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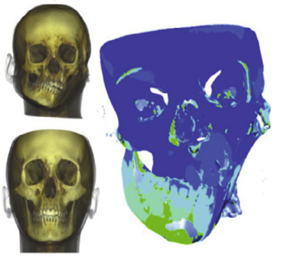
The use of geometric morphometry to study facial asymmetries: relationship between basicranial shape and maxillofacial and occlusal pathologies



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ABSTRACT

Describing an anatomical shape with a landmark points diagram allows the practitioner to use all the tools of geometric morphometry. Using a 14 point trigeminal for maxillofacial morphology, 10 points for basicranial morphology and 6 points for the orbital area, we have been able to identify the specific maxillofacial shapes associated with the major dysplasias (Class II or Class III ''surgical limit'') or simple malocclusions and to research the possible relationships between basicranial morphologies and maxillo*facial morphologies.*

The asymmetries have thus been linked to other pathologies.

We have compared these results with those obtained by using a three-dimensional cephalometric analysis and with results obtained from the literature.

The conclusions on the epidemiology of the asymmetries are in agreement. Basically, the mandible with dominance of the right hemi-face was confirmed as the causative factor. The stability of the basicranial shape makes a solid case that it is not responsible for maxillofacial or occlusal pathologies.

KEY WORDS

Maxillofacial dysplasias

Class II, surgical limit

Class III, surgical limit

Asymmetry

Geometric morphometry

Procruste's super imposition; 3D analysis

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1 – INTRODUCTION

The literature mainly concerning anteroposterior maxillofacial dysplasias,[19,28] and asymmetries[9,10,16,17,31,32] often attempts to establish a connection during the growth period between these pathologies[20,24-26].

Certain authors find a relationship linking the shape of the base of the cranium with primarily anteroposterior maxillofacial dysplasia[1-5,7,22,23,29] or asymmetries[14-16,19,25,30].

Recently the advent of 3D cephalometrics[11-14,19,25,30] makes it possible to perform three dimensional studies of the base of the cranium and maxillofacial architecture to rigorously measure symmetrical dysplasias (primarily anteroposteror at the maxillofacial level) and asymmetries[26].

The purpose of these studies that we have carried out (this article and Oueiss A.[26]) was to precisely determine the shape of the asymmetries and their relation with the other maxillofacial pathologies (anteroposterior, vertical and transverse). A more ambitious objective was to understand the maxillofacial pathological processes (symmetrical or asymmetrical) and their relationships with basicranial or orbital pathologies that might be causally related.

In order to do this, we studied a varied and extensive pathological cohort (Class II, division 1; Class II division 2; Class III, asymmetry):

- concerning the maxillofacial morphology, using a cephalometric analysis method that we designed, based mainly on 14 trigeminal points (C2000 Cepha 14 points);
- concerning the maxillofacial morphology, the basicranial architecture and the orbital area, using the classic tools of geometric morphometry.

2 – MATERIALS AND METHODS

2 – 1 Material

We had access, as part of URCAM funding intended for the detection and the follow-up of surgical cases, to two samples of 62 cases each composed of significant anteroposterior dysplasias that made it possible for us to develop a surgical solution (Class II, division 1 surgical limit and Class II, surgical limit).

The criteria for inclusion were:

– for the Class II, division 1: a full Class II molar relationship and an overjet in excess of 7 mm;
– for the Class III ; a Class III molar relationship and an underjet of -1 mm.

For the two groups, the major criterion was the development of a surgical solution, by the practitioner who prescribed scans and integrated them into the protocol.

We also had extended samples with standard occlusion

– of the Class I (reference sample of 62 cases);
– of the Class II, division 2 (62 cases);
– and of the asymmetry (126 cases).

The cohorts were selected based solely on occlusal criteria.

For the Class II, division 2 sample the criteria were a Class II maxillary molar greater than or equal to a half cuspid and 100% overbite; for the asymmetric sample, the criterion was only transverse: a mismatch in the midlines of greater than 4 mm.

Of the four study samples, two of them involved *a priori* maxillofacial pathologies, and two of them dealt strictly with occlusal pathologies.

For the Class II, division 1, the Class III and the reference standard, the asymmetry of the restricted sub-samples had been thoroughly studied using a specific version of the C2000 Cepha cephalometric analysis (Oueiss[26]).

2 – 2 Method

2.2.1. For our study samples, we began by comparing the maxillofacial shapes associated with each group.

The comparison of the samples is based on the description of the maxillofacial skeletal anatomy starting with the 14 trigeminal points proposed by J. Treil:

- head of maleus D and G,
- supraorbitals D and G,
- infraorbitals D and G,
- mentons D and G,
- pterygoid plates D and G,
- mandibular foramena D and G
- anterior palatine canal: superior and inferior orifices.

We next used the classic methods of geometric morphometry to compare individuals or average subjects described with a landmark points diagram (14 in this case):

- Procruste's super imposition of the average shapes of each group, as displayed by the diagrams of the points. This super imposition is applied by the Morphologica 2004 software;
- reliability test of the orbital stage represented by the 6 landmarks (right and left HM, SO, and IO) by Procruste's super imposition;
- benchmarks of the orbital area (landmarked by the right and left SO and IO points after having verified their reliability. This benchmarking is executed with the help of a Rapid Form 2004 Plus Pack 2 utility. For the basicranial benchmarks the super imposition points were the supra-orbital fissures and the right and left Foramena Rotundos.
- Goodall test (Simple 3D): this test makes it possible to assess, using the sum of the squares of discrepancy observed between the homologous points of the landmark diagrams, the differences between the average shapes;
- Wilks' lambda test (Morphologika vesion2.1): this test that was carried out using discriminatory analysis, checks the extent of the differences between the averages observed between the two comparison groups;
- ACP analysis and discrimination between the two principal groups being compared;
- visualization of the deformation grid (thin plate analysis, Brookstein FL, 1986[6]);
- colorized visualization of the individual differences of pathological subject/ortho-morphological subject, as illustrated by (Rapid Form 2004 Plus Pack 2).

