European Journal of Prosthodontics and Restorative Dentistry Mar 08 2023

EPA Consensus Project Paper: Shifting from the "Analogic Virtual Patient" to the "Digital Virtual Patient" in Prosthodontics. A Scoping Review

Keywords

Occlusion Analysis
Jaw Tracking Devices
Mechanical Articulator
Virtual Articulator
Facebow

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Received: 31.10.2022
Accepted: 07.02.2023

doi: 10.1922/EJPRD_2485Pradies17

ABSTRACT

Aims: To determine whether the use of single or combined mechanical and virtual articulators, as well as facebows, jaw motion trackers, face scanners, and related devices, actually improve the efficacy of the prosthesis obtained in terms of lifespan and patient-related outcomes. To coin the terms Analogic and Digital Virtual Patients (AVP and DVP) as an attempt to analyze, clarify and synthesize terminology and workflows related to previously so-called devices. Materials and Methods: A scoping review was accomplished involving different databases. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA-ScR) checklist and JBI guidance were followed to extract data regarding the Population, Context and Concept established. Results: Available literature on the efficacy of using devices and techniques related to both AVP and DVP workflows showed arguable study designs, great heterogeneity, and questionable quality. Conclusions: The terms AVP and DVP have been coined as a first step to clarify and simplify concepts and workflows related to the use of both mechanical and virtual articulators, as well as facebows, or facial and intraoral scanners, among others. This scoping review cannot claim that an AVP approach leads to more effective and efficient prosthetic restorations.

INTRODUCTION

Manufacturing dental prostheses has historically been supported by the use of different devices - such as mechanical articulators and facebows - to obtain the most realistic scenario to rehabilitate the patient during the prosthodontic workflow.[1]

These devices have tried to establish the 3D spatial situation of the dental arches in relation to the craniofacial complex as well as the correct simulation of the static positions between the maxilla and the mandible. On the other hand, detecting the hinge axis and the real dynamic movements of the patient have been systematically registered by means of axiography or pantography to individually adjust the articulator for all single patient's jaw positions and movements.[2-4]

At this point, the term Analogic Virtual Patient (AVP) is proposed to be coined as any attempt of reproducing the real anatomy, 3D spatial position and patient's kinetics during diagnosis, planning and treatment workflows by using whichever mechanical device (articulator, facebow, axiography or pantography) and its corresponding associated elements (plaster model, wax registers, etc.).

This simplified "virtual patient" version is not able to simulate the muscle patterns and resilience of the soft tissues, joint disc, tooth mobility, etc. Therefore, it is unable to reproduce real life conditions.[5]

Due to all the above-mentioned limitations, and added to its extensive time-consuming procedures and debated effectivity, many clinicians have abandoned the use of these devices with or without openly admitting it to their colleagues. In fact, in a near future, it will be assumed that only some traditional prosthodontists will continue to use them. Thus, perhaps it would be more reasonable to use them for educational purposes.[1,6-10]

Nowadays, due to the implementation of digital workflows in prosthodontics that start with the intraoral digitalization of the patient's mouth by means of intraoral scanners (IOS), Computer-Aided Design and Computer-Aided Manufacturing (CAD/CAM) technology have incorporated an important group of hardware/software that may include virtual articulators, digital facebows, jaw motion analyzer or jaw tracking devices as well as face scans.[11-16] In this sense, the continuous and quick improvement of the IOS has sped up the use of the rest of these devices.[17-20]

Following the same approach as in the Analogic Virtual Patient (AVP), it is also proposed to coin the term Digital Virtual Patient (DVP) as any attempt of reproducing the real anatomy, 3D spatial position and patient's kinetics during the diagnosis, planning and treatment workflows by using whichever digital device - virtual articulator, digital facebow, jaw tracking devices or facial scanners - and its corresponding associated elements (digital model, 2D pictures, etc.)

At the same time, the necessity of adapting occlusal surfaces according to functional and biological principles has gained more attention among specialists, particularly since the introduction of CAD/CAM monolithic restorations. Ascribed to the chemical characteristics of these types of ceramics, direct intraoral adjustments in their structure are not recommended - as they can be in cases of other materials like resin composite, feldspathic ceramic, or even metal surfaces. [21]

Currently, there are several methods to perform a complex and detailed occlusal analysis. Although some practitioners still use mechanic articulators to obtain prosthodontic restorations, computerized diagnostic methods are definitively entering the dental field to a greater degree every day, especially since the implementation of the IOS.[9,10]

At this point, it is important to thoroughly analyze the information published in order to avoid committing the same mistakes that were made in the analog world. We have been working with AVP without having demonstrated the efficacy of mechanical articulators and their associated devices. For this reason, the aims of this scoping review were:

a) to clarify terminology and concepts related to devices associated with the analogic and digital virtual patients (AVP and DVP) that is: mechanical and virtual articulators, face bows, jaw track analyzer and face scanners; and b) to determine whether the use of these devices really improves the virtual patient (AVP or DVP) obtained and the efficacy of the prosthesis created in terms of lifespan, and patients related outcomes.

MATERIALS AND METHODS

A scoping review was conducted on the available evidence of using different devices and techniques to create an AVP or DVP for effective and efficient prosthetic rehabilitations.

The Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) Checklist and the JBI guideline (JBI´s critical appraisal tools) were followed.

PROTOCOL AND REGISTRATION

This study was firstly submitted for registration to Prospero (in November 2021 with the ID 288802, N.CRD 4202128880, under the title: "Virtual articulators vs. Mechanical articulators. Do they improve the occlusion of our prosthetic restorations?". It was conformed to the Cochrane Handbook (Higgins and Green, 2011) and adopted the PRISMA items for Systematic Reviews (Moher *et al*, 2009).

However, after conducting the systematic search it was concluded that there were no publications with enough scientific quality. Moreover, the search strategy found many articles presenting different techniques and devices undoubtedly related and quite difficult to separate from the previous aim. With this scenario, it was decided to set up firstly this scoping review to address the existing problem and lay the groundwork for future clinical research.

POPULATION, CONTEXT AND CONCEPT (PCC)

Based on the objectives and clinical justification of this study PCC was proposed *(Figure 1*), and the following focus questions were established:

1. In dentistry, and specifically in its scientific literature, is there clear knowledge concerning terminology, role and workflows of the different devices involved in the creation of the so-called analogic and digital virtual patients?
2. Does the use of these devices combined to create AVP and DVP really improve the efficacy of the prosthesis obtained in terms of lifespan, and patients related outcomes when compared to not using them?

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SEARCH STRATEGY AND INFORMATION SOURCES

Systematic reviews/meta-analyses, RCTs (Randomized Controlled Trials) and observational studies, as well as articles included in the grey literature that contributed to the study, were reviewed.

The following search strategy was developed, including terms related to the Population / Concept / Context and Outcomes combined with Boolean operators:

((“Dental Models”[MeSH Terms] OR “dental model*”[Title/Abstract] OR “Dental Articulators”[MeSH Terms] OR “articulator*”[Title/Abstract] OR “virtual articulator*”[Title/Abstract] OR “facebow*”[Title/Abstract] OR “jaw tracking devices *”[Title/Abstract]) AND (“Dental Occlusion”[MeSH Terms] OR “occlus*”[Title/Abstract] OR “interocclus*”[Title/Abstract])) NOT (“Comment”[Publication Type] OR “editorial comment*”[Text Word] OR “Editorial”[Publication Type] OR “editorial*”[Text Word] OR “editors note”[Text Word] OR “Letter”[Publication Type] OR “letter to editor”[Text Word] OR “Retraction of Publication”[Publication Type] OR “retracted publication”[Text Word]).

