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EPA Consensus Project Paper: The Vertical Dimension of Occlusion. How to Determine and How to Alter? A Systematic Review

Keywords

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ABSTRACT

Purpose: The aim of this systematic review was to explore the dental literature to identify high quality clinical studies that introduced methods of determining the vertical dimension of occlusion (VDO), and additionally to find studies which assessed alterations in the VDO. Materials and methods: An electronic search of the literature was conducted through PubMed , Embase, and Cochrane Library databases referring to the determination and alteration of the VDO by 12/2021. Results: A total of 215 records were obtained from the initial search. After the first two screenings, 33 studies were selected for inclusion. Correlations in the morphometric group ranged between r=0.18-0.87, p<0.05-0.001, correlations in the cephalometric group ranged between r=0.28-0.92, p<0.05-0.001, and correlations in the mechanometric group ranged between r=0.21-0.75, p<0.05-0.01. Regarding the alteration of VDO, in all studies the increase ranged between 1.8-8 mm and the patients adapted . Conclusions: No clear guidelines can be established yet, in relation to the determination and alteration of the VDO. There is no apparent benefit in using more invasive and complex methods compared to the use of the facial anatomical landmarks. Patient adaptation seems to be successful when the range of VDO increase was 1.8-6.0 mm.

INTRODUCTION

The clinical procedures of determining and establishing the patients' Vertical Dimension of Occlusion (VDO) could still be considered as one of the dogmas in dentistry.[1] VDO has been defined as the distance between two selected anatomic or marked points (usually one on the tip of the nose and the other on the chin) when in maximal intercuspal position.[2] In healthy dentate patients VDO could be determined by the occlusal surfaces of the posterior teeth, while in edentulous patients by the contact of the wax occlusal rims on the record bases.[2] Therefore, tooth wear, tooth loss, or changes at the occlusal surfaces of existing protheses over time might require the need to restore the patients' initial VDO.[3] Additionally, concerns and reservations have been expressed as to whether the VDO could remain constant through patients' life or if the overeruption of worn teeth could compensate for the loss of the original VDO.[4]

Patients in need of extensive prosthodontic treatment might require additional space for restorative materials, harmonization of dentofacial esthetics, and optimization of occlusal relationships, all of which could be provided by carefully increasing the VDO.[5] Yet, there have been suggestions which advise that altering the patients' VDO could lead to masticatory muscles' hyperactivity, increase of bite force, and temporomandibular disorders (TMDs),[1] while other authors advocate the opposite.[6]

Several authors tried to correlate patients' VDO with different anthropometric or facial proportions measurements,[7-25] while others used cephalometric measurements.[26-30] In addition several authors used hydraulic jigs, kinesiographs or electromyography in conjunction with phonetics and deglutition.[31-34] Finally, few studies have evaluated the adaptation of patients to the increase of VDO.[35-44] It should be mentioned however that, there has been no universally accepted methods of establishing VDO despite the plethora of attempts for that purpose.

The aim of this study was to systematically review the dental literature in order to identify high quality clinical studies that introduced methods of determining the VDO, and additionally to find studies which assessed the alterations in the vertical relations between the maxilla and the mandible.

MATERIALS AND METHODS

This systematic review was conducted according to the guidelines of the preferred reporting items for systematic reviews and meta-analyses (PRISMA).[45] The review was registered on the PROSPERO register (CRD42022291191). The population, intervention, control, and outcomes (PICO) format was applied to define the research question. Two PICO questions were formulated for that purpose. The first question referred to the determination of the VDO: "In healthy adult dentate or edentulous patients, does the determination of the VDO based on an evaluation of aesthetic, phonetic and functional parameters has a different outcome, when compared to the determination of the VDO based on the rest position and freeway space?". The second question referred to the alteration of the VDO: "In healthy adult patients who have significant loss of tooth structure or loss of posterior support, does the alteration of VDO has different biologic, functional and aesthetic results, when compared to the maintenance of the VDO?"

An electronic search of the literature was conducted through PubMed (MEDLINE), EMBASE and Cochrane Library, using the following keywords: vertical dimension of occlusion, establishing, determining, ("vertical dimension"[MeSH Terms] OR ("vertical"[All Fields] AND "dimension"[All Fields]) OR "vertical dimension"[All Fields] OR ("vertical"[All Fields] AND "dimension"[All Fields] AND "occlusion"[All Fields]) OR "vertical dimension of occlusion"[All Fields]) AND ("establish"[All Fields] OR "established"[All Fields] OR "establishes"[All Fields] OR "establishing"[All Fields] OR "establishment"[All Fields] OR "establishments"[All Fields]) AND ("analysis"[MeSH Subheading] OR "analysis"[All Fields] OR "determination"[All Fields] OR "determinant"[All Fields] OR "determinants"[All Fields] OR "determinate"[All Fields] OR "determinated"[All Fields] OR "determinates"[All Fields] OR "determinating"[All Fields] OR "determinations"[All Fields] OR "determine"[All Fields] OR "determined"[All Fields] OR "determines"[All Fields] OR "determining"[All Fields])

