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AGE ESTIMATION ON 2D IMAGES: APPLICATION OF THE METRICAL FACIAL APPROACH FOR THE ASCERTAINMENT OF AGE IN CASES OF SUSPECTED JUVENILE PORNOGRAPHY

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This thesis is dedicated to the memory of my father

Summary

1. Introduction

Age estimation is one of the most difficult and sensitive procedure in forensic pathology, and is characterized by a long tradition and a number of fields of application: the most common cases of age estimation in the forensic scenario deal with dead people, and in detail with personal identification; however, in the last years, age estimation has begun to include also other forensic cases, especially within the so-called *Clinical Forensic Medicine*, which is the branch of forensic pathology dealing with the living, and consequent evaluation of clinical data for judicial purposes. The procedure of age estimation therefore is now applied to the living for the ascertainment of imputability before trial, or for the correct assignation of scholar classes of adopted children. In recent times, also the age estimation of the living adult, which in the most challenging and difficult field of application, has begun to be performed in order to verify the age of retirement, usually in old immigrants.

One of the most interesting phenomena recorded during this long evolution is the constant and progressive modification of methods of age estimation according to the specific field of application: some methods cannot be applied in specific cases, and this lack of tools has led to the evolution of new procedures, or the amelioration of the existing ones. However, the more specific the field of application, the fewer are the methods which can be applied. The extreme evolution of this phenomenon concerns the most recent field of application of age estimation in the living which deals with 2D images: the ascertainment of age in case of photos may be judicially important, since most Countries state the crime of juvenile pronography, which concerns all the images reproducing minors in a pornographic context (1). In these cases the forensic anthropologist may be requested to provide an age estimation of the persons in the photo: this is the final evolution of any procedure of age estimation, which has passed in the last year from the dead subject (where any investigative method is substantially allowed), to the living person (where only few methods can be applied) up to the *image* of the living person itself. One can clearly consider the pitfalls included in such as operation, since the forensic anthropologist or pathologist is usually requested to give an indication concerning the biological profile of a real person on his photos: from a philosophical point of view, it is not far from the correct identification of real persons and items whose shadows are casted on the wall of the cave in the Plato's famous myth (2), with somehow the same difficulties, and undoubtedly new limits. If in case of the living age estimation has tried to change its methods, now with photos the forensic anthropologist faces a new challenge which consists not only in the development of new tools, but also in verifying if such analyses can be performed also in photos. The tasks are therefore two, and both of them difficult to achieve: the first one consists in finding biological information related with age, and the second in ascertaining if such information is also verifiable in photo. As one can imagine, the procedure of age estimation in cases of images faces new challenges, with new questions which are still waiting for an answer.

However, before approaching the main issue of the present project, a brief discussion concerning the general context of age estimation in forensic anthropology is needed, in order to follow the evolution of this complex issue and understand the limits affecting such a procedure.

1.1 Age estimation in forensic anthropology

Aging in the forensic context is necessary both for the dead and the living; for the dead it is principally to aid identification increating a biological profile which can then be compared tomissing persons. For the living the aim is to solve judicial or civilproblems concerning age of minors as regards issues ofadoption, imputability, pedopornography and, for adults, civilissues on pensionable age and other similar matters for individualslacking valid identification documents (Table 1).

<table>
<tr><th></th><th>Age</th><th>Aims</th></tr>
<tr><td>Dead people</td><td>Minors and adults</td><td>Biological profile for general identification</td></tr>
<tr><td rowspan="4">Living persons</td><td>Children</td><td>Assignation to the correct scholar class in cases of adopted children</td></tr>
<tr><td>Subjects in transition phase juvenile adults</td><td>Ascertainment of imputability</td></tr>
<tr><td>Adults</td><td>Ascertainment of the age for retirement</td></tr>
<tr><td>Children and subjects in transition phase</td><td>Ascertainment of the crime of juvenile pornography</td></tr>
</table>

Table 1: cases of age estimation in the forensic context

Age estimation as few other procedures in forensic anthropology needs a constant updating in the last years, and has seen the proliferation of new methods, and consequent lack of harmonization and common guidelines. Thereare several age reviews, for instance, in the archaeological context, where age estimation has an epidemiological task (3,4). However these may not be exhaustive for forensic purposesbecause the goals are different and the human material may bedifferent, starting from the different states of preservation, taphonomic effects, etc.; in addition, also judicial requirements and time are another importantfactor. There cannot be a simple transferral of methods from thehistorical disciplines to the forensic context.

