Original Article

Digitization and validation of the open bite checklist manifesto: a step toward artificial intelligence

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ABSTRACT

Objectives: To introduce and validate newly designed computer software to aid in the diagnosis of anterior open bite (AOB).

Materials and Methods: The software was constructed based on the algorithm of a standardized open bite checklist, which considered skeletal, dental, and soft tissue components, as well as smile characteristics. Feeding the software with this input yielded a digital form output (DFO) in the guise of a diagnostic report characterizing the AOB phenotype, contributing components, severity, associated problems, and functional factors. For validation, DFO was compared to a conventional form output (CFO), created in a standardized manner according to expert opinions. Agreement between the DFO and CFO in terms of AOB phenotype was the primary outcome, while the secondary outcome was the number of missing diagnostic components in either method.

Results: Percentage of agreement between CFO and DFO was 82.2%, with a kappa coefficient of 0.78, which is considered a good level of agreement. There was a statistically significant relationship between the number of missing diagnostic components in CFO and level of disagreement, which rendered the DFO more reliable.

Conclusions: Newly constructed software represents an efficient and valid diagnostic tool for AOB and its contributing components. There was good agreement between CFO and DFO, with the latter being more comprehensive and reliable. The algorithm built in the software can be used as the basis for a future artificial intelligence model to aid in the diagnosis of AOB. (*Angle Orthod*. 2024;94:51–58.)

KEY WORDS: Open bite; Diagnostic software; Digital orthodontics; Decision support system; Artificial intelligence

INTRODUCTION

The orthodontic specialty has advanced greatly over the past decades. One of the most revolutionary changes in the practice is the invasion and dissemination of digital orthodontics (DO).[1] Despite the wide array of applications of DO, there remains an exclusively practice-changing domain, which is creating a robust decision support system to orthodontists.[2] This encompasses digitization and validation of diagnostic/therapeutic tools,[2] followed by data collation that would then enable machine learning.[3,4] Since orthodontic diagnosis and treatment planning is considered a complicated process with a multitude of interacting factors requiring great knowledge, experience and skills, the application of artificial intelligence (AI) might be of great need to aid practitioners in the decision-making process.[3,5] Whether these are expert orthodontists wanting to save time and operate at a higher level of efficiency, or others with less clinical experience who need guidance throughout their trajectory, AI is expected to be of utmost importance.[6] So far, AI-based models have been successfully applied to automated lateral cephalometric tracing, determination of the cervical vertebral maturational stages, assessment of facial attractiveness, diagnosis of temporomandibular joint osteoarthritis, and the need for orthodontic extractions or orthognathic

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surgery.[3,6–8] However, it has not yet been applied to the mere diagnosis of specific malocclusions with their various components.[3,5] Being the language of the era, AI is expected to be deliberately imperative, especially with the integration of various efficient models and their permissive application.[3]

One of the most challenging types of orthodontic problems are those occurring in the vertical dimension.[9] The involvement and interaction of various contributing factors, and their subsequent impact on treatment considerations and outcomes give them substantial priority over other malocclusions in different dimensions.[9] The anterior open bite malocclusion (AOB) represents a variant of vertical jaw dysplasia where there is lack of anterior tooth contact.[10] AOB might happen due to muscular factors, increased jaw divergence, under-eruption of anterior teeth, overeruption of posterior teeth or a combination of these factors.[11–14] There are also other local and systemic conditions that might cause or be associated with AOB, such as trauma, degenerative joint disease, inflammatory, or autoimmune diseases.[12] The basic types of AOB are the skeletal and dental variants,[12,13] However, more recently, AOB was further subclassified into distinct phenotypes depicting the co-occurrence of certain contributing components.[15] A systematic approach was described in the form of the open bite checklist and a diagnostic tree to discern the AOB phenotype of each patient.[15] Despite being insightful, the open bite checklist manifesto[15] is thought to be quite tedious and time-consuming. Therefore, it was speculated to design computer software using the idea of the open bite checklist, after its revision and modification.