A supplementary manual search was also conducted in the following dental journals: Journal of Prosthetic Dentistry, Journal of Oral Rehabilitation, Journal of Dentistry, International Journal of Prosthodontics, Journal of Prosthodontics, International Journal of Oral and Maxillofacial Implants, International Journal of Periodontics & Restorative Dentistry, and Journal of Prosthodontic Research. The titles of the articles were saved in a reference software (Mendeley Reference Manager, Mendeley Ltd.), which was used to eliminate duplicate articles from different searches. The search aimed to collect all articles published in peer-reviewed dental journals, written in English, referring to the alteration and determination of the VDO until the end of December 2021. The inclusion criteria set by the consensus committee of the European Prosthodontic Association were: *in vivo* clinical studies in humans, with at least five patients or cases and a minimum follow up period of 12 months. The exclusion criteria were: pilot studies, clinical studies with fixed or removable implant prostheses, *in vitro* studies, case reports, expert opinions and systematic or narrative reviews. The first outcome variable used was the determination of VDO by different methods and the second one was the establishment of VDO by different procedures.

The titles and abstracts of the resulted studies were assessed separately by 6 reviewers (A.P., S.K., Y.K., E.Z., R.K., K.M.). Analysis was performed according to title's relevance and abstract's content level, followed by the analysis at the full-text level. A prerequisite for the inclusion of an article in this systematic review was the initial agreement of the two principal reviewers for each article (Cohen's kappa score = 0.84). Disagreements were resolved by discussion and the consensus of all participating authors. All studies included in the final stage were evaluated for risk of bias according to the QUADAS-2 tool.[46] Meta-analysis was not conducted due to heterogeneity of the selected studies.

RESULTS

A total of 215 records were obtained from the initial electronic search, 210 from PubMed, 5 from the Cochrane library, while no articles were retrieved from the EMBASE. After excluding the 2 duplicate records and reviewing the remaining titles for relevance, 147 articles were excluded, which resulted in 66 articles suitable for abstract screening. Analysis of the abstracts led to the exclusion of 33 articles. Therefore, a total number of 33 studies were selected for full-text reading. After full text analysis and discussion between the co-authors, 5 studies were excluded with reason *(Table 1)*, and 5 additional studies were added after screening the references of the studies selected for full-text reading. In total 33 studies were selected for inclusion in the present review *(Figure 1)*.

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Table 1. Excluded studies and reasons for exclusion.

Study (Year)	Study Setting	Sample Size (n)	Sample Description	Measurement Method	Exclusion Reason
Unger (1990)	University clinic	20	Edentulous	Cephalometric	VDO changes after 20 years
Munakata and Kasai (1990)	University clinic	5	Edentulous	Mechanometric	Preferred VDO stable or unstable
Ekfeldt et al (1982)	University clinic	9	Dentate	Morphometric	Intra-oral vs extra oral landmarks comparison
Broekhuijsen and van Willingen (1982)	University clinic	15	Edentulous	Mechanometric	Preferred VDO stable or unstable
van Willigen et al (1976)	University clinic	20	Edentulous	Mechanometric	Preferred VDO stable or unstable

