Decodify® System: Cephalometrics as a risk manager applicative and administrative tool for the orthodontic clinic

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Abstract

Introduction: Cephalometrics may have limited use in orthodontics because of its subjective interpretation. An Artificial Intelligence (AI) system, the Decodify® System, was developed to allow the customized quantitative assessment of contextualized cephalometric data. In this article, the system is tested as an administrative tool in orthodontic offices. **Methods:** The development of algorithms includes the norms and standard deviations modeling of Brazilians' cephalometric data, measured in lateral radiographs. In order to test the system, initial cephalograms of 60 orthodontic patients of two different orthodontic offices (30 cases each) were processed and re-processed by three different technicians. The intra-observer and inter-observer reproducibility and reliability indices were checked by paired comparisons. The risk in each orthodontic case, assessed by the electronic analysis, was compared by covariance matrices and agreement coefficients. **Results:** Levels of paired agreement inter-observers (versus golden-pattern) for 23 pairs of variables ranged from 0.68 (S-Go distance) to 0.98 (Na-Me distance) in an orthodontic clinic (JU) and from 0.66 (L1.APg angle) to 0.98 (S-Go distance) in the other (SP). All the correlations were significant at the $p<0.001$ level. The average of the agreement coefficients was 0.78 for one clinic (JU) and 0.75 for the other (SP). The agreement coefficients were significant at the $p<0.001$ level. **Conclusions:** The results of such research support that the analyses provided by the Decodify® System are reproducible and reliable. Therefore, the system can be applied in order to contextualize conventional cephalometric measurements and to generate individualized risk indices. The system may be used by orthodontists as an administrative tool in the daily professional evaluations.

Keywords: Orthodontics. Diagnosis. Artificial Intelligence.

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» The authors declare to be developers of Decodify® System.

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LITERATURE REVIEW

Although cephalometrics presents known limitations, it is an important diagnostic tool for the orthodontist.[1-4] One of its limitations is the dependence of personal opinion, since each specialist "interprets" cephalometric data according to the biases built up by his/her academic education, clinical experience and type of clinical service. Technically, cephalometrics presents a limited internal validity due to the identification of cephalometric landmarks[5,6,7] and other methodological[8-11] or geometrical problems.[12] Naturally, new solutions in orthodontic diagnosis has been presented.[13-18]

An important update in cephalometrics would be the customization of cephalometric values measured in each case, what each orthodontist already subjectively makes in daily assessments. Such kind of improvement would not eliminate the need of different sources of information, as cast models and photos. However, in regard to cephalometrics, would be close to the ideal.

Up to date, cephalometric values were not considered in a contextualized model, that means, in the particular scenario of each patient. However, such constraint is more mathematical than biological. Such contextualization would be possible if an artificial intelligence system could provide decisions, imitating what the human being thinking already provides. Such software would need to take into account the degree of uncertainty and inconsistency associated to each cephalometric number, increasing or decreasing the importance of its contribution for the "final degree" of skeletal and dental compromise which each case of malocclusion presents.

Mathematicians and computer engineers have worked in diverse models of "intelligent" algorithms, based upon different types of logic and applied in diverse fields of science as logistics, robotics, defense, economics and medicine.[19,20]

When artificial intelligence systems make decisions in the medical field, they are called specialist systems, programmed to support physicians and other professional personnel of the health area, which; however, provide the final diagnosis or the hypotheses of diagnosis, at their own.

The model of logic applied in this project[21-24] allowed that diverse cephalometric variables were contextualized in each specific craniofacial scenario.

The fuzzy logic has been applied in medicine[25,26,27] and orthodontics[28,29] in order to prevent inadequate rigid allocations in pre-defined categories. However, fuzzy logic considers only certainty and it is not a sufficient mathematical tool in decision making processes. In other hand, paraconsistent logic[22,24] also works with the uncertainty, inconsistency and insufficiency of data, common features in cephalometric data bases, and because of that, was applied in the decision making processes here described.

In another article,[30] the Decodify® System was tested against the opinions of three specialists in orthodontics and, showing an expected variance, behaved as a specialist system.

In the current paper, the results of the Decodify® System were obtained by two trained technicians and, in a paired matter, were compared with the results of an experienced technician in the processing, source called "golden-pattern". Therefore, the article has two main goals: 1) To test the reproducibility and reliability of the results obtained by the Decodify® System and; 2) If the Decodify® System is reproducible and reliable to be introduced to the orthodontic community as an administrative tool used by the orthodontist to measure the degree of risk involved in each proposed orthodontic treatment.