The concept of digitization is intended to produce an efficient and standardized diagnostic tool for which reliability and validity reflect those of the algorithm built into the software.[8] This software is aimed to form the foundation of a future AI-based model for distinction of AOB phenotypes and their contributing components. This model is supposed to combine the merits of individualized diagnosis and treatment planning together with the efficiency and reliability of DO. Such a combination would enable the orthodontist to tailor the treatment for each particular patient by merely targeting the distinguished offending components.

Accordingly, the aim of this study was to present the newly designed software for AOB phenotype diagnosis. It also aimed at validating this software in comparison to the conventional method used for AOB diagnosis.

MATERIALS AND METHODS

The sample of this study was adult subjects with AOB malocclusion seeking orthodontic treatment at the outpatient clinic of the Orthodontic Department, Faculty of Dentistry, Cairo University in Egypt. The inclusion criteria were adult patients with AOB, skeletal or dental, with no history of systemic disease, chronic medications, or previous orthodontic treatment. The sample characteristics and demographics are summarized in Table 1. Informed consent was obtained from all patients before starting treatment and included using their records in research and publication. Ethics committee approval at Faculty of Dentistry, Cairo University, was obtained before conducting the study. Since this was a diagnostic study, only the pretreatment records of the patients were used, including photographs, radiographs and clinical examination data.

Table 1. Demographic Data of the Included Sample[a]

	N	Mean	SD	Percent
AGE (y)	101	22.81	4.28	
AOB (mm)	101	4.87	2.21	
Gender				
Male	68			67.33%
Female	33			32.67%
Angle Class				
I	60			59.41%
II Div 1	16			15.84%
III	25			24.75%

[a] AOB indicates anterior open bite; mm, millimeters; N, number of cases; SD, standard deviation; y, years.

A diagnostic checklist for AOB (Figure 1) was the foundation for constructing the specifically designed software. It was inspired by a previously published checklist,[15] but modified to include some overlooked components such as the extent of lower incisor show on smiling and anterior gumminess. Another amendment to the published checklist was modifying the conditions for obtaining the answers to the questions, as well as the norms provided for the upper/lower/anterior and posterior dentoalveolar heights.[16] The software was developed using Java FX, which is a high-level, class-based, object-oriented programming language. The formulated algorithm was used as a source to feed a future AI-based model in a forward chaining method. The software used the answers of the first four questions of the modified checklist as input, with the output being a diagnostic report (Figure 2) defining AOB phenotype, severity, habitual/functional factors, smile esthetics, skeletal/dental and soft tissue factors pertaining to the presenting malocclusion for that particular patient. Additionally, AOB phenotypes were recast to discern the co-occurrence of different components in both arches. For simplification, the AOB phenotypes were classified into main categories, as well as combination phenotypes (Table 2). The main categories were those having similar components in both arches, while combination phenotypes had different components for either arch.

Modified open bite checklist

Q1) Upon extra-oral examination, does the patient have:

- Increased mandibular plane angle (MP).
- Increased lower anterior facial height (LAFH).
- lip incompetence.

Q2) In cephalometric measurements, measure:

- SNMP > (32±5) ……….
- MMA > (25±3) ……….
- LAFH > (72 ±5) ……….
- Gonial angle > (122) …….
- TPFH < (73±5) ………….

Q3) Upon smiling,

- U Incisal show. - Normal. - Increased. - Decreased
- Smile arc - Consonant. - Flat. – Reversed
- L incisor show -Absent. – Slight. - Present
- Posterior gumminess. -Absent. – Slight. – Present
- Anterior gumminess -Absent. – Slight. – Present

Q4) In cephalometric measurements:

- UADH (28.1 ± 2.7 mm) ………. - Normal. - Increased. - Decreased
  (Upper anterior dento-alveolar height measured as the perpendicular distance from U1 cusp tip to the palatal plane)
- LADH (40.2 ± 2.3 mm) ………. - Normal. – Increased. - Decreased
  (Lower anterior dento-alveolar height measured as the perpendicular distance from L1 cusp tip to the mandibular plane)
- UPDH (22.0±2.2 mm) ………. - Normal. - Increased. -Decreased
  (Upper posterior dento-alveolar height measured as the perpendicular distance from mesio-buccal cusp of U6 to the palatal plane)
- LPDH (30.3±2.9 mm)……….. - Normal. - Increased. -Decreased
  (Lower posterior dento-alveolar height measured as the perpendicular distance from mesio-buccal cusp of L6 to the mandibular plane)
- U1/PP (112±5°) ………. - Normal. - Increased. -Decreased
- L1/MP (98±6°) ………. - Normal. - Increased. -Decreased