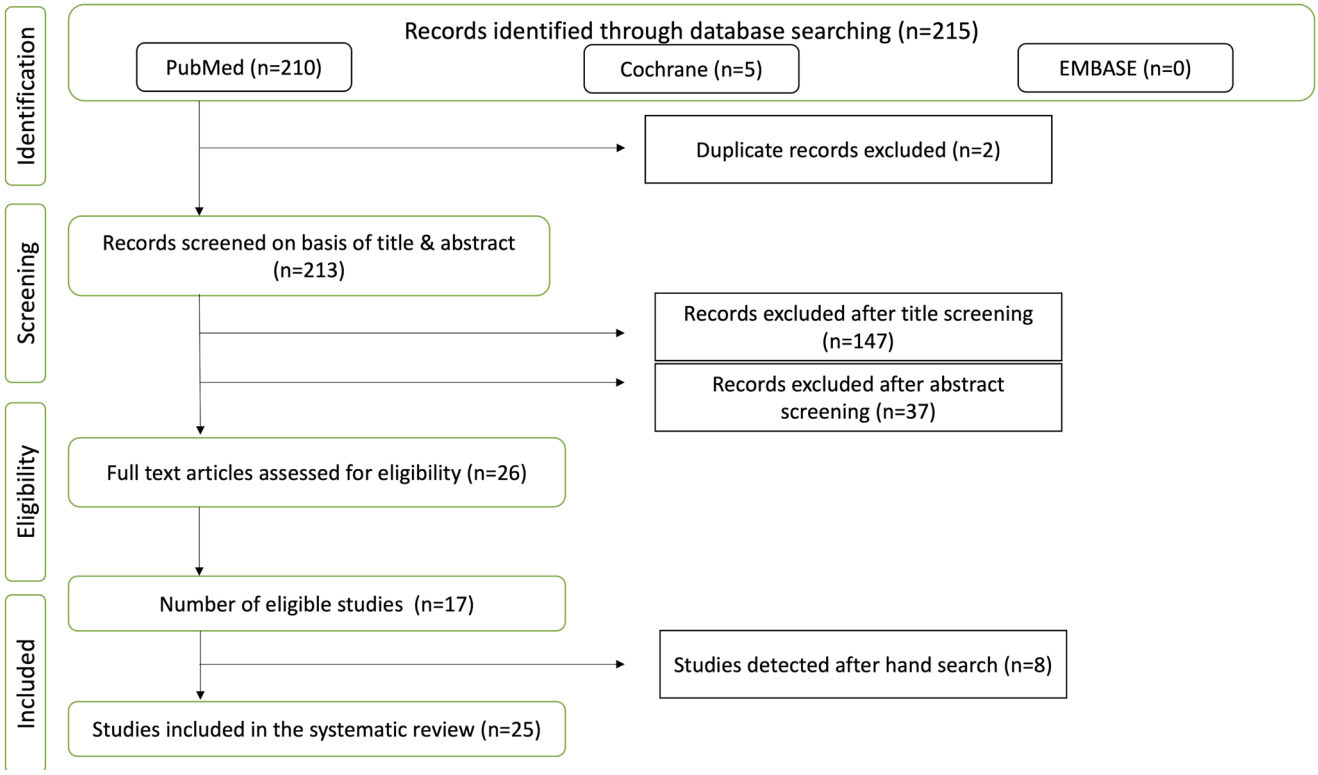

Figure 1: Article selection flowchart.

DETERMINATION OF VDO

Twenty-three cross sectional studies addressed the determination of VDO *(Table 2)*. Only one study[11] exhibited a low risk of bias. The remaining 22 included studies exhibited a high risk of bias in the patient selection domain *(Table 3)*. Studies' sample size ranged from 10 to 688 patients, with 3 studies[31,32,34] including both dentate and edentulous patients, 18 studies[7-18,20,23,24,26-28] comprising of dentate participants and only 2 studies[18,29] comprising of edentulous participants. Based on the method of VDO determination used, the studies were further classified in the following categories: morphometric, cephalometric, and mechanometric.

Morphometric Method

These studies correlated anthropometric measurements in dentate subjects, which could be used as a guide for the determination of VDO in edentulous patients. VDO was determined by using facial anatomical landmarks when teeth were in occlusion. Eleven studies[7-10,12-14,16,17,20,24] used the distance

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Table 2. Included studies for determination of VDO

Study (Year)	Study Setting	Sample Size (n)	Sample Description	Measurement Method	Results	
					Measurements (mm) (mean ± SD)	Correlations
Basutkar et al (2021)	University clinic	500	Dentate	Morphometric (Sn-Me´, IF, LF, TF, IC-RO, OC-RO)	Sn-Me´: 68.16 ± 6.24 (M) 61.18 ± 7.40 (F)	Sn-Me´ to IF: r=0.73, p<0.001 (M) Sn-Me´ to OC-RO: r=0.61, p<0.001 (M) Sn-Me´ to LF: r=0.58, p<0.001 (F) Sn-Me´ to IF: r=0.49, p<0.001 (F)
Sajjan et al (2020)	University clinic	688	Dentate	Morphometric (Sn-Me´, TF)	N/A	Sn-Me´ (VDR) to TF: r=0.83-0.77, p<0.001
Morata et al (2020)	University clinic	381	Dentate	Morphometric (Sn-Me´, R. EAM-OC, L. EAM-OC)	Sn-Me´: 70.74 ± 4.39 R. EAM-OC: 68.67 ± 3.45 L. EAM-OC: 68.45 ± 3.48	Sn-Me´ to L. EAM-OC: r=0.56, p<0.05 Sn-Me´ to R. EAM-OC: r=0.51, p<0.05
Hussain and Yazdanie (2019)	University clinic	250	Dentate	Morphometric (Sn-Me´, IF)	Sn-Me´: 70.81 ± 3.88 (M) 61.32 ± 4.23 (F)	Sn-Me´ to IF: r=0.75, p<0.001 (M) Sn-Me´ to IF: r=0.82, p<0.001 (F)
Montero and Bib (2019)	University clinic	93	Dentate Edentulous Partially edentulous	Mechanometric (Sn-MeLF, EMG)	Sn-MeLF: 55.4 ± 4.4 (Dentate) 52.2 ± 7.2 (Edentulous) Clin. based IRS: 2.8 ± 0.4 (Dentate) 1.4 ± 0.5 (Edentulous) EMG IRS: 3.6 ± 0.6 (Dentate) 2.2 ± 0.6 (Edentulous)	Clin. based IRS to Sn-MeLF: r=0.21, p<0.05 EMG based IRS to Sn-MeLF: r=0.28, p<0.05
Watarai et al (2018)	University clinic	1TT05	Dentate	Morphometric (Sn-Gn´, ULP, LLP, IRS)	IRS: 1.33 (Swallowing) 1.53 (Lip contact) 2.16 (Rest)	IRS to ULP: r=0.61, p<0.01 (Lip contact) IRS to LLP: r=0.24, p<0.05 (Lip contact)
Alhajj and Daer (2017)	University clinic	93	Dentate	Cephalometric (ANS-Me, Na-Se)	ANS-Me: 64.22 ± 5.35 Na-Se: 66.08 ± 3.92	ANS-Me to Na-Se: r=0.57, p<0.001
Alhajj et al (2016a)	University clinic	114	Dentate	Morphometric (Sn-Me´, OC-RO, Pn-Pg´)	Sn-Me´: 67.24 ± 4.59 OC-RO: 70.79 ± 4.0 Pn-Pg´: 69.60 ± 5.32	Sn-Me´ to OC-RO: r=0.3, p<0.01 Pn-Pg´ to OCRO: r=0.31, p<0.01
Alhajj et al (2016b)	University clinic	117	Dentate	Morphometric (Sn-Me´, IF, RF, LF, Pn-Pg´)	Sn-Me´: 65.93 ± 4.66 Pn-Pg´: 68.19 ± 4.08	Sn-Me´ to IF: r=0.24, p≤0.01 Sn-Me´ to RF: r=0.18, p≤0.05 Sn-Me´ to LF: r=0.19, p≤0.05 Pn-Pg´ to IF: r=0.36, p≤0.001 Pn-Pg´ to RF: r=0.32, p≤0.001 Pn-Pg´ to LF: r=0.28, p=0.002

