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Highlights

- Computer-aided cephalometric systems tend not to be practical and intuitive.
- A new haptic-enabled landmarking approach for 3D cephalometry is proposed.
- Several experimental tests were conducted to evaluate the proposed approach.
- Haptic technologies facilities the landmark selection process in 3D cephalometry.
- The haptic user interface allows the user to feel and touch the virtual patient's skull.

The evaluation of a novel haptic-enabled virtual reality approach for computer-aided cephalometry

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Abstract

Background and objective. In oral and maxillofacial surgery, conventional radiographic cephalometry is one of the standard auxiliary tools for diagnosis and surgical planning. While contemporary computer-assisted cephalometric systems and methodologies support cephalometric analysis, they tend neither to be practical nor intuitive for practitioners. This is particularly the case for 3D methods since the associated landmarking process is difficult and time consuming. In addition to this, there are no 3D cephalometry norms or standards defined; therefore new landmark selection methods are required which will help facilitate their establishment.

This paper presents and evaluates a novel haptic-enabled landmarking approach to overcome some of the difficulties and disadvantages of the current landmarking processes used in 2D and 3D cephalometry.

Method. In order to evaluate this new system's feasibility and performance, 21 dental surgeons (comprising 7 Novices, 7 Semi-experts and 7 Experts) performed a range of case studies using a haptic-enabled 2D, 2½D and 3D digital cephalometric analyses.

Results. The results compared the 2D, 2½D and 3D cephalometric values, errors and standard deviations for each case study and associated group of participants and

revealed that 3D cephalometry significantly reduced landmarking errors and variability compared to 2D methods.

Conclusions. Through enhancing the process by providing a sense of touch, the haptic-enabled 3D digital cephalometric approach was found to be feasible and more intuitive than its counterparts as well effective at reducing errors, the variability of the measurements taken and associated task completion times.

Keywords
Cephalometry; Haptic technologies; Cephalometric values; Landmark selection; Task completion time (TCT)

1. Introduction

Cephalometric analysis is a standard auxiliary diagnostic tool used in oral and maxillofacial surgery. Conventionally it is performed on the 2D lateral radiograph of a patient's head. However, this only represents a composite of the patient's skull on the sagittal plane. Most patients with congenital and acquired cranio-maxillofacial deformities are asymmetric and, as a consequence, the deformity is three-dimensional 0. Therefore, conventional 2D cephalometry is not ideal for deformity analysis, diagnosis and treatment. It is also time-consuming and with accuracy depending on the specialist's ability to locate landmarks and measure all of the cephalometric variables consistently.
Research suggests that 3D cephalometry has the potential to achieve more precise diagnosis and analysis of cranio-maxillofacial deformities over conventional 2D radiographic approaches 0 -0. Other work comparing 2D and 3D cephalometry 0-0 reports that tracing a 3D model is both difficult and time consuming as some landmarks are hard to identify on 3D models. Also, there is no standard set of cephalometric variables or standards that exist for 3D cephalometric measurement and diagnosis. Therefore, new landmark selection methods are required to both improve diagnosis and to facilitate the establishment of new reference norms and standards 0. The literature also highlights that there is a need to improve modern computer-based interactive cephalometric system usability, user friendliness and intuitiveness to facilitate easier and more accurate 2D and 3D cephalometric analyses.

This research attempts to resolve the issue of providing effective 3D cephalometric analysis through the use of haptic technologies in order to overcome many of the difficulties and disadvantages of current landmarking methods. Using the sense of touch in this way to enhance the user experience could potentially enrich the usability and intuitiveness of cephalometric computer-based systems.
Therefore the aim of this study was to evaluate the feasibility and effectiveness of using haptics in computer-aided cephalometric analysis.

1. Related work

Key general issues associated with conventional radiographic cephalometric analysis are: (i) errors in manual methods are multi-factorial with low reproducibility; (ii) landmark accuracy is highly dependent on the analyst's experience and knowledge, a key source of error 0; (iii) some 2D cephalometric analysis variables do not exist in 3D; (iv) 3D projections errors exist when 3D objects are projected onto 2D; (v) most patients are asymmetric and the measurements distorted in the presence of facial asymmetry 0; and many 3D deformities are three-dimensional and unsuitable for precise 2D diagnosis and treatment 0. It is also important to bear in mind that a cephalometric analysis and diagnosis cannot be carried out in a definitive manner; many important variables such as age, sex, type, anatomic limitations and ethnic differences are also required to be taken into account 0.

