


## Research Paper

# From bite marks to vertical facial phenotype: Investigating the relationship between craniofacial and dental arch parameters using conventional wax and digital models

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## ABSTRACT

**Objective:** This study aims to investigate whether a relationship exists between craniofacial structures and bite marks, thereby enabling the prediction of facial type based on bite mark characteristics.

**Materials and methods:** Thirty-eight volunteers (aged 19–25) without orthodontic treatment, craniofacial anomalies, or temporomandibular dysfunction participated. Bite marks were created on wax-covered sponge rollers. Inter canine distance, arch depth, and arch length were measured from wax models using a caliper and from intraoral scans using the iTero Scanner. Facial profile photographs were analyzed using GIMP software to calculate FH/GoMe angle and LFH/TFH ratio (Lower face height/Total face height). Statistical analyses included intraclass correlation, Wilcoxon and paired t-tests, and Spearman's correlation ( $p < 0.05$ ).

**Results:** Significant differences were found between wax and digital measurements except for arch length. FH/GoMe angle correlated with upper and lower wax arch lengths, and LFH/TFH ratio correlated with lower arch length. No correlation was found between the facial type parameters and inter canine and arch depth measurements.

**Conclusion:** Although distortion may influence wax impressions, the correlations observed suggest that certain bite mark metrics—particularly lower arch length—may provide morphologic indicators of facial phenotype. These findings are preliminary and not intended for individual identification; larger, diverse samples are needed to validate their forensic relevance.

## 1. Introduction

Teeth primarily function in mastication, aesthetics, and phonation; however, in certain circumstances, they may also be used as tools for aggression or self-defense.<sup>1</sup> Because bite marks reflect individual dental characteristics, their examination and analysis aim to scientifically associate the injury pattern with a potential suspect.<sup>2,3</sup> Bite mark comparison has had some big successes in forensic odontology in the past, but it is also one of the most criticized areas of the field because of major errors and ongoing debate.<sup>4</sup> Bite mark comparison involves analyzing the size, shape, and position of individual teeth, typically using overlays to compare a suspect's dentition with the injury pattern. Various techniques have been used to generate these overlays—including hand-tracing from study casts, wax impressions, xerographic images, radiopaque wax methods, and computer-based approaches.<sup>3</sup> Bite marks

may be identified on various materials at the crime scene, including numerous food products (such as fruits, sweets, and chewing gum) and on human skin.<sup>5</sup>

Biting is a complex process affected by various elements, including the occlusal relationship between the upper and lower teeth, the strength of the masticatory muscles, and the victim's physiological reaction to the bite. Bite marks may differ based on the properties of the substrate on which they are located and the accuracy of identification can also be affected by the characteristics of the substrate.<sup>6</sup> Bite marks are primarily produced by the upper and lower front teeth, although impressions from premolars and molars may occasionally be observed. Lower incisor marks are usually more noticeable because their narrow incisal edges focus occlusal forces over a smaller contact area, which can cause higher localized stresses.<sup>2</sup>

Decades of empirical evidence have demonstrated that bite mark

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analysis is fundamentally unreliable for criminal identification and has repeatedly contributed to wrongful convictions.<sup>7</sup> Numerous cases such as those of Robert Lee Stinson, Ray Krone, Steven Chaney, and Anthony Otero reveal that individuals were convicted based on odontologist testimony later disproven by DNA evidence, despite experts claiming near-absolute certainty in their identifications.<sup>7-9</sup> High false-positive rates observed in controlled simulation studies, including error levels reaching 63.5 % among American Board of Forensic Odontology (ABFO) members, further challenge the scientific credibility of the technique.<sup>7</sup> These failures arise from deeply flawed assumptions underlying bite mark comparison: the unproven claim of dental uniqueness, the absence of population frequency data, and the scientifically refuted notion that human skin functions as a stable impression surface.<sup>9</sup>

