BRAZILIAN JOURNAL OF IMPLANTOLOGY AND HEALTH SCIENCES

ISSN 2674-8169

Virtual Articulator: Integration of Functional Occlusion in Digital Workflows for Oral Rehabilitation

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https://doi.org/10.36557/2674-8169.2025v7n7p787-803
Artigo recebido em 03 de Junho e publicado em 13 de Julho de 2025

Technical Note and Scoping Review

ABSTRACT

This article explores the use of the virtual articulator within the Exocad software, emphasizing its significance in digital dentistry, particularly in oral rehabilitation. Although still underutilized by many professionals primarily due to a lack of knowledge regarding its theoretical foundations the virtual articulator is a key tool for precise prosthetic planning based on classical principles such as Bonwill's equilateral triangle and the studies of Rudolf Slavicek. Clinical experiences have demonstrated that proper application of these principles enhances clinical predictability, minimizes intraoral adjustments, and improves patient comfort. The workflow involves model digitization using either individualized parameters provided by the clinician or standardized values widely validated in the literature. Manual adjustments within the Exocad virtual articulator can be tailored to the patient's anatomical and functional characteristics, enabling a more personalized approach. Results indicate superior outcomes with the digital workflow when the virtual articulator is employed, especially in zirconia-based prosthetic structures, supporting safer, more predictable, and efficient oral rehabilitations.

Keywords: Algorithms, Computer Simulation, Dental Arch, Dentistry.

Articulador Virtual: Integração da Oclusão Funcional em Fluxos Digitais na Reabilitação Oral

RESUMO

Este artigo explora a aplicação do articulador virtual no software Exocad, destacando sua importância na odontologia digital voltada à reabilitação oral. Embora ainda pouco utilizado por muitos profissionais, trata-se de uma ferramenta essencial para o planejamento protético preciso, baseado nos princípios clássicos de Bonwill e Slavicek. Experiências clínicas demonstram que sua configuração adequada aumenta a previsibilidade clínica, reduz ajustes intraorais e melhora o conforto do paciente. O processo envolve a digitalização dos modelos com parâmetros personalizados ou valores médios reconhecidos. O uso do articulador virtual, especialmente em próteses de zircônia, mostrou resultados superiores, reforçando a importância de integrar fundamentos oclusais na prática digital.

Palavras-chave: Algoritmos, Arcada Dentária, Odontologia, Simulação Computacional.

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INTRODUCTION

In the era of digital dentistry, technological tools have substantially transformed the planning and execution of oral rehabilitations. CAD/CAM technology plays a central role by replacing analog workflows with more precise, efficient, and reproducible solutions (1,2). In this context, the virtual articulator available in the exocad software represents a significant advancement, enabling highly predictable and personalized prosthetic diagnostics and planning.

Despite its potential, many clinicians have yet to fully leverage this tool, largely due to unfamiliarity with proper virtual mounting techniques. The effectiveness of the virtual articulator is enhanced when configured based on well-established occlusal theories, such as Bonwill's equilateral triangle and the functional parameters described by Rudolf Slavicek (3,4). Exocad allows for detailed simulation of variables including condylar inclination, Bennett angle, and mandibular trajectories, thus supporting individualized functional analysis (5).

Studies have shown that virtual articulators offer precision comparable to that of traditional mechanical articulators, with added advantages in time efficiency, ease of use, and seamless integration into the digital workflow (6,7). Additionally, they have proven effective in assessing both static and dynamic occlusal contacts, with strong clinical correlation (8).

A randomized clinical trial evaluated three virtual mounting techniques: digitized facebow transfer, Bonwill triangle-based mounting, and 3D facial scanning. The results indicated no statistically significant differences in chairside adjustment time for single-unit restorations, validating the use of configurations based on average anatomical values (9).

In more complex rehabilitations, such as full-arch fixed prostheses, fully digital protocols beginning with virtual articulator configuration have shown excellent reproducibility and integration with functional dynamic models grounded in Bonwill and Slavicek concepts (10).