Q5) During the action of swallowing, the tongue thrusts:

- In the open bite area.
- Behind U incisors.
- Behind L incisors

Q6) Intra-orally, examine the resting position of the tongue:

- Posterior.
- In the open bite area.
- Behind U incisors.
- Behind L incisors
- In the floor of the mouth

Q7) Measure the anterior open bite at its most: ……mm

- Mild: 0-3 mm
- Moderate: 3-7 mm
- Severe > 7 mm

Q8) Record the lateral extension of the anterior open bite

…………………………………………………………………………………………..

Q9) Cervical vertebral maturation stage: …….

Q10) Any associated problems:

- Crowding: ……….mm in the upper arch.
- Crowding: ……….mm in the lower arch.
- Spacing: …………mm in the upper arch.
- Spacing: …………mm in the lower arch.
- Posterior cross-bite: ……………………………………………………………
- Anterior cross bite: …………………………………………………………….
- Others: Impactions/ enamel hypoplasia/ tooth agenesis/ supernumerary teeth/ TMD

Figure 1. The modified open bite checklist providing input for the computer software.[15]

The algorithm fed into the software was designated to include more variations of patients belonging to each AOB phenotype. The output of the software regarding AOB phenotype was termed digital form output (DFO).

For validation of the software output, a comparison was made to that of a conventional form checklist (CFC) used to manually reach the AOB phenotype (Figure 3). It was formulated based on the experience of two senior orthodontists by a consensus of the factors and measurements commonly used in the assessment of AOB cases, with a background of the formulated AOB phenotypes. The outcome of the CFC was termed conventional form output (CFO). Each patient was assessed using both methods, CFO and DFO, and the results were compared (primary outcome).

The secondary outcome of the study was the number of missing diagnostic components in the CFO or DFO and their subsequent impact on the agreement level. The missing components comprised the cephalometric measurements of the anterior and posterior, upper and lower dento-alveolar heights that were not included in the CFO.

Sample Size Calculation

Sample size calculation was done assuming the percentage of agreement between DFO and CFO to be 80% based on a pilot study and expert opinion, and a margin of error of 10%. Accordingly, a sample size of 62 patients would be required to ensure a type 1 error less than 0.05. A sample of 101 patients was successfully included in the study.

Statistical Methods

Statistical analysis for the study was performed using SPSS in general (version 20). *Percentage of agreement and Kappa coefficient* were used to assess the agreement between the two methods and also for intra- and inter-observer reliability analyses. The *Chi-square test* of independence was used for contingency table to assess the effect of the number of missing diagnostic components on the level of agreement. Significance level was considered at $P < .05$.

RESULTS

There was a statistically significant agreement between the CFO and DFO, with a percentage of agreement of 82.2% (83 cases out of 101), and a kappa coefficient of 0.78, which reflects a good level of agreement (Table 3). The AOB phenotype that showed the greatest level of agreement was the uncompensated skeletal open bite (SOB) (representing 28.7%; 29/101) (Table 3). On the other hand, the overall percentage