Photographic documentation plays a critical role in maintaining medical records, particularly in forensic contexts where precise evidence is vital for legal investigations. For instance, according to the American Board of Forensic Odontology (ABFO) standards, capturing bite marks or similar traces requires meticulous technique: the camera must be positioned parallel to the wound and angled at 90° to ensure the photographic evidence accurately represents the physical trace.<sup>10</sup> As a repeatable, reproducible, low-cost, and non-invasive diagnostic tool, photographs are also used to acquire anthropometric data. Through standardized photographs, cephalometric data can be analyzed.<sup>11</sup>

Arch forms are associated with an individual's growth pattern and facial type. From an orthodontic perspective, arch forms not only influence the type of malocclusion but are also critical for understanding facial morphology.<sup>12</sup> Vertical facial pattern has been described as hypodivergent, hyperdivergent, and normal.<sup>13</sup> The width of dental arches and, similarly, the presence of a hypo and hyperdivergent facial type are associated with distinct growth patterns arising from mandibular rotation during craniofacial growth and development. It is reported that individuals with hyperdivergent types exhibit narrower/shorter arch widths, whereas those with hypodivergent facial types are associated with wider/longer arch widths.<sup>14</sup>

In recent years, digital workflows have gained considerable importance in dentistry due to advances in technology. Compared with conventional impression techniques, intraoral scanners allow the intraoral condition to be transferred to the technician more accurately and reliably, without distortion or time-dependent dimensional changes.<sup>15</sup> Owing to these advantages, intraoral scanners have also begun to be utilized in bite mark research.<sup>16,17</sup>

This study aims to evaluate the concordance between dental measurements obtained from experimental bite marks and digital models, and to explore whether specific bite mark dimensions show measurable associations with vertical facial morphology. The objective is not individual identification, but rather to assess the potential biometric relationship between bite mark morphology and craniofacial parameters.

## 2. Material and methods

This cross-sectional observational study was conducted in accordance with the ethical standards set by the Istanbul Kent University Ethics Committee (Approval No: 2022/06). The research aimed to compare dental measurements obtained from wax-based bite marks with those derived from digital intraoral scans and to examine the relationship between bite mark dimensions and vertical facial morphology.

The study was conducted with 38 volunteers who met the inclusion criteria. The inclusion criteria for participation in the study were defined as follows: individuals aged 18–25 years, no history of orthodontic treatment or orthognathic surgery, absence of temporomandibular joint (TMJ) dysfunction, and no prosthetic dental procedures. Exclusion criteria included failure to meet the aforementioned criteria and lack of voluntary consent to participate in the study. Exclusion of orthodontically treated individuals was deliberate, as orthodontic interventions homogenize dental arch forms and reduce natural interindividual

variation that is essential for evaluating whether bite mark metrics can meaningfully reflect craniofacial morphology. It is established that orthodontic treatment alters both arch dimensions and facial growth direction, potentially confounding correlations between bite marks and facial phenotype.<sup>18</sup>

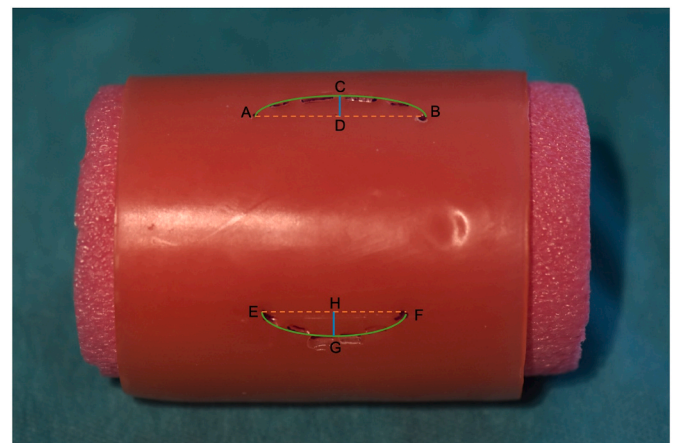
All individuals provided written informed consent prior to enrollment. Participants comprised 60.5 % females and 39.5 % males.