Accordingly, this article aims to explore the efficient use of the virtual articulator within exocad, focusing on the application of Bonwill and Slavicek's principles. It seeks

to provide an in-depth understanding of the importance of accurate configuration in facilitating the transition from conventional to digital workflows. Furthermore, it aims to demonstrate tangible clinical benefits, such as enhanced treatment predictability and reduced need for chairside adjustments, ultimately contributing to safer and more effective dental practice.

METHODOLOGY

The methodology adopted in this literature review focused on a critical and detailed analysis of scientific publications, as well as clinical case reports related to the application of the virtual articulator within the exocad software. The main emphasis was placed on the integration of classical principles such as Bonwill's equilateral triangle and the condylar adjustments described by Rudolf Slavicek.

Data Collection

Initially, publications describing the acquisition of digital models through intraoral scanning or, alternatively, using desktop scanners applied to gypsum models were selected. This process is essential for obtaining accurate anatomical representations, which are fundamental for the precise configuration of the virtual articulator.

The reviewed literature indicated that when working with clinical records obtained via facebows whether digital or analog the parameters entered the virtual articulator must strictly follow the guidelines provided by the supervising clinician. In the absence of such individualized records, standardized average values were adopted, including Bonwill's equilateral triangle and Slavicek's functional parameters, which offer a reliable foundation for mandibular motion simulation.

Configuration in exocad

The next methodological step involved the analysis of virtual articulator configuration procedures within the exocad software environment. The review highlighted that the system includes pre-set parameters, such as the intercondylar distance of 100 mm (according to Bonwill), while also allowing manual adjustments

tailored to the clinical needs of each patient.

Several studies have reported that in certain workflows, model positioning based on Bonwill's triangle is not automatically loaded and must be manually adjusted. It was found that the accurate positioning of models particularly the proper alignment of the first molar at the vertex of the triangle significantly enhances the precision of occlusal planning.

Adjustments Based on Rudolf Slavicek's Studies

The final methodological step involved analyzing condylar inclination and Bennett angle adjustments according to individual occlusal parameters, particularly overbite. Applying these adjustments, as outlined in Figure 1 and Table 1, facilitated a clearer understanding of how anatomical variations directly affect the performance and simulation of mandibular movements within the virtual articulator. The table below illustrates the relationship between mean overbite values and the corresponding condylar and Bennett angle adjustments based on the parameters described by Rudolf Slavicek. These values are valuable for configuring virtual articulators in the absence of individualized clinical data.

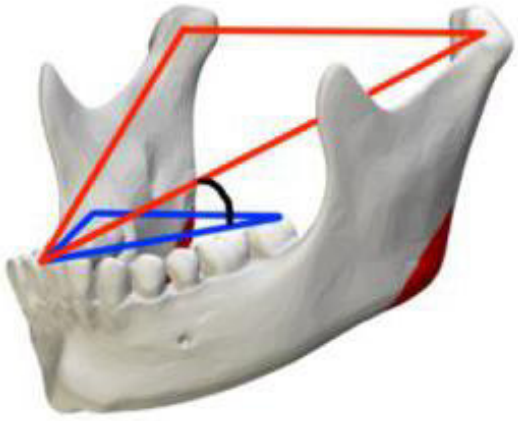

Figure. 1 – Representation of mandibular geometric relationships based on occlusal theories.

The figure 1 illustrates the anatomical foundation of Bonwill's Equilateral Triangle (in blue), formed between the mandibular condyles and the lower incisal point, and its extension into the Gysi triangle (in red), which includes the condylar paths. These

geometric models support functional mandibular movement simulations and are essential for articulator configuration in digital workflows.

Overbite (mm)	Condylar Angle (°)	Bennett Angle (°)
1.0 – 1.5	25	10
2.0 – 2.5	30	12
3.0 – 3.5	35	15
4.0 – 4.5	40	18
≥ 5.0	45	20

Table. 1 – Relationship between mean overbite values and the corresponding condylar and Bennett angle adjustments based on the parameters described by Rudolf Slavicek.

This methodological approach was essential for synthesizing the available knowledge, both from scientific studies and clinical experiences, and for drawing robust conclusions regarding the effectiveness of the digital tool under review. The accurate configuration of the virtual articulator in exocad, grounded in well-established biomechanical principles, proved to offer substantial benefits to dental practiceenabling more predictable, efficient, and individualized oral rehabilitations.