Research comparing 2D traditional (manual) cephalometry with 2D digital (computer aided) cephalometry 0-0 has shown no difference between these techniques when used to predict cephalometric values, with similar errors and low reproducibility apparent in each case. However, digital cephalometry streamlines the analysis by automatically computing the cephalometric variables, leading to a number of benefits such as reliability, repeatability, improved task completion times and greater ease of use. However, when using both methods, radiographic images generate inhomogeneous broadening and distortion of the skull side structures causing inaccurate references and, consequently, misdiagnosis 0.

To overcome the disadvantages of 2D cephalometry several studies have focused on the development and validation of 3D procedures and analysis. For example, a 3D-CT procedure to assess and diagnose patients with facial asymmetry by locating 3D reference points on a scan was proposed in 0 with results suggesting that 3D-CT has potentially powerful diagnostic capabilities; however, the high patient radiation dose associated with CT scanning limits its application. An investigation to evaluate the measurement accuracy of 3D volumetric images from spiral CT in vitro was presented in 0 which concluded that the 3D reconstructed skull and facial bone landmark measurement is quantitatively accurate for surgical planning and craniofacial fracture evaluation and treatment. The adaptation of 2D cephalometric analysis into 3D was proposed in 0. Using ACRO 3D rendering and measurement software, 3D CT surface renderings over profile X-ray were evaluated for 26 dry skulls and the results compared with those taken on the same skulls using a 3D measuring instrument showing that the software was a reliable tool which could be used to develop effective 3D CT cephalometric analysis.

Comparative analysis research between 2D and 3D cephalometry 0-0 has been focused on cephalometric landmarking by placing repeated marks to evaluate the error between the 2D and 3D cephalometric approaches. The results suggest that measurements from conventional 2D cephalometric radiographs differ significantly from those on 3D models of the same skull since in the latter the actual anatomical geometry is measured and not just its 2D projection. Several advantages of 3D cephalometry were acknowledged: 1) the actual anatomical structures can be identified; 2) cephalometric variables can be measured in 3D; 3) projection errors are eliminated; 4) the facial asymmetry errors are eliminated; and 5) patient position and orientation in the 3D scanner is not important since the final model can be located and reoriented to any desired position or orientation. However, the drawbacks that make 3D cephalometry currently clinically unusable are: 1) the free manipulation and tracing of 3D models are difficult because orthodontics and maxillofacial surgeons are experienced in the use of

2D radiographs 0; 2) landmarking is difficult and time consuming because inner cephalometric marks, e.g. sella, upper incisor apex, etc., are difficult to identify on 3D models, therefore CT slices have to be selected to mark their location 0; 3) the accuracy and reproducibility of 2D cephalometry measurements is higher than for 3D measurements 0; 4) current cephalometric analysis and variables are based on 2D projections; 5) 3D cephalometry is not yet an accurate or reproducible diagnostic technique, particularly when using linear and angular measurements 0; 6) no reference data or norms exist for 3D cephalometry 0; 7) 3D measurement validation protocols are not standardised 0; 8) CT scans are more expensive than conventional radiographic images; and 9) 3D cephalometry requires a 3D model of the patient's skull which can only be obtained using significantly higher radiation dose methods.

The literature highlights that while 3D cephalometry is not common in orthodontics it represents the next major step with many potential gains, particularly superior accuracy for malformation diagnosis, treatment and surgical planning. Current computer-aided 2D and 3D cephalometric systems tend to be neither practical nor intuitive for practitioners and none of the systems reported in the literature have addressed the application and evaluation of haptic technologies, demonstrating a substantial gap in the knowledge regarding this approach.

Therefore, this paper proposes the use of haptic technologies as a novel approach to enhancing the landmarking of 3D computer-aided cephalometric analysis. It is hypothesized that the touch sensitive nature of this technology can potentially help overcome the 3D cephalometry difficulties and drawbacks currently associated with landmark selection.

1. System description

OSSys (Orthognathic Surgery System) is a haptic-enabled virtual platform designed for planning, simulation and training of orthognathic surgeries. The system architecture (Figure 1) comprises eight modules, namely: an input data module, a visualization module, a haptic module (handling module), a cephalometric module, an osteotomy module, a surgical template module, a training and evaluation module, and a data export module.

