


Increasing Vertical Dimension of Occlusion (VDO): Review

Asmae Yadfout , Jihane El Aoud, Nadia Merzouk, Jihane Slaoui Hasnaoui

Department of Removable Prosthodontics, Faculty of Dentistry, Mohammed V University, Rabat, Morocco

Correspondence: Asmae Yadfout, Email asmae_yadfout@um5.ac.ma

Abstract: The need to increase the Vertical Dimension of Occlusion (VDO) to restore lost dental function or optimise specific dental treatments is a common occurrence in daily dental practice. The common belief that the Vertical Dimension at Rest (VDR) is fixed hinders the development of restorations with a VDO that encroaches on or surpasses the interocclusal rest space (IRS), thereby preventing potential tissue damage to the masticatory apparatus. Recent studies have shown that the mandible rest position falls within a range termed as the “comfort zone”. The range of this zone may vary from one person to another and within the same person over time due to factors such as age or health status. In this review, we have concluded that a permanent increase in the VDO, once indicated, is a safe procedure for dentulous patients. However, it is important to minimise the extent of the increase to simplify the prosthodontics treatment process. An inter-incisal increase exceeding 5 mm is seldom needed. Moreover, it is important to consider the functional, aesthetic, and biological elements associated with VDO. The biological and functional environment closely related to the VDO had great adaptive capacities, which have for a historically been underestimated. Patient adaptation has been observed in dentate patients, edentulous patients, and even cases involving implant-supported prostheses. Muscle relaxation and changes in muscle length are likely the primary adaptation mechanisms, rather than the restoration of the original VDO through dentoalveolar maturation. Intervention with a fixed restoration is more predictable and results in a higher and more rapid level of adaptation. Finally, the increase should include the entire arch to prevent relapse of the VDO to its previous value, and changes in VDO should be assessed by utilising temporary diagnostic restorations for a period before implementing definitive prostheses, in order to evaluate the adaptive muscle response.

Keywords: VDO, increasing VDO, VDR, temporomandibular joint disorders

Introduction

When faced with complex prosthetic projects requiring an increase in the VDO within their treatment plans, practitioners often grapple with how to proceed, the type of techniques to use, the safety of such actions, and the extent to which VDO can be increased. This subject has been surrounded by controversies for over 50 years, with numerous aspects remaining unexplored. Moreover, there is the belief that an increase in the VDO causes disorders of the masticatory apparatus, prompting many practitioners to opt for delegating the management of such patients. In this article, our aim is to simplify this subject matter. We endeavour to consolidate studies and research that have dissected each viewpoint, providing the practitioner with different opinions and theories, along with the appropriate explanations in one comprehensive document. The purpose is to clarify all ambiguous areas, identify situations requiring an increase in VDO, present the essential aspects for implementing this modification, and encourage practitioners to engage in this kind of therapy confidently and safely.

Definitions VDO, VDR

The VDO is a dental procedure used for dentate individuals, determined by the measuring the distance between two arbitrarily selected points, one on the maxilla and another on the mandible, when the teeth are in contact.¹⁻⁷ Conversely, VDR refers to the height of the lower part of the face measured between two reference points when the mandible is in a physiological rest position.^{7,8}

In the rest position, the mandible is in a neutral position and is suspended, while the head remained unsupported and aligned with bust. The opening and closing muscles are in a state of equilibrium, and the condyles are in a neutral, unstrained position in the glenoid fossa.⁹

The physiologic rest position is consistently assumed subconsciously and may also be voluntarily assumed.⁹ It is determined by three potential mechanisms:

- Postural tonicity of muscles: Many researchers have indicated that muscle tone plays a significant role in establishing the mandibular resting position. The temporal muscle primarily contributes to this resting position due to its status as the most powerful elevator of the mandible and having the largest number of spindles.^{10–14}
- Reflex mechanism: The reflex mechanism involves the mesencephalic nucleus and the sensory nucleus of the fifth cranial nerve, which receives information from proprioceptors and exteroceptors regarding the position and movement of the mandible. Depending on the feedback information, the motor nucleus of the fifth nerve will position the mandible in the resting position.^{15,16}
- Gravity-elasticity: It refers to the passive visco-elasticity of perioral soft tissues, including muscles and ligaments, which keeps the mandible against gravitational forces.^{10,17}

