2000, 45, 2–9.
14. Ruggiero, S.L. Guidelines for the diagnosis of bisphosphonate-related osteonecrosis of the jaw (bronj). Clin. Cases Miner. Bone Metab. Off. J. Ital. Soc. Osteoporos. Miner. Metab. Skelet. Dis. 2007, 4, 37–42.
15. Wheeler, T.T.; McArthur, W.P.; Magnussen, I.; Marks, R.G.; Smith, J.; Sarrett, D.C.; Bender, B.S.; Clark, W.B. Modeling the relationship between clinical, microbiologic, and immunologic parameters and alveolar bone levels in an elderly population. J. Periodontol. 1994, 65, 68–78.
16. Tanaka, E.; Ueki, K.; Kikuzaki, M.; Yamada, E.; Takeuchi, M.; Dalla-Bona, D.; Tanne, K. Longitudinal measurements of tooth mobility during orthodontic treatment using a periotest. Angle Orthod. 2005, 75, 101–105.
17. Piwowarczyk, A.; Köhler, K.C.; Bender, R.; Büchler, A.; Lauer, H.C.; Ottl, P. Prognosis for abutment teeth of removable dentures: A retrospective study. J. Prosthodont. Implant. Esthet. Reconstr. Dent. 2007, 16, 377–382.
18. Andresen, M.; Mackie, I.; Worthington, H. The periotest in traumatology. Part i. Does it have the properties necessary for use as a clinical device and can the measurements be interpreted? Dent. Traumatol. 2003, 19, 214–217.
19. Andresen, M.; Mackie, I.; Worthington, H. The periotest in traumatology. Part ii. The periotest as a special test for assessing the periodontal status of teeth in children that have suffered trauma. Dent. Traumatol. 2003, 19, 218–220.
20. Perlitsh, M.J. A systematic approach to the interpretation of tooth mobility and its clinical implications. Dent. Clin. N. Am. 1980, 24, 177–193.
21. Purkait, S.; Bandyopadhyaya, P.; Mallick, B.; Das, I. Classification of tooth mobility—Concept revisited. Int. J. Rec. Adv. Multidiscip. Res. 2016, 3, 1510–1522.
22. Newman, M.G.; Takei, H.; Klokkevold, P.R.; Carranza, F.A. Carranza’s Clinical Periodontology; Elsevier Health Sciences: Amsterdam, The Netherlands, 2011.
23. Azodo, C.C.; Ogbebor, O.G. Tooth mobility in a nigerian specialist periodontology clinic. Indian J. Oral Health Res. 2017, 3, 62.
24. Stoller, N.H.; Laudenbach, K.W. Clinical standardization of horizontal tooth mobility. J. Clin. Periodontol. 1980, 7, 242–250.
25. Goellner, M.; Schmitt, J.; Holst, S.; Petschelt, A.; Wichmann, M.; Berthold, C. Correlations between tooth mobility and the periotest method in periodontally involved teeth. Quintessence Int. 2013, 44, 307–316.
26. Ioi, H.; Morishita, T.; Nakata, S.; Nakasima, A.; Nanda, R.S. Evaluation of physiological tooth movements within clinically normal periodontal tissues by means of periodontal pulsation measurements. J. Periodontal Res. 2002, 37, 110–117.
27. Ashrafi, M.; Ghalichi, F.; Mirzakouchaki, B.; Zoljanahi Oskui, I. Numerical simulation of hydro-mechanical coupling of periodontal ligament. Proc. Inst. Mech. Eng. H 2020, 234, 171–178.
28. Mühlemann, H.R. Tooth mobility: A review of clinical aspects and research findings. J. Periodontol. 1967, 38, 686–708.
29. Laster, L.; Laudenbach, K.W.; Stoller, N.H. An evaluation of clinical tooth mobility measurements. J. Periodontol. 1975, 46, 603–607.

30. Yamane, M.; Yamaoka, M.; Hayashi, M.; Furutoyo, I.; Komori, N.; Ogiso, B. Measuring tooth mobility with a no-contact vibration device. J. Periodontal. Res. 2008, 43, 84–89.

