[Article] Computer Aided Morphological Analysis for maxillo-facial diagnostic: a preliminary study

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Computer aided morphological analisys for maxillo-facial diagnostic

Abstract

This paper compares most of the 3D morphometric methods currently proposed by the technical literature to evaluate their morphological informative value, applying them to a case study of five patients affected by the Malocclusion pathology. The methods compared are: Conventional Cephalometric Analysis (CCA), Generalized Procustes Superimposition (GPS) with Principal Component Analisys (PCA), Thin-Plate Spline analysis (TPS), Multisectional Spline (MS) and Clearance Vector Mapping (CVM).

The result shows that Multisectional Spline (MS) satisfy better the need of reliable and useful diagnostic information.

Key words: 3D Scanner, Shape analysis, Facial Morphology

1 Introduction

The assessment of the dimensions and arrangement of facial soft tissues is important for medical evaluations. Orthodontists, orthognathic maxillofacial and plastic surgeons often require quantitative data about the correlation between soft and hard tissues [1,2].

For many years these information have been obtained from 2D radiographies and photos, even if these have been consistently limited [1,3,4,5,6]. Significant improvements have been obtained with the use of computer vision algorithms, even if the use of bidimensional supports to analyze three-dimensional objects seems to be quite inadequate.

For this reason, many research efforts of the last ten years have been directed to develop computer vision tools, that with the use of 3D scanner devices are able to provide reliable and more complete data. These systems use different technologies, like active or passive light reflection analysis and are able to describe 3D real shapes with a point cloud, analyzable with 3D software.

But while the image processing methodologies are well known in the medical context, the situation for the 3D scanner is still quite marginal and fragmented. Some studies have been developed for proposing a structured procedure that could be used for driving the physician in the application of 3D scanner to medical diagnosis [7,8,9,10,11,12]. No one succeeded in the development of a standardized strategy and accepted by the whole medical context but, contrarily, the more employed methodology for the maxillo-facial diagnosis is still the conventional cephalometric analysis (CCA), that employs bidimensional radiographies.

Considering the necessity to support the development of a standardized procedure able to employ 3D data for an useful and reliable diagnosis for maxillo-facial pathologies, this paper proposes a first analysis of the advantages and limitations of the methods proposed in the technical literature. Without giving a clear and structured comparison of the different approaches, it's impossible to successfully develop a standardized methodology.

2 Methods synthesis

A short description of the methods applied to the study case is presented. The Conventional Cephalometric Analysis is widely employed although it still relies on 2D radiographies. The Generalised Procrustes Superimposition (GPS) and the Thin-plate spline analysis (TPS) are the two most important morphometric analysis techniques. Then are described the Multisectional Spline (MS) and the Clearance Vector Mapping (CVM) methods that treat the 3D information of the point clouds.

2.1 Conventional cephalometric analyses (CCA)

The use of conventional measurements in traditional cephalometric analyses is called Conventional Cephalometric Analysis (CCA) [11]. A set of linear distances and angles is measured between reference points (landmarks), laid on lateral radiographies. The CCA measures are processed with statistical methods like PCA, ANOVA, paired T-tests and F-tests to compare groups of patients [13].

2.2 Geometrical morphometrics

The use of geometrical morphometric tools in the shape analysis is also known as "statistical shape analysis". The two following techniques are the most important.

2.2.1 Generalised Procrustes superimposition (GPS) and Principal Component Analysis (PCA)

The Generalised Procrustes analysis can be used to compute, visualize and test the morphological differences between facial profiles. It's an iterative method that apply geometrical transformations like scales, translations, rotations and reflections, in order to compare reference points (landmarks) [14] that can be taken from different point clouds of the patient's face. For visualization purposes, sometimes the landmarks appear linked by straight lines, that have no effect on computations.

As first step, the average facial profile (consensus) it's calculated and it's possible to evaluate anthropometrical measures on it (fig. 1). As second step, it's usually performed a Principal Components Analysis in order to point out the morphological differences of the various facial profiles from the consensus.

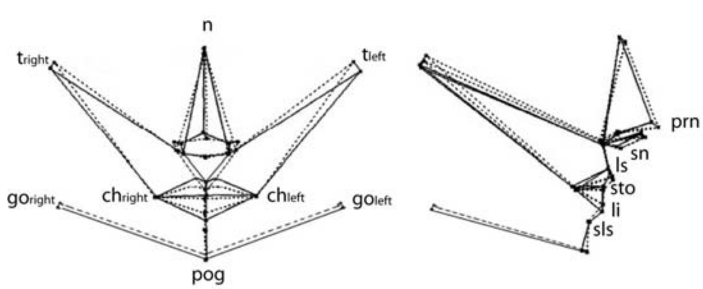


Figure 1. Examples of GPA "Consensus" evaluation.