The Variability of VDR

The mandibular physiologic rest position (MPRP) has been considered by some researchers to be naturally established and remain constant throughout life regardless of the presence or absence of the teeth. It is viewed with the same constancy as facial height.^{9,18,19}

According to Thompson, the mandible assumes its positional relationship with the base of the skull around the third month of life. This position does not subsequently change and corresponds to the mandibular resting position. It is not affected by the presence or absence of teeth, and it determines the height of the face.²⁰

Supporters of this position claim that MPRP is related to variation in the tonicity of the musculature that suspends the mandible, rather than muscle length. Since the muscle tonus is fairly constant for each individual, the MRP is also in an equally constant position and does not change after the extraction of teeth.^{21,22} The same authors think that excessive working of mandibular muscles, related to certain pathological conditions, may result in a small variation of the normal interocclusal distance. However, this variability is considered negligible.^{7,15,16,20}

Other authors like Tallgren and Atwood, in their longitudinal studies, and Saurabh have shown a decrease in VDR in adults after the extraction of their natural teeth.^{9,23–25} This can be explained by the destruction of proprioceptive nerve endings in the periodontal tissue, which may change the orientation of the mandible, thereby resulting in a decrease in vertical dimension at rest.²⁴

An increase in VDR was also observed by Olsen and Saurabh after the insertion of a complete denture prosthesis.^{24,26}

The authors concluded that VDR is not in a stable position and varies after the extraction of natural teeth and prosthodontic rehabilitation.

The VDR, like other physiological manifestations in living organisms such as blood pressure or temperature, has a range that changes with health, disease, emotional state, age, medication, etc. It is not rigidly stable. Its constancy does not mean fixity, but rather that the range of variation or variability is negligible.^{17,22,23,27}

Indications of Increasing VDO

Increasing VDO is often indicated in complex prosthodontic treatments. This approach is used in the following situations:

- Correction of anterior tooth relationship: Increasing VDO alleviates the broad area of anterior tooth contacts and provides a shallower and less constrained angle of disclusion in patients who suffer from vertical and horizontal overlap.^{3,28} It also enables the re-establishment of lost anterior tooth guidance in patients with severe wear of their anterior dentition.^{3,28–30}

- Improvement of maxillary lip support: Increasing the VDO allows the establishment of an incisal overjet that can augment support of the maxillary lips.³
- Minimisation of tooth preparation: Increasing VDO provides greater interocclusal space for restorative materials and may lessen the need for surgical crown-lengthening (CLS) procedures and endodontic treatments, resulting in reduced pulpal trauma. A combination of VDO and CLS may also be useful. Increasing VDO also avoids the need for occlusal tooth preparation to eliminate interference.^{3,28–30}
- Restoring lost vertical dimension of occlusion: Deficiencies in the VDO can result from uncompensated occlusal dental wear, hypoplasia of the mandible or a deficient dentoalveolar mass. VDO loss can significantly alter patient function, comfort and aesthetics.^{3,5,31} Occlusal dental wear, which is a natural physiological process, can be developed more rapidly or aggravated by pathological conditions such as attrition, trauma, chemical erosion and bruxism. It results in a reduction of tooth length with or without a reduction of the VDO.