The OSSys system uses the Microsoft Foundation Classes (MFC) of Visual Studio 2010, the Visualization Toolkit libraries (VTK) for graphics rendering, and the H3DAPI haptic rendering software development platform. Supported haptic devices include the Phantom Omni from Sensable and the Falcon from Novint. 3D skull models, such as X-ray radiographies, can be imported as standard images with file formats such as bmp, jpg, jpeg, png or, in the case of 3D skull models, as stl files.

1. Haptic-enabled cephalometry

OSSys' cephalometric module allows haptic-enabled cephalometric analysis in a virtual environment. The user can freely explore and touch the virtual scene and 3D objects via the haptic device and are able to identify and mark the cephalometric points on a 3D model of the patient's skull. Although OSSys has been designed for 3D haptics, the

system also supports 2D and 2½D and non-haptic 3D analysis with 2D used by orthognathic surgery medical practitioners in the experiments as a reference point for the 3D analysis. In the case of 2½D cephalometric analysis, the cephalometric points were marked on a 3D model but projected on the sagittal XY plane to acquire the corresponding measurements. Several of the 2½D cephalometric systems studied in the literature are based on this approach and are comparable with conventional 2D analyses 0, 0, 0. The main characteristics of the OSSys cephalometric module are:
Radiographic images can be uploaded as standard image file formats.
3D models can be imported as *.stl files.
3D models can be sliced with a sagittal plane.
2D images can be uploaded and placed on the sliced model.
Haptic rendering supports the touch and feel of virtual objects.
Haptic-enabled free manipulation and exploration of virtual objects is possible.
A haptic-enabled landmarking process for 2D and 3D cephalometry is embedded in the system.
Haptic rendering can be enabled or disabled.
An automatically generated cephalometric analysis report is provided at the end of the session.
The distance between any two points defined by the user can be calculated.
The visualization of cephalometric landmarks or lines can be turned on or off.
Free camera manipulation is available (rotation, zoom in, zoom out, pan, etc.).
Orthogonal views are available (front, rear, top, lateral, etc.).

OSSys' cephalometric analysis uses the Steiner methodology [19] which comprises 13 hard tissue landmarks and a simplified set of 11 widely used cephalometric values (see Table 1) and is based on landmarks defined on a 2D radiographic image. In 3D cephalometry many of these landmarks are bilateral, e.g. 'Or' and 'Po', and others, such as 'S', are inner or floating in free space. Since there are no standards for 3D cephalometric analysis, bilateral landmarks are selected in the system on only one side of the 3D model, i.e. the lateral view, in a manner similar to 2D cephalometry procedures. Inner cephalometric landmarks are hard to identify because they are inside the 3D model, which in most cases is an empty surface model. The cephalometric module in OSSys allows slicing of the 3D models with a sagittal plane in order to place a radiographic image and facilitate the identification of inner landmarks. The radiographic image acts as a haptic plane or wall that provides haptic feedback to the user.

Within OSSys the general procedure starts by importing the 3D model or 2D radiographic image. The user must then identify and mark the cephalometric points according to the order requested by the system. To mark a point the user locates the haptic cursor at the desired image or model position and presses the device button. Once all the cephalometric marks are defined the system automatically computes the cephalometric values and provides a report.

1. Evaluation

To evaluate the feasibility and effectiveness of OSSys an experimental methodology incorporating a set of trials and associated metrics was designed, conducted and analysed as follows: (i) training session, (ii) 2D cephalometry and questionnaire, (iii) 2½D cephalometry and questionnaire, (iv) 3D cephalometry and questionnaire; (v) analysis of results.

1.1. Case studies

A total of five cephalometric radiographs were selected and on which were performed haptic-enabled 2D cephalometry evaluations. These related to five patients aged 18-24 years with malocclusion problems requiring surgical intervention. These 2D case studies were selected for comparison purposes with the 3D cephalometry; however, in the latter case only one 3D case study model was considered necessary to effectively evaluate the feasibility, performance and user perception of haptics during computer-aided cephalometric analysis. This 3D model corresponded to the skull of an adult human being which was reconstructed from a set of CT DICOM images from a digital medical repository and imported into OSSys system as an stl file.