The Principal Component Analysis (PCA) evaluates the tendency of the landmarks distribution along x and y axis, locating a new working frame, centred on the average shape centre. The method creates new variables named principal components (PCs), that describe how much the landmark configuration of each sample is different from the average shape.

2.2.2 Thin-Plate Spline analysis (TPS)

This method works on 2D radiographies taken before and after the surgery treatment on the patient. Firstly, a point set of anatomical landmarks is defined on both of them; then the post-surgery radiography is considered as an infinitely thin metal plate that must be bended, in a direction orthogonal to the plane, in order to match its landmarks to the pre-surgery radiography, while the bending energy it's minimized [15,16]. If the two shapes are identical, the bending energy is zero and the plate is flat.

The choice of the spline function depends on mathematical properties rather than relevant biological data [11], but the result is a rigorous quantitative analysis of the spatial shape changes [17].

2.3 Multisectional Spline (MS)

To give information regarding the face morphology also in the regions around the landmarks, this approach employs section planes passing through a set of specific reference points of a point cloud (landmarks), in order to obtain a specific section spline. The shifts of the facial morphology between the pre and post surgery point clouds can be analyzed by comparing the two section profiles passing through homologous landmarks and section planes [18,19].

2.4 Clearance Vector Mapping (CVM)

While both the previous methods manage little portion of the point cloud separately, the Clearance Vector Mapping (CVM) is able to analyze the global morphological information of the point cloud [20], so to provide a more complete information of the face morphology behavior.

The pre and post surgery point clouds are firstly aligned using different kind of alignment algorithm such as ICP, CSM, . . . [21] or using a combination of the three invariant points of the Frankfort plane: tr (tragion of the ears) and or (orbital of the eyes).

Then, the magnitude of the 3D shape displacement can be computed working on triangulated meshes and following different approaches [22]: *radial*, if the distance between the two surfaces is measured along a ray starting from the centroid of the pre-surgery surface; *normal*, if the distance between the acquired surfaces is measured along the direction of the local normal of the pre-surgery scan and *closest*, if the distance between the two surfaces is measured searching the closest point on the post-surgery surface, starting from a pre-surgery point.

The magnitude of the displacement between the pre and post surgery point clouds is shown with a colour mapping.

3 Case Study selection

3.1 Identification of the facial pathologies

The selection of the facial pathology has been driven by the necessity of a simple surgery treatment to allow a simple understanding of the correlation between hard tissue modifications and soft tissue shifts. If the case study would analyze a pathology treated with many surgical hard tissues modifications, it would be very difficult to obtain a clear idea of the correlation between the resulting soft tissue shift due to an hard tissue displacement.

The selected facial pathology is the "malocclusion", characterized by a misalignment between upper and lower mandibular structures (fig. 2), that causes significant mastication problems. It is treated with a surgical translation of the mandible.

a) b) c)

Figure 2. Schematic example of malocclusion: a) Class I, b) Class II, c) Class III.

In this paper are analyzed patients affected by class I and class II malocclusion.

3.2 3D scanner device

For the methods requiring 3D point clouds, the acquisitions were made working with a 3D laser scanner Cyberware Scanner 3030RGB (fig. 3). The five patients have been digitized before and after the surgery treatment.

3.3 Morphological measures

All the morphological analysis methods have been compared to the consolidated conventional chephalometric method.

Two measures families of significant anthropometric points (landmarks) have been evaluated over the facial shape to perform a reliable and consistent comparison of the methods.

The first family of measures have been evaluated over the soft-tissue shape points for those who employ the 3D scanner devices and work on external surfaces, while the second one refers to points on hard (skeletal) tissues for those methods who employ radiographies.

Although some methods employ the first measures family, while others use the second one, the comparison will be at the same possible and reliable because soft tissue reference points overlap the hard tissue reference points, with a known shift given by the average thickness of the facial soft tissue.

For each patient the three-dimensional coordinates of the 16 facial soft tissue landmarks (fig. 4a) and of 8 hard tissue landmarks, on the cranium, (fig. 5a)

Motion Range	
X (θ)	0°- 360°
Y	300-340mm
Z	300mm
Sampling Pitch	
X	500μm - 2mm
Y	350μm
Z	75 - 300 μm
Full color digitizing 512 × 512 pixels	

Figure 3. Cyberware 3D laser scanner 3030RGB (Cyberware Lab. Inc., Monterey, California)