### 2.1. Obtaining dental records on bite marks

Bite marks were collected using custom-fabricated wax-coated (Qwax, Türkiye) sponge rollers (3.5 cm radius). Wax was selected because of its established reproducibility in forensic research and its widespread use in experimental bite mark studies on inanimate substrates. However, wax does not simulate the viscoelastic properties of human skin; therefore, bite marks generated in this study reproduce only non-biological, rigid-substrate scenarios.<sup>19</sup> The use of wax for bite mark replication in this study was justified by its proven reproducibility and established acceptance in forensic odontology protocols.<sup>20</sup>

Participants were guided to bite the blocks at maximum intercuspation. The resulting bite marks on the wax were then outlined using a ballpoint pen to enhance their visibility (Fig. 1).

Three dental parameters were measured from wax model for upper and lower jaws: The distance between the tip of right and left canine teeth on bite marks was assessed as intercanine width (WICUJ and WICLJ). Arch depth was quantified by constructing a perpendicular line from the mesial contact point of the central incisors to the intercanine line, ensuring standardized measurement of maxillary/mandibular arch morphology (WADUJ and WADLJ). A digital calliper was used to measure intercanine width and arch depth for both upper and lower jaws (accuracy 0.01 mm). Arch length was assessed by tracing the curvature from the cusp tip of one canine to the contralateral canine using a metal chain. The chain's length was subsequently recorded as the definitive arch length measurement (WALUJ and WALLJ). All distances were measured in millimetres.



**Fig. 1.** Dental measurements performed on bite marks obtained from wax bite registration material wrapped around a sponge. Intercanine distance: Orange dashed linear line extending between points A-B in upper jaw (WICUJ), orange dashed linear line extending between points E-F in lower jaw (WICLJ). Arch length: Curved green line extending between points A-B in upper jaw (WALUJ), curved green line extending between points E-F in lower jaw (WALLJ). Arch depth: Blue linear line extending between points C-D in upper jaw (WADUJ), blue linear line extending between points G-H in lower jaw (WADLJ). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

### 2.2. Obtaining digital dental records

Digital intraoral scans were performed on each volunteer using an intraoral scanner (iTero™ Elements, Align Technology, USA) to establish precise anatomical measurements of the dental data, generating patient-specific digital records. The iTero intraoral scanner used in this study is a device available within our faculty and is routinely employed for intraoral scanning procedures for all departments. The .stl files acquired via intraoral scanning were processed in the OrthoCAD (version 5.9.1.50, Kromopan, USA) software to perform standardized dental measurements (Fig. 2). Digital measurements for intercanine distance (DICUJ and DICLJ), arch length (DALUJ and DALLJ), and arch depth (DADUJ and DADLJ) for both upper and lower jaw were measured on the intraorally scanned digital models, adhering to the standardized reference points outlined above for wax-derived measurements in millimetres.

### 2.3. Obtaining photographic data

Standardized frontal and lateral facial photographs of all participants were acquired using a Nikon D5600 18–55 VR AF-P DSLR camera (Nikon Corporation, Tokyo, Japan) under controlled conditions by the same researcher (fixed distance, uniform background). Image analysis was performed in GIMP software (version 2.10.34) to quantify craniofacial parameters. Measuring tools in the software were used to calculate distances on photographic datas. In the frontal analysis, the lower facial height (LFH), measured from subnasale to menton, and the total facial height (TFH), measured from nasion to menton, were recorded, and the LFH/TFH ratio was subsequently calculated. In the lateral analysis, the FH/GoMe angle was determined as the angle formed by the intersection of the Frankfurt Horizontal plane (connecting porion and orbitale) and the mandibular plane (connecting gonion and menton). All measurements are presented in Fig. 3.