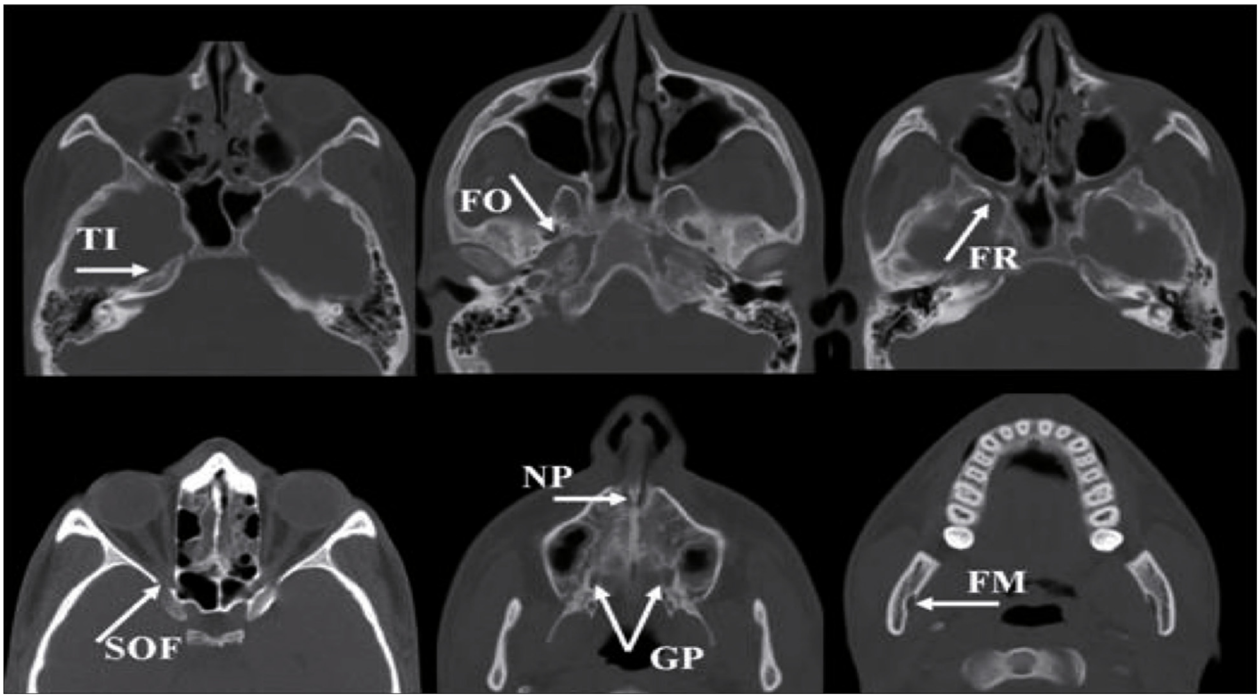


Figure 1

Localization of some maxillofacial or basicranial landmark points on native cuts: T1: trigeminal depression; FO: foramen ovale; FR: foramen rotundum; SOF supra-orbital fissure; GP: pterygoid plates; NP: naso-palatine foramena: FM: mandibular foramen.

2.2.2. In order to determine the possible role of the base of the cranium in the pathologies, particularly maxillofacial asymmetries, we studied and compared the basicranial shapes of each group in the study.

In this instance, the bony landmarks used are:

- the supraorbital fissure
- the foramen ovale
- the foramen rotundum
- the trigeminal depression (Gasser),
- the hypoglossal canal (Fig. 1).

We utilized the same methods derived from geometric morphometry.

3 – RESULTS

3 – 1 – Maxillo-facial shape

- **Stability of the orbital area**

Regardless of the major differences between the overall maxillofacial configuration found in the five groups, the Procruste's super impositions limited to the 6 landmark points framing the orbital area (head of maleus, supraorbitals, infraorbitals to the right and left) present a perfectly stable shape (Fig. 2).

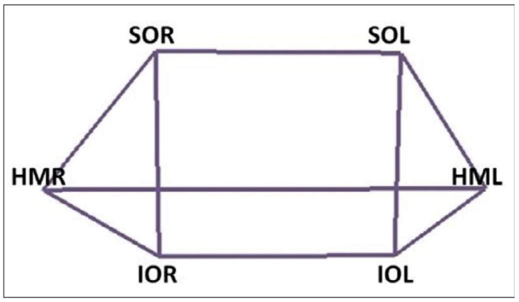


Figure 2
Procuste's super imposition of median shape diagrams on the orbital regions (defined by the points RHM, RSO, LSO, RIO, LIO). We cannot detect any difference between the 5 subsamples.

A Wilks' lambda test numerically confirms the result with a λ very close to 1.

This stability will allow us to recalibrate our coordinates for the orbital region and to more clearly highlight maxillofacial pathologies.

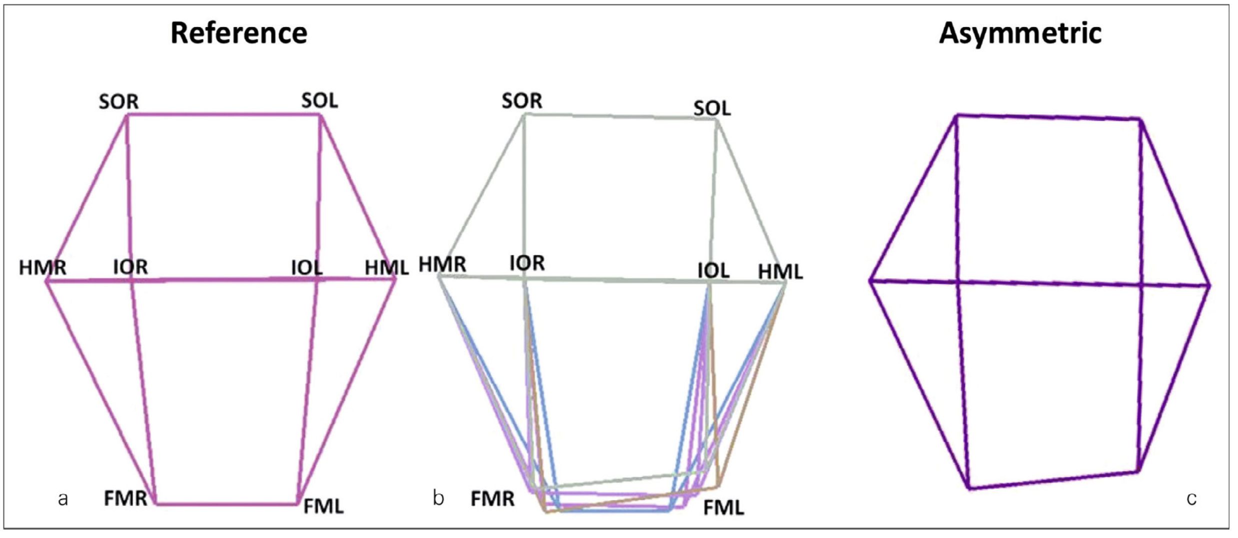
- **Comparison of the 5 study groups**

The median shapes of the different groups vary significantly. The **super impositions** of these shapes on the orbital region makes it possible to locate the differences in the lower third of the face above all in the antero-posterior and vertical dimension, and in the transverse dimension (Fig. 3).

The **Goodall test** confirms the specificity of each shape; the difference between the groups compared two to two is always significant at least at a threshold of 1% (tables I and II).

The **Wilks' lambda test** gives a l value = 0.35801 and confirms the specificity of the shapes.

The ***thin plate analysis*** clearly demonstrates the deformations of the different grids (Fig. 4 and 5).



Figures 3 a, b and c
Front view of average maxillofacial diagrams of the 5 subsamples:
a: reference sample; b: Procuste's super imposition of the 5 subsamples
c: Asymmetry sample.

Comparison samples	*F test*	*P*
Class II division 1 / Class I	2.0235	0.035
Class II division 2 / Class I	2.1401	0.019
Class III / Class I	2.121	0.015
Asymmetrical / Class 1	1.962	0.012

Table I

Goodall test comparing the different pathological subgroups to the reference group: maxillofacial morphology.
The difference is significant at the levels of confidence of 5%, 1%, and 1‰ for F>1.52, F>1.79 and 2.13 respectively.

Comparative pathologies	*F test*	*P*
Class II div. 1 / Class II div. 2	2.2013	0.0185
Class II div. 2 / Class III	2.4384	0.987
Class II div. 1 / Class III	3.2571	0.192
Asymmetrical / Class III	3.0321	0.0182
Asymmetrical / Class II div. 1	3.1360	0.0181
Asymmetrical / Class II div. 2	3.2181	0.0196

Table II

Goodall test comparing the different pathological subgroups two-to-two : maxillofacial morphology.
The difference was significant at the levels of confidence of 5%, 1% and 1‰ for F>1.52, F> 1.79 and 2.13 respectively.