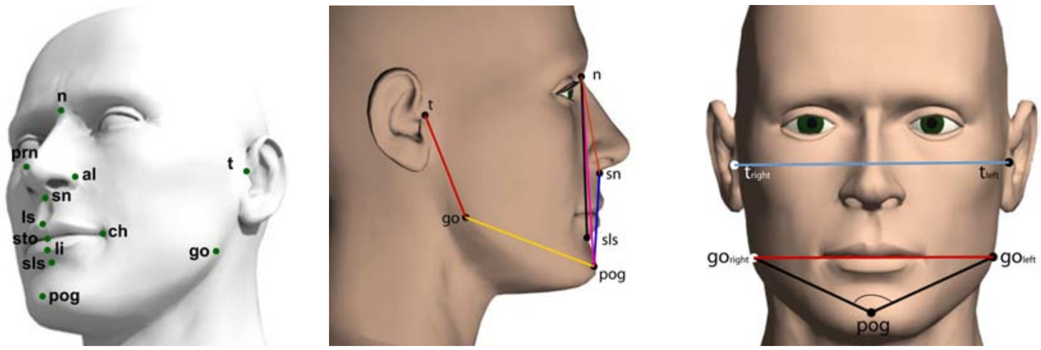
have been identified on point clouds and lateral cephalometric radiographs respectively. They are listed in table 1.

Table 1

List of soft and hard tissues morpohological reference points (landmarks).

Soft tissue landmarks		**Hard tissue landmarks**	
Name	**Abbr.**	**Name**	**Abbr.**
Nasion	n	Nasion	N
Pronasale	prn	Menton	Me
Subnasale	sn	Anterior Nasal Spine	SNA
Labiale superius	ls	Gnathion	Gn
Stomion	sto	Articulare	Ar
Labiale inferius	li	Gonion	Go
Sublabiale	sls		
Pogonion	pog		
Tragion	t_{right}, t_{left}		
Nasal alar crest	al_{right}, al_{left}		
Cheilion	ch_{right}, ch_{left}		
Gonion	go_{right}, go_{left}		

The (x, y, z) coordinates of the landmarks have been used to calculate a set of three-dimensional soft tissue measurements (figg. 4b and 4c), following [23,24] where they was applied to a reference group of 153 men with no previous history of craniofacial injury or operation, or congenital abnormalities. Precisely, the measures here considered are the mandibular corpus length (pg – go_m), the anterior lower facial height (sn – pg), the lower facial width (go_{right}



a) b) c)

Figure 4. a) Graphical location of soft tissue landmarks. b) and c) Three-dimensional soft tissue measurements.

– $\mathrm{go_{left}}$) and the nose width ($\mathrm{al_{right}} - \mathrm{al_{left}}$). Each "$\mathrm{landmark}_m$" is derived as the mid-point between two homologous landmarks.

Some important measurment ratios are also considered, like the facial width to facial height ratio $(\mathrm{t_{right}} - \mathrm{t_{left}})/(\mathrm{n} - \mathrm{pog})$ and the posterior facial height to anterior facial height ratio $(\mathrm{t}_m - \mathrm{go}_m)/(\mathrm{sn} - \mathrm{pog})$. Some angular measures are considered to complete the description: the mandibular convexity ($\mathrm{go_{right}}\ \widehat{\mathrm{pog}}\ \mathrm{go_{left}}$), the maxillary prominence relative to the mandible ($\mathrm{sls}\ \hat{\mathrm{n}}\ \mathrm{sn}$) and left and right goniac angles ($\mathrm{t_{left}}\ \widehat{\mathrm{go_{left}}}\ \mathrm{pog}$), ($t_{\mathrm{right}}\ \widehat{\mathrm{go_{right}}}\ \mathrm{pog}$).

Similarly, the cephalometric angular and linear measurements can be defined also for anatomical hard tissue landmarks (figg. 5b, 5c). The linear measures here considered are the facial height of the anterior face (N – Me), the anterior upper height of the face (N – SNA), the anterior lower height of the face (SNA – Me), the posterior height of the face (S – Go), the upper posterior height of the face (S – Ar), the lower posterior height of the face (Ar – Go). The angular measurements are defined by the intersection of lines passing through landmars, such as (ArGo – GoGn) who describe the slope of the mandibular plane relative to the anterior base of the skull as angle between the (Ar – Go) line with the mandibular plane (Go – Gn) and the Gnathion angle (ArGo – GoMe) who describes the slope of the ramous relative to the mandible body as angle between the (Ar – Go) line with (Go – Me) line