Some efforts were performed for the forensic scenario, among which the main one dates back to 2000 (5); however, it does not take into consideration the scientific developments of the last 12 years, and therefore necessarely requires an update. More recently Rosinget al. (6) and Schmeling et al. (7,8) published recommendations for the forensic diagnosis of age on skeletons. However this review does not seem to cover all forensic scenarios and gives no clear practical suggestions.

Finally, there is The Study group on Forensic Age Diagnostic, a German group, which produced articles (7,8) concerningaging the living in the forensic scenario. Although useful generalindications are given, the authors do not refer to specific methodsfor practical conditions, and therefore has only a partial importance in current practice.

Only in 2010 the first guidelines concerning age estimation were published, and indicated the suggested methods for each scenario and condition (9): in addition, this article provides the general principles of aging, especially for what concerns the general limits of such a procedure.

From a general point of view, aging consists of identifying biological variables or characteristics which should be strictly related with age: therefore the entire operation provides only an estimation of *biological* age, i.e. the age shown by the specific biological characteristics. However, the most relevant information from a juridical point of view is *chronological* age, which is the time elapsed between the birthdate and the age estimation moment. Therefore one may guess how close the two parameters are. If we consider only the underage individuals, we observe that the physiological growth follows a different trend than chronological age: in detail, modification of the body is fast in the early period, and becomes less and less relevant as the age approaches the 18 year threshold. On the contrary, chronological age shows a direct proportion with elapsed time (Fig. 1).

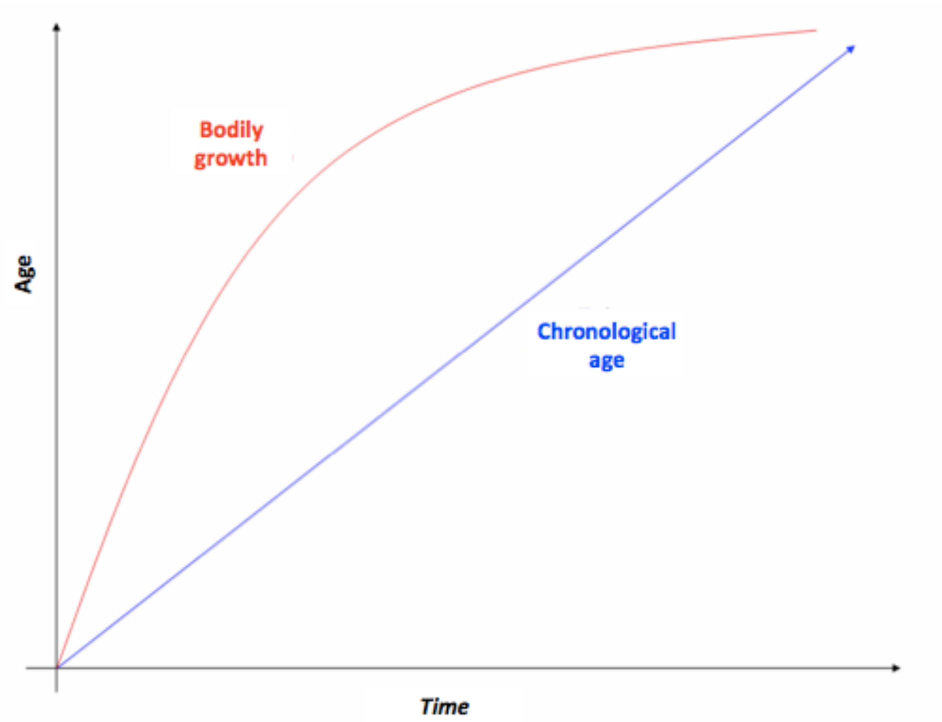


Fig. 1: comparison of growth and time trends

The first limit of age estimation therefore consists in the approximation of biological age to chronological age: however, such as operation can be performed where the two curves are similar, but shows relevant limits where they are different, i.e. near 18 years.