The analysis using the main components (Fig. 6) makes it possible to cleanly separate the 4 groups in relation to the two primary components.

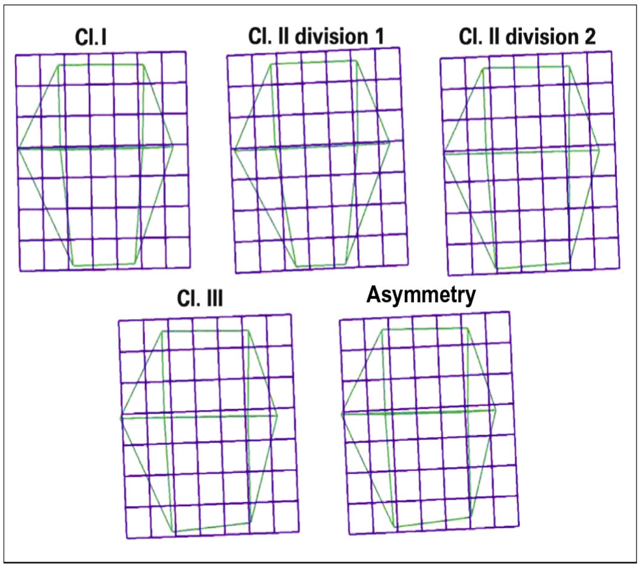
- Class I
- Class II, division 1
- Class II, division 2
- Class III and asymmetry

The first two principal components responsible for 37% and 29% of the variance respectively involve the anteroposterior and vertical dimension of the area of the menton as well as its transverse deviation.

To illustrate this, three cases presenting with strong maxillofacial pathologies (Fig. 7, 9, and 11) have been ''recalibrated'' with an ortho-morphological subject. Despite the extent of the dysplasias they only affected the mandibular area; the craniofacial complex (except for the mandible) and particularly the maxillary architecture remain blue, the color that identifies ortho-morphologic zones.

The conclusions of this study of specific maxillofacial shapes of these occlusal pathologies were utilized here as criteria to define the following groups:

- the reference group presents a weak ''normal'' asymmetry with excess of the right facial half (position below and in front of the right half of the mandible and above all a deviation of the menton to the left);
- the Class III group presents a left sided asymmetry again more marked than the reference sample;
- the Class II groups have a slight asymmetry in agreement with the reference ''relative asymmetry'' that indicates an absolute asymmetry very close to 0.
- the asymmetric group, with occlusion as the only criterion for selection, regardless of the side of the deviation, is in strong agreement with the asymmetry seen in Class III cases;



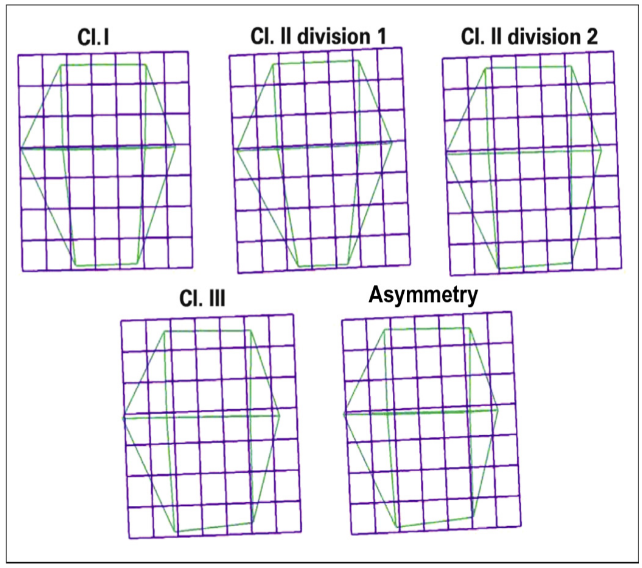


Figure 4 *Figure 5*

Thin plate analysis of 5 samples.

The different shapes of the 5 different subsamples are shown (Fig. 4) and their evolution toward the median morphology of the global sample are specified by the deformation of the grid (Fig. 5).

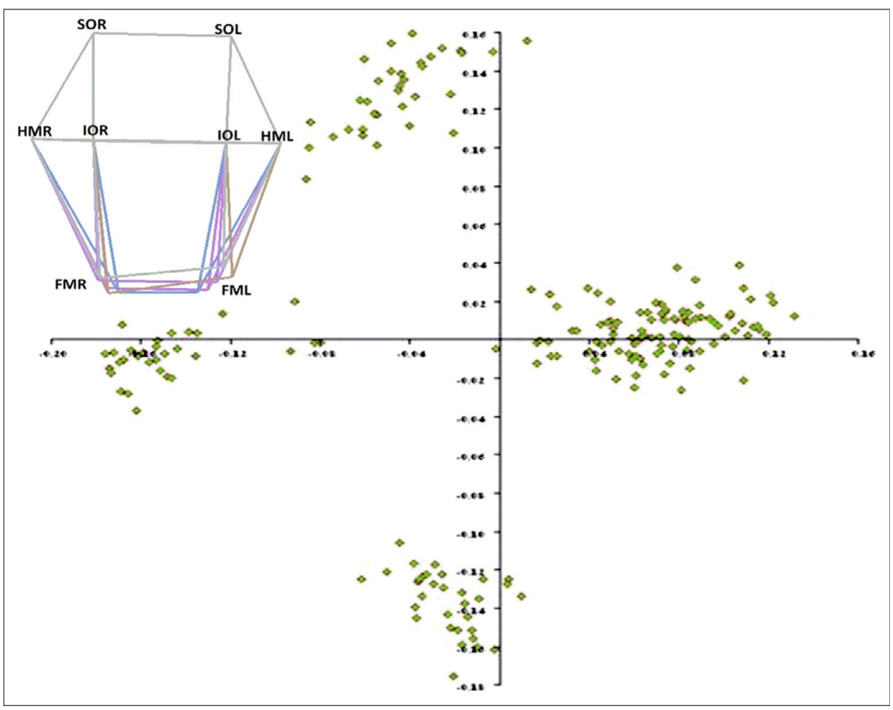


Figure 6

Results of the ACP analysis.

The location of the different subjects on the plane of the first 2 main components already *perfectly separates into 4 subgroups where four clouds of Class I points (reference)/Class II, division 1/ Class II, division 2/ Class III and asymmetric mixed together.*

The first main component is determined by the vertical direction.

The second main component is determined by the transverse direction.

