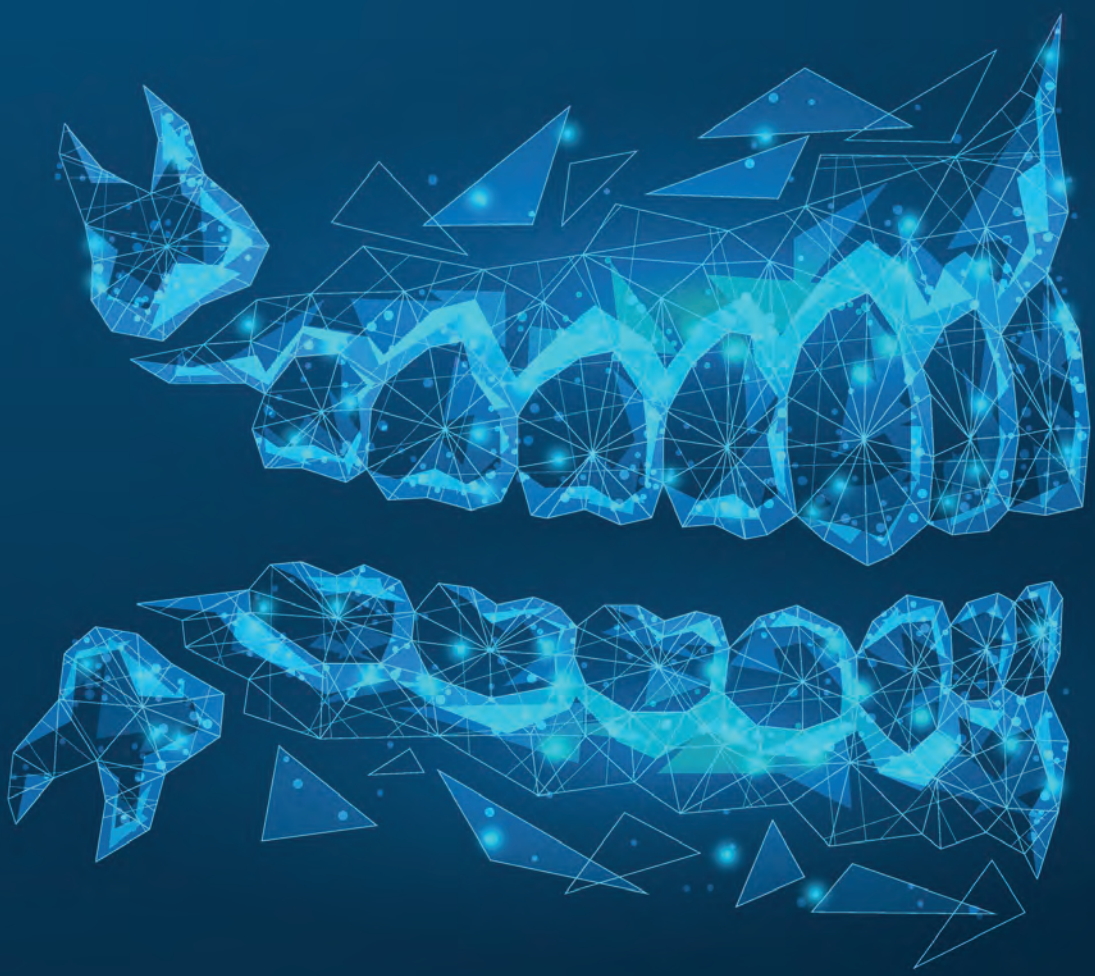
ARTIFICIAL INTELLIGENCE IN SMILE DESIGN:

Promises, Protocols, and Challenges



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Abstract

The perception of smile esthetics is highly complex, as it is influenced by a wide range of objective and subjective factors. These include orofacial parameters (e.g., facial symmetry, lip volume, gingival exposure, and tooth composition) as well as sociodemographic considerations. When integrated with 3D imaging and artificial intelligence (AI)-driven planning, smile design (SD) continues to offer innovative ways for clinicians and dental laboratories to visualize and enhance patients' smiles. The growing integration of AI into the SD process has shown promise in automating smile analysis and manipulation tasks, including suggestions for tooth alignment, shape, color, and brightness. While this technology can improve and accelerate the treatment process, the integration of AI technologies into SD procedures also raises ethical questions that are beginning to receive more focused attention.