### 2.4. Statistics

All data obtained from bite marks, digital scans, and facial photographs were imported into SPSS statistical software (v25.0; IBM Corp, Armonk, NY, USA). The normality of data distributions was assessed using the Kolmogorov Smirnov test. Pairwise comparisons were

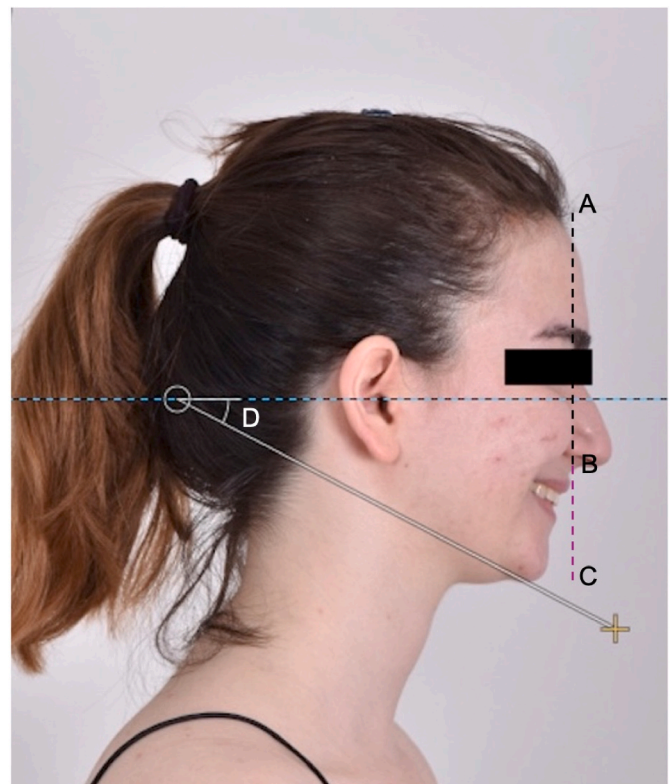


Fig. 3. Measurement of facial type parameters on a photograph. B-C/A-B: Ratio of lower facial height to total facial height (LFH/TFH). D: Angle between the Frankfurt Horizontal (FH) plane and the plane passing through Gonion (Go) and Menton (Me) (FH/GoMe angle).

performed to evaluate whether significant differences existed between the dental data obtained from wax-based bite marks and those derived from digital models. Pairwise comparisons for nonparametric variables were conducted using the Wilcoxon signed-rank test, while parametric variables were analyzed with paired-samples t-tests. Correlations between variables for each participant were evaluated using Spearman's rho ( $\rho$ ) test. Intra-class correlation coefficient (ICC) analysis was used to

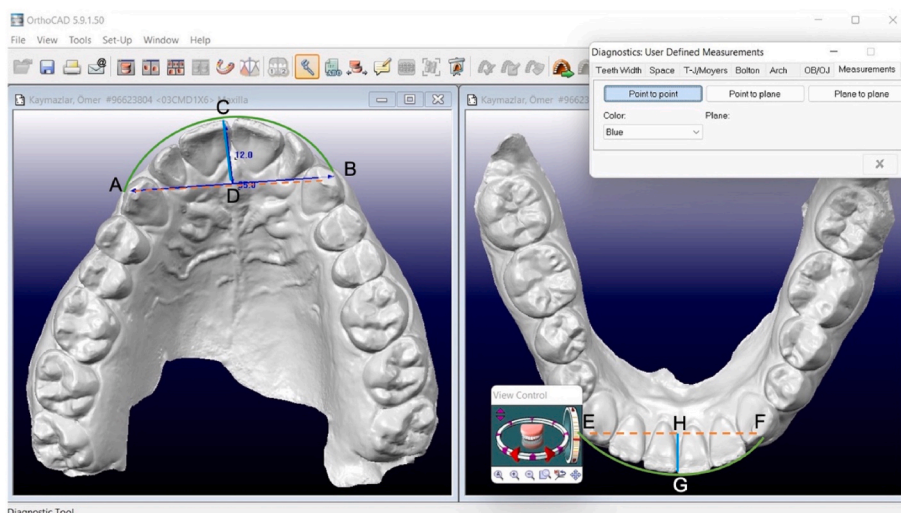


Fig. 2. Dental measurements performed on digital models. Intercanine distance: Orange dashed linear line extending between points A-B in upper jaw (DICUJ), orange dashed linear line extending between points E-F in lower jaw (DICLJ). Arch length: Curved green line extending between points A-B in upper jaw (DALUJ), curved green line extending between points E-F in lower jaw (DALLJ). Arch depth: Blue linear line extending between points C-D in upper jaw (DADUJ), blue linear line extending between points G-H in lower jaw (DADLJ). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

assess reliability of measurements. Correlation coefficients and their significance levels were determined, with a  $p < 0.05$  considered statistically significant.