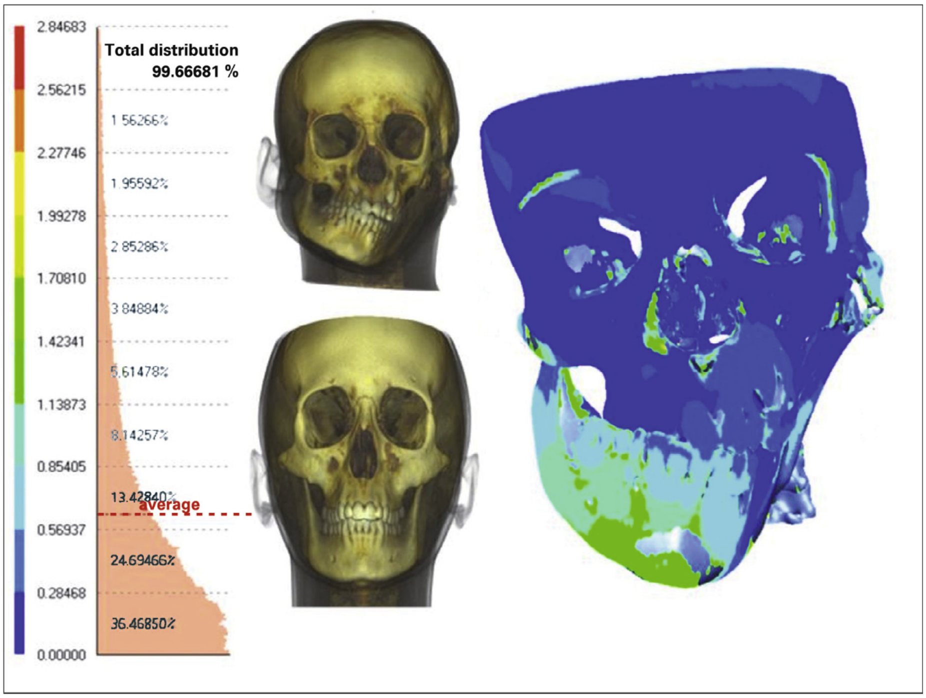


Figure 7

Figures 7 and 8

Patient presenting a significant Class III mandibular asymmetry with excess vertical.

Super imposition of patient/ ortho-morphological subject (separate colored scale showing deviations).

Classically, the asymmetry only affects the mandible, but in this exceptional case the inverse deviated from the classic, that is to say to the right and not to the left.

Notice the perfect normality of the craniofacial complex (mandible excluded) particularly the maxillary area (Fig. 7) and the base of the cranium (Fig. 8).

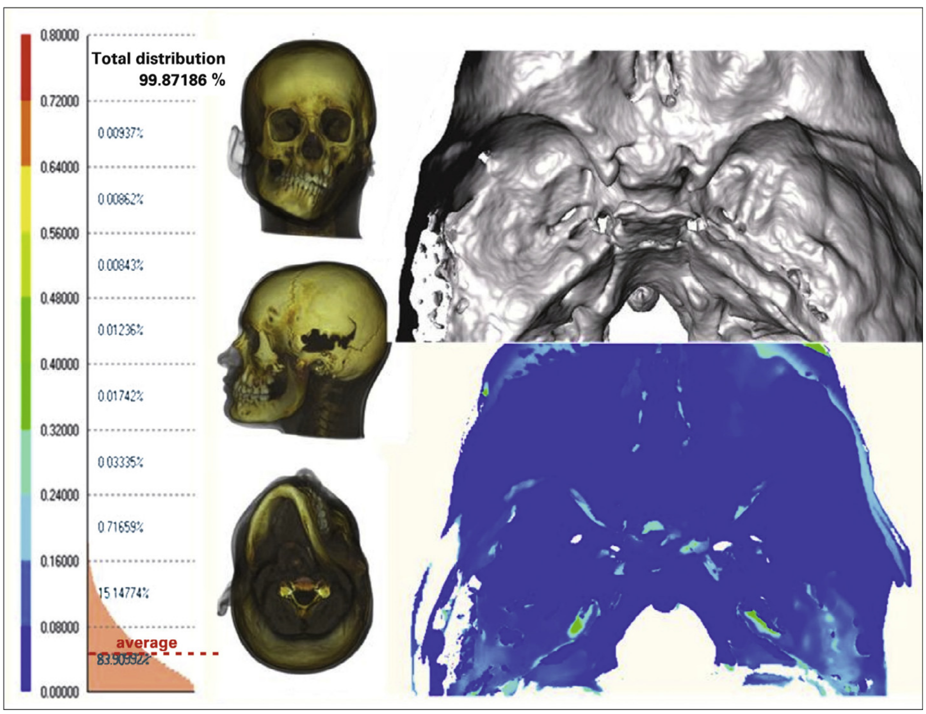


Figure 8

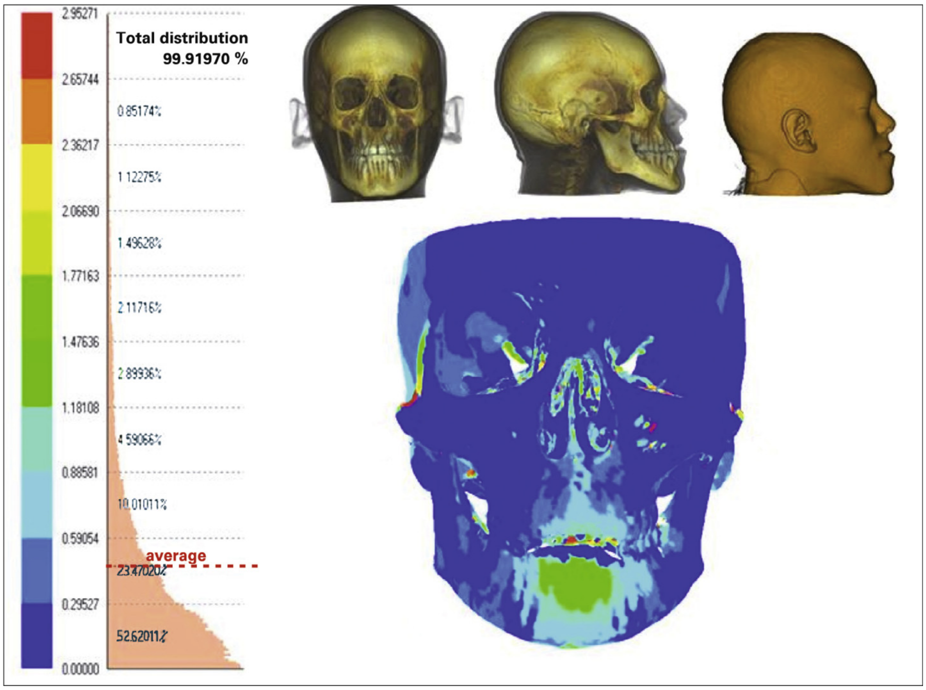


Figure 9

Figures 9 and 10
Patient presenting with a strong Class III with vertical excess.
Super imposition patient/orthomorphological subject (separate colored scale).
Classically, the asymmetry only affects the mandible.
Notice the perfect normality of the maxillary area (Fig. 9) and the base of the cranium (Fig. 10).