This article proposes addressing the ethical challenges posed by the use of AI in SD—including issues with accuracy, explainability, transparency, and sociocultural diversity of the technology—through a patient-centered approach aimed at building trust in this revolutionary technology among patients and clinicians.

Key Words: artificial intelligence, smile design, esthetic dentistry, cosmetic dentistry, AI ethics

> "The integration of AI into dentistry introduces complex ethical considerations that are becoming increasingly recognized and continue to warrant meaningful attention."

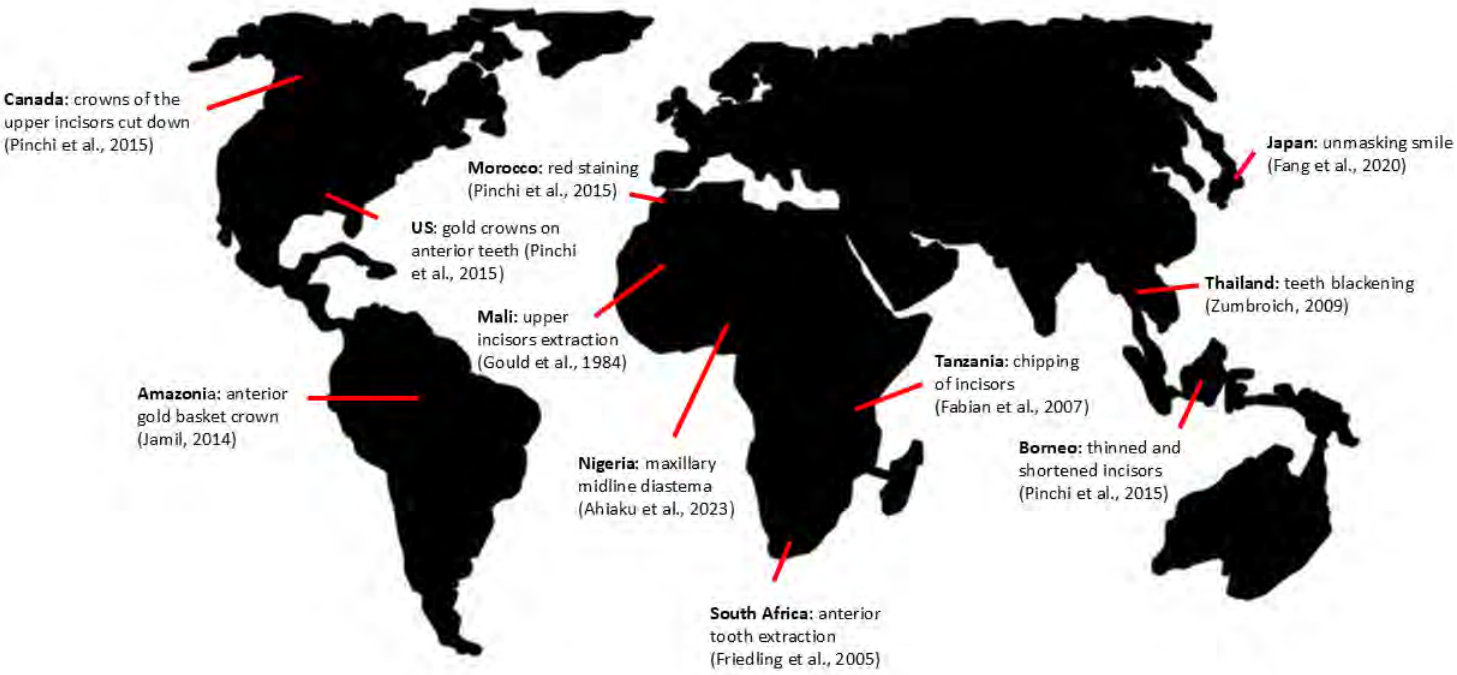

Figure 1: Graphic overview of various reported sociocultural specificities of smile esthetics.