Six databases were searched *(Figure 1)*.

CRITICAL APPRAISAL OF INDIVIDUAL SOURCES OF EVIDENCE AND SCREENING.

A light qualitative risk of bias assessment was made based on the study design chosen in each article.

The definition of study design reported in every article was accepted unless there was clear evidence that a different approach was applied. Thus, a classification of articles according to study design was made (Systematic Reviews, Meta-analysis, Randomized Controlled Trial, Observational Studies, Comparative Studies and Others Studies).

The quality assessment of the included studies was performed by two reviewers following the JBI guidelines (Joanna Briggs Institute; Prisma -SCR: Preferred Reporting Items for Systematic review and Meta-Analyses extensions for Scoping Reviews).

EXTRACTING AND CHARTING RESULTS (DATA CHARTING PROCESS AND DATA ITEMS); SYNTHESIS OF RESULTS

Using Rayyan web application (http://rayyan.qcri.org), a two-stage screening was carried out independently by two experienced reviewers. During the first stage titles and abstracts that were not clearly related to the PCC questions were discarded (2704 out of an initial total of 3441). During the second stage, screening of full-text articles, 737 articles were screened and 120 were selected. A table with this final figure (120) was developed to check the methodological quality and to clarify the selection of articles *(Figure 2)*.

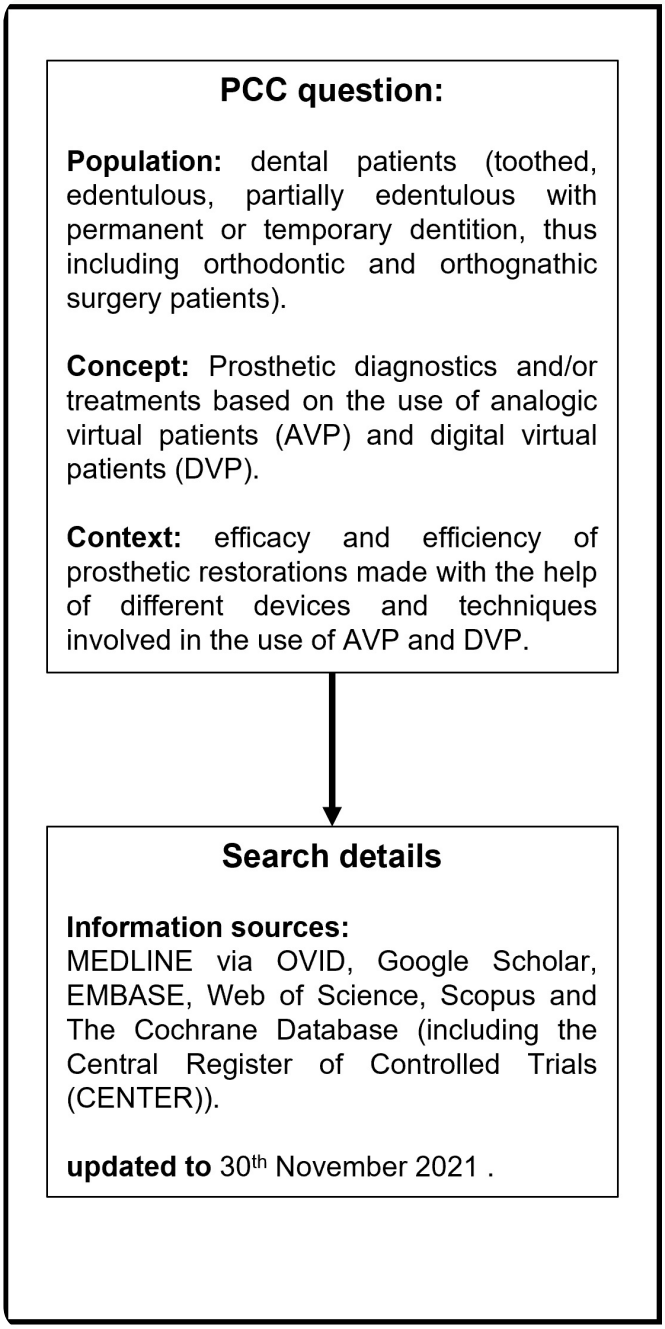

Figure 1: Population, Concept and Context (PCC) and search details.

All studies were analyzed by two reviewers (MR and AGN) to check the eligibility of each paper. Full articles of relevant papers and all those that were difficult to classify were compared. High agreement between reviewers was achieved (Kappa: 0.89). In case of disagreement, a third opinion (GP) was consulted, and a final decision was made. Results of the chosen studies were recorded, and a descriptive analysis was performed based on the technique used.

For data management Zotero bibliographic reference manager version 6 was used (https://biblioguias.biblioteca.deusto.es/Gestoresbibliograficos/zotero).