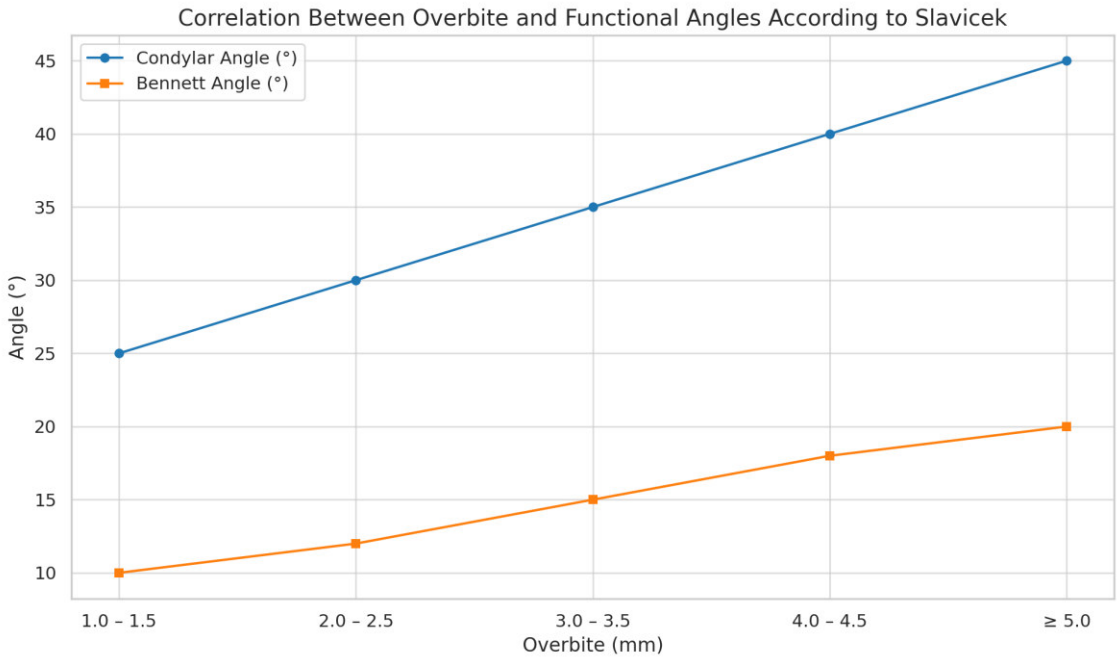

Figure. 2 – Distribution graph of the correlation between overbite and functional angles.

STUDY OUTCOME OF LITERATURE

Bonwill's Equilateral Triangle Theory

Bonwill's equilateral triangle is a foundational concept long used in dentistry to understand mandibular functional dynamics. This theory posits that the mandibular condyles and the lower incisal point form an equilateral triangle with sides measuring approximately 100 mm. This geometric configuration is essential for accurately simulating mandibular movements in study models, enabling clinicians to plan oral rehabilitations that respect the natural mandibular motion (11,12).

Practically, applying this theory allows a more precise representation of interocclusal relationships in both mechanical and virtual articulators. In digital dentistry, virtual articulators such as those in the exocad software incorporate this concept to enhance accuracy in mandibular movement simulation. Adhering to Bonwill's measurements, alongside the flexibility to adjust parameters according to patient-specific needs, is critical for achieving predictable outcomes (13).

Although some variations in measurement exist to accommodate intercultural anatomical differences, the 100 mm standard remains a widely accepted reference. Its consistency has been validated across diverse populations and time periods, reaffirming its relevance when integrated with modern digital tools like exocad (14).

Integrating Bonwill's triangle into exocad requires understanding to optimize model positioning and ensure rehabilitations maximize patient comfort and masticatory efficiency. This digital workflow facilitates smoother transitions and safer planning in restorative dentistry (15).

Mandibular Movement Parameters According to Slavicek

Rudolf Slavicek pioneered analyses of mandibular movements by developing parameters that allow personalized simulations based on individual characteristics such as overbite. This customization is essential for precise rehabilitative planning, especially in extensive or complex oral rehabilitations (16).