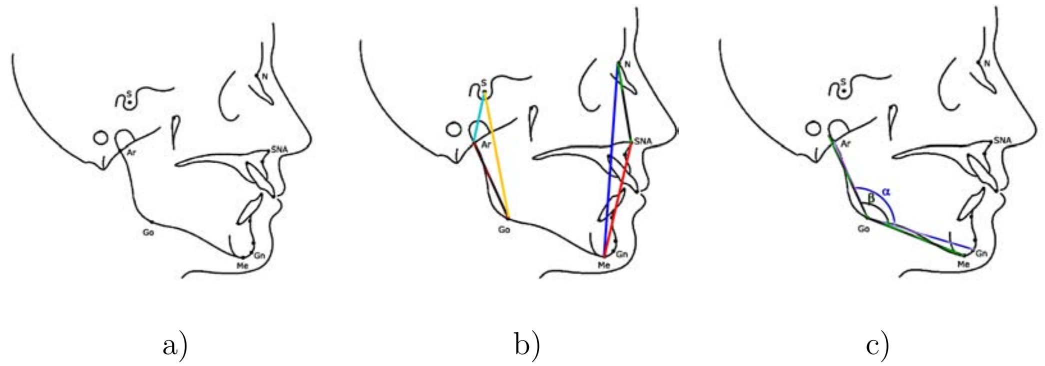


Figure 5. a) Graphical location of hard tissue landmarks. b) Landmark linear distance and c) landmark angular distances.

4 Experimental comparison of the morphological methods

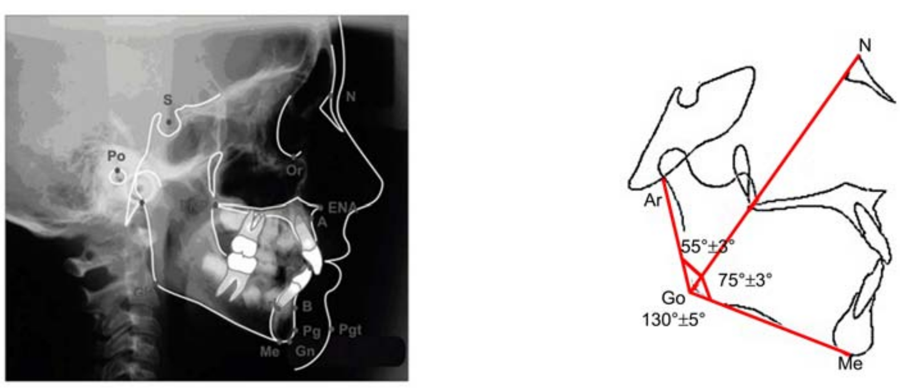
The 3D scanner was set-up with the most efficient parameters for the face acquisition and the five different patients were digitized before and after the surgery treatment. The evaluations methods, proposed by the technical literature, have been applied to the ten points clouds and their result have been compared to the conventional cephalometric approach (CCA), usually employed for facial malformation pathologies diagnostic.

The data here presented were measured on later cranial radiographies (fig. 6), that are normally employed by the physician to evaluate the soft tissue movements and will be used as first comparison term for the other morphological methods, in order to give the physician a more clear idea of their advantages and disadvantages.

It is possible to see in table 2, that after the surgery treatment the lower part of the facial profile (SNA – ME) has increased its length, with a consequent reduction of the upper part of the face (N – SNA). This is also confirmed by the Index of Anterior Facial Ratio (iPFA), namely the ratio between (N – SNA) and (SNA – ME), that decreases its value from the value of 0.85 in the pre surgery face profile, to the value of 0.75 in the post surgery. Following the medical standards proportions (N – SNA) represents the 45% of the total facial length and (SNA – ME) is the 55%.

In the case studies analyzed in the pre surgery morphology the proportions are maintained, but not in the post surgery, where the evaluated differences from the standard percentage are around 3%.

In order to verify the mandibular modification with other measures, the goniac angle β has been measured. Moving from pre to post surgery facial shape, this value has shown a significative increasing probably due to the rise of the measure (Ar – Go). To verify this hypothesis, the goniac angle β has been divided in two parts: the lower and upper goniac angle, that have been separately



a) b)

Figure 6. a) One instance of later cranial radiography. b) Lower and upper goniac angles with standardized values.

evaluated. Figure 6b shows the two angles and their standard values.

The calculated values are in table 3. The ratio between standard deviation σ and average value μ, of the two portions of the goniac angles also show that the lower goniac angle has a more stable behaviour, so it could give more reliable information about the facial shift between pre and post surgery.

Both in the pre and post surgery the measured angles are different from the standardized values (fig. 6b): the upper goniac angle is bigger than 55°, while the lower goniac angle is lower than 70°, but the surgery treatment has caused an horizontal increasing of the mandible measures, bringing it towards more normal values.

Table 2

Angular and linear cephalometric measures with the significance analysis of pre and post surgery facial morphology modifications (Average μ, Standard deviation σ). Dimensions in mm.