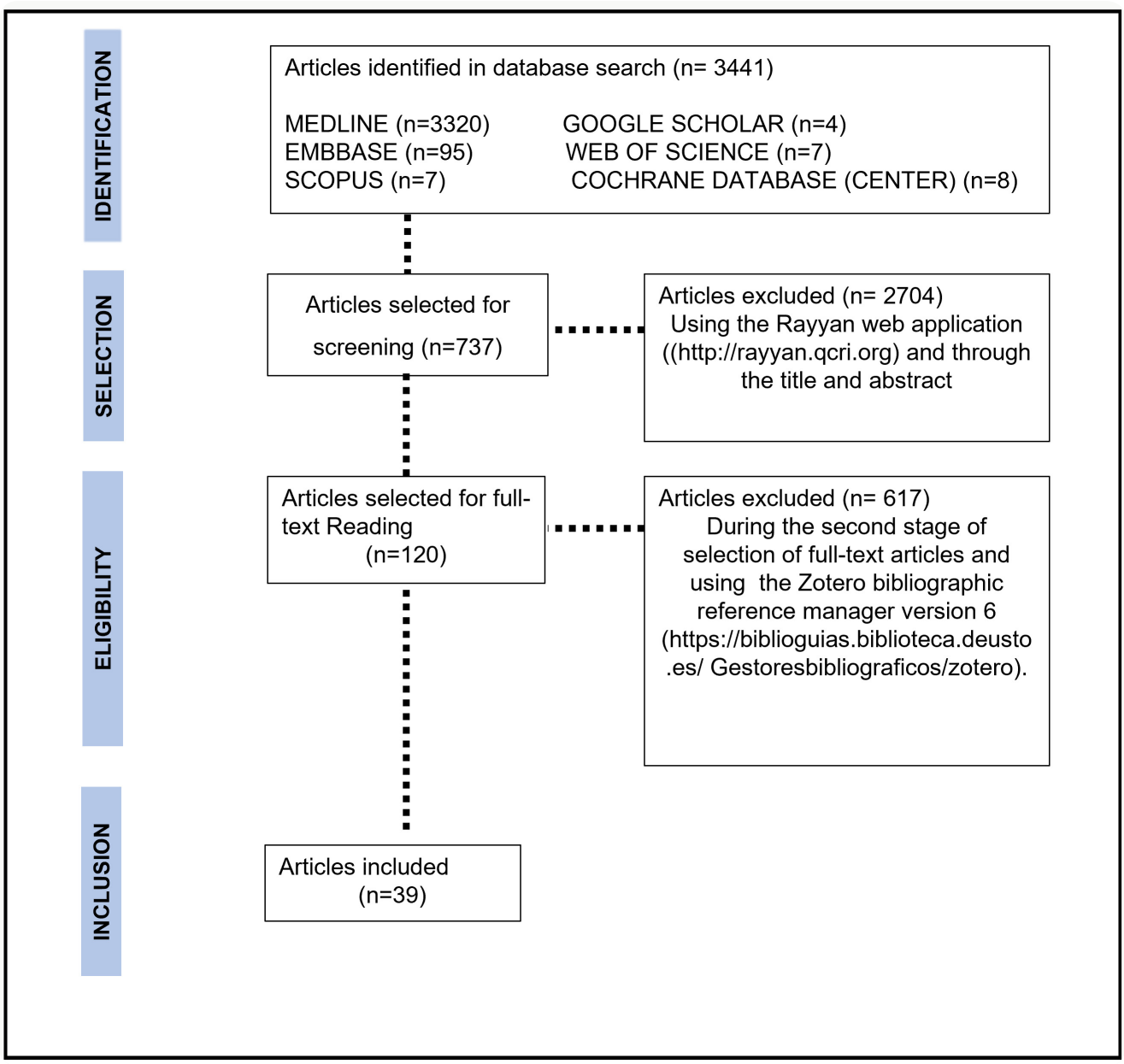

Figure 2: Flowchart of study search and selection process.

An Excel spreadsheet (Excel 16.64 for Mac, Microsoft, Redmond USA) was created with different items that were used to classify and finally select the pre-selected articles (120 articles out of an initial total of 3441). From it, a final Excel spreadsheet with its corresponding table was sketched with the final 39 full-text selected articles *(Table 1)* to summarize some qualitative considerations of the most representative articles that studied devices and techniques related to both AVP and DVP.

RESULTS

After a thorough review of the available literature in AVP and DVP, a great heterogeneity in study designs, devices, techniques, and workflows was found. Most of them were even based on concepts and considerations that had been accepted without any previous scientific validation. Equally, there was no evidence that prostheses obtained when using some of the devices related to AVP/DVP achieved better results than those fabricated without them. For a rationale and practical analysis of the state of the art of all different devices related to prosthodontic rehabilitation, the authors considered starting reviewing basic concepts, definitions, and different classifications as the only way for achieving a further in-depth analysis in this scoping review.

Dental articulators are mechanical instruments that try to recreate the relationship of the temporomandibular joint (TMJ), the maxilla, and the jaw, by mounting the upper and lower plaster models on the instrument.[7]

Face Bows, on the other hand, can be defined as caliper-like devices that transfer the position of the maxilla with respect to the cranium basis in the same 3D spatial position as the one found in the patient. At the same time, depending on the typology of these devices, the real hinge axis of the patient can also be transferred.[19,22-25]

Table 1. Characteristics of included studies.

Study	Year	Categories	Purpose/ Objective	Design	# Cases	RCT	Author's Conclusions/Findings	AVP or DVP
Piehslinger E., *et al.*[50]	1995	Convencional Face Bow	Evaluate the effect of arbitrary mounting of maxillary casts on occlusal relationships.	*In vivo*	31	No	The results revealed that the use of an arbitrary face bow causes a deviation of the hinge-axis points from the precise axis of more than 5 mm in 77% of the cases	AVP
Tamaki K., *et al.*[4]	1997	Conventional Articulator/ Conventional Facebow/ Determinant of occlusion	To assess the reproduction of excursive tooth contacts with a SAM2 "P" articulator set up with the aid of computerized axiography.	*In vivo*	45	No	Clinically, these findings suggest that there are limits to the ability of the articulator to reproduce excursive tooth contacts. These limitations should be kept in mind when an articulator is used for diagnostic and restorative dental procedures.	AVP
Kubrak J., *et al.*[25]	1998	Conventional Articulator/ Face Bow/ Determinant of Occlusion	Therefore the aim of my study was to elaborate a simple method of occlusal recording. I have also compared the treatment results of edentulous patients treated with the use of an articulator and the use of a traditional method. Prosthetic restorations were prepared among 60 patients. The study material was divided into two groups of 30 patients each. In the control group for preparing complete dentures the Gysi method was employed as the most common. In the study group a face-bow and articulator were used.	*In vivo*	60	Yes	In the control group adaptation period lasted 3 to 42 days, an average of 18.4 days (Table. 1). A significant difference was obtained. An analysis of the number of reviews with need of occlusal adjustment (Table. 2) in the QM group showed that most patients needed 1 adjustment or such procedure was not necessary. In the control group 2 or 3 adjustments were necessary (79%). Presented data show that dentures prepared with the use of an articulator are more physiologic and ensure a balanced occlusion. In the method with the use of an articulator a shorter adaptation period is necessary. A subjective patient estimation of the dentures was also positive for the articulator method. The introduced modification of recording the occlusion ensures an efficient and fast mounting and demounting of the face-bow and its use becomes very advantageous. Semiadjustable articulators should be essential instruments in rehabilitation of edentulous patients. The elaborated procedure is a simple and not time-consuming method. It ensures positive treatment results of edentulous patients assuring all basic aims of masticatory organ rehabilitation.	AVP
Bernhardt O., *et al.*[2]	2003	Jaw Track Motion/ Determinat of Occlusion	The goal of this study was to determine the measuring accuracy of the Cadiax Compact system in a clinical series of tests and to determine whether there is a clinically significant difference between the 3-dimensional measurements recorded from kinematically and arbitrarily determined transverse horizontal axes.	*In vivo*	30 subjects: 11 women, 19 men; ages 21 to 26	No	The kinematic and arbitrary measurements of the Cadiax Compact system could be reliably used for articulator programming. The results suggest that arbitrarily determined posterior reference points may be comparable to a kinematically determined transverse horizontal axis.	AVP / DVP
Ruge S., *et al.*[37]	2008	Virtual Articulator/Jaw Track Motion	This software (3D virtual articulation system module of the Zebris company, D-Isny) and its possibilities are described and explained by reference to individual cases.	*In vivo*	Not applicable	No	Should the occasion arise, the goal must rather be to replace systems with lower performance, such as the mechanical articulator. The model we have presented is indubitably interesting for patient communication, but it is also a type of virtual articulator that can clearly improve the static and dynamic occlusion of dental restorations produced by CAD-CAM techiques.	DVP
Zabarović D., *et al.*[53]	2009	Conventional Articulator	To research the possible influence of difference in construction of mechanical joint in arcon and non arcon articulators, upon the adjustment of condylar inclination by intraoral protrusive record.	*In vivo*	30	No	The arcon articulator, due to constant relation between occlusal plane and mechanical fossa, reproduces the movements more accurately. In daily clinical practice, errors in fabrication of prosthetic restorations, caused by construction of mechanical joint, are practically negligible. In education, arcon articulator is more suitable for the beginners, since the movements are identical to those of natural joint, and therefore easy to comprehend.	AVP