A patient's original VDO can be preserved by a dentoalveolar compensatory mechanism involving the slow extrusion of worn teeth and a super eruption of opposing teeth.^{3,29,32–34} However, aggressive bruxers often grind tooth structures at a greater rate than passive extrusion can compensate for.²⁹

According to Murphy, tooth attrition and compensatory mechanisms do not have a direct cause-and-effect relationship. The first varies with power used in mastication, and the second varies with skeletal growth pattern.³⁵

Loss of VDO can also occur when many teeth are lost due to caries or periodontal disease. The remaining teeth and supporting tissues cannot withstand the physiological occlusal forces and begin to tip over, resulting in a collapsed bite.^{2,29}

Several researchers have indicated that increasing VDO does not improve facial aesthetics in dentate individuals since it is limited to a maximum of 5 mm inter-incisally, which is not enough to induce a facial change.^{3,5,36}

But Mohindra reported that the increase in VDO can have great effects on the aesthetics of the whole face.

The muscle fibres stretch due to this increase, leading to increased protein activity and the release of growth factors, resulting in muscle hypertrophy and increased bone density. This increased cellular activity seems to lead to increased vascularisation in tissues and also prevents apoptosis.^{1,37} The improvement in the jawline is related to the improvement in the chin and tightening of the facial skin. The improvement in the cheeks is probably due to improvement in muscle tone and mass, and in the long term, there may be some re-modelling of the bone.^{1,37} The height of the smile window increases and its width decreases, increasing the vermilion show. The restoration of the lower facial height seems to enhance the proportions of the nose.³⁷ Improvement in eye appearance may be due to increased fat metabolism that takes place when the facial muscles work harder.¹

What is certain is that tooth display might improve by lowering the maxillary occlusal plane after increasing VDO, and pseudo-prognathism of the mandible may be reduced. These two manoeuvres have a visible aesthetic impact.^{3,5,36}

However, an improvement in facial aesthetics was observed in edentulous subjects after complete prosthetic rehabilitation constructed at an increased VDO.¹ This finding can be related to the significant loss in VDO for edentulous patients without compensation, in comparison to dentate individuals, and improvement of facial aesthetics after increasing VDO in edentulous individuals is probably due to the horizontal support of the facial tissues by the dentures.³

Conversely, increasing VDO can facilitate the treatment of many orthodontic cases such as reducing crossbites, allowing the placement of mandibular brackets in deep bite cases, or levelling the curve of Spee.^{37,38}

Adaptation of the Masticatory System to Increasing VDO

Dentate Patients

Yasumasa Akztgawa et al studied histologic changes in masticatory muscles in Wistar rats. An increase in VDO beyond the occlusal space caused tissue reaction in the deep masseter muscle, a lesser degree in the superficial masseter and anterior temporal muscles and no changes in the posterior temporal, medial pterygoid and anterior digastric muscles. Variable severity of tissue response in different masticatory muscles can be attributed to the amount of stretching of myofibers due to an increased VDO. Degenerative atrophy of myofibers in the lateral pterygoid muscle occurred within two days with no sign of inflammation.³⁹

Another study found that only transient acute inflammation occurred in the deep and superficial masseter muscles and the lateral pterygoid muscle when increasing the VDO within the extent of the interocclusal space. No degenerative changes of myofibers were revealed.⁴⁰

An increase in the VDO beyond the original rest face height was tested by Gunnar et al in healthy dentulous individuals. The result was the establishment of a new rest position for the mandible and a new interocclusal space. The subjects experienced moderate symptoms of discomfort, which decreased toward the end of the experimental period. No signs of increased muscle activity to restore the original VDO were found.⁴¹

Previous studies have tested the increase in VDO in dentulous patients. Among them, Carlson and Christensen reported the development of several mild symptoms. These diminished after a few days, and no masticatory muscle hyperactivity was recorded.^{41,42} This may be an expression of the patient's adaptive capacities being overcome either by an excessive or rapid increase or the occurrence of disruption of the occlusal context with dental, joint, and muscular repercussions.