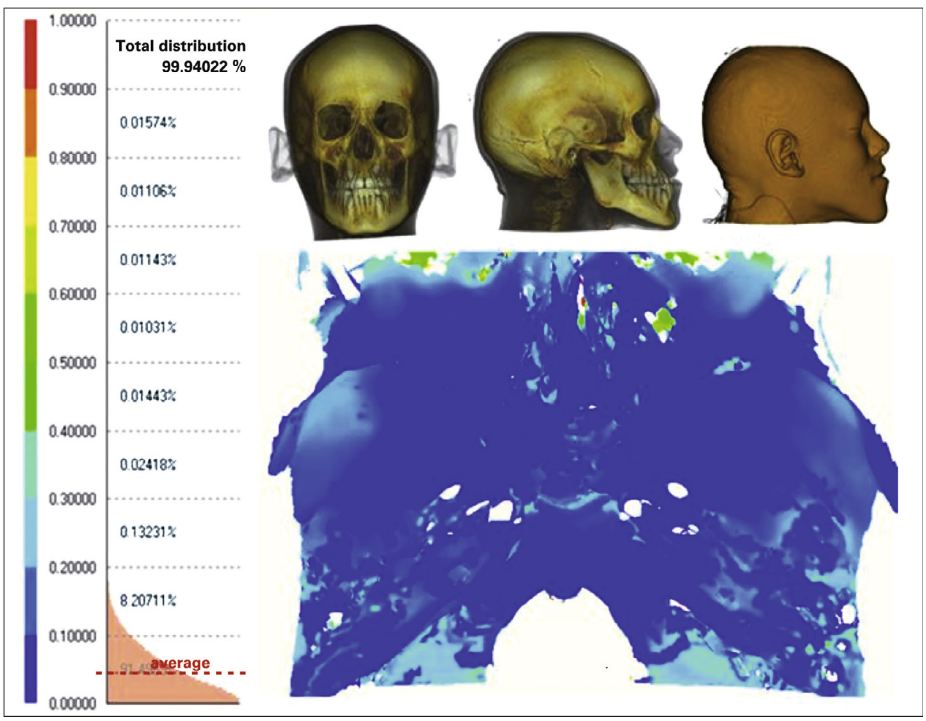


Figure 10

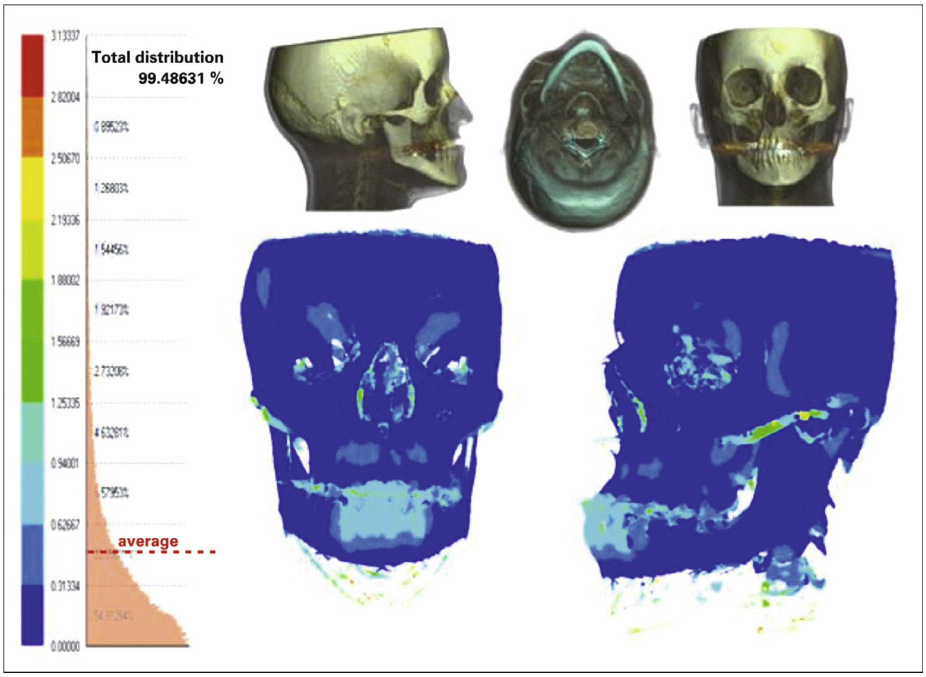


Figure 11

Figures 11 and 12
Patient presenting a strong Class III hyperdivergent asymmetry.
Super imposition patient/orthomorphological subject (separate colored scale).
Classically the asymmetry associated is a left lateral deviation and only affects the mandible and is essentially aveolar only.
Notice the perfect normality of the craniofacial complex (excluding the mandible) particularly the maxillary area (Fig. 11) and the base of the cranium (Fig. 12).

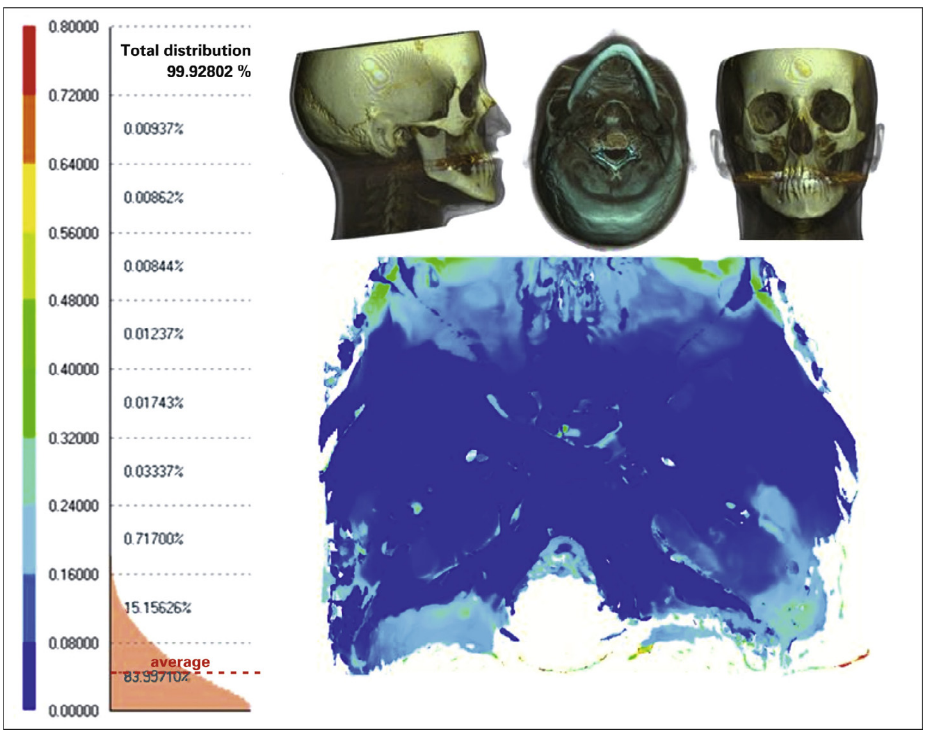


Figure 12

- the pathological groups do not have any particularities in the orbital area: this zone remains perfectly stable.

3 – 2 – Baso-cranial shape: comparison of 5 study groups

The visual examination of the polyhedral shapes that describe the base of the cranium already show perfect stability (Fig. 14). The **super imposition** is perfect and perfectly conforms to the shape of the reference sample (Fig. 13 a and b).

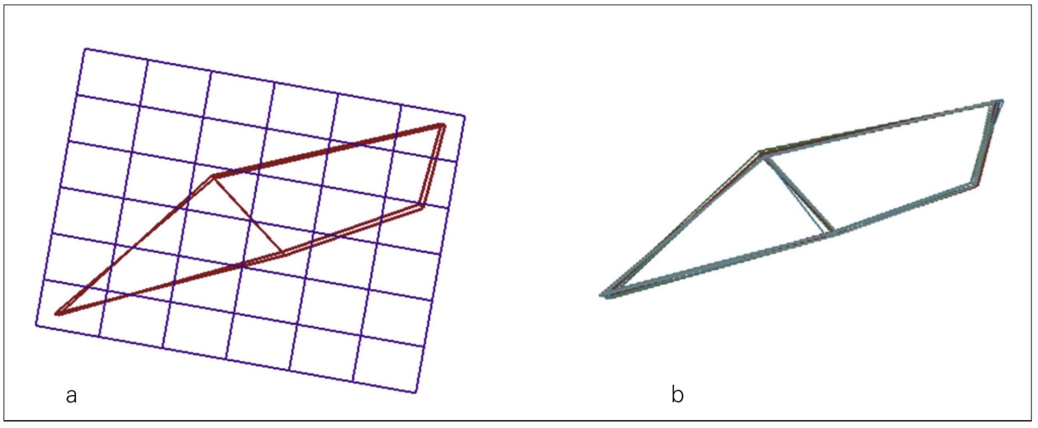
The **Goodall test** confirms the lack of any difference between the groups (tables III and IV).