Measure	Pre-surgery					Post-surgery					Significance analisys		
	Face 1	Face 2	Face 3	Face 4	Face 5	Face 1	Face 2	Face 3	Face 4	Face 5	μ	σ	σ/μ
ArGo-GoGn (α)	130.02	134.76	148.52	136.51	131.30	134.67	134.36	152.19	136.19	129.80	1.22	2.74	2.251
ArGo-GoMe (β)	136.26	139.10	151.37	138.65	132.49	139.81	140.00	156.60	139.16	136.08	2.75	1.99	0.72
S-Go	68.88	75.77	71.95	62.66	62.01	90.17	71.29	57.48	61.02	64.25	0.58	13.12	22.32
N-Me	126.68	111.95	135.35	117.36	116.36	125.22	110.80	126.41	116.58	124.53	0.83	6.07	7.29
N-SNA	68.53	64.84	64.21	57.85	54.47	52.72	58.86	59.54	58.29	58.28	4.44	7.48	1.68
SNA-Me	70.44	64.29	88.04	72.33	67.93	82.46	64.96	87.08	72.76	77.43	4.33	5.97	1.38
S-Ar	16.60	16.55	22.95	17.25	17.31	18.48	13.58	16.12	15.82	14.60	2.41	3.14	1.3
Ar-Go	65.37	57.95	55.14	59.40	48.57	67.93	58.03	44.68	59.50	51.99	0.86	5.57	6.47

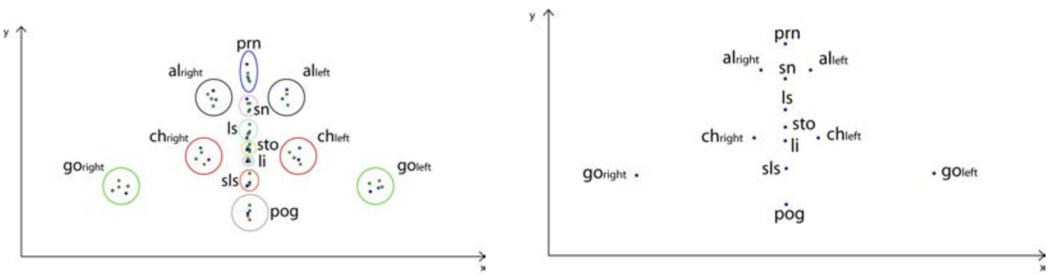
Table 3

Measures of Lower and Upper goniac angles (Average μ, Standard deviation σ).Dimensions in degree.

Measure	Pre-surgery					Post-surgery					Significance analisys		
	Face 1	Face 2	Face 3	Face 4	Face 5	Face 1	Face 2	Face 3	Face 4	Face 5	μ	σ	σ/μ
Ar $\widehat{Go}$ N	72.57	77.37	77.09	73.72	64.29	72.34	71.81	80.69	71.91	69.38	0.22	4.27	19.58
N $\widehat{Go}$ Me	66.98	62.69	74.50	64.10	72.48	63.95	65.66	74.15	62.80	68.85	1.07	2.61	2.45

4.1 Generalised Procrustes Analysis (GPA)

The graphical results of the Procustes superimposition are shown in figure 7.

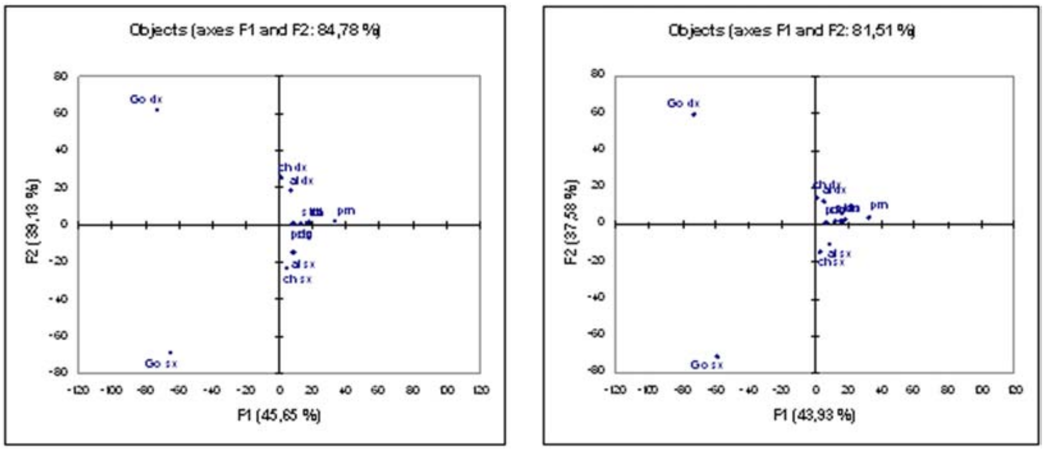


a) b)

Figure 7. Graphical GPA analysis output: a) Procustes fitting, b) average shape (Consensus).

The method also provides the sum of squares, mean squares, the residual values and a Fisher test in order to show which transformation has been significant for the average shape evaluation. The values of table 4 show that the most significant contribution over the entire average shape evaluation is the translation, immediately followed by the rotation and scaling.