Table 1 continued overleaf

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Zizelmann C., *et al.*[61]	2012	Conventional Articulator/ Virtual Articulator/ Conventional Facebow/ Extraoral scanner	Determine the magnitude of error in face-bow recording. Both device- specific inaccuracy and deviation from the reference plane were determined in this study. Assuming that the presented computer-assisted 3D analysis offers a precise evaluation	*In vivo*	15	No	The traditional use of face-bow devices showed inaccuracies in model mounting as well as in assignment of anatomic reference planes. Three-dimensional virtual computer-assisted planning seems to be more accurate than conventional methods.	AVP / DVP
Abizadeh N., *et al.*[74]	2012	Conventional Articulator/ Virtual Articulator	To compare measurements of occlusal relationships and arch dimensions taken from digital study models with those taken from plaster models.	*In vitro*	112 sets of plaster models and 111 sets of digital models.	No	Digital study models can therefore be considered for use as an adjunct to clinical assessment of the occlusion, but as yet may not supersede current methods for scientific purposes.	AVP / DVP
Farias-Neto, A., *et al.*[22]	2013	Face Bow/ Determinant of Occlusion/ Conventional Articulator	The aim of this investigation was to determine whether the transfer modality (anatomic facebow vs. average mounting) from the patient to the articulator affect the three-dimensional condylar shift between the MI and the CR in asymptomatic subjects with normal occlusal rela tionship (Angle class I).	Sistematic Review	Not applicable	Yes	Current scientific evidence suggests that face-bow transfer is not imperative to achieve better clinical results in prosthodontics. Randomised clinical trials suggest that simpler approaches for the construction of complete dentures and occlusal splints may present acceptable results, while no clinical study has investigated its use in fixed and removable partial dentures.	AVP
Solaberrieta E., *et al.*[11]	2015	Conventional articulator/ Virtual Articulator	To validate a virtual procedure to locate the mandibular cast in a 3-dimensional (3D) spatial position and to verify the occlusal contact points in reference to the corresponding maxillary cast on a virtual articulator	*In vitro*	1	No	The accuracy provided by a virtual occlusion procedure is greater than that of the traditional physical interocclusal record. Additionally, knowing the deviation of each alignment (best-fit operation or algorithm) is useful.	AVP / DVP
Abduo J., *et al.*[21]	2015	Conventional Articulator/ Virtual Articulator	This study aims to evaluate the impact of conventional and digital prosthodontic planning on lateral occlusion scheme.	*In vitro*	10 models	No	Observational study is to evaluate the effect of two forms of fixed prosthodontic planning. The difference in the number and pattern of contacts is very minimal between the two wax ups.	AVP / DVP
Shetty S., *et al.*[48]	2016	Convencional Face Bow/ Conventional Articulator	Compare the accuracy of the angle made by Frankfort horizontal planeocclusal plane on maxillary cast, mounted on Artex Amann Girrbach articulator using Rotofix Artex facebow which uses nasion as the third point of reference and Hanau Widevue articulator using SpringBow Hanau facebow which uses orbitale as the third point reference with cephalometrically derived Frankfort horizontal planeocclusal plane angle.	*In vivo*	30	No	From the statistical value (r) derived, it can be inferred that the Frankfort horizontal plane-occlusal plane angle of the casts articulated on Hanau Wide-vue articulator was more accurate in comparison to that on Artex Amann Girrbach articulator.	AVP
Hue O., *et al.*[62]	2016	Electronic Axiograph	Published literature on mandibular movements is extensive, but it lacks scientific robustness and is understandably controversial. This preliminary study recorded and assessed characteristic forms and condylar path inclination patterns during mandibular protrusion and opening in completely edentulous subjects.	*In vivo*	60	No	Completely edentulous subjects present radically different sagittal condylar paths when compared with dentate patients. These differences result from alterations in disc-condyle relationships and morphologic changes in bone structure. No link was observed between condylar paths recorded in protrusion and opening movements. Consequently, condylar guidance for articulators should be set using recordings from protrusive movements.	AVP / DVP

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Anusha C.V., *et al.*[23]	2016	Face Bow	The present study was aimed to assess the transferability of occlusal plane (OP) orientation from the patient to the articulators with the help of two different facebow systems and evaluated with a gold standard.	*In vivo*	20 dentate patients	No	Cephalometric evidence, which was considered as the gold standard for the study. Hanau articulator showed closer values to that of cephalometric values in comparison with Whip Mix articulator system. Orientation of the maxillary cast in an articulator is a crucial part of several techniques used in dentistry. Orientation of maxillary cast in the articulator acts as a baseline from which further steps for occlusal rehabilitation of the patients are carried out. Recording and transferring of the occlusal cant to articulators require facebow.	AVP
Bohner, Lauren Oliveira Lima, *et al.*[77]	2016	Intraoral Scanner	The aim of this review was to update the literature with regard to the digital methods available by CEREC Chairside system to register and design the occlusion, to report their efficacy and technical innovations in the field of Restorative Dentistry.	Sistematic Review	Not applicable	No	Digital technologies allow the design of occlusal surfaces of CAD-CAM fabricated prostheses using innovative approaches. This systematic review aimed to update the literature to help dentists determine the most appropriate digital method to register and design the occlusal surface of CAD-CAM crowns.	DVP
Arslan Y., *et al.*[75]	2017	Intraoral Scanner	To evaluate the accuracy of the CEREC CAD/CAM system in reproducing the maximum intercuspal contacts of the casts, which include posterior teeth preparation for a fixed partial denture.	*In vitro*	10 pairs of gypsum casts	No	When there is no posterior antagonist contact following tooth preparation for an FPD, taking a full-arch digital impression and designing the restoration on full-arch virtual models can be advocated.	DVP
von Stein-Lausnitz M., *et al.*[26,55]	2018	Convencional Face Bow	Evaluate the impact of face-bow registration for remounting complete dentures (CDs) on oral health-related quality of life (OHRQoL).	*In vivo*	32	Yes	From the patient's perspective, mean-value-based remounting methods are of value. The use of a face-bow was not perceived as superior.	AVP
von Stein-Lausnitz M., *et al.*[54]	2018	Convencional Face Bow/ Conventional Articulator	Evaluate the impact of face-bow registration for remounting complete dentures (CDs) on the occlusal parameters.	*In vivo*	32	Yes	Considering the complex multistep study design, a limited number of participants, and referring to one specific arbitrary face-bow, the following conclusion could be drawn: no substantial difference by the use of the arbitrary face-bow compared to a mean setting could be determined, when changing the vertical dimension in the articulator within a remounting procedure of complete dentures.	AVP
Khan Farhan Raza, *et al.*[24]	2018	Face Bow	The objective of this study is to assess the utility of facebow transfer in the fabrication of occlusal splints, complete dentures and full arch fixed dental prosthesis.	Sistematic Review	Not applicable	Not applicable	The use of facebow did not yield a superior fit or comfort of the complete dentures or occlusal splints. Therefore, there is no evidence of the utility facebow transfer for these prostheses. However, no inference could be drawn for its utility in full arch fixed dental prosthesis as there were no studies to draw an inference	AVP
Seo J-M., *et al.*[20]	2019	Intraoral Scanner/ Determinant of Occlusion	Describes a method of verifying the accuracy of virtual mounting against the actual occlusal contacts marked with colored articulating paper.	*In vivo*	1	No	This method can reduce occlusal errors and the chair time needed for occlusal adjustments by allowing the dental practitioner to verify the accuracy of the digital interocclusal record before fabricating CAD-CAM dental prostheses but this method of verification is not suitable for all commercially available computer programs and is applicable only to color intraoral scanners.	AVP / DVP
Robin P.K., *et al.*[49]	2019	Convencional Face Bow/ Conventional Articulator	Study and compare the clinical accuracy of orientation jaw relation recorded with various commercially available facebows.	*In vivo*	3	No	Hanau and Stratos facebow articulator systems appear to be significantly more accurate compared with the Artex, Denar and Whipmix facebow articulator systems and so can be considered as the system of choice to fabricate complex dental restorations.	AVP
Hsu Michael R., *et al.*[68]	2019	Mechanical Articulator/ Virtual Articulator	To study the effects of altering condylar settings and pin openings on the trueness and precision of virtual articulators vs. mechanical articulators.	*In vitro*	1	No	Dynamic movements on the virtual articulator were shown to be as true and precise as to the mechanical articulator. When there were deviations, these deviations were less than 100 µm and thus, these deviations may not be clinically relevant.	AVP / DVP