Another limit of age estimation concerns the need for a correction of the results according to the specific racial and ethnic group the individual belongs to; in fact, although the general development of underage individuals is genetically programmed, sometimes relevant differences among ethnic groups may be observed, and require a correction of the result, or even the preferential choice of other methods.

This issue is even more relevant in case of age estimation in the living, where the entire procedure needs to be individualizing and corrected according to the specific variabilities which may be observed (Fig. 2). The need for the analysis of racial variables has led in the last years some scientific journals such as the Forensic Science International to assign a part of the online contents to the so-called "population data" articles, which aim at verifying the accuracy and precision of different age estimation methods applied to specific populations.

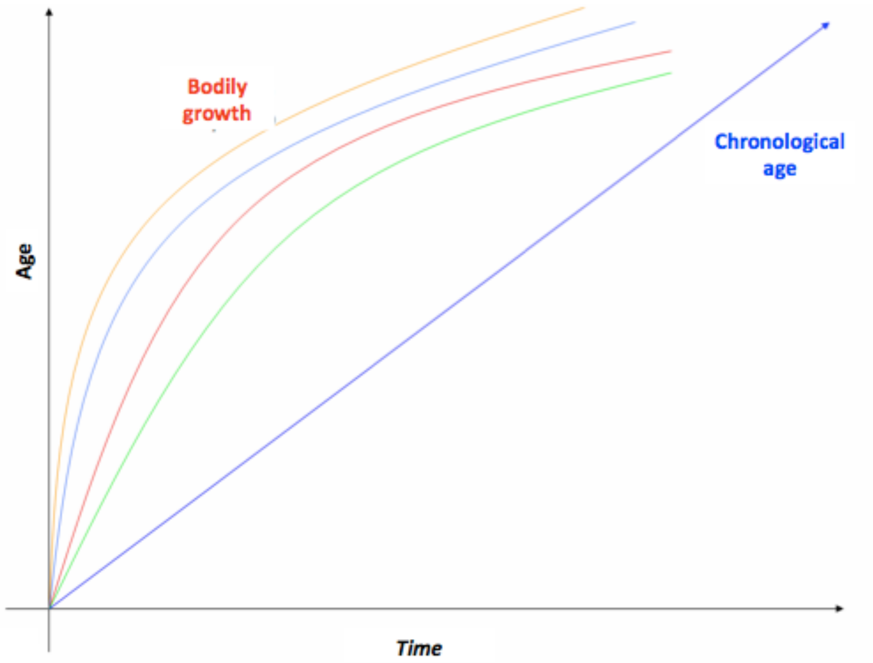


Fig. 2: influence of racial variability on the growth trend: there is no a unique curve, but different growth programs according to the specific racial and ethnic group

Finally, there is not only a racial variability, but also inter-individual modifications which depend upon the environmental and physiological conditions: for example, malnutrition, physical and psychological abuse, deficiency of nutrients, congenital pathologies, etc. may radically modify the bodily development, and therefore the evolution of those biological characteristics used for age estimation. This means that the biological base we use for aging is "polluted" by other modifications which are not related with age, and as a consequence the precision of the result decreases. Surprisingly, literature is poor of indication concerning the possible corrections which may be added to age estimation in such conditions: in most of cases in fact pathologies are excluded from population studies since they may alter the results, especially if one aims at applying a specific method to test the racial variability. The few exceptions concern studies dealing with infectious diseases, which proved to alter the skeletal and dental development (10); however, at the moment the information concerning possible environmental variables theoretically renders useless any attempts at extrapolating an age estimation from biological characteristics.