Slavicek's studies detail how variables like the sagittal condylar angle and Bennett angle should be adjusted in relation to overbite. These adjustments prevent functional discrepancies that could lead to discomfort or treatment failure. Rather than fixed values, Slavicek's system incorporates dynamic variables offering flexibility tailored to clinical scenarios (17).

In exocad, these parameters can be fine-tuned to simulate mandibular movements accurately, ensuring prostheses or rehabilitations achieve maximum functionality and durability. Precisely setting condylar inclination and Bennett angle allows for harmonious adaptation to each patient's unique morphology (18).

Thus, applying Slavicek's rules within exocad not only streamlines professional workflow but also enhances patient satisfaction and reduces the need for multiple adjustment visits, representing a significant advancement in dental practice (19).

Data Acquisition and Configuration in exocad

The effectiveness of the virtual articulator in exocad heavily depends on the accuracy of the initial data captured. Whether through intraoral scanning or digitizing plaster models with desktop scanners, data quality is paramount for precise treatment planning. Correct use of clinical records such as facial arcs digital or analog is a fundamental initial step in exocad application (20,21).

When patient-specific data are unavailable, exocad allows incorporation of average values based on Bonwill's triangle and Slavicek's parameters. This ensures clinicians can still achieve predictable, functional results in the absence of personalized records. The software's flexibility to manually adjust parameters also significantly contributes to treatment customization (22,23).

Selecting and configuring the articulator type in exocad are critical steps. Although the software includes presets aligned with Bonwill and Slavicek norms, fine adjustments tailored to each case optimize results. Proper use of these digital tools markedly reduces errors and inefficiencies in the final treatment (24).

Therefore, exocad's configuration tools, when applied alongside the theoretical foundations of Bonwill and Slavicek, transform technological potential into tangible clinical outcomes, making them indispensable in contemporary dentistry (25).

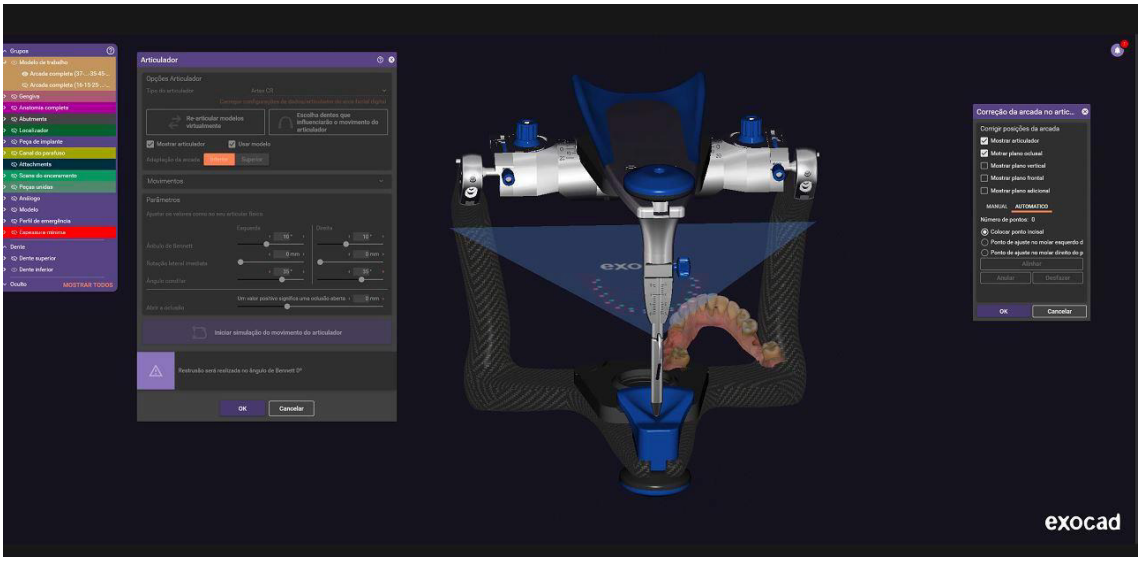

Figure. 3 – Configuration interface of the virtual articulator in exocad software.