Table 2 continued overleaf....

Table 2 continued....

Abraham et al (2015)	University clinic	79	Dentate	Morphometric (Sn-Me´, SW)	Sn-Me´:62.82 ± 3.11 (F) 69.23 ± 2.28 SW: 64.59 ± 3.71 (F) 69.34 ± 3.72 (M)	Sn-Me´ to SW: r=0.76, p<0.001
Basnet et al (2015)	University clinic	500	Dentate	Morphometric (Pn-Pg´, TF, EAM-OC, RO-Pu)	Pn-Pg´: 66.26 ± 5.04 EAM-OC: 70.60 ± 4.51 RO-Pu: 65.52 ± 5.28	Pn-Pg´ to TF: r=0.87, p <0.001 Pn-Pg´ to EAM-OC: r=0.26, p<0.001 Pn-Pg´ to RO-Pu: r=0.32, p<0.001
Yamashita et al (2015)	University clinic	58	Dentate	Cephalometric (Angular: LFH, FH-SN, SNA, Nasal floor-SN, Nasal floor-FH, GA, Cranial deflection Linear: N-S, N-ANS, N-PNS, Go-Me)	LFH angle: 47.9° ± 4° FH-SN: 6.9° ± 2.9° SNA: 82.1° ± 3.8° Nasal floor-SN: 8.7° ± 3.9° Nasal floor-FH: 1.8° ± 3.8° GA: 123.6° ± 6.8° Cranial deflection: 26.2° ± 2.7° N-S: 71.5 ± 3.4 N-ANS: 59.4 ± 4.2 N-PNS: 75.2 ± 3.9 Go-Me: 77.0 ± 5.5	LFH to GA: r=0.60, p<0.05 LFH to SNA: r=-0.53, p<0.05 LFH to N-S: r=-0.39, p<0.05 LFH to Go-Me: r=0.33, p<0.05 LFH to Nasal floor-FH: r=-0.28, p<0.05 LFH to Nasal floor-SN: r=0.28, p<0.05 LFH to FH-SN: r=-0.28, p<0.05
Ladda et al (2013)	University clinic	400	Dentate	Morphometric (Sn-Me´, IF, LF, TT-IT)	Sn-Me´: 61.4 ± 4.2 (M) 56.7 ± 3 (F)	Sn-Me´ to IF: r=0.41, p<0.001 (M) r=0.26, p<0.001 (F) Sn-Me´ to LF: r=0.39, p<0.001 (M) r=0.39, p<0.001 (F) Sn-Me´ to TT-IT: r=0.31, p<0.001 (M) r=0.27, p<0.001 (F)
Gomes et al (2008)	University clinic	84	Dentate	Morphometric (Sn-Me´, R. OC-RO, L. OC-RO)	Sn-Me´: 73.89 ± 6.57 R. OC-RO: 75.361 ± 5.65 L. OC-RO: 74.96 ± 5.71	Sn-Me´ to R. OC-RO: r=0.60, p<0.001 Sn-Me´ to L. OC-RO: r=0.63, p<0.001
de Souza and Compagnoni (2004)	University clinic	94	Dentate Edentulous	Mechanometric (IRS, CSS, Kinesiograph)	IRS: 1.59 ± 1.17 (Dent.) 2.34 ± 1.15 (Edent.) CSS: 2.23 ±1.35 (Dent.) 2.67 ±1.47 (Edent.)	IRS to CSS: r=0.41, p<0.01 (Dent.) IRS to CSS: r=0.75, p<0.01(Edent.)
Millet et al (2003)	University clinic	15	Edentulous	Morphometric (Pn-Pg´)	Pn-Pg´: 21.8 ± 1.6 (Swallowing) 20.0 ± 0.5 (Rest)	N/A
Miralles et al (2001)	University clinic	15	Dentate	Morphometric (Pn-Pg´, IRS)	IRS: 1.53 ± 0.52 (Swallowing) 1.82 ± 0.73 (Rest) 3.39 ± 1.13 (Phonetics)	N/A

Table 2 continued overleaf....