Introduction

Restoring a patient's smile is essential for both esthetic and functional reasons. However, improving an individual's smile is a complex process. Close collaboration between clinicians and laboratory technicians is necessary to assess the patient's initial condition and develop the most appropriate treatment plan.[1] Over the years, smile design (SD) procedures have progressed from physical analog methods to digital approaches that have introduced various technological innovations (e.g., mock-ups, video analysis, and 3D facial scanners) that facilitate patient involvement in the decision-making process.[1]

Artificial intelligence (AI) technologies have been increasingly incorporated into SD software to facilitate communication with patients and enable dentists and dental technicians to provide more effective treatments.[2-4] These groundbreaking technologies can reduce the workload and the time needed for SD procedures, as well as improve the quality of the results.[5-7] However, the integration of AI into dentistry introduces complex ethical considerations that are becoming increasingly recognized and continue to warrant meaningful attention.[8-10] The limited critical examination of these ethical complexities is concerning, particularly when considering that smile design, already regarded as a marketing tool, may be perceived by some as potentially prioritizing economic considerations over patients' actual needs.[11-13]

This article examines the implications of integrating AI technologies into SD software. The complexity of SD analysis and the ways in which AI could help address this complexity are discussed, as well as the ethical implications that should be considered when integrating such technologies into clinical practice.

Determining Smile Esthetics

Parameters

Smile esthetics is a field of research in which scientists from various disciplines and backgrounds are working to identify objective and subjective factors that determine perceptions of smile attractiveness. Dental professionals have already identified numerous objective measures that influence smile esthetics. These parameters have been used to develop standards to help analyze and diagnose esthetic issues and guide strategies for enhancing patients' smiles.[14]

Smile esthetics is often analyzed at three levels: the face, the oral cavity, and the teeth. At the face level, the focus is on the facial asymmetries and disproportions in relation to the smile.[15,16] At the oral cavity level, the position, shape, and movement of the lips are analyzed.[17-19] At the teeth level, the shape, orientation, and position of the teeth are studied.[14,17,20,21]

Cultural Differences and Avoiding Bias

Available SD software integrates some of the objective and technical parameters of smile esthetics. However, smile design is a complex, multifactorial exercise that must objectively assess a patient's facial features and dental structures and should consider other patient-specific parameters (e.g., sociodemographic)[22] that might influence the smile's perceived attractiveness. To avoid cultural biases when creating SD strategies, clinicians need to be sensitive to and knowledgeable about how beauty standards can vary across sociocultural populations. For example, in Western societies, a smile is usually associated with positive emotions, whereas in Eastern cultures such as Japan, a reserved or subtle smile that reflects modesty and restraint is considered more appropriate and polite. In certain Middle Eastern cultures, a closed-lip smile is more common, as showing teeth in public can be perceived as immodest or rude. In some African cultures, a smile can convey a range of emotions, including happiness, respect, and fear.

Accordingly, it is highly recommended that clinicians use both objective and subjective parameters to design esthetically pleasing smiles that address and respect the varying beauty standards and cultural biases of diverse populations worldwide **(Fig 1)**.[23-30] Not surprisingly, the complexity of this multifactorial exercise has led to a growing demand for tools that can help clinicians diagnose and plan SD treatments, as well as facilitate patient communication. In response, there has been a rise in digital software development, which aims to integrate some, if not all, of these parameters.