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Mazurkiewicz P., *et al.*[52]	2019	Determinant of Occlusion	The purpose of the present review was to demonstrate the utility of articulator systems and link instrumentation in determining the occlusal plane. The impact of the natural head position and anatomical landmarks on the occlusal plane location has been reported in the literature. Properly chosen instrumentation and management methods eliminate errors in determining the occlusal plane.	Narrative Review	Not applicable	Not applicable	11 original approaches to occlusal plane determination were identified. based on real or virtual solutions. Owing to the large variety of devices, additional comparative studies are needed.	AVP / DVP
Hasan K., *et al.*[32]	2019	Virtual Articulator	In this modern world of advanced in information technology, it has greatly improved our standard of living, gaining experience, communicate, and entertain. Many innovative and technological advancements have been introduced in the field of dentistry. The change in trends from numerous mechanical articulator designs to recently developed virtual articulators is an advance in the development of articulator design.	Narrative Review	Not applicable	No	Virtual technologies in dentistry are used to provide better education and training by simulating complex recording of mandibular movements and enhancing procedures that are traditionally limited, such as work with the mechanical articulator. The virtual articulator is intended to use as a tool for the analysis of the complex static and dynamic occlusal relations.	AVP
Úry E., *et al.*[35]	2020	Conventional Articulator/ Virtual Articulator/ Conventional Facebow/ Extraoral scanner	To investigate the accuracy of the virtual dental space using the indirect digital workflow (extraoral scanning of plaster models).	*In vitro*	18	No	The correspondence between the number and position of analog and virtual contacts was high. The mean absolute deviation of the matching point-pairs was better than that reported for the direct digital method. Under the conditions described, the virtual dental space created with the indirect digital method can be reliably used for virtual occlusal analysis in clinical practice.	AVP / DVP
Huang Y.T., *et al*[72]	2020	Virtual Articulator	To review the recent progress in the field of operation and clinical application of multiple virtual articulators.	Narrative Review	Not applicable	Not applicable	Although it has been studied for about 20 years, virtual articulator has not been widely applied because of technical sensitivity and high cost. The transfer of articulator needs to scan the mandible model and record the mandibular movement relation. To define mandibular movement relation, average mandible parameters can be used, the ultrasonic sensor, photoelectric sensor, digital face bow or cone beam computed tomography for individualized records can also be used. At present, virtual articulator has been used in fields of orthognathic surgery, temporomandibular joint disease, implant, and aesthetic repair. Comparative studies have shown that accuracy can meet clinical requirements and save time. However, differences between occlusal systems need to be detected. Virtual articulator can save clinical operation time, improve accuracy, make up for the limitations of mechanical articulator, and has a wide range of application prospects.	DVP
Naqash T.A., *et al.*[58]	2020	Conventional Articulator/Face Bow/CBCT	The goal of registering the condylar guidance is to recreate the patient's occlusion as exactly as possible on the articulator, and is therefore essential for successful prosthodontic rehabilitation. Clinical, radiographic, and pantographic methods are used to determine sagittal condylar guidance angles (SCGAs). These methods generate different angles in the same patients. The present study is the first disquisition to evaluate and correlate SCGAs determined by the use of pantographic tracing (PT), protrusive records (PR), and radiographic (CBCT) techniques.	*In vivo*	23	No	Strong correlations were found between SCGAs obtained using PT, PR, and CBCT techniques.	AVP / DVP

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Buduru S., *et al.*[65]	2020	Jaw Track Motion / Conventional articulator/ Face bow/ Intraoral scanner	Identifying the optimal method for occlusion analysis by comparing examination sensitivity of the static and dynamic occlusion using three systems: clinical occlusion analysis, semi-adjustable articulator and virtual articulator (3Shape, Denmark) occlusion analysis.	*In vivo*	16 subjets	Yes	The semi-adjustable articulator was superior in static and dynamic occlusion analysis compared to the virtual articulator.	AVP / DVP
Carossa M., *et al.*[66]	2020	Jaw Track Motion/ Determinant of Occlusion	Bionic Jaw Motion system is based on two components: a jaw movement analyzer and a robotic device that accurately reproduces recorded movements. The jaw movement analyzer uses an optoelectronic motion system technology made of a high frequency filming camera that acquires 140 frames per second and a custom designed software that recognizes and determines the relative distance at each point in time of markers with known geometries connected to each jaw.	Narrative Review	Not applicable	No	This robotic system represents an important advancement compared to available analogical and digital alternatives both in clinical and research contexts for cost reduction, precision and time saving opportunities.	AVP / DVP
Yang S., *et al.*[43]	2021	Facial Scanner	To align the intraoral scans to a virtual articulator by using a facial scanner to locate the patient's cutaneous landmarks of the arbitrary hinge axis and the reference plane, and to customize the sagittal condylar inclination of the virtual articulator through a digital protrusive interocclusal record and a dental computer-aided design software program.	*In vivo*	1	No	It enables individual cast orientations and virtual articulator parameter settings without conventional facebow transferring and bite registration procedures and can be easily integrated with most virtual articulator systems on the market to allow clinicians and technicians to work in a complete digital workflow and facilitate customized treatment planning and dental prosthesis fabrication.	DVP
Zhang R., *et al.*[19]	2021	Conventional articulator/ Virtual Articulator	To evaluate and compare the occlusal fit of zirconia crowns designed using a digital articulator method and the traditional method in a self-controlled clinical trial.	*In vivo*	12	No	During the clinical occlusal evaluation, no significant differences were observed between the two groups of crowns regarding occlusal adjustment time, articulating paper examination, T-Scan and EMG examinations, and patients' subjective evaluations. The results indicate that single complete crowns fabricated using a digital articulator meet clinical standards but show no advantages over crowns fabricated using the traditional method.	AVP / DVP
Lepidi L., *et al.*[69]	2021	Conventional Articulator/ Virtual Articulator/ Determinant of Occlusion	The aim of this review was to discuss the current knowledge surrounding the various techniques and methodologies related to virtual mounting in dentistry, and whether virtual articulators will become commonplace in clinical practice in the future.	Narrative Review	Not applicable	Not applicable	This review outlines the current status of VA assembly procedures in digital dentistry and provides encouraging evidence supporting the clinical implementation of fully-digital workflows aimed at assembling VAs to aid in the diagnostic and treatment planning phases of complex cases.	DVP
Iwauchi Y., *et al.*[28]	2021	Intraoral Scanner/ Determinant of Occlusion	The purpose of this clinical study was to compare the precision of IOS interocclusal registration with that of conventional methods with a silicone impression material and a gypsum cast.	*In vivo*	8	No	These results suggest that the intermaxillary relationship captured by the digital scan method by using IOSs had better precision than that obtained by the conventional method	AVP / DVP
Li J., *et al.*[73]	2022	Facial Scanner	To investigate the trueness and precision of virtual facebow records using a smartphone as a three-dimensional (3D) face scanner.	*In vivo*	2 (20 repetitions)	No	Virtual facebow records made using smartphone-based face scan can capture the maxilla position with high trueness and precision. The deviation can be anticipated as around 1 mm in linear distance and 1° in angulation.	DVP