Implementation

The Decodify® System was written in Delphi 11.0 language and filed in Oracle databases, between 2000 and 2004. The algorithms allow that independent cephalometric variables were integrated, considering the uncertainty, inconsistency and insufficiency carried by each variable. The inferences of the system are based upon the degrees of evidence of abnormality (DEA) in specific units: Skeletal (anteroposterior and vertical) and dental (upper and lower teeth).

The components of the Decodify® System (softwares Decodify® e DecodeCAD®) are registered in Brasil in the INPI (Instituto Nacional da Propriedade Industrial) under the licences 00070981 and 00075342. In the USA, the softwares are registered in the Copyright Office – Library of Congress/USA under the protocols TXu1-326-513 (7/31/06) and TXu1-326-514 (7/31/06).

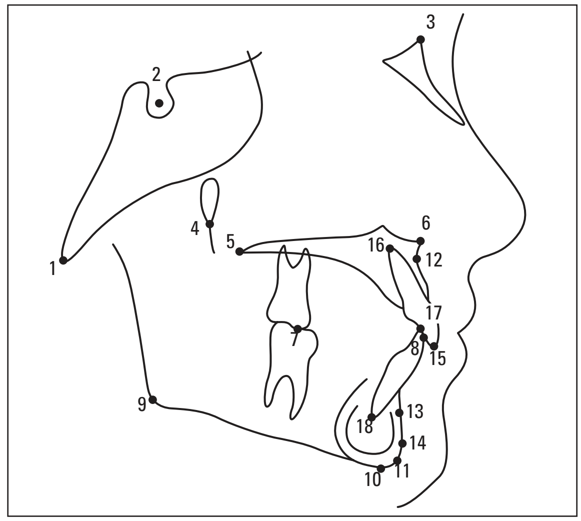

FIGURE 1 - Selected cephalometric landmarks.

MATERIAL AND METHODS

Samples

The samples, retrospectively collected, included 60 initial cephalograms, from patients of both genders, who seek for orthodontic treatment in two clinics, in Jundiaí (JU) and São Paulo (SP). In Jundiaí, 13 male and 17 female individuals, from 12 to 29 years-old, were included in the sample. In São Paulo, 10 male individuals and 20 female individuals, from ages of 19 to 55 years-old, were included in the sample. Patients who presented compromised lateral cephalograms or craniofacial deformities were not included in the sample. There was not discriminate rule in regard to the malocclusion initially presented by the patient, neither in regard to its severity.

Data collection

Eighteen cephalometric landmarks (Fig 1) were identified, traced, re-identified and re-traced in acetate paper, with mechanical pencil 0.3 mm, by three trained technicians (golden-pattern, Jundiai clinic and São Paulo clinic). All the tracing were digitalized in the tablet Trust TB 7.300 Wide Screen Design Table (PO Box 8043, 3301 CA Dordrecht, The Netherlands) and the data analyzed by the Excel software (Windows 7, Redmond, Washington, USA).

Landmarks and cephalometric measurements

The following landmarks and cephalometric measurements were identified and digitalized (Fig 1):

1) Basion (Ba): The most postero-inferior point on the posterior margin of the foramen magnum.
2) Sella (S): The center of the pituitary fossa of the sphenoid bone.
3) Nasion (N): The junction of the frontal and nasal bones, at the fronto-nasal suture.
4) Pterygo-maxillary fissure (PtgI): the most inferior point of the pterygo-maxillary fissure.
5) Posterior nasal spine (PNS): The most posterior point on the bony hard palate.
6) Anterior nasal spine (ANS): The tip of the median anterior bony process of the maxilla.
7) Upper molar: The most inferior point of the mesial cuspid tip of the first upper molar, posterior reference for the occlusal plane.
8) Anterior reference of the occlusal plane: Established by bisecting the overbite or open bite of the incisors, considering the incisal edges of the upper and lower incisors.
9) Gonion (Go): The most postero-inferior point of the angle of the mandible.