In the analyzed case studies, the PCA approach has given evidence that in the pre-surgery facial shape the 84,78% of the entire shape modification presents a more significant tendency along the x axis, 45.65% of the points cloud employed for the average evaluation, than along y. This situation seems to be maintained quite constant also in the post-surgery shape, with 43.93% along x and 37.58% along y. Comparing the average shapes, with the PCA graphical synthesis, of pre and post surgery (fig. 8) it is possible to see that there is a significant compression of the nose-labial region, as verified with the traditional cephalometric approach cited in the previous paragraph.



a) b)

Figure 8. PCA outputs: a) PCs pre-surgery; b) PCs post-surgery.

Table 4

Procrustes Analysis case study evaluation (DF Residuals, S.S. Sum of Squares, M.S. Mean Squares). Dimensions in mm.

	Pre-surgery					Post-surgery				
Source	DF	S.S.	M.S.	F	$Pr > F$	DF	S.S.	M.S.	F	$Pr > F$
Residuals after scaling	128	2921.93	22.83			128	6855.6	53.56		
Scaling	4	47.78	11.95	0.52	0.719	4	431.05	107.76	2.01	0.097
Residuals after rotation	132	2969.71	22.5			132	7286.65	55.2		
Rotation	12	602.44	50.2	2.2	0.015	12	21150.01	1762.5	32.91	< 0.0001
Residuals after translation	144	3572.15	24.81			144	28436.66	197.48		
Translation	12	3515.85	292.99	12.84	< 0.0001	12	2657.24	221.44	4.13	< 0.0001
Corrected Total	156	7088.01	45.44			156	31093.9	199.32		

But while the traditional standardized approach underlines that the Gonion (Go) location has been moved down from the pre-surgery location, the results of this approach shows an opposite translation, giving a wrong information. The graphical synthesis employed by this method, wich considers only the landmark points, is not able to provide information about the global soft tissue shape variation. Making more than one test, about the repeatability of the method, it has been evidenced that the approach needs a precise selection of the correct landmark location. If during the method implementation the operator does not locate precisely the real landmark, but only a close point, the method will evaluate the average figure including the erroneous point and this will also affect the consesus. Instead, the traditional approach [25,26] provides more reliable information because the selection of an erroneous landmark in the definition of a reference plane, for example the Po in defining the Frankfort horizontal, will be clearly evident in the morphological and graphical evaluation outputs (for example the Frankfort-mandibular plane angle, the Frankfort-mandibular incisor angle, the facial angle . . .) [27].

Finally, in the Procrustes method are defined several approach [28], particularly for the shape scaling, that leads to significant different results. This has been verified using different commercial software.

4.2 Thin Plate Spline (TPS)

The Thin Plate Spline method is a chephalometric approach as the CCA. For this reason the evaluation of its performances has been developed employing the hard tissues landmarks. Thin-plate spline algorithm computes the orthogonal least-squares Procustes average configuration of landmarks in group at pre and post treatment using the generalized orthogonal least-squares [29]. The average craniofacial configurations has been subjected to TPS analysis by contrasting the average configuration at post-surgery with that at pre-surgery. The total spline is then decomposed into affine and non affine components. The affine transformation provides information about size differences, rotation and uniform shape change. Non-affine transformations delineate non-uniform or local deformations. These can be further decomposed into localized components, represented by partial warps corresponding to deformations at different geometrical scales. The partial warps have anatomical interpretability and they are necessary to understand the statistical significance of the overall shape changes (fig. 9).

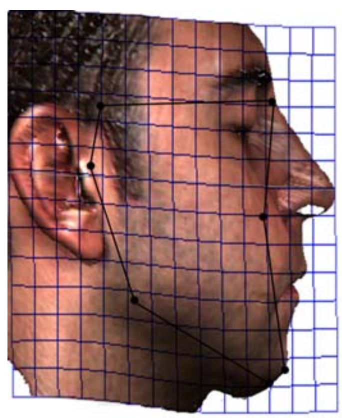


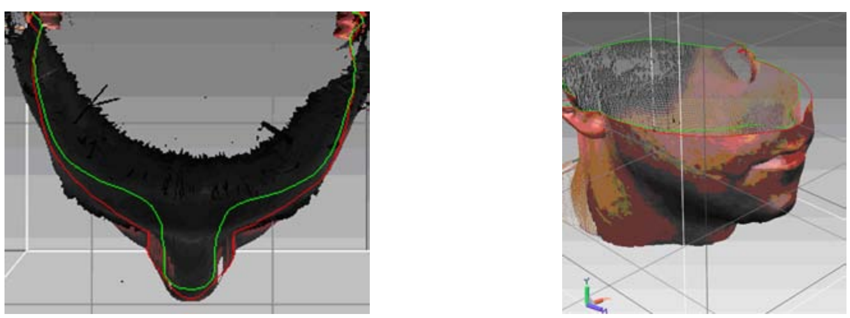
Figure 9. Graphical display of pre and post comparison: craniofacial shape changes with TPS approach.