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Table 2 continued....

Orthlieb et al (2000)	University clinic	505	Dentate	Cephalometric (VDO sup, VDO med, VDO inf, FMA, M arch, GA)	VDO sup: 39.5° ± 3.88° VDO med: 43.44° ± 5.56° VDO inf: 48.46° ± 5.21° FMA: 23.03° ± 6.56° M arch: 36.42° ± 6.88° GA: 126.38° ± 7.09°	GA to VDO sup: r=0.32, p<0.001 GA to VDO med: r=0.44, p<0.001 GA to VDO inf: r=0.69, p<0.001 GA to FMA: r=0.66, p<0.001 M arch to VDO sup: r=0.36, p<0.001 M arch to VDO med: r=0.57, p<0.001 M arch to VDO inf: r=0.58, p<0.001 M arch to FMA: r=0.64, p<0.001
Chou et al (1994)	University clinic	600	Dentate	Morphometric (Sn-Me´, L. EAM-OC)	N/A	Sn-Me´ to L. EAM-OC: r=0.75, p<0.001 (White M) Sn-Me´ to L. EAM-OC: r=0.87, p<0.001 (White F) Sn-Me´ to L. EAM-OC: r=0.64, <0.001 (Asian M) Sn-Me´ to L. EAM-OC: r=0.60, p<0.001 (Asian F)
Koller et al (1992)	University clinic	13	Edentulous	Cephalometric (IP, MRR)	IP-MRR:24 ± 5.3 (CD) 25 ± 5.0 (Rest) 26 ± 5.0 (Swallowing)	CD to Rest: r=0.92, p<0.05 CD to Swal.: r=0.75, p<0.05
Babu et al (1987)	University clinic	40	Dentate Edentulous	Mechanometric (Pn-Pg´, EMG)	VDR (Pn-Pg´): 71.1 ± 3.32 (Dent. - Swal. and Phon.) 70.91 ± 30.3 (Dent. - EMG) 62.08 ± 7.79 (Edent. with CD. - Swal. and Phon.) 62.18 ± 8.15 (Edent. with CD. - EMG) 61.12 ± 7.97 (Edent. without CD. - Swal. and Phon.) 62.09 ± 7.91 (Edent. without CD. - EMG)	N/A
Rugh and Drago (1981)	University clinic	10	Dentate	Mechanometric (IRS, EMG, kinesiograph)	IRS: 10.4 ± 1.7 (EMG M) 2.1 ± 0.48 (Rest M) 6.8 ±1.4 (EMG F) 2.1 ± 0.73 (Rest F)	N/A
Domitti and Consani (1978)	University clinic	380	Dentate	Morphometric (Sn-Me¢, ZZ, Na-Sn)	Sn-Me´: 67.9 NO SD ZZ: 133.0 NO SD Na-Sn: 47.5 NO SD	Sn-Me´ to ZZ: r=0.37, p<0.01 Sn-Me´ to Na-Sn: r=0.51, p<0.01

IF: index finger, LF: little finger, TF: thumb finger, RO: rima oris, OC: outer canthus, R: right, L: left, Sn: subnasion, Pn: pronasion, Me: menton, Na: nasion, Gn: gnathion, RF: ring finger, Pu: eye pupil, XI: center of mandibular ramus, PM: mental protuberance, TT: thumb tip, IT: index tip, LC: labial commissure, ID: interocclusal distance, MeLF: Mentolabial fold, ULP: upper lip prolabium, LLP: lower lip prolabium, SW: smile width, Go: Gonion, LFH angle: ANS-XI and XI-PM, EAM: External Auditory Meatus, IP: Incisive papilla, MRR: mandibular residual ridge, Se: sella, Pg: pogonion, ZZ: bizygomatic

Table 3. Risk of bias for included studies regarding the determination of VDO.

Study (year)	Risk of bias				Applicability concerns		
	Patient Selection	Index Test	Reference Standard	Flow and Timing	Patient Selection	Index Test	Reference Standard
Basutkar et al (2021)	-	-	+	+	+	+	+
Sajjan et al (2020)	-	-	+	+	?	?	+
Morata et al (2020)	-	+	+	+	-	+	+
Hussain and Yazdanie (2019)	-	-	+	+	-	-	+
Montero and Bib (2019)	-	?	+	-	-	-	+
Watarai et al (2018)	+	+	+	+	-	+	+
Alhajj and Daer (2017)	-	-	+	+	+	-	+
Alhajj et al (2016a)	-	?	+	+	-	-	+
Alhajj et al (2016b)	-	?	+	+	-	?	+
Abraham et al (2015)	-	-	+	+	+	+	+
Basnet et al (2015)	-	-	+	+	?	?	+
Yamashita et al (2015)	-	?	+	+	-	+	+
Ladda et al (2013)	-	-	+	-	-	-	+
Gomes et al (2008)	-	-	+	-	-	-	+
de Souza and Compagnoni (2004)	-	-	+	-	-	?	+
Millet et al (2003)	-	-	+	-	-	-	+
Miralles et al (2001)	-	-	+	+	-	-	+
Orthlieb et al (2000)	-	-	+	-	-	-	+
Chou et al (1994)	-	-	+	-	-	?	+
Koller et al (1992)	-	?	+	?	-	-	+
Babu et al (1987)	-	-	+	-	-	?	+
Rugh and Drago (1981)	-	+	+	+	-	+	+
Domitti and Consani (1978)	-	-	+	+	-	-	+