10) Menton (Me): The most antero-inferior point on the mandibular symphysis.
11) Gnathion (Gn): The most antero-inferior point on the contour of the symphysis. Determined by bisecting the angle formed by the mandibular plane (Go-Me) and the Nasion-Pogonion line.
12) A Point: The most posterior point on the anterior curvature of the maxilla.
13) B Point: The most posterior point on the anterior curvature of the mandibular symphysis.
14) Pogonion (Pg): The most anterior point on the contour of the bony chin.
15) Upper incisor edge: The incisal tip of the maxillary central incisor.
16) Upper incisor apex: The root tip of the maxillary central incisor.
17) Lower incisor edge: The incisal tip of the mandibular central incisor.
18) Lower incisor apex: The root tip of the mandibular central incisor.

The following cephalometric measurements were considered (Fig 2):

1) S-N: Plane that represents the anterior cranial base.
2) Palatine plane: Angle between the anterior cranial base (S-N) and the palatine plane, considering the landmarks ANS and PNS.
3) Occlusal plane: Angle between the anterior cranial base (S-N) and the occlusal plane, considering the landmarks molar and incisor.
4) Mandibular plane: Angle between the anterior cranial base (S-N) and the mandibular plane (Go-Me).
5) Ba-Na: Plane that represents the cranial base.
6) Y Axis: Smaller angle between the cranial base (Ba-N) and the facial axis (Ptg-Gn).
7) S-Go: Distance between Sella and Gonion, representing the posterior facial height.
8) N-ENA: Distance between Nasion and ANS, representing the upper part of the anterior facial height.

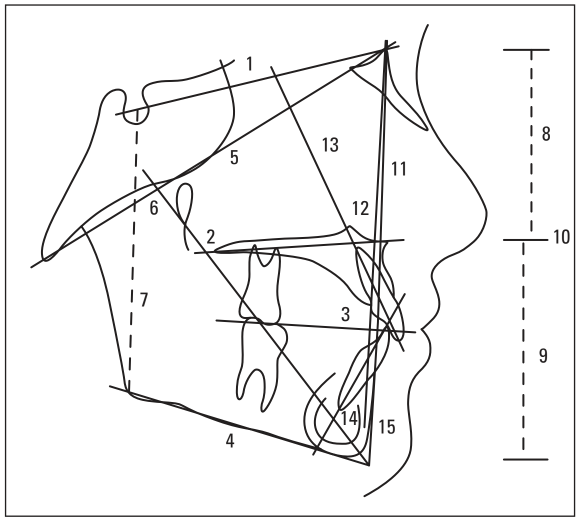

FIGURE 2 - Selected cephalometric measurements.

9) ANS-Me: Distance between the ANS and Menton, representing the lower part of the anterior facial height.
10) N-Me: distance (mm) between Nasion and Menton, representing the antero-posterior facial height.
11) SNA: angle between the anterior cranial base (S-N) and the A Point, representing the antero-posterior positioning of the maxilla.
12) SNB: angle between the antero-posterior cranial base (S-N) and the B Point, representing the antero-posterior positioning of the mandible.
13) Long axis of the upper incisor.
14) Long axis of the lower incisor.
15) A Point-Pg plane: Plane representing the maxilla-mandible skeletal profile.

Wits: distance between the perpendicular projections of the A and B Points in the occlusal plane, representing the antero-posterior relationship between the maxilla and the mandible.

Research model and statistical method

The system was developed in 3 units: 1) Antero-posterior, 2) Vertical and 3) Dental. The central tendency measurements (average and standard deviation) for each age (6 to 18 years-old) from both genders were obtained for the Craniofacial Growth Atlas from Bauru.[31]

The chosen golden-pattern was the digitalization and processing operated by the a technician (BioLogique S/S Ltda Company, São Paulo-SP, Brazil) and hosted in the central server Hostlocation (HostLocation S/C Ltda. Company, R. Maestro Cardim 7081, 01323-001, São Paulo-SP). Each one of the two offices provided 30 lateral radiographs and a technician (examiner) to digitalize and process the data.

After the golden-pattern was established, the intra-examiners reproducibility was tested for each one of the examiners. The results of each examiner were independently compared with the golden-pattern (it was called inter-examiner comparison). The results of each sub-sample of 30 cases were also self-compared (re-digitalized 4 weeks after the first trial). The intra-examiners correlations targeted to measure the systematic error and the inter-examiner correlations targeted to measure the method error. Epistemologically, the null hypothesis of no difference intra-examiners and the null hypothesis of no difference inter-examiner (examiner against the golden pattern) were tested.