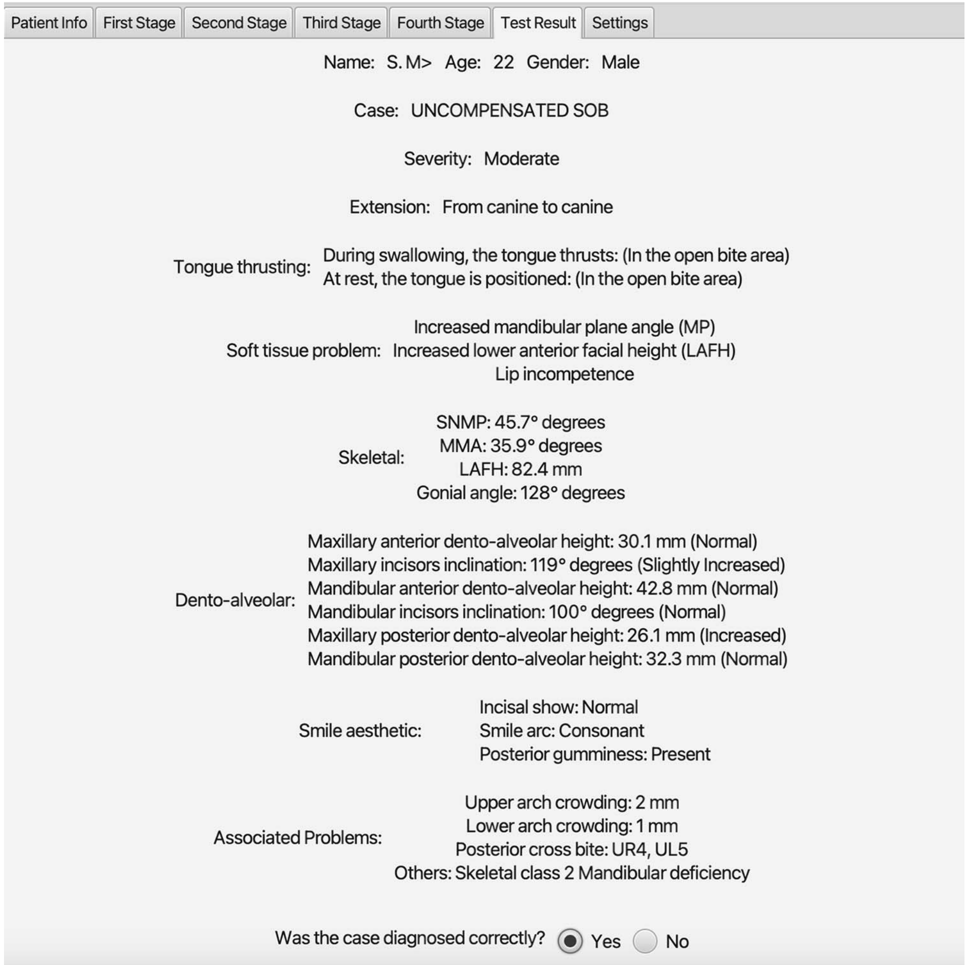

Figure 2. The diagnostic report representing the digital form output (DFO).

of disagreement between the CFO and DFO was 17.8% (18 cases out of 101) (Table 4). The greatest disagreement took place between the uncompensated SOB and the combination phenotype of uncompensated SOB in the upper arch, with dental contribution in the lower arch (Table 4).

The number of missing diagnostic components was determined for all the cases, and the percentages are shown in Table 5 with their association to the agreement and disagreement cases. Seventy-eight percent of all the cases (79 cases out of 101), and 100% of the cases that showed disagreement had missing diagnostic components when using the CFO. The chi-square test showed a statistically significant correlation between the number of missing diagnostic components and the level of disagreement between CFO and DFO.

The intra- and inter- observer reliability analyses of the CFO showed kappa coefficients of 0.87 and 0.84, respectively (Table 6), which indicate very good levels of agreement. The DFO method showed a kappa coefficient of 1, which reflects a 100% agreement for intra- and inter-observer reliability analyses (Table 6).

DISCUSSION

Vertical dysplasia of the jaws and, specifically, AOB malocclusion represents a complex dentofacial condition, with functional, esthetic, and biological impact.[12,13] Several reports aimed at analyzing the contributing components of AOB,[14,15,17] and, lately, certain phenotypes have been ascribed, with a checklist and a systematic approach to distinguish each patient's phenotype.[15] However, upon application of this approach, some modifications were deemed essential to the checklist and the diagnostic approach to include a wider array of patients, while preserving the concept of phenotypic distinction.