The figure 3 shows the setup panel of the virtual articulator in the exocad software, where users can define the parameters for condylar guidance and Bennett angle. It includes the option to re-articulate models virtually and to select anatomical reference points that influence mandibular movement. On the right, the occlusal plane correction window allows for alignment of the dental arch in the articulator, with both manual and automatic adjustment options. These settings are critical for accurate simulation of mandibular dynamics in digital prosthetic planning.

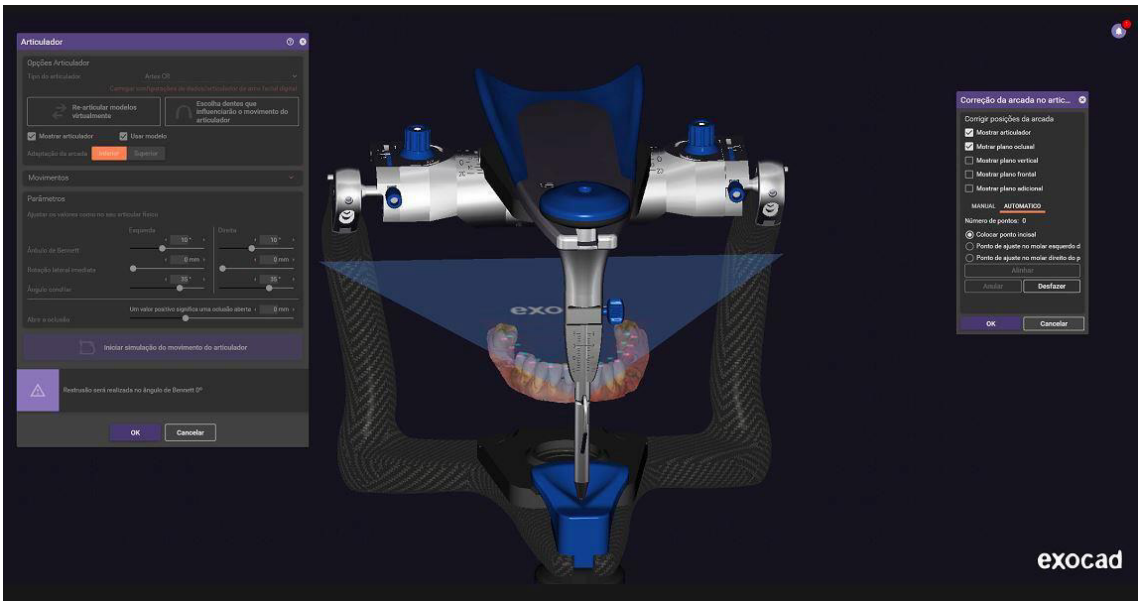

Figure. 4 – Configuration of the virtual articulator and occlusal alignment interface in exocad.

This figure 4 presents the virtual articulator module in the exocad software, where users can configure mandibular motion parameters such as the Bennett angle, immediate side shift, and sagittal condylar inclination. On the right side, the occlusal plane correction panel enables the adjustment of the digital dental arch in relation to reference planes (occlusal, sagittal, and frontal) either manually or automatically. These tools are essential for accurate reproduction of mandibular dynamics and interocclusal relationships in digital prosthetic workflows.