### 3. Results

Intra-observer reliability, assessed via intraclass correlation coefficients (ICC), yielded values between 0.94 and 0.97, reflecting near-perfect consistency in measurements.

The analysis demonstrated measurable correlations between specific bite mark dimensions and vertical facial type parameters.

Comparisons between dental data obtained from wax bite marks and digital models revealed statistically significant differences in all parameters ( $p < 0.05$ ) except for maxillary arch length (WALUJ vs. DALUJ) and mandibular arch length (WALLJ vs. DALLJ). Pairwise comparisons are presented in Table 1.

Correlation analyses were performed by pairing each participant's wax derived bite mark measurements with their own facial morphology parameters, ensuring that all comparisons were conducted within individuals. Statistically significant associations ( $p < 0.05$ ) were observed between the LFH/TFH ratio and WALLJ ( $r = 0.327$ ). LFH and TFH individually showed no significant correlations with bite mark measurements. The FH/GoMe angle demonstrated positive correlations with WALUJ ( $r = 0.345$ ) and WALLJ ( $r = 0.359$ ). These correlations were given in Table 2.

### 4. Discussion

These results imply that bite mark analysis could serve as an indicator for estimating mandibular arch dimensions, thereby contributing to facial phenotype assessment. The concordance between wax-based and digitally derived arch length measurements underscores the reliability of these parameters in vertical facial pattern diagnostics.

Bite marks are generally analyzed by assessing their shape, size, and alignment with the suspect's dental morphology, including tooth positions and overlap ratios. Comparative methods include examining dental plaster models, cross-referencing wax-based bite marks, photographic documentation, and computer-aided analyses. Although bite marks are presumed unique, their reliability is compromised on human skin due to anatomical site variability, tissue elasticity, and distortion during biting. Additional confounding factors include bite force, angle of contact, and substrate compliance.<sup>21</sup> In this study, rather than requiring exact bite mark congruence, alternative approaches explored in the broader context of understanding craniofacial morphology rather than suspect identification.

Studies in the field of forensic odontology reveal that teeth are frequently utilized for determining gender and age, which can also play a decisive role in identifying potential suspects.<sup>22-25</sup> According to the American Board of Forensic Odontology (ABFO), bite marks can serve three primary purposes: excluding a suspect, failing to exclude a suspect,

**Table 1**

Descriptive statistics and pairwise comparisons of dental parameters derived from bite marks and digital models.

|           |              | Digital (mean ± S.D.) | Wax (mean ± S.D.) | p value             |
|-----------|--------------|-----------------------|-------------------|---------------------|
| Upper Jaw | Inter canine | 35.32 ± 2.08          | 34.82 ± 2.14      | 0.07 <sup>a</sup>   |
|           | Arch length  | 40.47 ± 3.24          | 41.1 ± 3.11       | 0.311 <sup>b</sup>  |
|           | Arch dept    | 9.94 ± 1.06           | 9.18 ± 1.73       | 0.005 <sup>a</sup>  |
| Lower Jaw | Inter canine | 27.21 ± 2.46          | 26.64 ± 1.89      | <0.001 <sup>a</sup> |
|           | Arch length  | 29.51 ± 3.53          | 30.73 ± 2.53      | 0.08 <sup>a</sup>   |
|           | Arch dept    | 7.74 ± 1.69           | 5.47 ± 1.1        | <0.001 <sup>a</sup> |

$p < 0.05$  is statistically different.

<sup>a</sup> Wilcoxon Signed Rank test.

<sup>b</sup> Paired Samples T test.

or indicating insufficient evidence.<sup>26</sup> To enhance the reliability of dental evidence in suspect identification, the collection and analysis of additional data are necessary. Facial morphology may also be considered a criterion for suspect profiling; however, current literature lacks sufficient research on this subject.