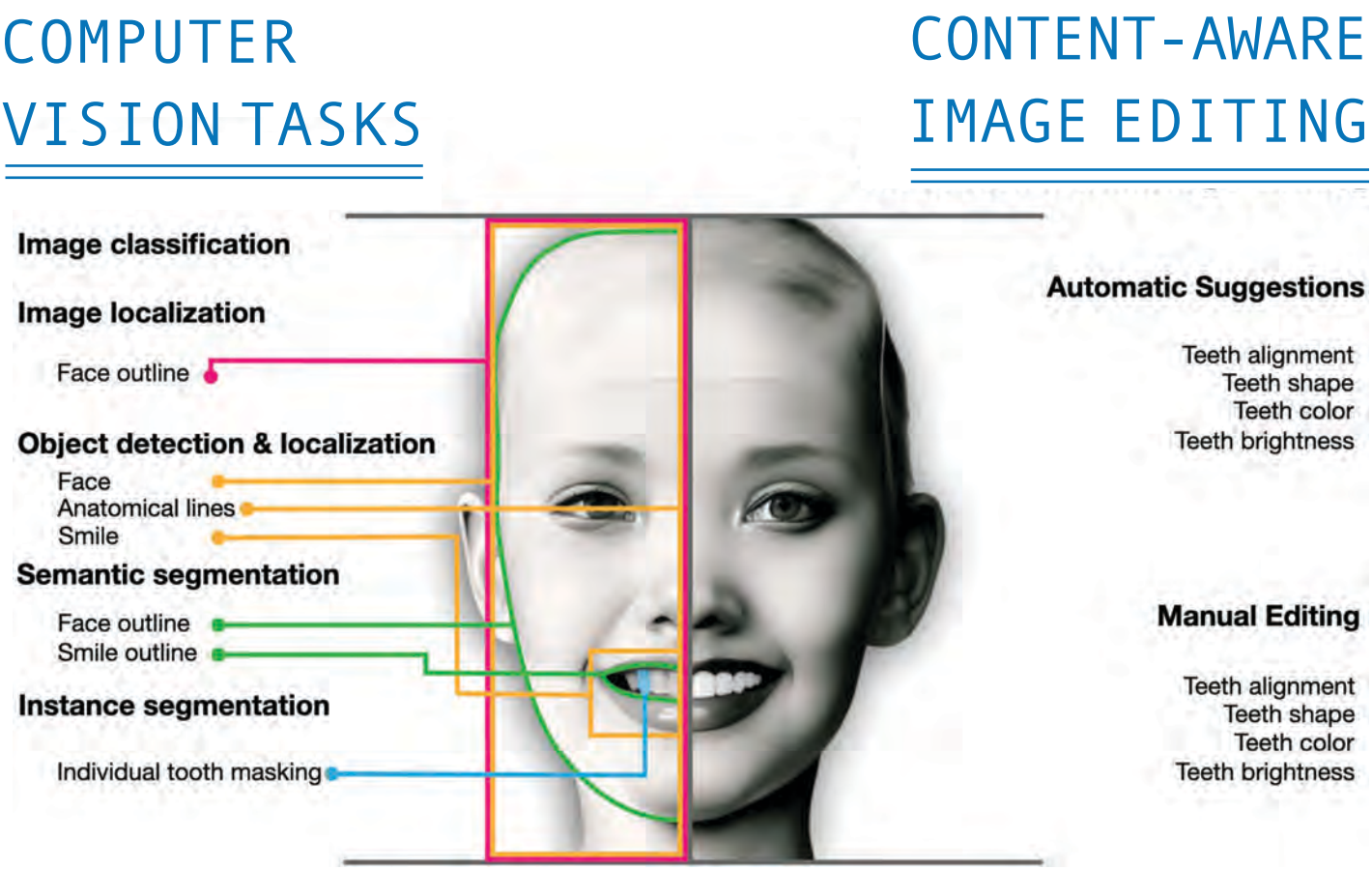

Figure 2: Description of AI tools used for AI-SD.

> TRANSPARENCY IS CRUCIAL TO MAINTAINING PATIENT TRUST AND PREVENTING OVERRELIANCE ON TECHNOLOGY AT THE EXPENSE OF HUMAN AND CLINICAL EXPERTISE AND SOUND JUDGMENT.

AI's Potential for Smile Design

Table 1 lists some examples of commercial digital SD software that incorporate (or appear to incorporate) AI technologies. Most of the available literature presents case reports that illustrate the digital workflow and share positive feedback from both clinicians and patients. However, it rarely highlights the limitations.[5]

Table 1: Examples of Commercially Available AI-Integrated SD Software

Product and Company	Country	Website
DTS PRO, Dental Treatment Simulation	India	https://www.dentaltreatmentsimulation.com
Smile Designer Pro, Tasty Tech Ltd.	Canada	https://www.smiledesignerpro.com
VisagiSMile, Web Motion	Bulgaria	https://visagismile.com/
Smile Designer, Neuralp Software Inc.	Turkey	https://www.smiledesignerapp.com/welcome/
Rebel Simplicity, Visagismile	Bulgaria	https://rebel.dental
IvoSmile, Ivoclar	USA	https://www.ivoclar.com/en/dental-professional-/ivosmile-orthodontics-app
Preteeth, Preteeth AI	Taiwan	https://preteeth.com
Richsmile Design, Rich Smile Design Lip	India	https://richsmiledesign.com
SmileFy, SmileFy	USA	https://smilefy.com/
Smilo.ai, Smilo.ai	Australia	https://www.smilo.ai
Smilecloud, Smilecloud	Romania	https://www.smilecloud.com/

Automating Tasks

Most currently available software employs vision technologies that analyze and manipulate images of a patient's teeth and mouth to facilitate clinicians' analysis of objective smile parameters **(Fig 2)**. This software can perform various automated tasks such as image classification.[5] It can recognize the content of an image, use image localization to locate the face, and detect defects in the face, teeth, and other anatomical features **(Fig 3)**. *Semantic segmentation* assigns a label to each object identified in the image (e.g., face, teeth, and other features). *Instance segmentation* is used to segment each object (i.e., tooth), and there is a "mask" tool to manipulate the teeth further.