1.1. Participants

21 dental surgeons were selected to perform the system evaluation tests. They were divided into three groups: 1) 7 third-year students (Novices), aged 20-23 years; 2) 7 graduate dental surgeons (Semi-experts), aged 28 – 32 years; 3) 7 orthodontics specialists (Experts), aged 35 – 42 years. The Novices had experience of using lateral radiographic images and knowledge regarding skull morphology but no experience of 2D or 3D cephalometric analysis. The Semi-experts were some experience in 2D cephalometric analysis, landmarking and radiograph interpretation but not 3D. The The Experts had professional orthodontic training and experience including 2D cephalometric analysis. All participants were right-handed and none had previous experience of either haptics or virtual reality.

1.1. Experimental procedure

Each participant was instructed on the use of the OSSys system and the associated haptic device and given the opportunity to ask questions and comment. They were then given a short compulsory 10-minute familiarization period of training including the use of viewpoints and camera and haptic device manipulation. This also included single 2D and 3D cephalometry pilot trials the results of which were not included in the final analyses. To assess the academic, professional and computer experience of the participants a 5-question survey addressed: academic background, clinical experience, cephalometry experience, orthodontics experience, and video games experience.

After the familiarization process each participant completed all of the 2D cephalometry case studies after which they performed the 3D cephalometry case study. Task Completion Times (TCTs) were measured for every cephalometric task. When finished, each subject completed a 12-question survey to evaluate their experience of performing the OSSys haptic-enabled 2D and 3D cephalometric analysis. The survey comprised the following statements graded on a 10-point scale, ranging from 10 (strongly agree) to 1 (strongly disagree):

It was easy to identify and mark landmarks.

It did not take long to identify landmarks.
It was easy to access the points of interest.
The system was accurate when locating landmarks.
The graphics quality of the system was good.
It was easy to control the haptic device.
The system was accurate in its qualification.
I was confident when using the system.
The systems approximates reality.
The virtual landmark selection process is similar to the conventional approach.
My hand movement corresponded to the associated virtual movements.
The system is good at performing cephalometry.

1. Results

The participants performed the OSSys 2D and 3D cephalometric case studies as shown in Figure 2. The experimental results were analysed in terms of the cephalometric values and positional errors and then compared with benchmark values achieved by an expert using the traditional manual approach. The results were also analysed in terms of the average TCT for the three groups, namely: Novice (N), Semi-experts (S) and Experts (E).

The haptic-enabled 2D cephalometry results are given in Table 2 and show the average errors for each cephalometric value, group of participants and case study. These were computed as the absolute value of the difference between the average cephalometric value obtained for each group and the cephalometric value obtained by an expert using the conventional manual approach. The table also presents the global average error and the standard deviation for each group.
With regard to performance, the average TCT for the haptic-enabled OSSys 2D cephalometry were 99.3 s, 108.3 s and 91.9 s for the N, S and E participant groups respectively.

Depending on whether haptic-enabled 2½D or 3D was used, the 3D cephalometric values were calculated in two ways: 1) for 2½D the cephalometric value computations were determined from the projection of the 3D landmarks onto a lateral plane; and 2) for 3D the cephalometric values computations were obtained from the actual 3D landmark positions, i.e. 3D angular and linear measurements.
The results of the OSSys 3D cephalometry for both 2½D and 3D are shown in Table 3. It was found that the 2½D cephalometric values were comparable with those from the conventional digital or manual 2D cephalometry.
Since there is not a standard for 3D cephalometric analysis, the average cephalometric values obtained by the group of experts were used as reference to evaluate the 3D measurement errors, the results of which are shown in Table 3 along with the average 2½D and 3D standard deviations. The average OSSys TCT for a haptic-enabled 3D cephalometry was 19 minutes.

1. Discussion of results

The TCT to manually complete a conventional 2D cephalometry varies from 10 to 25 minutes depending on the specialist's experience, the case under consideration and the cephalometric methodology used; however, the OSSys 2D cephalometry achieved an average completion time of less than 2 minutes. This large reduction in the completion time is associated with the elimination of manual measurements and the rapid calculations carried out by the system.
For the full 3D cephalometry, the average task completion time was 19 minutes where the bulk of the high completion time related to the length of time required by the user to manipulate the 3D model in the 3D virtual environment before identifying landmarks. These results provide evidence that digital haptic-enabled 2D cephalometry can lead to improved cephalometric analysis in terms of speed when compared to conventional 2D cephalometry. For 3D analysis it is in the same region. This is the first published case study that compares cephalometry performance TCTs for either 2D or 3D approaches 0, highlighting the novelty not only of this cephalometric evaluation solution but also the methodology applied for comparing such systems.