According to current literature, the use of bite marks in forensic practice remains highly controversial. Numerous wrongful convictions have been linked to the misinterpretation of bite marks on human skin, and consequently, such evidence is no longer regarded as a reliable method of forensic identification in court.<sup>7,8</sup> In the present study, bite marks were obtained exclusively on inanimate substrates using wax-coated sponge rollers, a method supported in forensic odontology literature for its reproducibility and suitability for controlled experimental comparison.<sup>27</sup> However, wax cannot replicate the viscoelastic properties or deformation patterns characteristic of real bite marks on human skin. Therefore, this study focuses on exploring possible connections between bite marks which created experimentally and vertical facial characteristics, without extending these findings to biological or forensic identification contexts.

The statistically significant differences observed between dental data derived from wax-based bite marks and digital models in this study could stem from the inherent dimensional instability of wax materials or the biomechanical complexities involved in bite mark formation. Wax, while commonly used in dentistry, is prone to thermal contraction, plastic deformation, and moisture absorption, which can lead to measurable distortions in arch dimensions.<sup>28</sup> These distortions could misrepresent the suspect's actual dentition when compared to precise digital scans. In addition, the morphology of bite mark is influenced by dynamic variables such as bite the distribution of bite force, the movement of the jaw, and the compressibility of tissue during biting. For example, the elasticity of soft tissues and the resistance of the substrate can affect how clearly a tooth imprint appears and its accuracy in terms of position, leading to deviations from the actual occlusion.<sup>29</sup> Sweet and Bowers also stated that bite marks rarely match the exact congruence with the perpetrator's dental anatomy; even under controlled conditions, bite marks on human skin showed position changes of up to 3 mm due to tissue resiliency and deform unevenly.<sup>30</sup>

Research analyzing bite mark reproducibility on cadaveric skin demonstrated discrepancies between cutaneous impressions and their underlying dentition. Despite attempts to map incisal cusp angles, skin elasticity and tissue distortion led to inconsistent mark morphology, challenging forensic reliability.<sup>20</sup> Also in this study, functional dynamics during biting caused deviations in intercanine distance and arch depth from their stable intraoral positions. However, arch length remained consistent in both the maxillary and mandibular arches. This finding suggests that arch length may serve as a reliable parameter in bite mark analysis, highlighting its potential utility in forensic evaluations.

In orthodontics, determining facial type is crucial for deciding the appropriate treatment plan. The treatment approach differs significantly for individuals with hypodivergent, hyperdivergent or normal facial type.<sup>31</sup> Therefore, certain parameters serve as reliable indicators of an individual's facial morphology. It has been demonstrated a proven correlation between the LFH/TFH and vertical facial patterns.<sup>32,33</sup> The observed difference between the mandible and maxilla may suggest that the maxilla is subject to greater distortion in wax. Mandibular arch length (WALLJ) demonstrated significant positive correlations with vertical facial parameters (LFH/TFH ratio and FH/GoMe angle), maxillary arch length (WALUJ) showed correlation with FH/GoMe but there was no correlation with LFH/TFH ratio. This discrepancy underscores the better diagnostic reliability of WALLJ in bite mark forensics. The observed positive correlation between WALLJ and craniofacial parameters implies that bite mark analysis may serve as a noninvasive indicator for estimating vertical facial growth patterns in forensic or orthodontic contexts.

The main limitation of this study is its relatively small sample size, which restricts the how widely the findings can be applied. Finding

**Table 2**  
Correlations between facial parameters and dental data of bite marks.

|       | LFH    |       | TFH    |       | LFH/TFH |        | FH/GoMe |        |
|-------|--------|-------|--------|-------|---------|--------|---------|--------|
|       | r      | p     | r      | p     | r       | p      | r       | p      |
| WICUJ | -0.140 | 0.402 | -0.010 | 0.952 | -0.040  | 0.812  | -0.091  | 0.587  |
| WALUJ | 0.020  | 0.907 | -0.024 | 0.885 | 0.327   | 0.045  | 0.345   | 0.034* |
| WADUJ | 0.058  | 0.727 | 0.041  | 0.809 | -0.063  | 0.706  | 0.169   | 0.311  |
| WICLJ | -0.316 | 0.053 | -0.163 | 0.329 | -0.125  | 0.454  | 0.159   | 0.340  |
| WALLJ | -0.195 | 0.241 | -0.375 | 0.21  | 0.327   | 0.045* | 0.359   | 0.027* |
| WADLJ | 0.117  | 0.484 | 0.113  | 0.501 | 0.150   | 0.358  | 0.118   | 0.482  |