Coefficients of correlation compared similar cephalometric variables in a paired manner, isolating as dependent variable the examiner. The risk involved in each case, result of the electronic processing by the Decodify® System and presented as a quantitative ranking, was measured in an ordinal mode. The risks were matched by matrices of covariance and such comparisons were expressed by agreement indices, again testing the null hypotheses of no difference intra-examiners and the null hypotheses of no difference inter-examiner (examiner against the golden pattern).

Logic of the artificial intelligence system

Decodify® is an artificial intelligence system that can calculate the degrees of cephalometric severity, skeletal and/or dental, after the mathematical contextualization of the selected variables. The “neural” network is build with paraconsistent logic,[22,24] capable of making non-trivial decisions, based in its sensibility to uncertainty, inconsistency and insufficiency of the treated data.

RESULTS

The results of reproducibility and reliability of the selected cephalometric variables are described

TABLE 1 - Matched correlation, golden-pattern intra-examiners (IRA) and inter-examiners (IER). Significance level: [p< 0.001].

Variable	Golden-pattern IRA	IER-JU	IER-SP
SNA	0.91	0.74	0.96
SNB	0.94	0.91	0.95
ANB	0.93	0.81	0.97
Wits	0.87	0.86	0.88
M-U1	0.89	0.85	0.77
M-L1	0.84	0.79	0.70
S-Go	0.97	0.68	0.98
Na-Me	0.98	0.98	0.96
Na-ENA	0.90	0.82	0.90
ENA-Me	0.94	0.93	0.97
SN/PP	0.79	0.82	0.82
SN/PO	0.90	0.89	0.89
SN/PM	0.95	0.90	0.97
Y Axis	0.97	0.86	0.97
U1.SN	0.94	0.92	0.95
U1.PP	0.92	0.89	0.95
U1.Na	0.93	0.88	0.96
L1.GoMe	0.90	0.94	0.83
L1.NB	0.79	0.93	0.74
L1-NB	0.93	0.93	0.93
L1.APg	0.84	0.88	0.66
L1-APg	0.81	0.77	0.84
U1.L1	0.90	0.91	0.90

IRA: intra-examiners evaluation.
IER: inter-examiner evaluation.

TABLE 2 - Matched correlation, between intra-examiner and golden-pattern. Significance level (p< 0.001).

Variable	IER-JU	IER-SP
SNA	0.86	0.73
SNB	0.94	0.64
ANB	0.69	0.85
Wits	0.81	0.92
M-U1	0.88	0.60
M-L1	0.83	0.56
S-Go	0.98	0.83
Na-Me	0.98	0.62
Na-ENA	0.86	0.77
ENA-Me	0.96	0.69
SN/PP	0.83	0.73
SN/PO	0.90	0.67
SN/PM	0.97	0.75
Y Axis	0.94	0.61
U1.SN	0.86	0.62
U1.PP	0.85	0.61
U1.Na	0.81	0.55
L1.GoMe	0.91	0.81
L1.NB	0.78	0.73
L1-NB	0.91	0.77
L1.APg	0.52	0.62
L1-APg	0.67	0.83
U1.L1	0.75	0.69

IRA: intra-examiners evaluation.
IER: inter-examiner evaluation.

TABLE 3 - Definition of ranking of risk. Ordinal classification of the quantitative results.

Risk: Decodify® result	Clinical significance	Extension of the treatment*	Cost of the Treatment*
Risk I	Dental compromise only	12 months	$
Risk II	Light skeletal compromise	18 months	$$
Risk III	Moderate skeletal compromise	24 months	$$$
Risk IV	Severe skeletal compromise	30 months	$$$$

*As a reference, up to each clinician.

TABLE 4 - Degrees of agreement measured by matrices of covariance, comparing the measured risk by the two examiners against the golden-pattern. Significance level: [p< 0.0001].

Risk-Result	JU	SP
Minor Correlation	0.54	0.47
Major Correlation	0.90	0.88
Average Correlation	0.78	0.75
Degree of Agreement	0.78	0.75

in the Tables 1 and 2. Table 3 describes the ranking of assessed risk and the Table 4 shows the agreement indices between the risks presented in the two examiners assessments compared with the pre-defined golden-pattern.