In terms of accuracy, as shown in Table 2, the N group demonstrated the largest cephalometric errors and standard deviations during 2D cephalometry analysis, whereas the experts, as would be expected, obtained the lowest errors and standard deviations. Table 2 and Table 3 also reveal that the errors obtained using 3D cephalometry are less than those for 2D and 2½D cephalometry. In general, the standard deviations of the 2½D and 3D cephalometric variables are also much lower than those for 2D. This large difference is due to the enhancement of landmark selection using haptics; this was also highlighted by verbal and questionnaire feedback from the users.

The results show that the cephalometric variables with the largest errors and variability in 2D cephalometry are 'INA', 'INB', 'FMA' and 'IMPA' all of which depend on the Nasion point. In addition, the 'A' point, the 'B' point, the 'Is' point, and the 'Ii' point locations which are defined in terms of the surface characteristics of the skull bone are also more difficult to identify on a 2D image. From the user feedback it was shown that with the use of haptics the users could feel and touch the surface characteristics to identify these points more accurately, leading to less variation in the detection of these key landmarks. Therefore the tracing and identification of 3D model landmarks 0 are substantially improved using haptics-based 3D cephalometric analysis. This more detailed user analysis of landmarks when supplemented by a sense of touch also explains the length of time spent identifying these in the 3D haptic case when using the navigation tools. A more sensory environment maybe slowed down the process of identification simply because the users had more fidelity in their supporting senses when determining the final variable positions, thus producing more accuracy.

In terms of the user feedback, the results of the user perception show that they consider the haptic-enabled approach as a potentially useful tool to perform 3D cephalometry analyses. On the other hand, it was more difficult to identify the landmarks in 3D models than in 2D radiographic images due to the more complex geometries. These results are associated to the lack of experience in 3D navigation and haptic exploration and also in the lack of standards for 3D cephalometry. The participants recommended the use of OSSys not only as a tool to carry out digital 3D cephalometry but also as an education and training tool to support teaching and learning by introducing modern engineering touch sensitive technologies into this process. Such a unique environment can also be used to capture expert domain knowledge in a fashion carried out previously in engineering domains using haptic environments 0.

1. Conclusions

A novel haptic-based approach to enhance the landmarking selection process in digital cephalometric analysis has been presented and evaluated. This provides the user with a sense of touch while interacting with the virtual environment to identify cephalometric landmarks. The proposed approach was justified in a series of experimental trials involving a range of users. The results demonstrated that a haptic-enabled approach is feasible in 2D, 2½D and 3D environments and that benefits were obtained in the reduction of measurement errors, lower variability and reduced task completion times. User feedback validated that these benefits were directly associated with the enhancement of the landmarking process using haptics which, in turn, facilitated a more intuitive and practical identification of cephalometric metrics when supported by a sense of touch.

Future work will consider a complete statistical analysis of the accuracy and errors of the data, including errors made when superimposing or digitizing 3D models as well as the use of more 3D cephalometry case studies and the intra-observer analysis of a complete orthodontic treatment. The analysis and evaluation of the system as a teaching and learning tool as well as an expert knowledge capture and retrieval tool are also part of planned future work.

1. Conflict of interest

None.

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Figure 1. OSSys main architecture.
Figure 2. Digital cephalometry in OSSys: a) 2D landmarking, b) 2D landmarks and lines, c) 3D cephalometry case study d) 3D landmarking and lines, e) sliced 3D model, f) location of a radiographic image.

Table 1 Steiner cephalometric landmarks and values (simplified) 0.