AI-SD software also includes automated image-editing features, such as content-aware suggestions for tooth alignment, shape, color, and brightness. However, it is important to note that these automated suggestions should always be complemented by manual adjustments and edits performed by the clinician to ensure the desired outcomes are achieved. This possibility proposes integrating and considering subjective parameters as a complementary part of the first automated analysis of objective parameters. Integrating these automated elements in smile design significantly shortens the treatment process by streamlining many previously time-consuming tasks **(Fig 4)**.

> DEVELOPING CULTURALLY SENSITIVE AI-SD ALGORITHMS THAT ACCOMMODATE THE DIVERSE SOCIOCULTURAL ASPECTS OF SMILES IS ESSENTIAL TO ENSURE THAT THESE SMILE DESIGNS ALIGN WITH INDIVIDUAL AND SOCIETAL PREFERENCES.

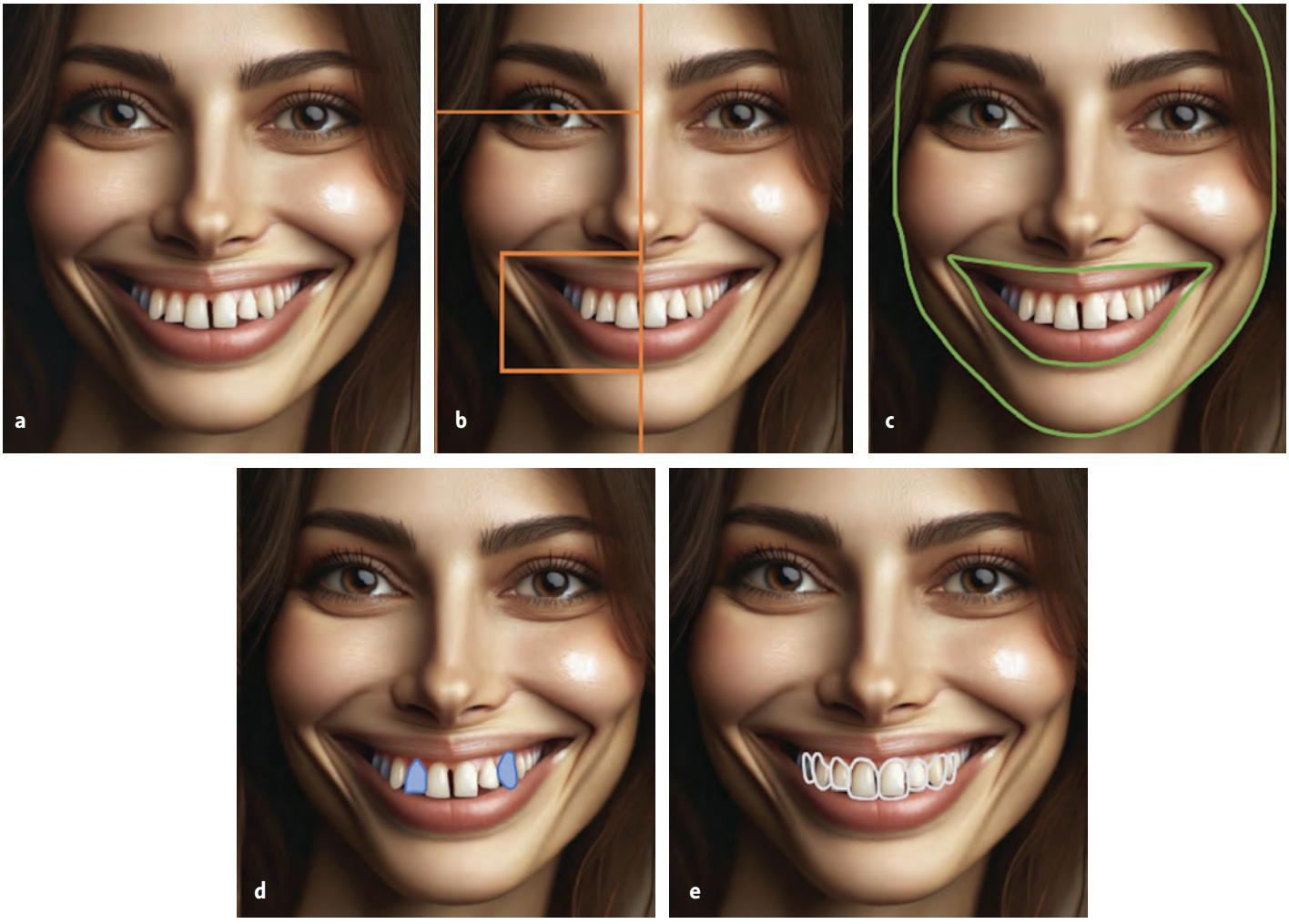

Figure 3: As a communication tool, AI-illustrated examples help visually explain the different steps for smile design to the patient. (a) Initial image. (b, c, d) Identification and segmentation of different facial zones; (e) Application through overlaying a custom layer for the patient's smile.

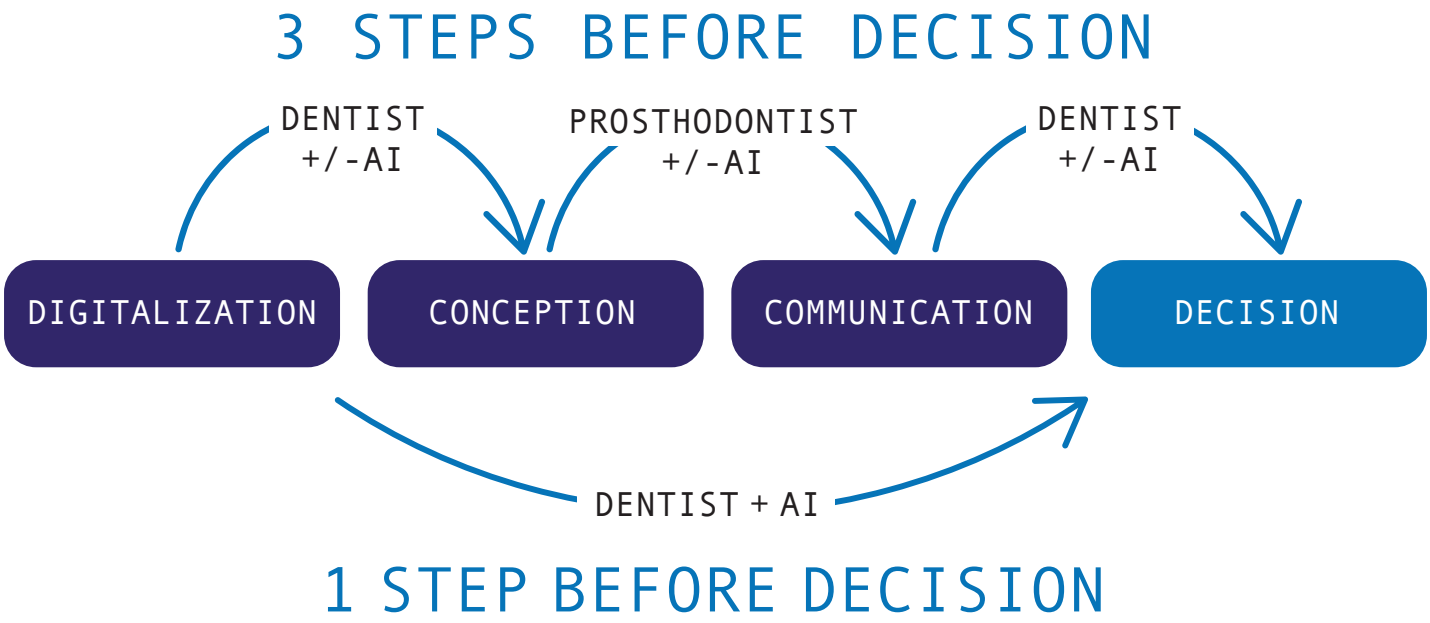

Figure 4: Comparison of two different protocols using AI for smile design: One is carried out in three separate steps and involves the dentist, the patient, and the prosthodontist; the other integrates all the steps during a single office visit and involves only the dentist and patient, thus expediting the patient's decision-making.