Low risk: (+), High risk: (-), Unclear risk: (?)

from Subnasion (Sn) to soft tissue Menton (Me´). Three studies[15,18,19] used the distance from Pronasion (Pn) to soft tissue Pogonion (Pg´) and one study[11] used the distance from Subnasion (Sn) to soft tissue Gnathion (Gn´) Additionally, six studies[7,8,10,13,15,16] measured the patients' thumb and index fingers length. In three studies,[7,8,10] the fingers' length has been determined to be moderately to strongly correlated (r=0.49-0.83, p<0.05-0.001) with the Sn-Me´ distance, while two of the included studies[13,16] reported a weak correlation (r=0.18-0.39, p<0.05-0.001). Anatomical measurements related to patients' eyes, such as the distance from the outer canthus (OC) or pupil to rima oris (RO), have been also moderately to strongly correlated (r=0.60-0.63, p<0.001) with the Sn-Me´ distance in two studies[7,17] and weakly correlated (r=0.30, p<0.01) in one.[12] Two studies[9,20] also moderately to strongly correlated (r=0.51-0.87, p<0.05-0.001) the Sn-Me´ distance to external auditory meatus - outer canthus (EAM-OC) distance, while one study[15] reported a weak correlation (r=0.26, p<0.001). Moreover, the authors of one study,[14] reported a strong co-relation (r=0.76, p<0.001) between smiling width and lower facial height, whereas the authors of another study[11] moderately correlated (r=0.61, p<0.01) the upper lip prolabium to the Interocclusal Rest Space (IRS) of the patients.

Cephalometric Method

Four studies[26-29] correlated skeletal landmarks in cephalometric radiographs of dentate and edentulous subjects to determine the VDO. This was achieved either by linear or angular measurements. Linear measurements included the distances of ANS-Me and Na-Se with a moderate reported correlation (r=0.57, p<0.001)[26] and the distance from incisive papilla to mandibular residual ridge with a strong correlation (r=0.92-0.75, p<0.05).[29] Angular measurements included the lower facial height (LFH) angle (ANS-Xi / Xi-Pm) and Gonial Angle (GA) with mathematical formulas been generated to calculate the quantitative relationship between the moderately correlated distances (r=0.60, p<0.05).[27] In a second study[28] that also used angular measurements the VDO median (VDO med) angle (ANS-Xi / Xi-Pm) and GA were moderately correlated (r=0.44, p<0.001). Additionally, in the same study[28] the VDO inferior (VDO inf) angle (ANS-Go / Go-Me) and the Frankfort Mandibular angle (FMA) were moderately correlated (r=0.69-0.66, p<0.001) to the GA of the patients.

Mechanometric Method

Four studies[23,31,32,34] determined the VDO directly or indirectly through the VDR and IRS with the use of special devices. One of the devices used was the kinesiograph, which comprised of a magnetic jaw-tracking device that measured the IRS during the pronunciation of the "m" and "s" sound. In a clinical study[32] the correlation between IRS and closest speaking space (CSS) was strong (r=0.75, p<0.01) in edentulous patients and moderate (r=0.41, p<0.01) in dentate patients. Electromyography was used in three studies,[23,31,34] as an accessory instrument to establish IRS and VDR in both dentate and edentulous patients by recording the nerve signals of specific muscles. A weak correlation (r=0.28, p<0.05) was established for the EMG based IRS to Sn-Mentolabial fold distance,[31] while no correlation was reported for the other two studies.[23,34]

ALTERATION OF VDO

Regarding the alteration of VDO, ten clinical studies,[35-44] all comprising of dentate patients were included (*Table 4*). All exhibited a high risk of bias (*Table 5*). Studies' sample size ranged from 6 to 45 patients with a follow-up evaluation period between 5 days to 14.1 years. VDO increase ranged between 1.8-8 mm. This was achieved by either fixed interim and definitive restorations,[35-37,40,41] or by removable Dahl type devices[39,43] and acrylic resin splints.[38,42,44] In all studies[35-44] the patients adapted to the increased VDO with no TMD symptoms after an adaptation period that ranged between 2 to 6 weeks. Additionally, it should be noted, that in one photographic evaluation study[38] a VDO increase of 2-6 mm was not apparent extra-orally and the increase in face height was 50% the interincisal value increase.

DISCUSSION

The objective of this systematic review was to investigate the different methods of VDO determination, and the impact VDO alteration has on biologic, functional and aesthetic outcome of healthy adult patients. It was the main intention of the authors to identify clinical/in vivo studies of the highest possible scientific evidence. Unfortunately, it was proven that the published literature in this area lacks high quality documentation.