In a study by Gross et al, VDO was increased (>5 mm) in healthy subjects with severe dental wear. The study reported speech difficulties and muscle discomfort that subsided after 1–2 weeks. A new interocclusal space was restored after the increase in VDO, which remained stable during the two-year follow-up.⁴³

Dahl et al increased the VD (>5 mm) in patients with severe tooth attrition. The study reported that this procedure caused short and transient discomfort, and no temporomandibular disorders (TMDs) symptoms were evident after a long period of follow-up.^{3,34,43,44}

Ormianer et al examined the differences in increasing VDO (≤ 5 mm) in dentate patients, which was followed for a long period. They reported that all the patients adapted to the new VDO.⁴⁵

All these experiments confirmed that increasing VDO may affect the different components of the masticatory system at a histological and morphological level. However, the response is a general compensation and adaptation characterised by the establishment of a new resting position of the mandible and a new interocclusal space.⁴⁰

In their study of healthy dentate patients with angle class I occlusion, Yu-Fu Shen et al demonstrated that an increase in VDO greater than 3 mm could alter the extent of the mandibular trajectory during swallowing. There is a positive correlation between the amplitude of mandibular movement during swallowing and the increase in VDO.⁵

Edentulous Patients

Most clinical techniques for VDO establishment in edentulous patients aim at reproducing a patient's natural VDO because that is believed to be most suitable. This premise has not been scientifically studied and remains an unproven assumption. In this study, VDO increases were found to be higher because the original VDO was often completely lost in completely edentulous patients.²⁹

In another study, an increase in VDO in patients with prolonged edentulism and wearing old dentures seemed to lower the pretreatment hyoid bone position. The level of muscle activity appeared to decrease just after the placement of the new prostheses and returned to a level close to that of pretreatment after a few months of use.³¹

Helsing, in 1987, studied adaptability in edentulous patients after modifying the VDO. He demonstrated that patients adapt very quickly to a new VDO, creating a new interocclusal distance.⁴⁴

Christensen, in 1970, increased the VDO in complete dentures. Symptoms developed by complete denture patients were less frequent compared to dentate individuals, and they were of mild intensity.⁴²

Dentally Implanted Patients

In a multi-centre retrospective clinical study conducted by Fabbri, VDO was increased by ≤ 5 mm in patients with fixed rehabilitations supported by implants and with no removable dentures as antagonists. The development of prosthetic and functional complications after increasing VDO was not frequent. Functional complications were more frequent in cases of restorations completely supported by implants, but they would usually disappear within two weeks. The authors concluded that when necessary and properly performed, increasing VDO by up to 5 mm can be considered a safe and viable clinical procedure and that maintaining optimal occlusal stability plays a key role in achieving this objective.²⁹

In 2009, Ormianer and Palty increased VDO by ≤ 5 mm in patients with fixed implant-supported restorations. All patients adapted to the new VDO. Some patients developed tooth clenching or grinding, but the latter usually disappeared within two months. Mechanical complications, such as porcelain fractures, were more observable when fixed implant-supported restorations were opposed to other fixed implant-supported restorations.⁴⁵

A prolonged period of grinding and clenching (parafunctional activity) for implant-supported prostheses is probably due to the lack of sensory feedback from the periodontal ligament, which could prevent rapid patient adaptation after an increase in VDO. Another explanation for the increased duration of symptoms accompanying implant-supported restorations is that the treated patients were initially edentulous and had significant alveolar bone resorption and masticatory muscle atrophy. As a result, the VDO may be considerably reduced.³ Since implant-supported prostheses can restore the VDO to near-original values (in comparison with conventional complete dentures), these patients will be subjected to a greater adaptation burden.³

Clinical Considerations for Increasing VDO

Physiological vertical dimension occurs within a range, commonly known as the comfort zone, rather than a specific constant level. Consequently, it can be expected that a patient can adapt to an alteration in VDO as long as it remains within this zone.^{3,46}

When indicated, a permanent moderate inter-incisal increase in the VDO (< 5 mm) in dentulous patients can be considered a safe and predictable procedure without detrimental consequences, provided that occlusal stability is established. The stomatognathic system can adapt rapidly to moderate changes under the rotation of the hinged axis, and any consequential signs and symptoms have been reported to be self-limiting.^{8,30,39,43,44,47,48}

A greater increase (> 5 mm) in the VDO in dentate patients may not be dangerous, but may lead to a more extensive masticatory muscle inflammatory reaction and a more complex rehabilitation.