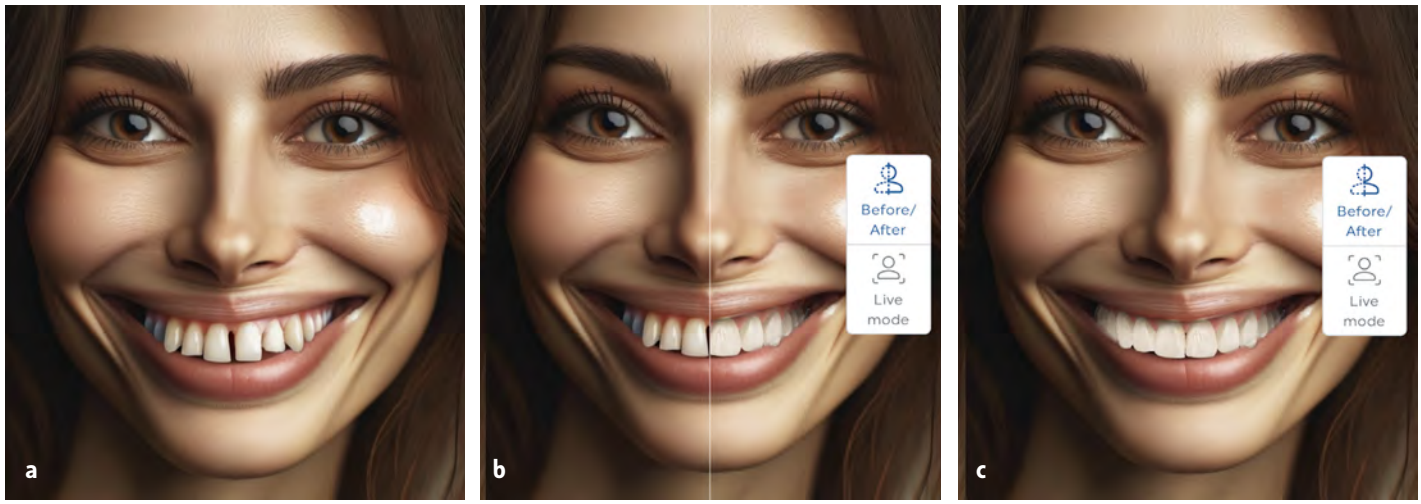

Figure 5: Illustration of AI smile design (IvoSmile, Ivoclar).

> ALL STAKEHOLDERS, INCLUDING DENTAL PROFESSIONALS AND AI DEVELOPERS, SHOULD COLLABORATE TO BALANCE USING AI TO STREAMLINE THE DESIGN PROCESS WITH MAINTAINING A PATIENT-CENTERED APPROACH.

AI Protocols for Smile Design

AI likely will lead dental professionals to change their approach to patient treatment. This section compares two possible AI-SD treatment protocols, as follows:

1. The first protocol is carried out three separate times and involves three people: the dentist, the patient, and the prosthodontist **(Fig 4)**. The initial digitalization step, acquiring the patient's digital data, occurs at the dental office. Next, the patient's data is transferred to the prosthodontist, who will perform the smile design (either physically or virtually). Once this work is completed, the dentist will present the design to the patient using various communication tools, allowing the patient to decide whether to accept the treatment.

2. The second protocol directly integrates an AI-SD tool into the dental office. Only the dentist and the patient are involved **(Fig 4)**. Digitalization, SD conception, and communication of the treatment plan to the patient can be done during the same appointment, enabling the patient to accept or decline the treatment right away.

Integrating a laboratory step into the process in the first protocol allows the prosthodontist to thoroughly analyze the treatment's feasibility. However, the laboratory time extends the treatment duration and the number of appointments. It also limits the patient's participation in the decision-making process.

Avoiding Biasing Patients

In the second protocol, AI decreases the duration of care while facilitating patient collaboration. Patients can actively participate in developing their new smile thanks to the AI decision support tool, which allows them to preview the proposed result before beginning treatment **(Fig 5)**. This personalized and interactive approach provides patients with a better understanding at every step of the SD process. However, it is important to ensure that the use of computer technology does not influence the patient's decision. Since the results presented by these new technologies can be highly idealized, they may bias the patient's perception of the outcome, possibly leading them to alter their decision-making process. Moreover, in this second protocol, the dental laboratory becomes involved only after the patient has accepted the treatment plan. Therefore, it is the dentist's responsibility to determine the proposed restoration's technical feasibility in the mouth. The dentist must also vigilantly monitor the AI software throughout the entire process to avoid automation bias.

Both approaches have advantages and disadvantages. The choice between them will ultimately depend on factors such as the individual patient's specific needs, the dentist's preferences, and the complexity of the clinical case.