Determining the patients' VDO and subsequently altering or re-establishing it, has been considered as one of the greatest hurdles in prosthetic rehabilitation procedures.[1] In healthy dentate patients without TMD symptoms or tooth attrition the benefit of precisely determining their VDO has little merit compared to patients with severe attrition or with complete edentulism. Most of the studies, comprising dentate patients, have focused on providing a correlation between VDO and the length of the patients' thumb or index fingers.[7,8,10,13,15,16] All patients were instructed to bring their teeth in MIP. No direct comparisons could be drawn since the extra-oral facial points used in determining the VDO were different (Sn-Me´ or Pn-Pg´ or Sn-MeLF or Sn-Gn´). It should be noted that for purposes of standardization the names of the facial anatomic points were altered from the original context. The inherent difficulty of measuring unstable and compressible facial points has been increased with the use of modified measuring instruments in several studies.[8,12-16,19] Only one study[15] reported a strong correlation (r=0.87, p<0.001), between the thumb finger's length and patient's VDO. However, the risk of bias in this study was high. Furthermore, several authors[7,9,12,14,15,17,20] tried to establish correlations between VDO and other facial distances (EAM-OC, OC-RO, smile width). Two studies[9,20] established a moderate to strong correlation between VDO and EAM-OC with the authors cautioning that the resulting algorithm

Table 4. Included studies for alteration of VDO.

Study (Year)	Study Design	Sample Size (n)	Sample Description	Intervention	Evaluation Period	Results
Liu et al (2019)	P	6	Dentate	VDO increased 4.5-6.0 mm Interim and definitive restorations Cephalometric analysis	24 months	Increased VDO did not relapse to baseline Teeth intrusion Stable alveolar process height All patients adapted
Fabbri et al (2018)	R	25 (Group A)	Dentate	VDO increased 3.2 ± 0.8 mm Interim and definitive ceramic restorations	36.5 ± 24.1 months	Functional complications up to 2 weeks in 24% of patients All patients adapted up to 6 weeks
Ormianer and Palty (2009)	R	10 (Group A)	Dentate	VDO increased 3-5 mm Interim and definitive FPDs opposing natural dentition	4-11 years	Minimum prosthetic complications 4.9% tooth failures All patients adapted
Gross et al (2002)	P	22	Dentate	Maxillary acrylic resin onlay restorations (2, 4, 6, 8 mm interincisally) Photographic evaluation at MIP and CR	N/A	Increase of 2-6 mm not apparent extra-orally Increase in face height 50% the interincisal value
Gough and Setchell (1999)	R	45	Dentate	VDO increase not recorded Dahl type devices (Cemented 78%, Removable 22%) Definitive restorations	Up to 14.1 years (median 4.4 years)	96% additional IRS created 94% no pulpal symptoms, no TMD 90% no periodontal symptoms
Ormianer and Gross (1998)	P	8 (Group 1)	Dentate	VDO increased 3.5-4 mm Interim and definitive restorations IRS and EMG measurements	24 months	IRS consistent up to 2 years No significant difference on EMG values up to 1 year All patients adapted
Gross and Ormianer (1994)	P	8	Dentate	VDO increased 3.5-4.5 mm Interim FPDs IRS, subjective patient symptoms	5 weeks	New IRS was maintained No muscle tenderness and speech difficulties after 2 weeks All patients adapted
Burnett and Clifford (1992)	P	6	Dentate	VDO increased 4 mm Cemented mandibular acrylic resin splint CSS evaluation	5 days	CSS reduction Adaptation rate: N/A
Dahl and Krogstad (1982)	P	20	Dentate	VDO increased 1.8-4.7 mm Maxillary Co-Cr splint on 6 anterior teeth Lateral ceph. X-rays	6-14 months	Posterior teeth eruption Anterior teeth intrusion No subjective symptoms or pain reported after 2 weeks All patients adapted
Carlsson et al (1979)	P	6	Dentate	VDO increased 3-4.2 mm Mandibular acrylic resin splint Clinical and EMG evaluation	7 days	IRS increased 0.5 mm Decrease in EMG activity 83% of patients adapted

P: prospective, R: retrospective, N/A: not available

Table 5. Risk of bias for included studies regarding the alteration of VDO.

Study (year)	Risk of bias				Applicability concerns		
	Patient Selection	Index Test	Reference Standard	Flow and Timing	Patient Selection	Index Test	Reference Standard
Liu et al (2019)	-	?	+	-	-	?	+
Fabbri et al (2018)	-	?	+	+	+	?	+
Ormianer and Palty (2009)	-	-	+	+	+	-	+
Gross et al (2002)	-	?	+	+	+	-	+
Gough and Setchell (1999)	-	?	-	+	-	?	-
Ormianer and Gross (1998)	-	-	+	+	-	-	+
Gross and Ormianer (1994)	-	-	+	+	-	?	+
Burnett and Clifford (1992)	-	?	+	-	-	-	+
Dahl and Krogstad (1982)	-	-	+	-	-	?	+
Carlsson et al (1979)	-	?	+	+	-	?	+

Low risk: (+), High risk: (-), Unclear risk: (?)