The **Wilks' *lambda* test** gives λ = 0.992021 with p = 0.999887: there is no significant difference.

The **thin plate analysis** does not demonstrate any difference (Fig. 14 and 15).

The analysis of principal components shows in the space of the two first components a cloud of perfectly homogeneous points (Fig. 16).

The super imposition for example of cases of a significant occlusal and maxillofacial pathology, does not



Figures 13 a and b
Basicranial morphological diagrams:
a: Median diagram of the reference sample;
b: Procuste's super imposition of the 5 subsamples: there is no apparent visible difference.

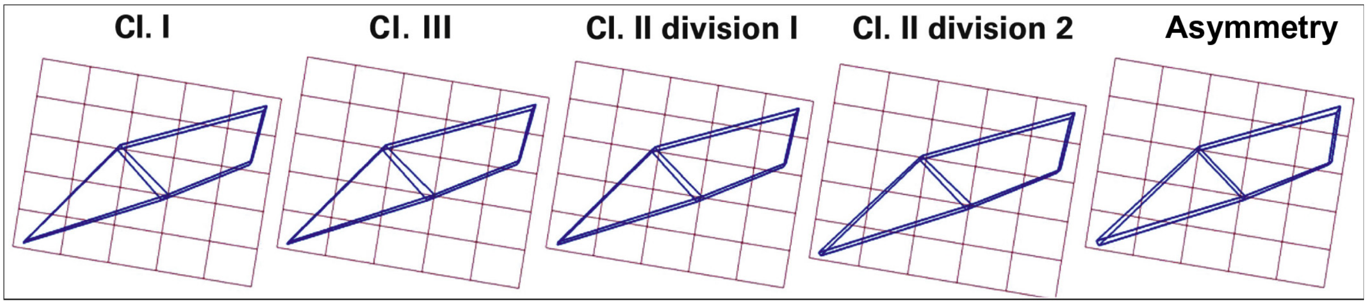


Figure 14
Basicranial morphological diagrams of the different subsamples.

Cohorts compared	*F test*	*P*
Class II division I / Class I	0.0235	1
Class II division 2 / Class I	0.1401	0.09999
Class III / Class I	0.0104	1
Asymmetry / Class I	0.0041	1

Table I
Goodall test comparing the different pathologic sub-groups to the reference group: maxillofacial morphology.
The difference is significant to a level of confidence of 5%, 1% and 1% for F>1.52, F>1.79 and 2.13 respectively.

Pathologies compared	*F test*	*P*
Class II div. 1 / Class II div. 2	0.0013	1
Class II div. 2 / Class III	0.1384	0.0987
Class II div. 1 / Class III	0.2571	0.9998
Asymmetry / Class III	0.0046	1
Asymmetry / Class II div. 1	0.0308	1
Asymmetry / Class II div. 2	0.2581	0.09987

Table II
Goodall test comparing the pathologic sub-groups two-to-two:maxillofacial morphology.
The difference will be significant at a level of confidence of 5%, 1% and 1% for F>1.52, F>1.79 and 2.13 respectively.

show any impact on the basicranial area (Fig. 8, 10, and 12). These three cases are the same ones studied previously for maxillofacial morphology):

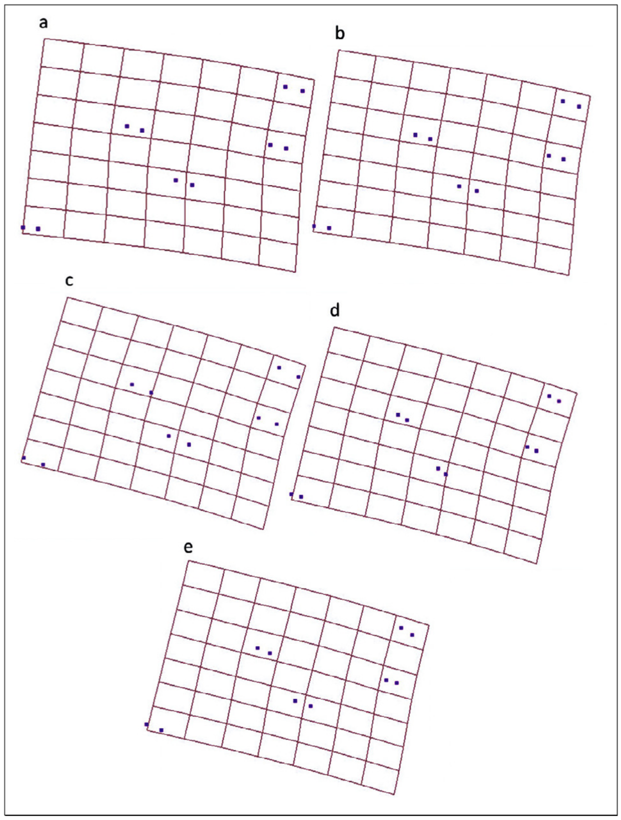


Figure 15
Thin plate analysis of 5 subsamples:
The shapes of the 4 different subsamples present tiny differences (Fig.14) and their evolution towards the median sample global morphology, specified by the deformation of the grid, are not visible.

- specific basicranial shapes (see the basicranial asymmetries) do not correspond to serious maxillofacial pathologies;
- the basicranial shape remains perfectly stable irrespective of the maxillofacial pathology, even if major.

4 – DISCUSSION

On the one hand, the results presented here should rightly be associated with the body of works published on asymmetries, as well