As one can observe, age estimation is far from being the mere application of mechanic ofmethods, but consists rather in the constant correction of the general results to the specific individual where such methods are tested. To these theorical and somehow philosophical limits, we have to add the practical problems of age estimation on the living, which will be better explained in the next section.

1.2 Age estimation of the living

In the last years cases of age estimation in the living have become more and more frequent. The main issues of age estimation in the living concern adoption, imputability (14,16,18,21 years depending on the country), and old age pension (50, 55, 60, 65 years, again depending on the country). With respect to the dead and the relative requirements for a biological profile, aging the living requires a) the use of non invasive methods and b) a higher accuracy and precision because of specific legal requests. Criteria for age estimation in the living have been given recently by The Study Group on Forensic Age Diagnostic (7,8), with special attention to sensitive legal and ethical implications; the group has proposed guidelines for age estimation in the living, with a three-step procedure including a physical examination and anthropometrical analysis, sexual development assessment (clinical/medical examination is first of all important to diagnose retardation, disease and syndromes which could influence the estimation of skeletal or dental maturation), dental analysis by orthopantomogram, and X-ray study of left hand; if the 21-year threshold is considered, clavicle sternal end X-ray examination (11) is suggested. Generally, age estimation is reached by the analysis of radiographic material, and in detail X-ray examination of hand and wrist and ortopantomograph: with time, different methods have been developed which allow us to provide a skeletal and dental age. In this context, the physical examination, although preliminary to radiological tests, aims at verifying the suspect of possible modification of sexual development which may be related to malnutrition, abuse, pathology, although the limits and cautions of this assessment need to be taken into consideration.

The first evaluation should consider a physical observation and collection of the medical information from the proband through a complete anamnesis. First, height and weight must be accurately measured and the measurements should be compared with the specific percentiles concerning the standard growth of children (12,13) provided by WHO (World Health Organization) and CDC (Centre for Disease Control). These charts however are commonly used in clinical practice, and therefore should only be applied in order to obtain a general orientation for forensic purposes; in addition, physiological and pathological factors, as well as the social and economic contexts have proven to influence body development (14). The same can be said for the assessment of sexual development; pediatricians commonly use the Tanner stages, based on the analysis of sexual traits in males and females (15,16) (Figg. 3,4).