Table 1 continued overleaf

Table 1. continued...

Li L., *et al.*[71]	2021	Intraoral Scanner/ Virtual Articulator	The purpose of this clinical study was to record patient-specific motion by using an intraoral scanner and to analyze its ability to design the morphology of the wear facets on mandibular first molar crowns.	*In vivo*	11	No	The occlusal surface of the crowns designed by using the patient-specific motion recorded with the intraoral scanner had the best coincidence with the morphology of the wear facets on the original teeth.	DVP
Bapelle M., *et al.*[76]	2021	Jaw Track Motion/ Conventional Articulator	The literature review aimed to compile and summarize the results of research relating to the recordings of condylar displacements obtained with extraoral devices, to guide clinicians to set dental (virtual) articulator parameters.	Sistematic Review	Not applicable	No	All 20 articles selected corresponded to a total of 933 subjects evaluated. The recording devices and horizontal reference planes had a significant impact on the SCI values	AVP / DVP
He M., *et al.*[64]	2021	Virtual Articulator/ Determinant of Occlusion	To analyze the accuracy of transferring casts in maximal intercuspal position to a virtual articulator by using transfer plates in the laboratory scanner beforeand after occlusal optimization.	*In vitro*	5	No	The accuracy of transferring casts in maximal intercuspal position to a virtual articulator using transfer plates in the laboratory scanner could be improved after occlusal optimization and can meet the clinical needs for occlusal design and analysis of prostheses.	AVP / DVP
Hong S-J., *et al.*[70]	2021	Facial Scanner/ Intraoral Scanner/ Determinat of Occlusion	This technique article describes obtaining the sagittal condylar inclination (SCI) by using a facial and an intraoral scan of the protrusive interocclusal position.	Narrative Review	Not applicable	No	The SCI can be used on a virtual articulator in dental computer-aided design (CAD) software programs, which can facilitate the fabrication of functional prostheses without occlusal interferences.	DVP

Abbreviations: #RCT: Randomized Controlled Trials, #AVP: Analogic Virtual Patient, #DVP: Digital Virtual Patient.

Historically the first articulator was no more than a plaster key to articulate models (Philip Pfaff,1713-1766). Most people consider Jean Baptiste Gariot as the inventor of the first "articulator of hinge" in 1805. The first scientific articulator reported was the one developed in 1805 by Bonwill, based on his triangle theory. From this point on, mechanical articulators have suffered many different proposals and modifications, which can be classified depending on different characteristics.[26-28]

At this point, some important considerations about the different categories must be bearded in mind:

First, a hinge articulator should not be considered as an articulator since its own reliable position will be the maximal intercuspation and the only reliable movement would be opening and closing. Hence, it can be stated that the mounting of the model is totally arbitrary – owing to the lack of the use of any facebow, thus, the radius from the center of rotation to the lower incisors of the patients is totally invented.[29]

Average value articulators, also known as fixed value articulators, tend to be a good option for clinicians that don't want to invest a lot in their acquisition but want to work with these devices. A prerequisite in these cases may be that clinicians have to use an arbitrary facebow and that the articulator selected has to be able to accept this registration in order to have a supposedly correct cranio-maxillary transference.[1,30] For these articulators, the most frequent fixed values are 40/15 or 25/10, being the first value the Sagittal Condyle Inclination (SCI) and the second one the Bennet Angle (BA). These articulators usually don't usually have any other parameters - neither fixed nor adjustable.

Semi adjustable Articulator should be the most reasonable option since it accepts the use of a facebow and the modification of parameters such as SCI or BA.[31] However, most clinicians do not invest time in making axiographic or wax registers (protrusive and lateral), so they ultimately use this articulator with the same fixed values no matter the clinical case they are working on. This averts any possibility of a reasonable coincidence between the reality and the case.

Fully adjustable articulator is a kind of articulator in which it is not only possible to program parameters such as intercondyle distances, SCI, BA, side shift or immediate Bennet movement (SS) or retrusive area, among others, but also the customized movement trajectories for each patient. To do so, the location of the real hinge rotation and the use of a pantograph device specially developed for this articulator is mandatory. The adjustable articulator and the pantograph have only been used for full prosthodontic rehabilitations in the hands of expert prosthodontists and, predominantly, in an educational environment.[32] *(Table 2)*.

Regarding Facebow, its mission is to allow the superior model to be held in the articulator in the correct 3D spatial position regarding the cranio-maxillary relationship of the patient. There are mainly two types of facebows: the one considered as arbitrary, which basically obtains an average position of the hinge

Table 2. Classification of Mechanical Articulators

	Classification of Mechanical Articulators		
			Trade Marks
Regarding the position of the condyle	ARCON: Articulated Condyle	The condyle is attached to the lower arm.	Denar® Whipmix® Stratos® Protar® 2 Artex® Arquímedes® PRO A7 PLUS® E Perfect® Dentatus® ARA Hanau® 130-21 Quick Master®
	NON ARCON: Non articulated condyle	The condyle is attached to the upper arm.	Dentatus® ARH,ARL Balance® 105 Hanau® H2
Regarding to its capability to accept registers and position by using different devices	Hinge axis	No possibility of any adjustment is available although some parameters might have predetermine fixed values. No face bow is accepted.	Sdent® Mestra® Asa® 5050
Regarding to its capability to be programmed *** All of them accept the use of at least and arbitrary face bow**	Nonadjustable or Fixed Values	They have some parameters like Sagittal condylar inclination Bennet angle, etc. with predetermined fixed values.	Quick® 25/10 Quick® 40/15 Stratos® 100 Protar Evo® 2
	Semi adjustable	Different parameters such as Sagittal condylar inclination, Bennet angle, etc. can be adjusted.	Stratos® 200 Stratos® 300 Protar® III Protar® IV Artex® Sam® 2
	Completely Adjustable * Accept the use of kinematic face bow	Accept parameters regulations as well as dynamic tracks customization.	Panadent® Denar® Stuart®

axis; and the kinematic, that previously uses another device to locate the exact hinge axis of the patient and then transfers it to the articulator. The use of kinematic facebows has been almost anecdotic in the daily clinical practice over the years.[22,23]

As it was previously stated, since the implementation of CAD/CAM protocols and devices - especially IOS and dental cad software - the concept of Virtual Articulators has come up.