could be used only as an additional aid to existing physiologic measurements. In several studies, the authors opted to correlate the Vertical Dimension at Rest (VDR) or the IRS of patients to the length of different fingers[8] or extra-oral anatomical landmarks.[11,19] This study design might have included an additional variable, the method of determining the patients' VDR, which could be obtained by different physiologic methods. These included the swallowing technique,[8,11,19,23,31,34] relaxing technique,[11,19,31,34] and phonetic evaluation,[19,23,31,32,34] all of which could be technique sensitive and operator dependent. Additionally, most of the studies identified by this systematic review, report mean measurements without considering that outliers affect this mean as has been stated by a previous consensus statement on the subject.[3]

On the contrary, cephalometric studies have employed the method of tracing fixed anatomic landmarks on lateral cephalometric radiographs, mostly in dentate patients. These skeletal points have been universally accepted and recognized by dental professionals, which adds to the validity and comparability of the measurements.[28] Yet, the application of the cephalometric method in every clinical practice could be debated, since the additional radiation exposure might rise ethical concerns. Only one study[29] applied the cephalometric method of determining the VDO to a small edentulous group of patients. In that study a strong correlation ($r=0.92-0.75$, $p<0.05$) was established between complete dentures fabricated with the swallowing and relaxation method compared to the conventional method, which was not described by the authors.

One study,[32] which employed a kinesiograph device to correlate the IRS to closest speaking space, established a strong correlation in edentulous patients, but a weak one in dentate patients. Since the study design was cross-sectional, a cause/effect relationship could not be justified, although a functional adaptation could be expected. Furthermore, in a study[31] which employed an EMG device and 5 different IRS determination methods, a weak correlation was established between the IRS and VDO. Nevertheless, an EMG device could not be used routinely in a private practice environment to help the practitioner in determining the VDO.

On the second question of the current systematic review regarding the alteration of the VDO, few studies with limited number of patients and high risk of bias have been identified. During prosthodontic procedures and especially in full mouth rehabilitations, the main goal of the clinician has been to acquire the necessary space for the restorative materials.[4] In most of the cases this has been achieved by increasing the patients' VDO. The magnitude and the methods of the increase, as well as the adaptation period and the subjective symptoms reported have been evaluated. The golden standard and starting point has been the patient's IRS, which was reported by

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Niswonger as an average distance of 3 mm.[47] The increase was tested either by interim restorations[35-37,40,41] or by occlusal splints.[38,39,42-44] This increase ranged above the 3 mm point, except for one prospective study which reported a value of 2.84 ± 0.73 mm.[43] Yet, the patients sufficiently tolerated the VDO alteration even when the increase reached the 6 mm point.[35] This could be attributed to the adaptation capability and muscle plasticity of the stomatognathic system, which allows for a range of different VDOs to be comfortably tolerated by the patients. However, this may not apply in all cases i.e. patients with neuro-muscular disease, dementia, etc. although this is not supported by the published literature. Alteration of VDO in patients with severe attrition was associated with signs of neuroplastic changes in the corticomotor control of the masseter muscles.[48] Additionally, not all authors provided detailed justification or additional diagnostic data for the magnitude of the VDO increase, so no direct comparisons could be made. It should be stated that this systematic review did not include publications focusing on the stability of the VDO position[22,25,33] but only on the tolerance of the VDO alteration. Furthermore, several studies[50,51] and reviews[52-56] exist in the dental literature, which describe an increase of the VDO, ranging from 0.5 to 1.5 mm, that assessed the tolerance of the patient to that VDO increase, addressing the cracked tooth syndrome. Despite the significant number of cases that were assessed with favorable tolerance outcome, there were not included in this systematic review because they did not comply with the set inclusion and exclusion criteria.

Regarding the use of dahl type devices or occlusal splints to increase the VDO, a wide variety of application methods, materials, and intra-oral positions have been described. Metal splints positioned on the anterior teeth[39,43] resulted in less reported complications, such as speech difficulties or muscle tenderness, when compared to acrylic splints on mandibular teeth.[44] In terms of removable versus cemented splints, one prospective[42] and one retrospective study[39] concluded that the fixed appliances provided better acceptance and adaptation to the patients. This could be attributed to more stable occlusal contacts and harmonized anatomic contours. However, the retrospective study[39] has severe methodology flows and thus the evidence could be considered very weak. Finally, authors reported that there was no relapse of the new VDO to baseline, even after 5.5 years of follow-up period.[49] This finding might suggest that either through teeth eruption or intrusion processes and wear, patients could function comfortably. However, the individual contribution of each to the result, remains unclear.

A limitation of the present systematic review was the heterogeneity of the included studies, namely the type of the study, the cohort size, and the evaluation periods. Well-designed randomized controlled trials are needed to compare the different methods of determination and patients' adaptation to alterations of VDO.

CONCLUSIONS

Based on the findings of the current systematic review, the following conclusions were drawn:

- No clear guidelines can be established yet, in relation to the determination and alteration of the VDO.
- No substantial benefit could be provided by using the more time consuming, higher risk invasive cephalometric radiography and other elaborate equipment. Clinicians may still use the simplest and safest non-invasive methods, the facial anatomical landmarks.
- Patient adaptation seems to be successful when the range of VDO increase was 1.8-6.0 mm.

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