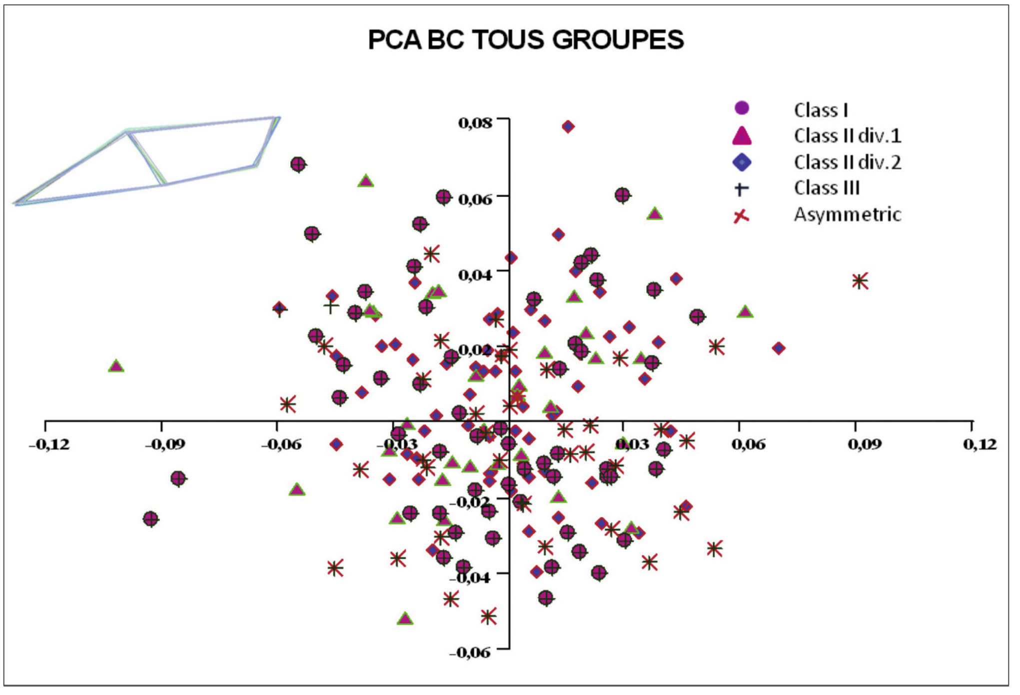


Figure 16
Results of the ACP analysis. The location of the different subjects on the plane of the first two principal components in no way separates any of the pathological subgroups: the basicranial shape is perfectly homogeneous.

as with our results on the samples of major anteroposterior pathologies that we treated by implementing a specific and very precise biometric algorithm[26].

We will develop our observations concerning the epidemiology, the global nature of asymmetry, that is to say its effect in the three planes of space, the privileged connections between the major anterioposterior dysplasias.

We will discuss the pathological hypotheses addressing the growth of the base of the cranium or the growth of the mandible.

4 – 1 – General epidemiology

The literature essentially outlines the following points:

- asymmetry is clinically visible in close to 30% of the subjects but, in fact, it affects three quarters of the population[17,30,31];
- the extent of involvement of the cranio-facial area is limited, and uniquely mandibular in the majority of cases;
- transverse deviation is principally to the left side[9,20,25,30];

The majority of the cases are Class III[17,30], although Letzer and Kronman[24] did not observe the relation between malocclusion and asymmetry;

- asymmetry is not age-dependent[15,16]).

The results stemming from this study and the use of C2000 Cepha confirm the results in the bibliography, but above all they complement and accurately refine them.

The global incidence of asymmetric pathology in the population was not a part of our research objectives but the extent to which it appears in the works of various authors is far from a surprise to us.

The predominance of the mandibular deviations to the left and the link with Class III are confirmed by our own results: the vast asymmetrical sample is ample proof of a right-face excess and the Class III sample is clearly defined by a left lateral shift and possesses a medial morphologic asymmetry that is very close to the ''asymmetric'' sample.

4 – 2 – Global nature of asymmetry, as it pertains to the three planes of space, but with commonly occurring links with the major anteroposterior dysplasias

Our work confirms the global nature of the asymmetric pathology that generally affects the three planes of space, although a clinical examination might sometime indicate for example only a transverse asymmetry, since that is what first draws the attention of the clinician.

The specificity of the maxillofacial shapes and the asymmetries that are observed in the Class II or Class III samples (in this study in tables V, VI and VII, Oueiss A.[26]) strongly supports this idea of global dysplasia or of a global excess of a half-face.

The significant correlations (table VIII[26]) once again reinforce the idea of the interdependency of the three planes of space in contributing to the asymmetry.

But certainly the anteroposterior pathology seems to be strongly linked with the asymmetry, because this is the pathology that is most easily quantified (due to Angle's Classification, the generally accepted qualitative criterion), and because our two studies are based primarily on occlusal groups.

4 – 3 – Growth of the base of the cranium

The role of the base of the cranium in the genesis of maxillofacial dysplasias is the subject of an on-going debate[1-5,7,17,20-23,29]; some authors suspect that the base of the cranium is responsible for the development of the anteroposterior dysplasias, because of the much-discussed angle of the base of the cranium as well as for the genesis of the asymmetries being linked to a primary asymmetry of the base of the brain.

First of all we must point out the surprising and obviously very approximate nature of an assessment of a shape as complex as the cranial base, diagrammed by two planes, that are reduced to two axes in a lateral view in order to finally measure the angle between the two axes. How does one evaluate such a complex surface from an angle plane between two imaginary lines[29,33]!

The problem is so debatable that there are more than 10 different definitions for the angle of the base of the cranium (George, SL, 1978[18]). The most frequently accepted definition is Basion-Sella-Nasion. The choice of these distant benchmark points (Na for example) gives a more accurate measurement but then we are dealing with points that obviously depend on the functional matrices although it is questionable whether they are part of the cranial base.

The modifications of the cranial base during growth [8,18,21,32,33], the ethnic differences, evolutionary changes between primates and homo sapiens, the relationship with encephalization, upright stature or speech are some subjects that are largely controversial. Further the published results are most often contradictory.

Other more precise methods than this simple angular measure are beginning to be used[18,32,27].

We do not want to engage in these debates, and therefore we have preferred to use the classic tools of geometric morphometry.

The choice in adopting these benchmark points completely encompasses the cranial base and avoids the use of less precise defining benchmarks or ones that are somewhat dependent on function.

The results show perfect stability of the shape of the cranial base and its independence vis-à-vis the different occlusal or maxillofacial dysplasias. Any involvement of the cranial base in the genesis of asymmetries or anteroposterior dysplasias can be, for us, rejected.

Certainly a study dealing with patients who present with major primary or central basicranial asymmetries would be enormously interesting. But the study of cases presenting peripheral basicranial asymmetries, in the various functional areas necessarily dependent on the same functional influences that support the maxillofacial architecture, would have no probative value.

4 – 4 – Orbital area

The stability of the shape of the orbital area of the face, as described by the 6 landmark points (head of maleus, supraorbitals, infraorbitals, right and left) has been established, regardless of the the occlusal or maxillofacial dysplasia.

For the same reasons and with the same limits as the base of the cranium, a study using a selection of cases dealing with severe orbital involvement would be highly interesting.

Therefore, we can exclude any role that the orbital area plays in the development of dysplasias.

Additionally, these results determined our choice of a orthonormal reference points coordinate system based on the orbital floor, and developed for 3D cephalometry (C2000 Cépha):

- origin: the middle point O between the infraorbitals R and L;
- Ox axis: axis passing through infraorbitals, from left to right;
- Oy axis: axis passing through O and resting on the line joining the two heads of maleus.

4 – 5 – Generally minor asymmetric deviation

This is a consequence of our previous remarks: in cases of major asymmetry that we studied, the base of the cranium and the orbital floor were not affected. Most often the deviation was solely mandibular, with minimally occurring compensatory maxillary and morphological asymmetries.

5 – CONCLUSION

Therefore, the body of published research makes it possible to put forth a hypothesis concerning the development of asymmetry as:

– a global morphological process of right half-face excess above all affecting the mandible;
– a process therefore including a low and anterior position of the right half-mandible with left deviation of the chin;
– an excess of mandibular growth in class III will present increased asymmetry and right excess, whereas a deficit in mandibular growth will present decreased asymmetry and right excess, and even reverse asymmetry with left excess;
– a process independent of basicranial or orbital morphogenesis.

Of course, when there is a unilateral pathological cause (trauma, infection…) the right/left imbalance will be random.