In some studies, rapid changes in VDO in healthy individuals also seem to lead to the development of mild TMD symptoms. However, these symptoms appear to resolve quickly.⁴⁴

The adaptation of the stomatognathic system occurs through muscle relaxation and muscle lengthening rather than a return to the original VDO through dentoalveolar maturation or muscle hyperactivity.^{5,44}

When increasing VDO, the use of complete arch coverage (all or most of the teeth) is an essential condition for the immediate establishment of occlusion with minimal alteration in the dentoalveolar complex. An increase in VDO through partial arch coverage results in dentoalveolar alteration, muscular changes, and temporomandibular joint (TMJ) disorders. It is now understood that the symptomatology reported in several studies may have been the result of occlusal instability rather than the increase in VDO.^{3,40,41,43,49,50}

Another parameter that could influence adaptation to increased VDO is age. Research conducted by Wen and Wang in teenage and young adult Wistar rats has concluded that increasing VDO in teenagers probably produces more stable results than in young adults. Thus, young adults require sufficient treatment time and long-term maintenance after increasing VDO.⁴⁷

However, it should be noted that an increase in the VDO should be considered and conducted with caution. Indeed a significant increase in DVO may cause joint compression in the presence of TMDs, labial incompetence in the presence of thin or short lips and may aggravate a skeletal class II by accentuating the posterior rotation of the mandible.^{51,52}

Treatment Options for Increasing VDO

Studies that increased VDO with fixed prostheses indicated less severe symptoms than studies that increased VDO with a removable appliance. This could be attributed to the advantages of fixed prostheses, such as fixity in the mouth, mimicking natural tooth morphology, minimising dental crowding, reducing interference with speech and improving patient comfort.³

Additionally, the fixed nature of the prosthesis enhances patient compliance and acceptance of the treatment. Therefore, whenever possible, an increase in VDO in TMD-free patients should be performed with fixed restorations rather than with a removable appliance. Removable appliances could cause patient maladaptation due to factors other than increased VDO.^{3,4,48}

Using a removable splint to increase the VDO in patients without TMDs is not advised, as it may instead lead to splint wearing. For patients with TMDs, increasing the VDO with removable appliances helps control TMD-associated symptoms before irreversible procedures are performed.^{3,4,48}

Conclusion

Nowadays, it seems more reasonable to accept that the mandibular physiologic rest position occurs within a range known as the comfort zone. The range of this zone may vary from one person to another and in the same person at different times. At the end of this review the main ideas to emphasise are

1. The primary adaptation to VDO increase is muscular.
2. 5 mm seems to be the safe value for increasing VDO.
3. Fixed and removable prosthetic treatments are acceptable for increasing VDO, but the fixed solution with complete covering remains the most suitable.

Acknowledgments

The authors thank Mr N. Abghough for editing the language of the manuscript.

Funding

This research has not received any external funding.

Disclosure

The authors declare no conflicts of interest in this work.