AI Challenges for Smile Design

All of the AI-SD implementations were reported to contribute to a faster, more efficient treatment process and quicker results for the patient.[10] However, along with enthusiasm for the evident benefits of AI-assisted automation of human tasks, there has come a growing awareness of specific ethical concerns and challenges, which are less clear-cut and objective. These issues are significant and should be addressed to ensure responsible and sustainable implementation of AI in esthetic dentistry.[8,9,31] Ethical challenges include the following:

Accuracy and Explainability

AI-SD must be carefully and transparently developed and validated both internally and externally to ensure it provides accurate and reliable results across diverse populations. It is essential to evaluate the cultural biases embedded in any AI-SD and actively mitigate any potential harm or misrepresentation. *Explainability* refers to the concept that AI software and its decisions should be explained to everyone, including clinicians, in a way that makes sense and can help them evaluate the AI-SD's decisions.[32]

Responsibility and Transparency

Dental professionals and AI developers must urgently consider the implications of using AI-SD, including questions related to user responsibility, informed consent, privacy, patient autonomy and identity, and data security. It is essential to ensure that patients fully understand the AI-based design process, its limitations, and the potential implications of its outcomes.[33] "Transparency" also implies that companies developing and marketing AI-SD software should explain the type of AI used, how it was developed and validated, and how and when AI algorithms operate and influence SD decisions. Transparency is crucial to maintaining patient trust and preventing overreliance on technology at the expense of human clinical expertise and sound judgment.[34]

Well-Being

Poor smile esthetics can damage a patient's sense of well-being. However, *well-being* is a subjective term and is poorly defined in the SD literature. For example, in its Sustainable Development Goals (specifically SDG 3), the United Nations envisions well-being as related to health.[31] In the same vein, the European Union (EU) offers a narrow interpretation of well-being, primarily related to health and "equality in the distribution of economic, social and political opportunity."[35] Nonetheless, the EU emphasizes that the "ubiquitous exposure to social AI systems" might have social impacts "in all areas of our lives...may alter our conception of social agency or impact our social relationships and attachment."[35] This ambiguity and lack of consensus could inadvertently lead to some patients being or feeling ostracized due to their smiles, which would diminish rather than enhance their well-being.

The commercialization of smile design—particularly regarding the "Wow!" effect this tool's idealized preview results may have on patient perception and decision-making—is causing concern that the situation will lead to a focus on profit rather than on addressing patients' medical needs or preferences.[11] All stakeholders, including dental professionals and AI developers, should strive to balance utilizing AI to streamline the design process with maintaining a patient-centered approach that prioritizes the individual's well-being.

Sociocultural Diversity

AI-SD algorithms must be sensitive to cultural nuances to avoid imposing a single, standardized notion of an "ideal" smile that may not align with diverse cultural preferences. Failing to incorporate societal considerations may result in smile designs that are perceived as unnatural or unattractive by patients from some ethnic backgrounds. Developing culturally sensitive AI-SD algorithms that accommodate the diverse sociocultural aspects of smiles is essential to ensure that these smile designs align with individual and societal preferences. Otherwise, the result might be smiles that conform to Western standards without incorporating local specificities.[36] This tendency to establish regulatory tools at a high level of abstraction is linked to the universalist approach to ethics that is predominant in most Western countries. This propensity for universalism raises many questions regarding respect for cultural diversity.[37]

Summary

The use of AI in smile design generates enthusiasm in the esthetic dentistry community, but it presents significant ethical challenges. As attention around these issues continues to grow, it is essential to address concerns related to accuracy, transparency, explainability, and unbiased consideration of subjective factors such as patients' well-being and sociocultural diversity. Thoughtful consideration of the various nuanced and subjective influences and implications of AI in the context of esthetic dentistry can help dental professionals and patients alike in their approach to and perception of AI-SD treatment plans. All stakeholders, including dental professionals and AI developers, should collaborate to balance using AI to streamline the design process with maintaining a patient-centered approach. By doing so, they will not only offer all parties involved the best of both methods but will also maintain the trust of patients and clinicians in a patient-centered approach to smile rehabilitation.

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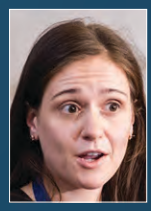

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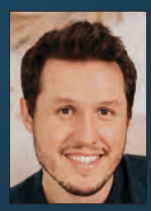

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