Another limitation of the previously published checklist and diagnostic tree was its complexity of application and the presence of overlapping phenotypes when considering the upper and lower arches separately. With

Table 2. Phenotypes of Anterior Open Bite[a]

Phenotypes	Description
Main Anterior Open Bite Phenotypes	
Uncompensated SOB	Features of skeletal open bite (extra-oral and/or cephalometric), with neither dental compensation nor contribution of upper and lower arches
Compensated SOB	Features of skeletal open bite (extra-oral and/or cephalometric), with evidence of dental compensation (clinical ± cephalometric) of anterior dentoalveolar segments of upper and lower arches
SOB with dental contribution of U, L	Features of skeletal open bite (extra-oral and/or cephalometric), with evidence of dental contribution of upper and lower arches (clinical ± cephalometric).
Dental open bite	Features of dental open bite (extra-oral and/or cephalometric), with dental contribution of upper/lower/upper and lower anterior dentoalveolar segments
Combination Phenotypes of Anterior Open Bite	
SOB; Uncompensated U, compensated L	Features of skeletal open bite (extra-oral and/or cephalometric), with neither dental compensation nor contribution in the upper arch, but with dental compensation in the lower arch
SOB: Compensated U, uncompensated L	Features of skeletal open bite (extra-oral and/or cephalometric), with dental compensation in the upper arch, while the lower arch neither shows dental compensation nor contribution
SOB; Uncompensated U, with dental contribution of L	Features of skeletal open bite (extra-oral and/or cephalometric), with neither dental compensation nor contribution in the upper arch, but with dental contribution in the lower arch
SOB; Compensated U, with dental contribution of L	Features of skeletal open bite (extra-oral and/or cephalometric), with dental compensation in the upper arch, while the lower shows dental contribution
SOB; Uncompensated L, with dental contribution of U	Features of skeletal open bite (extra-oral and/or cephalometric), with neither dental compensation nor contribution in the lower arch, but with dental contribution in the upper arch
SOB; Compensated L, with dental contribution of U	Features of skeletal open bite (extra-oral and/or cephalometric), with dental compensation in the lower arch, while the upper shows dental contribution

[a] SOB indicates skeletal open bite; L, lower anterior segment; U, upper anterior segment.

this fact, coupled with the rising pace of digital orthodontics, it was decided to create fully customized software to surmount the hurdles of this diagnostic procedure. The software would take the answers of the modified checklist as inputs and create a diagnostic report as the output, which takes only a couple of minutes. This diagnostic report not only distinguishes the AOB phenotype for the particular patient, but also the various soft tissue, skeletal, and dental components. Additionally, the habitual and functional factors are included together as well, with the severity of the AOB, smile esthetics, and other associated factors like crowding/spacing, discrepancies in anteroposterior or transverse dimensions, etc.

For the different AOB phenotypes, the basic distinction between skeletal and dental types depends on certain clinical and cephalometric variables.[18,19] However, it seems pertinent to elucidate whether there is any sort of dental compensation/contribution in cases of SOB as this greatly affects not only the treatment plan, but also the treatment sequence, mechanics, and, hence, the expected outcome. Dental compensation in AOB cases is defined by the vertical eruption of the upper/lower anterior dentoalveolar segments to compensate partly for the jaw divergence, while dental contribution reflects the involvement of anterior segments to the AOB by their under-eruption.[15] So, they basically represent opposite phenomena, and each of them implies a certain intervention based on their extent, other contributing factors, and smile esthetics. Understanding these terms, together with respecting the individualized nature of malocclusions and benefiting from the advances in technology, mapped the foundation of designing this study.

The main and combination phenotypes of AOB described in Table 2 are expected to cover most if not all the possible variants of AOB cases. The algorithm built into the software was established with the ability to identify the AOB phenotype, prioritizing the clinical over the cephalometric findings, and providing for variations caused by the multiplicity of involved factors.