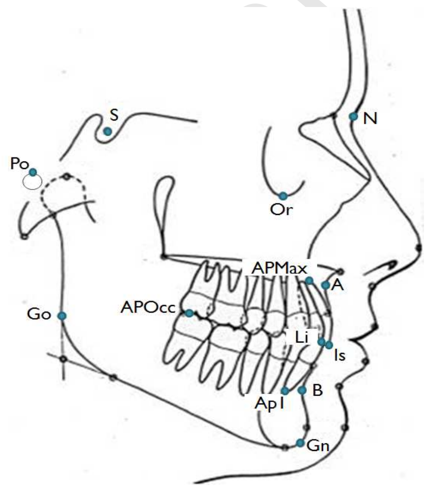
Cephalometric landmarks	**Notation**	**Location**	**Cephalometric values (simplified)**
Nasion	N		SNA **(°)**
A-subspinale	A		SNB **(°)**
B-supramentale	B		ANB **(°)**
Sella turcica	S		INA **(°)**
Incision superius apicalis	APMax		INA (mm)
Incision superius	Is		INB **(°)**
Incision inferius	Ii		INB (mm)
Incision inferius apicalis	ApI		Sn-GoGn **(°)**
Gonion	Go		FMA (°)
Gnathion	Gn		OC-SN **(°)**
Orbitale	Or		IMPA **(°)**
Porion	Po		
Posterior point of occlusion for the occlusal plane	APOcc		

Table 2 2D Cephalometric errors and standard deviation for each group and case study.

	Average cephalometric errors															**Global Average error**			**Global standard deviation**		
Case study	**1**			**2**			**3**			**4**			**5**								
Group / Variable	**N**	**S**	**E**	**N**	**S**	**E**	**N**	**S**	**E**	**N**	**S**	**E**	**N**	**S**	**E**	**N**	**S**	**E**	**N**	**S**	**E**
SNA (°)	1.6	6.3	2.4	0.0	3.4	3.1	10.5	3.2	1.9	10.0	3.2	0.5	4.9	4.1	2.7	5.40	4.04	2.12	4.77	1.32	1.01
SNB (°)	0.0	8.4	4.6	0.8	1.9	1.4	2.6	0.7	10.0	0.6	6.5	3.9	0.7	3.5	2.9	0.95	4.20	4.56	0.97	3.20	3.27
ANB (°)	2.0	0.4	0.2	11.3	8.5	8.3	9.7	5.9	5.5	5.3	1.4	1.2	14.2	10.2	10.3	8.50	5.28	5.10	4.85	4.30	4.38
INA (°)	0.4	0.7	2.1	1.0	4.9	3.2	19.9	2.8	0.1	12.2	3.9	4.8	7.5	1.7	1.9	8.20	2.80	2.42	8.16	1.68	1.73
INA (mm)	2.1	6.2	4.7	4.5	1.9	1.7	6.0	1.1	0.1	17.4	4.7	3.5	13.9	3.9	1.8	8.78	3.56	2.36	6.55	2.07	1.78

INB (°)	0.1	0.4	1.3	1.7	0.5	1.6	2.8	6.6	3.8	3.5	9.6	11.6	7.7	7.8	9.0	3.15	4.98	5.46	2.86	4.27	4.61
INB (mm)	0.1	2.7	0.4	0.6	2.2	0.2	4.3	1.0	1.2	9.6	6.4	4.0	7.1	5.4	2.0	4.35	3.54	1.56	4.09	2.27	1.54
Sn-GoGn (°)	0.2	4.1	1.5	0.3	0.7	2.5	6.4	2.6	1.0	6.6	0.2	1.5	0.2	5.0	5.5	2.74	2.52	2.40	3.43	2.08	1.82
FMA (°)	0.3	9.9	0.8	12.5	12.8	5.8	10.9	14.3	3.9	8.9	8.0	2.8	2.6	2.4	0.2	7.04	9.48	2.70	5.33	4.66	2.29
OC-SN (°)	0.0	4.7	4.2	2.0	1.4	3.0	0.7	2.0	0.7	3.3	1.0	0.1	1.3	1.2	0.3	1.47	2.06	1.66	1.26	1.52	1.83
IMPA (°)	0.1	3.8	15.2	0.9	2.0	13.8	5.0	2.5	3.3	8.5	14.3	17.6	2.8	1.7	0.6	3.45	4.86	10.10	3.40	5.34	7.62

Table 3 3D cephalometric values, errors and standard deviations for 2½ D and 3D.