The graphical output of non affine transformation principal component has shown, as the previous method, a slight compression in the vertical axis in the anterior region of the maxilla, and an extension in the mandibular region. The partial warp with the largest magnitude has confirmed the compression in the anterior part of the maxilla and the extension in the chin area. While the Procrustes method has given only partial reliable information about the soft-tissues changes between pre and post surgery this strategy seems to be more reliable showing the same shifts evidenced in the CCA.

This method gives limited visual information about the facial morphology shifts because it could only separately analyze the lateral or frontal facial profiles. Considering the necessity to give simple and direct information to the physician this method seem to be quite limited in relation with the complexity of the graphical output evaluation.

4.3 Multisectional Spline

The objetive of the method is to define bidimensional section profiles on the pre and post surgery point clouds and to perform on them cephalometric measures. An example of output is shown in figure 10, while the results are listed in table 5.



a) b)

Figure 10. Multisectional spline output on: a) xz plane section b) yz plane section (green colour for pre surgery profile and red colour for post surgery profile).

The results of the sectioning show a significant asymmetry between the right and left side of the patient, both before and after the surgery treatment. This information is found the first time using this method because the section profiles are more suitable to describe the global facial shifts than the other methods [30]: CCA and TPS works only on planar radiographies and GPA/PCA works only on a point set so it is diffucult to obtain global information.

Table 5

Pre and post-surgery cephalometric measures comparison for Multisectional Spline method and significance analysis (Average μ, Standard deviation σ). Dimensions in mm.

		Pre-surgery					Post-surgery					Significance analysis		
	Ref. value	Face 1	Face 2	Face 3	Face 4	Face 5	Face 1	Face 2	Face 3	Face 4	Face 5	μ	σ	σ/μ
$\mathrm{pog} - \mathrm{go}_m$	82	102.26	80.23	96	100	92.69	109.31	83.58	84.98	103	78	2.46	9.71	3.94
$\mathrm{sn} - \mathrm{pog}$	55	59.44	45.89	58.69	49.55	59.40	54.86	49.01	59.64	48.97	61.04	0.11	2.94	26.73
$\mathrm{go}_{\mathrm{right}} - \mathrm{go}_{\mathrm{left}}$	116	140.26	123.14	133.18	126.52	127.98	144.86	128.77	128.57	122.59	131.76	1.09	4.95	4.52
$\mathrm{al}_{\mathrm{right}} - \mathrm{al}_{\mathrm{left}}$	36	37.83	31.86	40.44	39.01	40.35	33.12	29.36	37.37	34.86	30.91	4.77	2.75	0.57
$\mathrm{go}_{\mathrm{right}} - \widehat{\mathrm{pog}} - \mathrm{go}_{\mathrm{left}}$	71	84.80	82.23	98.64	77.98	91.05	85.38	82.85	93.83	80.65	92.32	0.07	2.85	43.24
$\mathrm{sls} - \widehat{n} - \mathrm{sn}$	12	7.83	8.67	7.51	9.10	11.84	8.57	8.06	3.69	7.60	21.29	0.85	5.09	5.97
$\mathrm{t}_{\mathrm{right}} - \widehat{\mathrm{go}_{\mathrm{right}}} - \mathrm{pog}$	130 ± 6	132.26	135.92	145.84	129.13	132.47	131.61	134.25	139.55	132.18	134.89	0.63	3.74	5.96
$\mathrm{t}_{\mathrm{left}} - \mathrm{go}_{\mathrm{left}} - \mathrm{pog}$	130 ± 6	134.84	136.72	141.85	137.33	136.04	136.17	137.92	139.55	136.56	133.05	0.71	1.97	2.79
$(\mathrm{t}_{\mathrm{right}} - \mathrm{t}_{\mathrm{left}})/(\mathrm{n} - \mathrm{pog})$	1.32	1.4	1.46	1.4	1.41	1.3	1.32	1.5	1.34	1.4	1.34	0.01	0.06	3.96
$(\mathrm{t}_m - \mathrm{go}_m)/(\mathrm{sn} - \mathrm{pog})$	1.29	0.14	0.26	0.19	0.22	0.16	0.03	0.23	0.21	0.25	0.14	0.02	0.06	2.52

With the results of this method it's also possible to see an increasing of the nose width, of the posterior facial height and of the anterior facial height, as confirmed in the CCA approach. Another proof of the asymmetry found by this method is given by the goniac angles, wich increase from the pre surgery to the post surgery condition and presents a bigger value on the left side than the one in the right side. The angle sls $\widehat{\mathrm{n}}$ sn shows an increased value between the pre and post surgery which means that the mandibular region has been moved ahead.