After the software was executed, the validation process had to include a comparison to a conventional method for AOB diagnosis. A CFC was created by asking expert orthodontists about the factors they

Conventional form checklist (CFC)

Patient's name:

Age: Sex:

Chief complaint:

Presence of habits:

Family history:

A. CLINICAL EXAMINATION

Extra-oral examination:

- Increased mandibular plane angle (MP).
- Increased lower anterior facial height (LAFH).
- lip incompetence.
- Profile convexity
- U Incisal show on smiling. - Normal. - Increased. – Decreased
- L Incisal show on smiling. – Present. – Absent
- Smile arc - Consonant. - Flat. - Reversed
- Posterior gumminess. – Present. – Absent
- Anterior gumminess – Present. – Absent

Intra-oral examination:

- Amount of OB:…………………..mm
- Upper posterior dento-alveolar height:…………………………..
- Lower posterior dento-alveolar height: …………………………
- Upper anterior dento-alveolar height:……………………………
- Lower anterior dento-alveolar height: ……………………………

B. CEPHALOMETRIC MEASUREMENTS

- SNMP > (32±5) ……….
- MMA > (25±3) ……….
- LAFH > (72 ±5) ……….
- Gonial angle > (122) …….
- PFH < (73±5) ………….
- U1/PP (112±5°) ……….
- L1/MP (98±6°) ……….

Accordingly; AOB phenotype is:………………………………………………

Figure 3. The conventional form checklist (CFC).

would examine in an open bite patient, being familiarized with the AOB phenotypes. The CFC did not include the upper/lower, anterior and posterior dento-alveolar heights, as they were not commonly used as reported by expert orthodontists. Instead, the clinical variables reflecting these components were included.

The percentage of agreement between CFO and DFO was 82.2%, while the kappa coefficient was 0.78, which reflected a good level of agreement between the two methods, displaying high statistical significance. These findings primarily represent good performance of digitized diagnostic procedures, which would save a lot of precious time and effort for expert orthodontists, and also allow less experienced practitioners to unravel diagnostic information that would otherwise be ambiguous.[2,4]

The highest percentage of agreement was for the uncompensated SOB phenotype. The reason behind this finding might have been the greater occurrence of this phenotype and the relative simplicity of its diagnosis, as it neither involves dental compensation nor contribution.[15] On the contrary, the greatest disagreement was reported between the uncompensated SOB and the combination phenotype of uncompensated SOB in the upper arch, with dental contribution in the lower arch. The main difference between these phenotypes is the reduction of the lower anterior dentoalveolar height (LADH) in the latter that is diagnosed clinically or cephalometrically. Since the CFC did not use the dento-alveolar heights in their input, clinical judgment offered the single source of diagnostic information regarding LADH. However, the software gained information regarding LADH from clinical assessment and cephalometric measurements. Therefore, the DFO was found to be more intricate in diagnosing this phenotype.

Since the upper/lower, anterior and posterior dento-alveolar heights were not commonly used by experienced orthodontists and, accordingly, were not included in the CFO, the DFO based on the modified checklist had a better ability to pursue the AOB phenotype. Although the software was designed to prioritize the clinical over the cephalometric findings, Including both in the decision making led to a more robust diagnostic ability of the DFO over the CFO. Interestingly, there was a direct relationship between the number of missing diagnostic components and the occurrence of disagreement between CFO and DFO. This highlights the importance of these components, despite being overlooked even by experienced orthodontists. Nevertheless, a considerable number of cases showed agreement despite having missing cephalometric

Table 3. Percentage of Agreement and Kappa Coefficient Between DFO and CFO[a]

AOB Phenotype	*Frequency*	*Percent*	Kappa coefficient	*P* Value
Uncompensated SOB	29	28.70%		
Compensated SOB	9	8.91%		
SOB with dental contribution of U&L	3	2.97%		
Dental open bite	8	7.92%		
SOB Uncompensated U, compensated L	12	11.88%		
SOB Uncompensated L, with dental contribution of U	13	12.87%		
SOB Compensated U, Uncompensated L	4	3.96%		
SOB Compensated L, with dental contribution of U	5	4.95%		
Total (out of 101 cases)	**83**	**82.18%**	**0.78**	**0.00000***

[a] AOB indicates anterior open bite; CFO, conventional form output; DFO, Digital form output; L, lower anterior segment; SOB, skeletal open bite; U, upper anterior segment.