References

1. Mohindra NK, Bulman JS. The effect of increasing vertical dimension of occlusion on facial aesthetics. *Br Dent J.* 2002;192(3):164–168. doi:10.1038/sj.bdj.4801324
2. Alhajib MN, Khalifa N, Abduo J, Amran AG, Ismail IA. Determination of occlusal vertical dimension for complete dentures patients: an updated review. *J Oral Rehabil.* 2017;44(11):896–907. doi:10.1111/joor.12522
3. Abduo J, Lyons K. Clinical considerations for increasing occlusal vertical dimension: a review. *Aust Dent J.* 2012;57(1):2–10. doi:10.1111/j.1834-7819.2011.01640.x
4. Mack MR. Vertical dimension: a dynamic concept based on facial form and oropharyngeal function. *J Prosthet Dent.* 1991;66(4):478–485. doi:10.1016/0022-3913(91)90508-t
5. Shen YF, Wei MC, Li HP, et al. Vertical dimension of occlusion related to mandibular movement during swallowing. *Biomed J.* 2021;44(2):217–222. doi:10.1016/j.bj.2019.12.006
6. Azar B. The glossary of prosthodontic terms. *J Prosthet Dent.* 2005;94(1):10–92. doi:10.1016/j.prosdent.2005.03.013
7. College National d'Occlusodontologie (CNO). *Lexique de l'occluso-dontologie*. Paris: Quintessence International; 2001.
8. Igić M, Nebojsa K, Ljiljana A, et al. Determination of vertical dimension of occlusion by using the phonetic vowel 'O' and 'E'. *Vojnosanit Pregl.* 2015;72(2):123–131. doi:10.2298/vsp1502123i
9. Swerdlow H. Vertical Dimension Literature Review. *J Prosthet Dent.* 1965;15:241–247. doi:10.1016/0022-3913(65)90093-4
10. Yilmaz G, Uginčius P, Sebik O, Türker KS. Tonic activity of the human temporalis muscle at mandibular rest position. *Arch Oral Bio.* 2015;60(11):1645–1649. doi:10.1016/j.archoralbio.2015.08.013
11. Michelotti A, Farella A, Vollaro S, Martina R. Mandibular rest position and electrical activity of the masticatory muscles. *J Prosthetic Dent.* 1997;78(1):48–53. doi:10.1016/S0022-3913(97)70087-8
12. Goldberg LJ, Derfler B. Relationship among recruitment order, spike amplitude, and twitch tension of single motor units in human masseter muscle. *J Neurophysiol.* 1977;40(4):879–890. doi:10.1152/jn.1977.40.4.879
13. Rilo B, Santana U, Mora MJ, Cadarso CM. Myoelectrical activity of clinical rest position and jaw muscle activity in young adults. *J Oral Rehabil.* 1997;24(10):735–740. doi:10.1046/j.1365-2842.1997.00565.x
14. Emshoff R, Bertram S, Strobl H. Ultrasonographic cross-sectional characteristics of muscles of the head and neck. *Oral Surg Oral Med Oral Pathol Oral Radiol.* 1999;87(1):93–106. doi:10.1016/S1079-2104(99)70302-1
15. Weinberg LA. Vertical dimension: a research and clinical analysis. *J Prosthet Dent.* 1982;47(3):290–302. doi:10.1016/0022-3913(82)90159-7
16. Araki NG, Araki CT. Head angulation and variations in the maxillomandibular relationship. Part I: the effects on the vertical dimension of occlusion. *J Prosthet Dent.* 1987;58(1):96–100. doi:10.1016/s0022-3913(87)80151-8
17. Sicher H, Tandler J. *Anatomie für Zahnärzte*. J. Springer; 1928.
18. Fayz F, Eslami A. Determination of occlusal vertical dimension: a literature review. *J Prosthet Dent.* 1988;59(3):321–323. doi:10.1016/0022-3913(88)90182-5