Spearman's rho correlation test.

r: correlation coefficient.

p < 0.05 is statistically different.

participants who had never had orthodontic treatment was challenging. However, this requirement was necessary because orthodontic treatment significantly changes the shape of the dental arch, occlusal relationships, and facial morphology, thereby introducing a significant confounding effect on the associations examined in this study. Therefore, the strict exclusion criteria allowed for the evaluation of natural differences in arch dimensions and facial types, without the influence of changes caused by treatment. Future research should aim to include larger samples with balanced representation across vertical facial types and, when possible, incorporate stratified analyses comparing orthodontically treated and untreated individuals to better understand the extent of treatment-related confounding. Additionally, because methodological limitations inherent to wax-based substrates may influence the accuracy of bite mark measurements, further studies employing alternative experimental materials or three-dimensional approaches may help clarify the robustness of these findings. Finally, it should be emphasized that facial typology assessments intended for forensic or anthropometric applications must be performed by qualified professionals using standardized lateral cephalometric imaging to ensure diagnostic validity.

Given the broader scientific and legal context surrounding bite mark analysis, we must be careful when interpreting the current findings. Bite mark analysis has repeatedly been shown to contribute to wrongful convictions, with studies documenting high false-positive rates even among certified experts and demonstrating that neither dental uniqueness nor the stability of skin as a recording substrate can be empirically supported.<sup>8</sup> Given these limitations, the correlations identified in our study should not be interpreted as supporting forensic identification. Instead, they provide insight into the morphological relationship between bite mark dimensions and vertical facial type under controlled, non-biological conditions, emphasizing the need for continued research that clearly distinguishes biomechanical exploration from forensic individualization.

## 5. Conclusion

The differences found between bite marks made with wax and digital dental models highlight the limitations of methods that depend on materials for bite mark analysis, especially when applied to real-world forensic situations. Although mandibular arch length demonstrated consistent correlations with vertical facial type, these findings should be interpreted strictly within the controlled, non-biological context of this study and not as evidence supporting individual identification. The results, however, highlight a potential morphological connection, which could help us better understand craniofacial patterns. Given the ongoing concerns about the scientific reliability of bite mark comparison in forensic science, further validation is essential. This should involve larger and more diverse sample groups, as well as the use of different experimental materials. Therefore, future research should focus on refining the biomechanical principles behind bite mark patterns, rather than supporting forensic identification claims that lack sufficient

evidence.

## Author contributions

**ED:** Original draft writing, data curation, statistical analysis.

**MK:** Acquisition of dental records, review and editing of the manuscript.

**ÖÖK:** Study conceptualization and framework design.

**SB:** Literature review and supervision.

**ES:** Project administration and methodological guidance.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Abbreviations

|       |                                       |
|-------|---------------------------------------|
| ABFO  | American Board of Forensic Odontology |
| TMJ   | Temporomandibular Joint               |
| WICUJ | Wax-intercanine-upper jaw             |
| WALUJ | Wax-arch length-upper jaw             |
| WADUJ | Wax-Arch depth-upper jaw              |
| WICLJ | Wax-intercanine-lower jaw             |
| WALLJ | Wax-arch length-lower jaw             |
| WADLJ | Wax-arch depth-lower jaw              |
| DICUJ | Digital-intercanine-upper jaw         |
| DALUJ | Digital-arch length-upper jaw         |
| DADUJ | Digital-arch depth-upper jaw          |
| DICLJ | Digital-intercanine-lower jaw         |
| DALLJ | Digital-arch length-lower jaw         |
| DADLJ | Digital-arch depth-lower jaw          |
| LFH   | Lower face height                     |
| TFH   | Total face height                     |

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