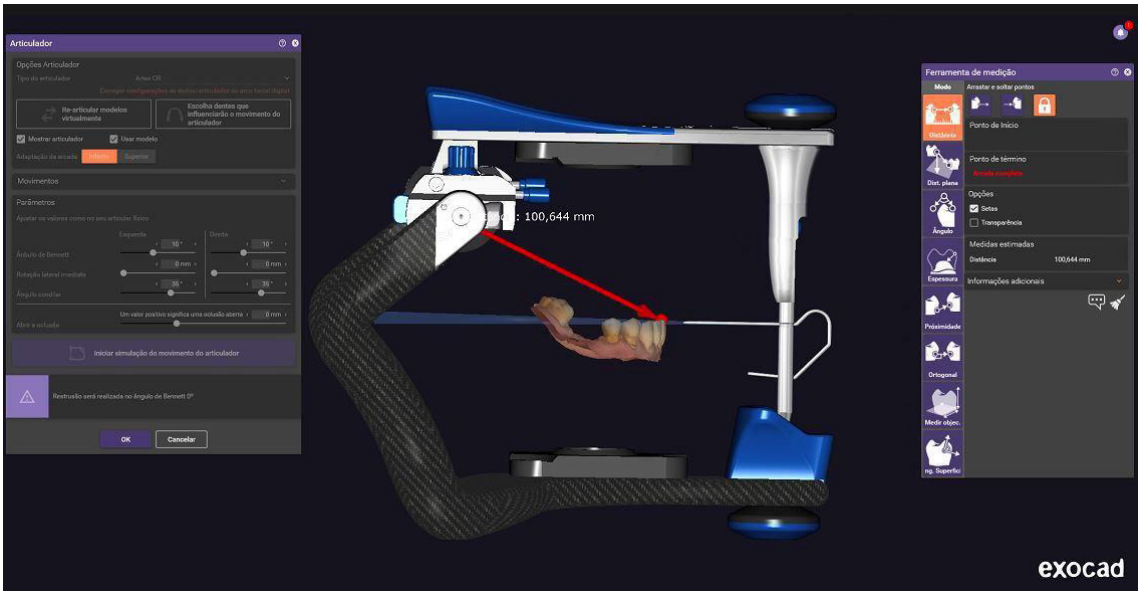

Figure. 5 – Measurement of Bonwill's triangle in virtual articulator configuration using exocad.

This figure 5 demonstrates the measurement of the distance between the condylar hinge axis and the lower central incisal point representing the side of Bonwill's equilateral triangle (approximately 100.6 mm) within the exocad software environment. The left panel displays articulator settings for simulating mandibular movements by adjusting parameters such as Bennett angle, immediate side shift, and sagittal condylar inclination. On the right, the measurement tool interface provides linear distance estimation, which is crucial for accurate simulation when individual patient data are unavailable.

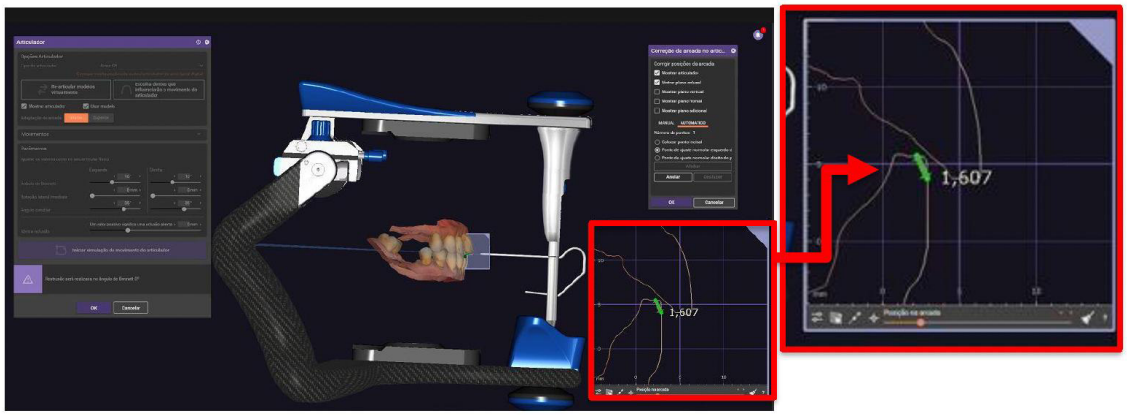

Figure. 6 – Simulation of Bennett movement and displacement tracking in exocad virtual articulator.

This figure 6 illustrates the digital simulation of lateral mandibular movement using the virtual articulator in exocad. The left panel shows the parameterization of the articulator, including adjustments for Bennett angle and immediate side shift. The central image displays the lateral excursion pathway of the mandible under simulated conditions, with the trajectory being influenced by the defined condylar parameters. On the right, the zoomed-in red frame highlights a precise displacement value of 1.607 mm, confirming the measured mandibular deviation during simulation. This tracking feature allows clinicians to validate occlusal behavior and mandibular kinematics prior to prosthetic fabrication, improving predictability in complex oral rehabilitations.