DISCUSSION

Cephalometrics is a worldwide accepted orthodontic diagnostic tool and considered essential information to offer a reliable treatment plan to the patient. It is based upon measurements on head lateral radiographs and it describes skeletal and dental discrepancies with considerable precision. An experienced clinician can well interpret, although subjectively, cephalometric numbers and apply such information in his/her daily practice. Because only numbers cannot be directly applied in the clinic, such subjectivity has been referred as a drawback in the potential value of cephalometrics for routinely use.

The point to be discussed is not if cephalometrics should be or should not be used, but how cephalometric numbers might be interpreted before its application, since that interpretation holds significant variance. This occurs because of two main reasons: first, because the degree of clinical abnormality is not quantitatively measured and; second, because there is no way to establish a golden-pattern. Golden-pattern is the pattern reference established in order to have other references compared to it and, according to this comparison, become acceptable or not.

In our research project, we established a golden-pattern (Table 1), contextualizing cephalometric measurements of wide application. The result of such contextualization is called risk. It is important to highlight that such risk was based upon expected norms for each one of the elected measurements, individualized by gender and age, measured in the same population of the evaluated cases (Brazilians, Caucasians, with average degree of ethnic miscegenation). The contextualization (or risk) can be defined as: “What we should expect as the degree of severity of malocclusion, skeletal or dental, in that particular patient.”

From our results, it was observed that the inter-examiners comparison (against the golden-pattern) varies according to the cephalometric measurement. Such result is what we expected from the human evaluation of cephalometric landmarks with different degrees of identification and reproduction. Notice that such degree of variation involves the degree of accuracy of the examiner and of the golden-pattern as well. As examples of landmarks vulnerability in regard to the identification and reproduction the point A (due to the thickness of the maxillary bone), the inclination of the lower incisor (due to the lower incisors images superimposition) and the geometric location of the Gonion point (constructed bisect).

Such variations also account the intra-examiner variation, isolated in the Table 2. The variation in reproducibility of the technicians implies in the fact that there are examiners with better knowledge and/or expertise to trace a cephalogram, what is reasonably expected.

The quantitative results provided by the Decodify® System as risk are presented in an ordinal ranking in the Table 3. Then, parameters that we consider useful for the daily orthodontic practice are suggested. For instance, the greater the skeletal compromise of a case, greater its risk and consequently greater the treatment time required and the cost involved.

The contribution of our work is evident when the degrees of agreement are presented. When we have a calibrated system which presents degrees of severity, throughout algorithms that contextualize individual cephalometric variables, we have the level of risk in each evaluated case. The degrees of agreement show that such level of risk is reproducible and trustable and, therefore, evaluations are minimally based in personal opinions. The “cephalometric guessing” is exchanged by the “evidence” of the cephalometric risk. In few words, the Decodify® System works as a “ruler”, to measure the degree of difficulty to treat a specific orthodontic case.

With such instrument, therefore, the orthodontist can measure, with high level of precision, how much “energy” the office must dedicate to that particular case. And the practical consequences of such measurement are many: The orthodontist might estimate the extension of the treatment, the approximated number of appointments, and the need of his/her attention as the chief clinician (and consequently the possibility to delegate less important functions to his /her assistants), the potential problems, the fee to be charged etc.

Metaphorically, in a near future if not today, orthodontic treatment will be offered to the patients as a “well defined flight script”, with an estimated time to take off, estimated time to last and estimated time to land, well defined destination and well forecasted flight conditions. Who does not have scientific premises to base on, will still “take off its orthodontic airplane” with no information about the airport to be addressed, what is the estimated flight duration and what are the expected weather conditions ahead. Such professionals will be naturally avoided by their potential patients, who will look after better services. And it is impossible to be different: nowadays everybody expect to receive quality services, reliably delivered with trust and comfort, in estimated time and by acceptable fees.

CONCLUSION

Our results support that the risk measured by the presented system is reproducible and reliable. Therefore, we accept the null hypotheses of no difference intra-examiner and inter-examiners evaluations, in all the matched comparisons performed.

As a direct consequence of the acceptance of these null hypotheses, we suggest that the Decodify® System is an important cephalometric tool for the orthodontist to establish clear parameters about the service that will be provided to his/her clients. Then, the patient can have a reliable estimation on the degree of severity of his malocclusion, the difficulties to treat it and the necessary time to accomplish such goal. Consequently, the patient will pay the fair fee for the contracted service, according to the market in which it is inserted.

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