Table 4. Percentage of Disagreement Between DFO and CFO Phenotypes[a]

AOB phenotype			
CFO	*DFO*	*Frequency*	*Percent*
Uncompensated SOB	Compensated SOB	1	0.99%
Uncompensated SOB	SOB Uncompensated U, L with dental contribution	7	6.93%
Uncompensated SOB	SOB Uncompensated U, compensated L	2	1.98%
Uncompensated SOB	SOB Compensated U, uncompensated L	1	0.99%
Compensated SOB	SOB Compensated U, uncompensated L	1	0.99%
SOB with dental contribution of U&L	SOB uncompensated L, U with dental contribution	1	0.99%
SOB Uncompensated U, L with dental contribution	SOB Uncompensated U, compensated L	1	0.99%
SOB Uncompensated U, compensated L	Compensated SOB	1	0.99%
SOB uncompensated L, U with dental contribution	SOB with dental contribution of U&L	1	0.99%
SOB Compensated U, uncompensated L	Compensated SOB	2	1.98%
Total		**18**	**17.82%**

[a] AOB indicates anterior open bite; CFO, conventional form output; DFO, Digital form output; L, lower anterior segment; SOB. skeletal open bite; U, upper anterior segment.

components. Such a finding might emphasize the need to investigate the reliability of the norms of these variables and, perhaps, study population/age/gender and skeletal classification-specific values that should be based on reliable landmarks. This is because there are suggestions that dentoalveolar heights vary according to the vertical and sagittal skeletal relations.[16] Then, the true contribution of these variables to the AOB phenotypes can be better instituted. Also, the probable inconsistency in lateral cephalometric tracing previously reported[20] could be a reason for the agreement in cases having missing diagnostic components.

The reliability analysis performed showed good and very good reliability of the CFO and DFO, respectively. This gives confidence in the expert opinion used in the construction of CFO, and in the algorithm built into the software. The DFO showed 100% reliability, indicating robustness of the included components and the logic built to produce the output. Accordingly, the newly designed software can be considered a reliable, updated digital tool for detailed diagnosis of AOB.

The detailed diagnostic report created by the software is considered the basis for individualized treatment planning. Besides being accurate, fast, and comprehensive; automatically detecting the diseased component "etiological factors" for each patient will allow practitioners to tailor the treatment toward the defective components aiming for a better treatment outcome with enhanced stability and esthetics.[4] This is particularly intriguing in an era with scarce evidence and lack of methodologically sound trials,[21,22] which might be attributed primarily to the diagnostic shortcomings of the studied samples.

The findings of this study provide a profound standpoint from which data mining could be started, taking a step toward machine learning.[3,5] This process would involve image recognition, digital cephalometric tracing, then automatically filling the checklist on the software to produce the final output.

CONCLUSIONS

- The newly constructed software represents an efficient and valid diagnostic tool for AOB phenotype and its contributing components.
- There was good agreement between the conventional form output and the digital form output, with the latter being more comprehensive and reliable.
- The digitization and validation of the modified open bite checklist manifesto accomplishes the first step toward initiation of the machine learning process

Table 5. Number of Missing Diagnostic Components and Correlation to Agreement/Disagreement Groups

	Agreement (n = 83)		Disagreement (n = 18)		Total (101)			
No. of missing components	Frequency	Percent	Frequency	Percent	Frequency	Percent	Chisquare value	*P* Value
0	22	26.50%	0	0.00%	22	21.78%		
1	30	36.14%	7	38.89%	37	36.63%		
2	23	27.71%	4	22.22%	27	26.73%		
3	6	7.23%	4	22.22%	10	9.90%		
4	2	2.41%	3	16.67%	5	4.96%		
Total							**18.18**	**0.00114****

Table 6. Intra- and Interobserver Reliability Analysis of CFO and DFO[a]

	Kappa coefficient	*P* Value
Intra-observer reliability		
CFO	0.87	$P < .001$**
DFO	1	$P < .001$**
Interobserver reliability		
CFO	0.83	$P < .001$**
DFO	1	$P < .001$**

[a] CFO indicates conventional form output; DFO, digital form output.

concerning the diagnosis of anterior open bite malocclusion.

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