Clinical Impact and Benefits of the Virtual Articulator

Clinically, the use of a virtual articulator configured on theoretical foundations has proven essential for optimizing oral rehabilitations. Cases utilizing this technology have shown significant improvements in prosthetic fit, reducing the need for multiple intraoral adjustments and demonstrating practical effectiveness. Data personalization based on specific clinical needs translates into more comfortable and esthetically satisfactory rehabilitations (26,27).

Reduced wear of restorative materials, especially zirconia, is another notable benefit. Accurate data minimize unnecessary invasive interventions, preserving material integrity and thereby increasing prosthesis longevity. This preservation enhances patient experience and promotes cost savings for both clinician and patient by avoiding

costly remakes (28,29).

The virtual articulator also serves as a valuable educational tool, enhancing the teaching and comprehension of complex concepts related to occlusion and mandibular dynamics. Its use has been associated with consistent improvements in practical skills and a deeper understanding of occlusal principles and oral rehabilitation strategies (30). When properly configured, virtual articulators not only improve the efficiency and predictability of oral rehabilitation but also represent a significant advancement in bridging scientific tradition with state-of-the-art technology in contemporary dentistry (14).

DISCUSSION

The implementation of the virtual articulator within the exocad software, grounded in well-established principles of occlusion and mandibular dynamics, has led to significant improvements across various aspects of dental practice. Analyses of cases adhering to precise configurations based on the theories of Bonwill and Slavicek have demonstrated clear superiority in prosthetic adaptation and a reduced need for clinical adjustments post-insertion (1,6,10).

Clinicians who adopted the virtual articulator following functional protocols reported more accurate prosthetic fittings, resulting in increased patient comfort and fewer adjustment sessions. This reduction is particularly important for materials such as zirconia, whose structural integrity can be compromised by repeated wear from adjustments (2,5,8).

Moreover, the predictability of clinical outcomes improved with the use of personalized data, adjusting condylar inclination and Bennett angle according to the parameters proposed by Slavicek. This customization enhanced clinicians' confidence in treatment planning and execution, yielding more effective and satisfactory experiences for both practitioners and patients (3,9).

Negative outcomes were confined to cases in which the virtual articulator was used without proper configuration based on studied principles. In such instances, frequent rework and multiple adjustments were necessary, underscoring the importance of adherence to evidence-based protocols (4,12).

Broadly speaking, the use of the virtual articulator in exocad, when optimized by the application of Bonwill's and Slavicek's concepts, stands out as an indispensable tool for modern digital dentistry. Its benefits extend beyond simple reduction of clinical time, adding layers of safety and precision particularly critical in extensive and complex rehabilitations (5,7).

Proper recognition of the benefits provided by the virtual articulator should thus be prioritized in continuing professional education, maximizing the potential of technological advances in dentistry. Consequently, dentistry progresses towards safer, more effective, and outcome-driven practices, benefiting both patients and professionals alike (6,11,13).

FINAL CONSIDERATIONS

The integration of the virtual articulator within the exocad software when grounded in classical dental principles such as Bonwill's theory and Slavicek's guidelines proves to be an essential tool in contemporary digital dentistry. Proper configuration not only enhances the predictability of clinical outcomes but also significantly reduces the need for chairside adjustments. This technological advancement benefits both clinicians, by improving efficiency and precision, and patients, by providing greater comfort and treatment security. The positive impact of training and the incorporation of foundational occlusal concepts highlight the transformative potential of aligning theory with clinical practice. Embracing and promoting the correct use of the virtual articulator in platforms like exocad is therefore crucial to meeting the evolving demands of the field and ensuring high-quality, long-lasting oral rehabilitations.

FINANCIAL SUPPORT AND SPONSORSHIP

This work was supported by the São Paulo Research Foundation (FAPESP – grant numbers 2019/24903-6 and 2021/11499-2).

DATA AVAILABILITY

All data analyzed during this study are available from the corresponding author

upon reasonable request.

DISCLAIMER OF LIABILITY AND DISCLOSURE

All data analyzed during this study are available from the corresponding author upon reasonable request. The authors report no conflicts of interest regarding any of the products or companies discussed in this article.

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