31. Schulte, W.; Lukas, D. The periotest method. Int. Dent. J. 1992, 42, 433–440.

32. Konermann, A.; Al-Malat, R.; Skupin, J.; Keilig, L.; Dirk, C.; Karanis, R.; Bourauel, C.; Jäger, A. In vivo determination of tooth mobility after fixed orthodontic appliance therapy with a novel intraoral measurement device. Clin. Oral Investig. 2017, 21, 1283–1289.

33. Meirelles, L.; Siqueira, R.; Garaicoa-Pazmino, C.; Yu, S.H.; Chan, H.L.; Wang, H.L. Quantitative tooth mobility evaluation based on intraoral scanner measurements. J. Periodontol. 2020, 91, 202–208.

34. Mühlemann, H.R. Tooth mobility: The measuring method. Initial and secondary tooth mobility. J. Periodontol. 1954, 25, 22–29.

35. Manly, R.; Yurkstas, A.; Reswick, J. An instrument for measuring tooth mobility. J. Periodontol. 1951, 22, 148–155.

36. Miller, P.D., Jr.; McEntire, M.L.; Marlow, N.M.; Gellin, R.G. An evidenced-based scoring index to determine the periodontal prognosis on molars. J. Periodontol. 2014, 85, 214–225.

37. Glickman, I. Clinical Periodontology: Recognition, Diagnosis and Treatment of Periodontal Disease in the Practice of Genearal Dentistry; Saunders: New York, NY, USA, 1964.

38. Oleary, T.J.; Rudd, K.D. An Instrument for Measuring Horizontal Tooth Mobility; Aerospace Medical Division, Brooks AFB: San Antonio, TX, USA, 1963.

39. Barbakow, F.; Cleaton-Jones, P.; Austin, J.; Andreasen, J.; Vieira, E. Changes in tooth mobility after experimental replantation. J. Endod. 1978, 4, 265–272.

40. Robertson, R.G. The Multiple Impulse Method of Tooth Mobility Assessment. Ph.D. Thesis, University of London, London, UK, 1995.

41. Parfitt, G.J. Measurement of the physiological mobility of individual teeth in an axial direction. J. Dent. Res. 1960, 39, 608–618.

42. Körber, K.; Körber, E. Patterns of physiological movement in tooth support. In The Mechanisms of Tooth Support; John Wright, Bristol: Bristol, UK, 1967; pp. 148–153.

43. Körber, K.H. Periodontal pulsation. J. Periodontol. 1970, 41, 382–390.

44. Wedendal, P.R.; Bjelkhagen, H. Dental holographic interferometry in vivo utilizing a ruby laser system ii. Clinical applications. Acta Odontol. Scand. 1974, 32, 345–356.

45. Wedendal, P.R.; Bjelkhagen, H. Dental holographic interferometry in vivo utilizing a ruby laser system: I. Introduction and development of methods for precision measurements on the functional dynamics of human teeth and prosthodontic appliances. Acta Odontol. Scand. 1974, 32, 131–145.

46. Burstone, C.; Pryputniewicz, R.; Bowley, W. Holographic measurement of tooth mobility in three dimensions. J. Periodontal. Res. 1978, 13, 283–294.

47. Yoshida, N.; Koga, Y.; Kobayashi, K.; Yamada, Y.; Yoneda, T. A new method for qualitative and quantitative evaluation of tooth displacement under the application of orthodontic forces using magnetic sensors. Med. Eng. Phys. 2000, 22, 293–300.

48. Yoshida, N.; Koga, Y.; Mimaki, N.; Kobayashi, K. In vivo determination of the centres of resistance of maxillary anterior teeth subjected to retraction forces. Eur. J. Orthod. 2001, 23, 529–534.

49. Persson, R.; Svensson, A. Assessment of tooth mobility using small loads: I. Technical devices and calculations of tooth mobility in periodontal health and disease. J. Clin. Periodontol. 1980, 7, 259–275.

50. Lee, J.; Pyo, S.-W.; Cho, H.-J.; An, J.-S.; Lee, J.-H.; Koo, K.-T.; Lee, Y.-M. Comparison of implant stability measurements between a resonance frequency analysis device and a modified damping capacity analysis device: An in vitro study. JPIS 2020, 50, 56–66.