Cephalometry	**2½D**			**3D**			**Error 2½D**		**Error 3D**		**Standard deviation**	
Group / Variable	**N**	**S**	**E**	**N**	**S**	**E**	**N**	**S**	**N**	**S**	**2½D**	**3D**
SNA (°)	89.8	87.8	85.7	89.4	87.0	87.8	4.08	2.12	1.62	0.83	2.04	1.25
SNB (°)	92.6	89.3	86.0	90.9	87.2	89.3	6.64	3.36	1.60	2.10	3.32	1.85
ANB (°)	3.5	3.3	3.1	4.8	4.3	3.3	0.40	0.18	1.56	1.04	0.20	0.79
INA (°)	21.0	23.3	24.7	24.9	26.0	23.0	3.74	1.42	1.87	2.96	1.89	1.49
INA (mm)	9.5	9.2	7.2	10.7	8.5	9.7	2.26	1.92	1.03	1.22	1.22	1.13
INB (°)	24.7	23.8	25.5	25.3	26.8	24.7	0.88	1.76	0.69	2.12	0.88	1.08
INB (mm)	5.9	6.1	5.6	7.7	6.8	6.9	0.25	0.50	0.77	0.06	0.25	0.46
Sn-GoGn (°)	32.2	31.4	30.4	33.0	31.6	31.3	1.80	1.00	1.64	0.30	0.90	0.87
FMA (°)	20.5	25.3	30.0	26.9	31.2	25.3	9.48	4.68	1.61	5.96	4.74	3.08
OC-SN (°)	12.3	12.5	13.7	14.1	14.9	12.8	1.40	1.20	1.24	2.10	0.76	1.06
IMPA (°)	93.5	89.1	92.5	90.7	93.7	91.7	1.00	3.40	1.03	2.04	2.31	1.56