19. Niswonger ME. The Rest Position of the Mandible and the Centric Relation. *J Am Dent Assoc.* 1934;21(9):1572–1582. doi:10.14219/jada.archive.1934.0258
20. Thompson JR. The rest position of the mandible and its significance to dental science. *J Am Dent Assoc.* 1946;33:151–180. doi:10.14219/jada.archive.1946.0034
21. Unger JW. Comparison of vertical morphologic measurements on dentulous and edentulous patients. *J Prosthet Dent.* 1990;64(2):232–234. doi:10.1016/0022-3913(90)90184-e
22. Joy TE, Kiran SM, R R, Jasmin S, Babu SK. Evaluation of vertical facial height reduction and severity of temporomandibular joint disorders using Shimbashi number and cephalometric analysis. *Cranio.* 2021;39(4):287–293. doi:10.1080/08869634.2019.1631944
23. Atwood DA. A critique of research of the rest position of the mandible. *J Prosthet Dent.* 1966;16(5):848–854. doi:10.1016/0022-3913(66)90008-4
24. Uppal S, Gupta NK, Tandan A, Dwivedi R, Gupta S, Kumar S. Comparative evaluation of vertical dimension at rest before extraction, after extraction and after rehabilitation with complete denture - A Cephalometric study. *J Oral Biol Craniofac Res.* 2013;3(2):73–77. doi:10.1016/j.jobcr.2013.04.001
25. Tallgren A. Changes in Adult Face Height Due to Ageing, Wear and Loss of Teeth and Prosthetic Treatment: a Roentgen Cephalometric Study Mainly on Finnish Women. *Acta Odontol Scand.* 1957;15(24):1–22.
26. Olsen. *A Radiographic Study of Variations in the Physiologic Rest Position of the Mandible in Seventy Edentulous Individuals.* University of Minnesota; 1951.
27. Atwood DA. Some clinical factors related to rate of resorption of residual ridges. *J Prosthet Dent.* 2001;86(2):119–125. doi:10.1067/mpr.2001.117609
28. Chou JC, Thompson GA, Aggarwal HA, Bosio JA, Irelan JP. Effect of occlusal vertical dimension on lip positions at smile. *J Prosthet Dent.* 2014;112(3):533–539. doi:10.1016/j.prosdent.2014.04.009
29. Fabbri G, Sorrentino R, Cannistraro G, et al. Increasing the Vertical Dimension of Occlusion: a Multicenter Retrospective Clinical Comparative Study on 100 Patients with Fixed Tooth-Supported, Mixed, and Implant-Supported Full-Arch Rehabilitations. *Int J Periodontics Restorative Dent.* 2018;38(3):323–335. doi:10.11607/prd.3295
30. Mehta SB, Bronhorst EM, Lima VP, et al. The effect of pre-treatment levels of tooth wear and the applied increase in the vertical dimension of occlusion (VDO) on the survival of direct resin composite restorations. *J Dent.* 2021;111(103712). doi:10.1016/j.jdent.2021.103712
31. Sierpiska T, Golebiewska M, Kuc J, Lapuc M. The influence of the occlusal vertical dimension on masticatory muscle activities and hyoid bone position in complete denture wearers. *Adv Med Sci.* 2009;54(1):104–108. doi:10.2478/v10039-009-0018-3
32. Levartovsky S, Matalon S, Sarig R, Baruch O, Winocur E. The association between dental wear and reduced vertical dimension of the face: a morphologic study on human skulls. *Arch Oral Biol.* 2015;60(1):174–180. doi:10.1016/j.archoralbio.2014.09.016
33. Zanardi PR, Santos MS, Stegun RC, Sesma N, Costa B, Laganá D. Restoration of the Occlusal Vertical Dimension with an Overlay Removable Partial Denture: a Clinical Report. *J Prosthodont.* 2016;25(7):58–5588. doi:10.1111/jopr.12351
34. Deng H, Gao S, Lu S, Kumar A, Zhang Z, Svensson P. Alteration of occlusal vertical dimension induces signs of neuroplastic changes in corticomotor control of masseter muscles: preliminary findings. *J Oral Rehabil.* 2018;45(9):710–719. doi:10.1111/joor.12682
35. Murphy T. Compensatory mechanisms in facial height adjustment to functional tooth attrition. *Australian Dental Journal.* 1959;4(5):312–323. doi:10.1111/j.1834-7819.1959.tb03727.x
36. Sun J, Lin YC, Lee JD, Lee SJ. Effect of increasing occlusal vertical dimension on lower facial form and perceived facial esthetics: a digital evaluation. *J Prosth Dent.* 2021;126(4):546–552. doi:10.1016/j.prosdent.2020.07.013