Virtual articulators are specific software modules integrated into general software suites devoted to designing dental prostheses. This module simulates the specific mandibular positions and/or movement of the patient based on their digital models in Standard Triangle Language (STL) format. The program analyzes the occlusion and calculates the specific occlusal anatomy that the prosthetic teeth should have in order to avoid premature interferences or contacts according to a previously specified pattern.[28,32-34]

Virtual articulators are basically divided into those based on existing mechanical articulators[35] and those that try to emulate the complex temporomandibular joint (TMJ) system.[36] According to that, although some secondary considerations could be included, they can be categorized as follows:

- Mathematically simulated virtual articulator.
- Completely adjustable virtual articulator.

Mathematically simulated virtual articulator: It is based on mathematical algorithms of the articulator movements of many different virtual articulator copycats from the mechanical ones according to specific modifiable parameters such as: inter-condyle distance, Sagittal Condyle Inclination, Bennet Angle, Immediate side shift, Bonwill Angle, Balkwill Angle, etc.

Dental CAD software allows the virtual simulation of the digital models without any previous customization of the single parameters and the physical cranio-maxillary transference of the patient. However, in an ideal protocol, to use the mathematical virtual articulator as it has been designed and developed, it would be necessary to scan the conventional articulator with the plaster models mounted in it or by means of a special transfer mounting piece after using the physical face bow of the conventional articulator system.

Completely adjustable virtual articulator: This would be the digital interpretation of the old-fashioned mechanical fully adjustable articulator. Therefore, to use it, it is firstly necessary to register the hinge axis of the patients as well as the exact movement paths of the mandible by using a 3D computerized jaw track analyzer (JMA) or motion (JTM).[37]

Jaw tracking devices / Jaw motion analyzer systems: Basically, Jaw tracking systems are devices with different designs and technologies (photographic, magnetic, ultrasonic, optical photogrammetric, etc.)[38] capable of registering the exact hinge axis of the patient as well as the whole real mandibular movements. At the same time, their computerized system offers us the value of parameters such as sagittal condyle inclination, bennet angle, etc.

If you only use the parameters obtained from the device, then you may need to use a mathematical model virtual articulator. On the contrary, if you use all the registered movements registered, you will need to export the file from the Jaw Tracking motion devices to the virtual articulator module of the dental CAD design software as an .XML file extension. It is important to note that not every dental CAD software is capable of accepting this type of files coming from a Jaw Motion Analyzer.[39,40] *(Table 3)*.

Apart from all the previously mentioned devices, to design a correct and functional occlusal anatomy Coachman and Calamita published in 2012 the article: "Digital Smile Design (DSD) a tool for treatment planning and communication in Esthetic dentistry".[41] This article marked an important change in the digital protocols to study and design an harmonic and esthetic smile related to gum tissues, lips and the rest of the main facial characteristics of our patients using specific 2D extra oral pictures. Main dental design CAD software quickly adopted this protocol and, by means of a best fit algorithm, integrated the picture information with the 3D model of the patients to generate final anterior teeth anatomies according to all that.

Table 3. State of the art of current marketed as Virtual Facebows and/or Jaw Tracking devices.

Technology	Virtual Facebow	Company	Expert-Import Capabilities
Ultrasounds (3D)	Zebris® for Ceramill	Amann Girrbach (Austria)	Closed
Ultrasounds (3D)	PlaneSystem ®	Zirkonzahn (ITA)	Open
Ultrasounds (3D)	Jaw Motion Analyzer ®	Zebris Medical (GER)	Open
Ultrasounds (3D)	Arcus Digma ®	Kavo Dental (GER)	Open
Ultrasonic Axiography (3D)	Sam Axioquick ®	Sam (GER) Software	Closed
Optical (4D)	Mod Jaw ®	Mod jaw (FRA)	Open
Optical Sensor Technology Optical (4D)	Jaw Motion Analyser ® Optic Axiographcondylograph	Zebris Medical (GER)	Open

Although DSD protocol has helped clinicians and lab technicians for a better planning and communication, some important limitations have been pointed out regarding to 2D photographs deformation and the correct 3D orientation of the maxilla with respect to the pictures and the 3D models. To solve these problems, offering a 3D picture that better integrates with the 3D models of the patients (.stl files) without deformations, the use of facial scanners was proposed.

Facial scanners are devices using optical technology mainly based on laser light, structured light, or stereophotogrammetry, to record the patient's face in 3D.

They generally provide digital files with information about the morphology, texture and color in 3D file formats such as Object file (.obj) or Polygon File Format (.ply)

The justification for using facial scanners was at first:

1. To analyze and propose in a prosthodontic treatment plan the correct position of the patient's teeth with respect to the lips, facial extraoral esthetic lines and intraoral soft tissues avoiding the typical distortions present in 2D pictures.
2. To facilitate a 3D correct orientation of the digital models in .stl format with respect to the patient's face and the cranio-maxillary position. In this sense, the facial scanner would work as a face bow by using accessory pieces such as fiducial markers associated with the digital models and with specific skin face points. Many different commercial or customized systems have been developed [42,43] despite their arguable effectivity due to graphical distortions produced when aligning the different captured images.[44,45]

DISCUSSION

This manuscript was firstly conceived as a systematic review with possible meta-analysis of the state of the art of using mechanical and virtual articulators.

The search revealed many different devices, concepts, and techniques closely connected with the use of both conventional and virtual articulators, such as mechanical and computerized face bows, mechanical axiographs or pantographs, jaw tracking motion or analyzer systems, facial scanners, etc.

At the same time, the registration of different inter occlusal positions, vertical dimension (VD) and fixed anatomical determinant of occlusion -by means of intraoral wax registers, radiology explorations, orthopantomography (OPG) or cone beam computer tomography (CBCT), among others - are inevitably part of the same workflows and devices described above.

Bearing all this in mind, performing a scoping review was considered to be the best approach, being its main objectives: a) to coin the terms Analogic Virtual Patient and the Digital Virtual Patient as an attempt to group and clarify devices and workflows, and b) to evaluate if their use (single or combined) would provide the most efficient prosthesis in terms of function, lifespan, and patient-reported outcomes (PROs).