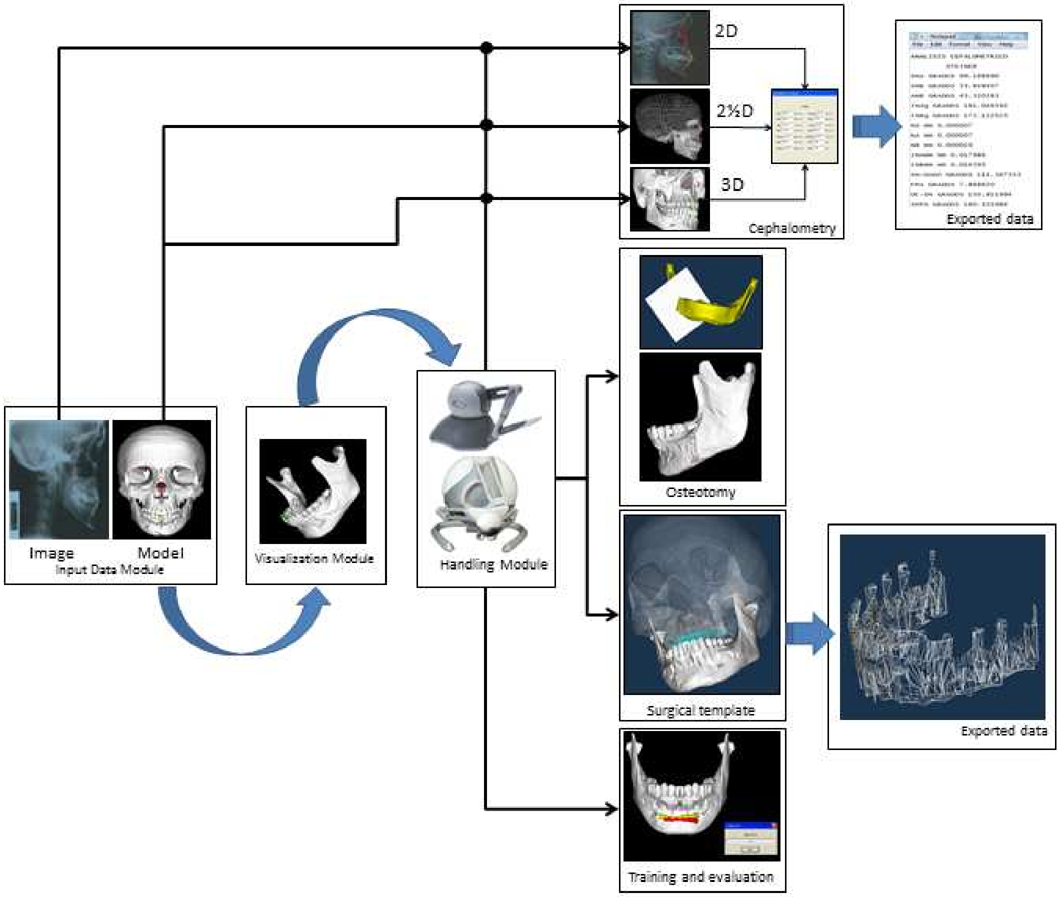
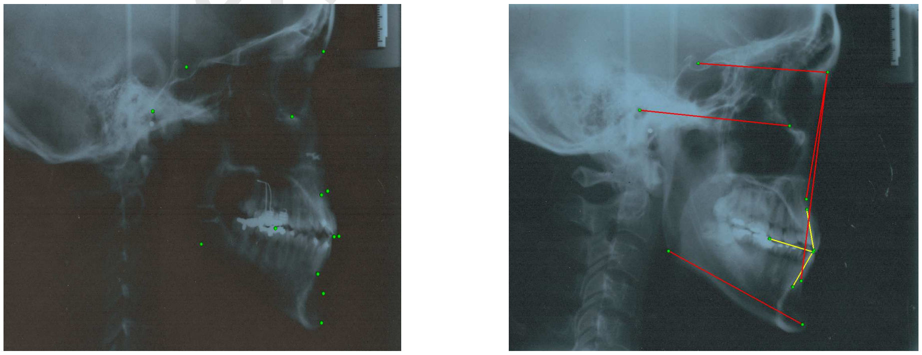
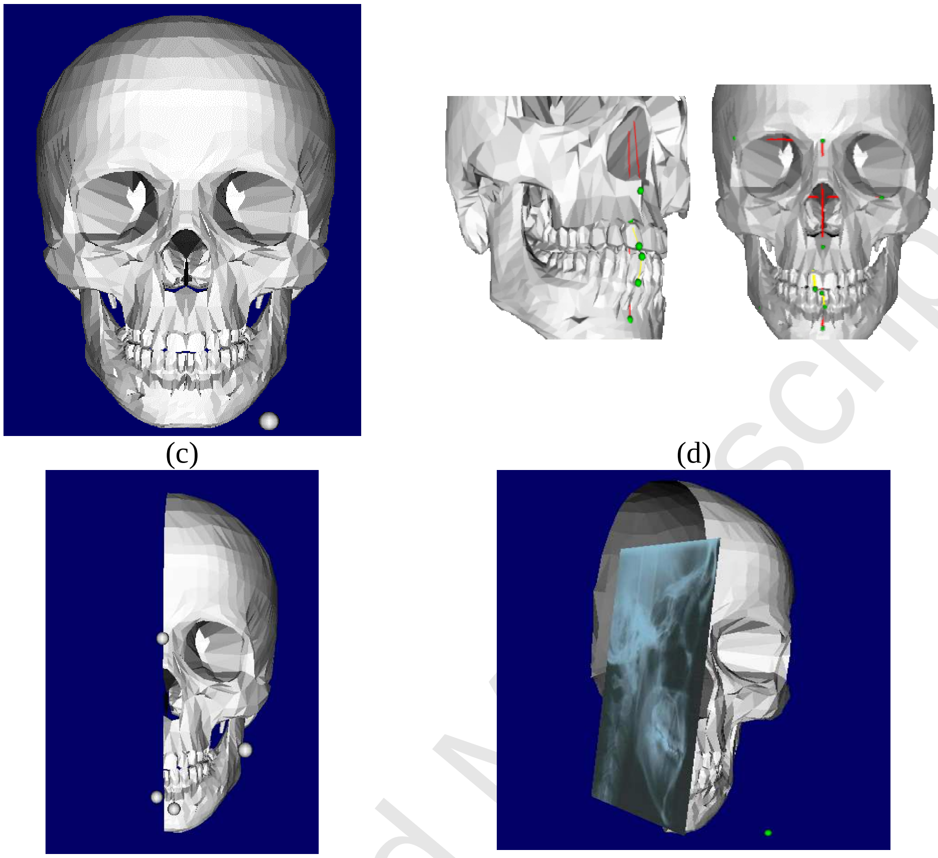

2D
2½D
3D
Cephalometry
Exported data
Osteotomy
Image
Model
Input Data Module
Visualization Module
Handling Module
Surgical template
Exported data
Training and evaluation

Fig. 1



(a) (b)



(c) (d)

(e) (f)

Fig. 2