REFERENCES

1. Anderson D, Popovich F. Relation of cranial base flexure to ccranial form and mandibular position. Am J Phys Anthropol 1983;61:181-7.
2. Baccetti T, Antonini A, Franchi L, Tonti M, Tollaro I. Glenoid fossa position in different facial types: a cephalometric study. Br J Orthod 1997;24(1):55-9.
3. Bacon W, Eiller V, Hildwein M, Dubois G. The cranial base in subject with dental and skeletal Class II. Eur J Orthod 1992;14(3):224-8.
4. Battagel JM. The aetiology of Class III malocclusion examined by tensor analysis. Br J Orthod 1993;20(4):283-95.
5. Dhopatkar A, Bhatia S, Rock P. An Investigation into the relationship between the cranial base angle and malocclusion. Angle Orthod 2002;72(5):456-63.
6. Bookstein FL. Size and shape spaces for landmark data in two dimensions. Statistical Science 1986;1(2):181-242.
7. Dibbets JM. Morphological associations between the Angle classes. Eur J Orthod 1996;18(1):111-8.
8. Diewert VM. A morphometric analysis of craniofacial growth and changes in spatial relations during secondary palatal development in human embryos and fetuses. Am J Anat 1983;167(4):495-522.
9. Farkas LG, Cheung G. Facial asymmetry in healthy North American Caucasians. An anthropometrical study. Angle Orthod 1981;51(1):70-7.
10. Faure J, Baron P, Milheau JF, Treil J, Gardes Ch. Asymétries non-chirurgicales à prédominance verticale. Orthod Fr 2002;73:179-97.
11. Faure J, Baron P, Treil J. Analyse céphalométrique tridimensionnelle : diagnostic des dysmorphies antéropostérieures et verticales. Orthod Fr 2005;76(2):91-110.
12. Faure J, Marchal-Sixou C, Dah-Jouonzo H, Oueiss A, Baron P. Analyse céphalométrique tridimensionnelle à 14 points : compensation des dysmorphies maxillo-faciales. Orthod Fr 2008;79:251-61.
13. Faure J, Oueiss A, Marchal-Sixou C, Braga J, Treil J. Céphalométrie tridimensionnelle : applications en clinique et en recherche (Rapport du Congrès SFODF-SIDO Venise) Orthod Fr 2008;79:13-30.

14. Faure J, Treil J, Borianne P, Casteigt J, Baron P. Céphalométrie tridimensionnelle en orthopédie dento-faciale. Les possibilités actuelles du logiciel Cépha 3Dt. Orthod Fr 2002;73(1):19-37.
15. Ferrario VF, Sforza C, Miani A, Tartaglia G. Craniofacial morphometry by photographic evaluations. Am J Orthod Dentofacial Orthop 1993;103(1):327-37.
16. Ferrario VF, Sforza C, Poggio CE, Tartaglia G. Distance from symmetry: a three-dimensional evaluation of facial asymmetry. J Oral Maxillofac Surg. 1994;52(11):1126-32.
17. Fukushima K, Yasui K, Oatuka Y, Matsui S, Hirase N, Takayanagi J, *et al.* Morphological characteristics of patients with jaw deformity - Frontal cepharometric evaluation of facial symmetry. Meikai Univ Dent J 2003;32:118-23.
18. George SL. A longitudinal and cross-sectional analysis of the growth of the postnatal and cranial base angle. Am J Phys Anthropol 1978;49(2):171-8.
19. Guyer EC, Ellis EE, McNamara JA, Behrents RG. Components of Class III malocclusion in juveniles and adolescents. Angle Orthod 1986;56(1):7-30.
20. Haraguchi S, Takada K, Yasuda Y. Facial asymmetry in subjects with skeletal Class III deformity. Angle Orthod 2002;72(1):28-35.
21. Jeffery N, Spoor F. Ossification and midline shape changes of the human fetal cranial base. Am J Phys Anthropol 2004;123(1):78-90.
22. Kasai K, Moto T, Kanazawa E, Iwasawa T. Relationship between cranial base and maxillofacial morphology. Eur J Orhtod 1995;17(5):403-10.
23. Kerr WJS, Hirst D. Craniofacial characteristics of subjects with normal and postnormal occlusions – a longitudinal study. Am J Orthod Dentofacial Orthop 1987;92(3):207-12.
24. Letzer GM, Kronman JH. A posteroanterior cephlometric evaluation of craniofacial asymmetry. Angle Orthod 1979;37(3):205-11.
25. Melnik AK. A cephalometric study of mandibular asymmetry in a longitudinally followed sample of growing children Am J Orthod Dentofacial Orthop 1992;101(4):355-66.
26. Oueiss A, Pages C, Treil J, Braga J, Baron P, Faure J. Étude des asymétries dans les grandes dysmorphies antéro-postérieures. Orthotod Fr 2010;81(3):235-44.
27. Quintero JC, Trosien A, Hatcher D, Kapila S. Craniofacial imaging in orthodontics: historical perspective, current status, and future developments. Angle Orthod 1999;69(6):491-506.
28. Renfroe EW. A study of the facial patterns associated with Class I, Class II division 1, Class II division 2 malocclusion. Angle Orthod 1948;18:12-15.
29. Scott JH. The cranial base. Am J Phys Anthrop 1958;16(3):319-48.
30. Severt TR, Proffit WR. The prevalence of facial asymmetry in the dentofacial deformities population at the University of North Carolina. Int J Adult Orthodon Orthognath Surg 1997;12(3):171-6.
31. Shah SM, Joshi MR. An assessment of asymmetry in the normal craniofacial complex. Angle Orthod 1978;48(2):141-8.
32. Singh GD, McNamara JA, Lozanoff S. Finite element analysis of the cranial base in subjects with Class III malocclusion. Br J Orthod 1997;24(2):103-12.
33. Strait DS. The scaling of basicranial flexion and length. J Hum Evol 1999;37(5):701-19.
34. Treil J, Casteigt J, Escude B, Roch P, Puech C. Intérêt de l'imagerie 3D dans le bilan pré-chirurgical des dysmorphoses maxillo-faciales. Radiol J Cepur 1992;12:20-5.
35. Treil J, Casteigt J, Faure J, Madrid C, Borianne P, Jaeger M. Architecture cranio-facio-maxillo-dentaire. Un modèle tridimensionnel. Applications en clinique orthodontique et chirurgie orthognathique. Encycl Méd Chir (Elsevier SAS, Paris), Odonto/Stomatologie 2000;23-455-E-40.

36. Treil J, Casteigt J, Jaeger M, Cavezian R. La charpente maxillo-mandibulaire : nouvelle approche cranio-faciométrique tridimensionnelle. Actual Odonto Stomatol 1993; 188:627-37.
37. Treil J, Casteigt J, Madrid C, Borianne P. Une nouvelle construction céphalométrique tridimensionnelle. Un nouveau paramétrage d'analyse tridimensionnelle : les axes d'inertie. Un nouveau concept de l'équilibre maxillo-facial. Orthod Fr 1997;68:171-81.
38. Treil J, Casteigt J, Roch P, Puech C, Cavezian R. Imagerie 3D des dysmorphoses maxillo-faciales. Orthod Fr 1994;64:295-308.
39. Treil J, Casteigt, Faure J, Horn A, Horn A, Labadie MP. Orthodontie et tomodensitométrie. Rev Orthop Dento Faciale 2003;37:9-21.
40. Treil J, Faure J, Braga J, Casteigt J , Borianne P. Imagerie et céphalométrie tridimensionnelles des asymétries cranio-faciales. Orthod Fr 2002;73:179-97.