This three-dimensional approach has been able to give a global morphological shift evaluation of the soft-tissues without employing invasive procedures. Considering the necessity to give to the physician simple and direct information, it seems the most efficient solution.

4.4 Clearance Vector Mapping

The CVM method has been applied aligning the point clouds with the three invariant points of the Frankfort plane, then the distances have been calculated with the most frequently used algorithm: the radial method. The distances are shown by the colour maps in figure 11.

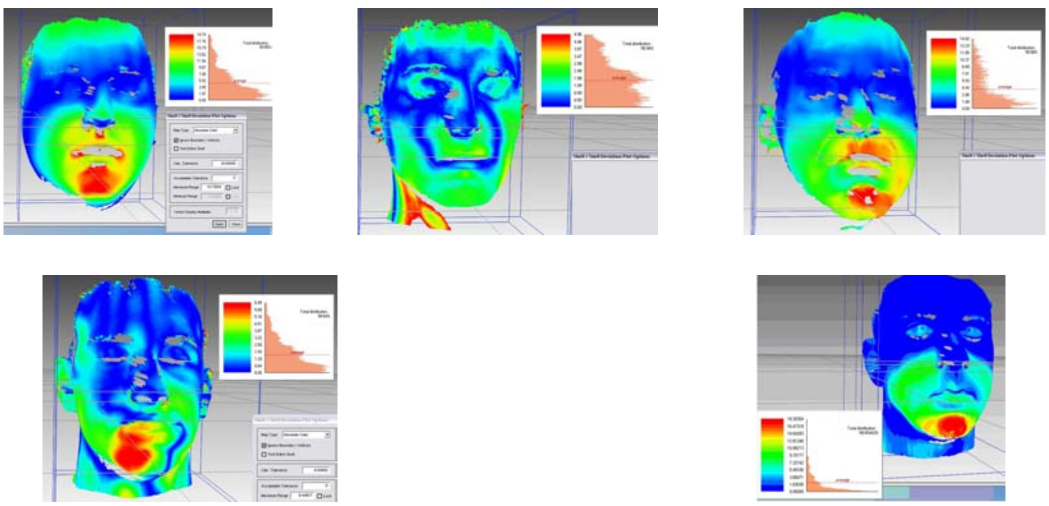


Figure 11. Clearance Vector Mapping graphical outputs.

This method can't manage the landmark measures, because it considers globally the displacement of the entire point cloud, but it is possible to validate its results verifying if the colour map of the nose shows a clear indication of the shape modification that has been found by the physician with the traditional method. Looking at the results (fig. 11) obtained with the five patients analyzed, it is possible to understand that the method is not stable. It in fact it shows for three case studies a significant modification of the mandibular region, while for the other two, it presents other soft-tissue shifts or no movements. This is probably due to the blindness of the method that compares non homologous points between the two point clouds.

Also working with the normal or the closest methods it always associates a point of the first point cloud with another on the second, that can be uncorrelated because of a definite shape change. Unfortunately the surgery causes a complex modification of the face shape that often displaces the location from the original location.

This method seems to be not useful for diagnostic purpose.

4.5 Results comparison

The most important considerations are summarized in table 6. CCA has been left out because it is the well-known traditional method.

5 Conclusions

The analysis developed on the methods proposed in the technical literature has evidenced the Multisectional Splines as the most reliable and most informative about tissues shifts, because it is able to give reliable information about the tissues shifts, as the CCA approach, but more than CCA is able to give additional global information, as for instance the lateral asymmetry verified in this paper employing the 3D point clouds.

But there are some significant points on which it is necessary to work to develop a diagnostic procedure that could be accepted by the entire medical context. It is necessary to define a method that extracts shape morphology measures starting from the landmarks as reference points, so to guarantee consistent morphological comparison, but also considering the entire facial shape (point cloud) so to consider each useful information. The morphological shape analysis tool must also provide reliable information and clear and simple outputs also for big dimensions samples.

6 Acknowledgements

The authors want to thank Prof. G. Ramieri and Prof. L. Verzè of the "Università di Torino" that collaborating with the authors in the LAFAV laboratory, financed by Compagnia di San Paolo, have provided precious suggestions and data for this study.

Table 6

Global comparison between the facial morphological analysis methods .

Method	Disadvantages	Advantages	Support
GPA	Not simple output Not reliable information Not global morphlogical analysis	Average facial shape evaluation	Point cloud
TPS	Very complex output Not global morphlogical analysis	Reliable information	Radiography
MS		Reliable Data Global morphological analysis Simple output	Point cloud
CVM	Not reliable data Not flexible method		Point cloud

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