51. Fu, Z.-F.; He, J. Modal Analysis; Elsevier: Amsterdam, The Netherlands, 2001.

52. Zix, J.; Hug, S.; Kessler-Liechti, G.; Mericske-Stern, R. Measurement of dental implant stability by resonance frequency analysis and damping capacity assessment: Comparison of both techniques in a clinical trial. Int. J. Oral Maxillofac. Implants 2008, 23, 525–530.

53. Choi, H.-H.; Chung, C.-H.; Kim, S.-G.; Son, M.-K. Reliability of 2 implant stability measuring methods in assessment of various periimplant bone loss: An: In vitro: Study with the periotest and osstell mentor. Implant Dent. 2014, 23, 51–56.

54. Berthold, C.; Thaler, A.; Petschelt, A. Rigidity of commonly used dental trauma splints. Dent. Traumatol. 2009, 25, 248–255.

55. Filippi, A.; Pohl, Y.; Von Arx, T. Treatment of replacement resorption by intentional replantation, resection of the ankylosed sites, and emdogain®—Results of a 6-year survey. Dent. Traumatol. 2006, 22, 307–311.

56. Mackie, I.; Ghrebi, S.; Worthington, H. Measurement of tooth mobility in children using the periotest. Dent. Traumatol. 1996, 12, 120–123.

57. Derhami, K.; Wolfaardt, J.F.; Faulkner, G.; Grace, M. Assessment of the periotest device in baseline mobility measurements of craniofacial implants. Int. J. Oral. Maxillofac. Implants 1995, 10, 221–229.

58. Inaba, M. Evaluation of primary stability of inclined orthodontic mini-implants. J. Oral. Sci. 2009, 51, 347–353.

59. Schulte, W.; Lukas, D. Periotest to monitor osseointegration and to check the occlusion in oral implantology. J. Oral. Implantol. 1993, 19, 23–32.

60. Uchida, H.; Wada, J.; Watanabe, C.; Nagayama, T.; Mizutani, K.; Mikami, R.; Inukai, S.; Wakabayashi, N. Effect of night dentures on tooth mobility in denture wearers with sleep bruxism: A pilot randomized controlled trial. J. Prosthodont. Res. 2021, 66, 564–571.

61. Nagayama, T.; Wada, J.; Watanabe, C.; Murakami, N.; Takakusaki, K.; Uchida, H.; Utsumi, M.; Wakabayashi, N. Influence of retainer and major connector designs of removable partial dentures on the stabilization of mobile teeth: A preliminary study. Dent. Mater. J. 2020, 39, 89–100.

62. Rosenberg, D.; Quirynen, M.; van Steenberghe, D.; Naert, I.E.; Tricio, J.; Nys, M. A method for assessing the damping characteristics of periodontal tissues: Goals and limitations. Quintessence Int. 1995, 26, 191–197.

63. Kindlova, M.; Matena, V. Blood vessels of the rat molar. J. Dent. Res. 1962, 41, 650–660.

64. Atsumi, M.; Park, S.-h.; Wang, H.-L. Methods used to assess implant stability: Current status. Int. J. Oral Maxillofac. Implant. 2007, 22, 743–754.

65. Meredith, N.; Friberg, B.; Sennerby, L.; Aparicio, C. Relationship between contact time measurements and ptv values when using the periotest to measure implant stability. Int. J. Prosthodont. 1998, 11, 269–275.

66. Lim, H.-K.; Lee, S.-J.; Jeong, Y.; Lee, J.-S.; Ryu, J.-J.; Shim, J.-S.; Song, I.-S. Clinical validation of dental implant stability by newly designed damping capacity assessment device during the healing period. Medicina 2022, 58, 1570.

67. Pyo, S.-W.; Kim, H.G.; Kwon, O.; Otgonbold, J.; Lee, K.-W. Reliability verification of damping capacity assessment through in vitro analysis of implant micromotion in peri-implant bone loss model. Int. J. Oral Maxillofac. Implants 2021, 36, 106–114.