37. Widmer C, Nguyen VD, Chiang H, Morris-Wiman J. Increased vertical dimension effects on masseter muscle fiber phenotype during maturation. *Angle Orthod.* 2013;83(1):57–62. doi:10.2319/122111-786.1
38. Makiguchi M, Funaki Y, Kato C, et al. Effects of increased occlusal vertical dimension on the jaw-opening reflex in adult rats. *Arch Oral Biol.* 2016;72:39–46. doi:10.1016/j.archoralbio.2016.08.009
39. Akagawa Y, Nikai H, Tsuru H. Histologic changes in rat masticatory muscles subsequent to experimental increase of the occlusal vertical dimension. *J Prosth Dent.* 1983;50(5):725–732. doi:10.1016/0022-3913(83)90216-0
40. Rivera-Morales WC, Mohl ND. Relationship of occlusal vertical dimension to the health of the masticatory system. *J Prosthet Dent.* 1991;65(4):547–553. doi:10.1016/0022-3913(91)90298-b
41. Carlsson GE, Ingervall B, Kocak G. Effect of increasing vertical dimension on the masticatory system in subjects with natural teeth. *J Prosthet Dent.* 1979;41(3):284–289. doi:10.1016/0022-3913(79)90008-8
42. Christensen J. Effect of occlusion-raising procedures on the chewing system. *Dent Pract Dent Rec.* 1970;20(7):233–238.
43. Dahl BL, Krogstad O. The effect of a partial bite raising splint on the occlusal face height. An x-ray cephalometric study in human adults. *Acta Odontol Scand.* 1982;40(1):17–24. doi:10.3109/00016358209019805
44. Moreno-Hay I, Okeson JP. Does altering the occlusal vertical dimension produce temporomandibular disorders? A literature review. *J Oral Rehabil.* 2015;42(11):875–882. doi:10.1111/joor.12326
45. Ormianer Z, Palty A. Altered vertical dimension of occlusion: a comparative retrospective pilot study of tooth- and implant-supported restorations. *Int J Oral Maxillofac Implants.* 2009;24(3):497–501.
46. Goldstein G, Goodacre C, MacGregor K. Occlusal Vertical Dimension: best Evidence Consensus Statement. *J Prosthodont.* 2021;30(1):12–19. doi:10.1111/jopr.13315
47. Wang W, Jie W, Hai-Yan L, et al. The effects of increasing occlusal vertical dimension on the deep masseter of rat at different ages. *Arch Oral Biol.* 2017;74:12–20. doi:10.1016/j.archoralbio.2016.10.031
48. Dahl BL, Krogstad O. Long-term observations of an increased occlusal face height obtained by a combined orthodontic/prosthetic approach. *J Oral Rehabil.* 1985;12(2):173–176. doi:10.1111/j.1365-2842.1985.tb00632.x
49. Harper GW, Stewart CJ. Treatment and management of temporomandibular joint dysfunction (TMJ) with a modified removable partial denture. *W V Dent J.* 1993;67(2):10–12.
50. Pullinger AG, Seligman DA, Gornbein JA. A multiple logistic regression analysis of the risk and relative odds of temporomandibular disorders as a function of common occlusal features. *J Dent Res.* 1993;72(6):968–979. doi:10.1177/00220345930720061301

51. Slavicek R, Pédinielli A, Orthlieb J. Typologie squelettique et choix de la Dimension Verticale d'Occlusion. *Réalités Cliniques*. 2013;24(2):119–125.
52. Yamashita S, Shimizu M, Katada H. A newly proposed method to predict optimum occlusal vertical dimension. *J Prosthodont*. 2015;24(4):287–290. doi:10.1111/jopr.12223

Clinical, Cosmetic and Investigational Dentistry

Dovepress

Publish your work in this journal

Clinical, Cosmetic and Investigational Dentistry is an international, peer-reviewed, open access, online journal focusing on the latest clinical and experimental research in dentistry with specific emphasis on cosmetic interventions. Innovative developments in dental materials, techniques and devices that improve outcomes and patient satisfaction and preference will be highlighted. The manuscript management system is completely online and includes a very quick and fair peer-review system, which is all easy to use. Visit <http://www.dovepress.com/testimonials.php> to read real quotes from published authors.

Submit your manuscript here: <https://www.dovepress.com/clinical-cosmetic-and-investigational-dentistry-journal>