In fact, according to the article published by to Munn *et al*, the aim of a scoping review (2018) "is to identify knowledge gaps, scope a body of literature and clarify concepts"[46] thus being a helpful precursor to subsequent systematic reviews.[47]

Starting with mechanical articulators and face bows, it must be noted that, even over the decades, it has not been possible – in terms of scientific quality - to prove their reliability in the reproduction of accurate mandibular movements and positions other than the intercuspal occlusal position.[48,49] Nowadays, with the appearance of virtual articulators, numerous articles are being published based on the same principles of mechanical articulators and, in the same way, their real effectiveness in the reproduction and simulation of mandibular movements is yet to be proven. In addition, there is much confusion about the terminology used and its classification.[19,50]

Semi-adjustable articulators are usually programmed with arbitrary values or by using individual static records, which reliability has always been questionable. These articulators do not simulate the patient's temporomandibular joint (TMJ) anatomy and are based on average condylar settings.[51,52] Not to mention hinge instruments or occluders, which, being the most commonly used devices, are only capable of simulating the relationship of two plaster models in an interocclusal position.[53-55]

Several studies have shown the unreliability of recording and reproducing condylar guidance in semi-adjustable articulators.[56,57] Despite this affirmation, researchers have made great efforts to assess the different methods used to register sagittal condyle inclination values, concluding that independently of the method used - axiography, wax registers, orthopantomography, lateral X-ray, etc. - the values highly correlate, although axiography always obtains higher values.[51,58]

When manufacturing mucosa-supported complete prostheses, comparing the use of mechanical articulators versus not using them, showed no significant differences. In terms of clinical success and patient's quality life.[59]

Regarding arbitrary Facebows, they are inseparably related to articulators, as it is not possible to obtain a correct craniomaxillary relationship without their use. Despite this affirmation making sense, the fact is that Khan *et al*, (2018)[24] in their systematic review concluded that the use of a facebow did not produce superior fit or comfort at least for full dentures or occlusal splints, not having enough information about its usefulness in full-arch fixed dental prostheses. Khan results agreed with the ones obtained by Farias *et al*, (2013).[22] In the same line, Galekovic *et al*, (2015)[60] stated that the use of the facebow and/or average mounting in asymptomatic subjects with normal occlusion were clinically equally effective to transfer the relationship between upper and lower jaws into dental articulators. Moreover, Von Stein-Lausnitz *et al*[54-55] in a multistep double-blind randomized controlled clinical trial over 32 patients in 2018 evaluated, among other variables, the impact

of facebow registration for remounting complete dentures on oral health-related quality of life (OHQRoL). No differences were observed between using the arbitrary face-bow when compared to a mean setting-based procedure.

Over the years, there have been numerous attempts to accurately reproduce each patient's jaw track movements with mechanical articulators, and every increase in accuracy has unfortunately led to a more complex design. This has been the case of Fully adjustable articulators and their corresponding pantographs.[61]

The evolution of these old-fashioned mechanical pantographs led to the development of the first electronic devices capable of digitally recording mandibular movements and calculating fixed determinants of occlusion such as Sagittal condyle inclination, Bennet angle, etc.[2] Although these devices seem to give more reliable information, the data obtained requires to be fitted with the mechanical articulators and their discussed limitations.[62]

At this point of the prosthodontic evolution, research starts combining the use of conventional (mechanical) devices with the use of digital devices and, therefore, the need of establishing a clear terminology arises to determine the role and efficacy of each device.[63,64] Hence, the suggestion to coin the terms AVP and DVP. Analogic Virtual Patient (AVP) represents all the workflows in which mechanical articulators, mechanical face bows, etc. are implicated; while Digital Virtual Patient (DVP) should aim to eventually find a way in which the limitations of the analogic workflows could be solved.

The keywords involved when speaking about DVP in prosthodontics rehabilitation are: 2D photography, intraoral scanner, extraoral scanners, virtual articulator, face scanner and jaw tracking motion systems.[58,65,66] There is currently extensive literature regarding the single or combined use of technologies mentioned above to obtain the digital virtual patient that leads to a successful prosthesis, although just as with AVP, more robust scientific support is needed.

Regarding the use of a virtual articulator based in a mathematical model, it has to be pointed out that the final setting needs the use of an extraoral scan of a conventional articulator and facebow, with their previously discussed efficacy. Interestingly, Buduru *et al*, (2020) concluded in their *in vivo* study that the semi-adjustable articulator was superior in static and dynamic occlusion analysis compared to the virtual articulator.[65] Chkhikvadze *et al*,[67] concluded that the use of a CAD/CAM approach for relaxation splints is preferred to the use of splints made with the aid of a mechanical articulator (the effectiveness of the therapy is 88 and 81.8%, respectively). In contrast, Hsu *et al*, (2019) stated that dynamic movements in the virtual articulator proved to be as true and precise as in the mechanical articulator.[68]

Regarding the use of the so-called real virtual articulator it is clear that its usefulness comes with the combination of a specific jaw tracking system. For that, this device has to be capable of exporting a digital file (normally an XML file) with the jaw movement information and the CAD software has to be able to accept this file and configure the customized algorithm for the specific patient.[64,69] Needless to say, the clinician must own a specific tracking system which is expensive and their success depends on the skill and experience of the operator.[31]

Different alternatives have been described in literature to program virtual articulators without acquiring jaw tracking devices. Lepidi *et al*, (2019) proposed using CBCT and an intraoral scanner, to take advantage of technology that is frequently available in a modern digital office. The workflow described implies the use of additional software to convert the dicom files and to manage the stls generated files.[33] In the same way, Hong *et al*, (2021) described obtaining the sagittal condylar inclination (SCI) by using facial and intraoral scanning of the protrusive interocclusal position. The SCI can be used in a virtual articulator in dental computer-aided design (CAD) software programs, which can facilitate the fabrication of functional dentures without occlusal interference.[70]

Ideally, when programming the virtual articulator all the information should come from the use of an intraoral scanner, without the need to acquire or use any other device. Some interesting developments can be seen in this aspect according to the studies published by Li *et al*, (2021),[71] in which the intraoral scanner is capable of recording the patients jaw movement and then reproducing them in the CAD software. (Jaw Specific Motion, Trios® -3 Shape).

On the other hand, the correct use of a virtual articulator and any associated CAD design software will depend on having a correct occlusal plane according to the cranio-maxillary position of the upper jaw stl file. In this aspect, many proposals have been done by using facial scanners and different accessory devices and workflows emulating a virtual facebow.[42,72]

Finally, the methodology described in many of the published articles, specially devoted to creating DVP workflows refers to customized devices specifically designed for each research study and therefore not accessible to other clinicians. In other publications the devices used, although commercially available, combined with the scarce "material and method" description do not allow their scientific validation by peer researchers.[52,71,73-77]

CONCLUSIONS

1. The terms AVP (analogic virtual patient) and DVP (digital virtual patient) have been coined as a first step to clarify and simplify concepts, and to classify the different devices used to create them (mechanical articulators, virtual articulators, facebows, JTM, facial scanners, intraoral scanners, etc.), in view of the confusion observed in the scientific literature.
2. It has not been demonstrated that an AVP approach leads to more effective and efficient prosthetic restorations, and therefore, a DVP should not be created from analogic workflows as they may introduce more errors in these prosthetic restorations.

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3. It has also not been demonstrated that DVP results in more effective and efficient prosthetic restorations since many of the numerous workflows stablished for DVP in the literature are no more than a technical description of procedures without posterior verification.
4. Given the rapid advance of the digital world in dentistry and the lack of certainty about the efficacy of analogic devices, it is likely that the DVP (once simplified and made accessible) will replace the AVP, both clinically and in teaching.

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