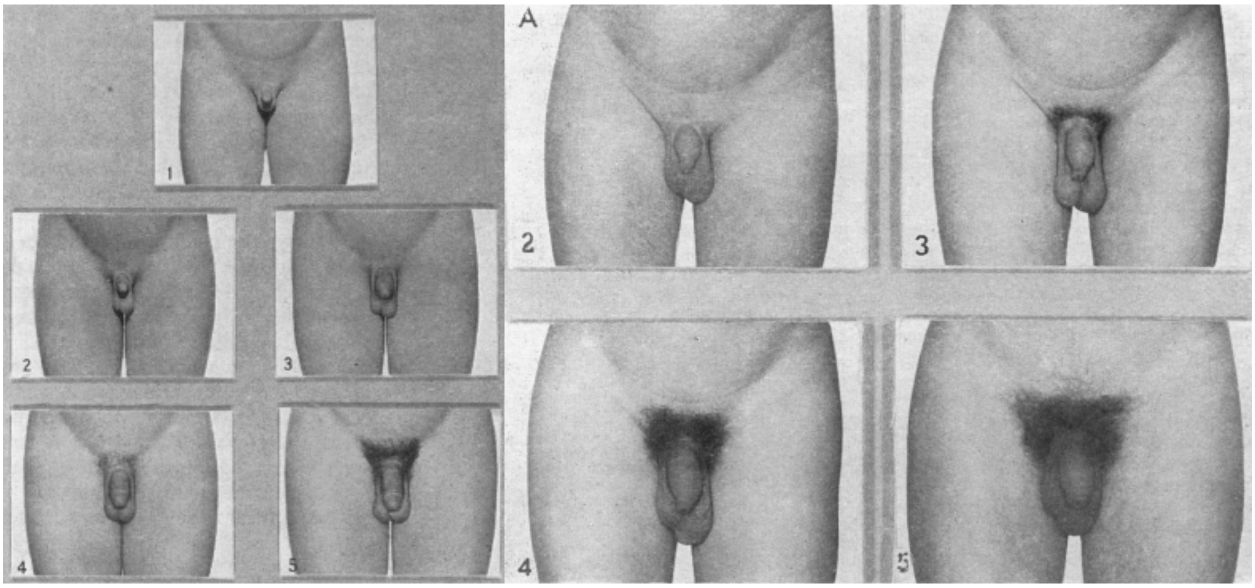


Fig. 3: Tanner stages in male subjects

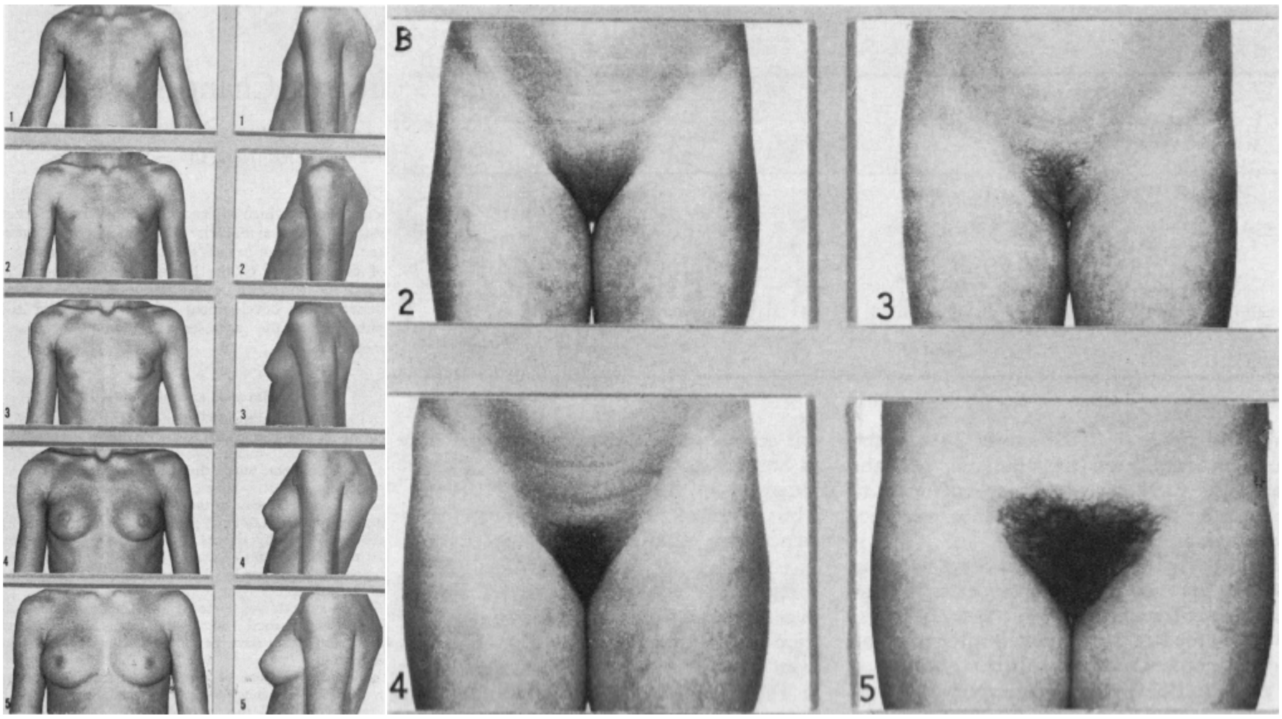


Fig. 4: Tanner stages in female subjects

In detail, the Tanner method considers in females breast and pubic hair development, and in males increase in testicular volume and pubic hair. This method is used in the clinical context. However, important limits concerning racial and inter-individual variability have been pointed out (17-20), and Tanner himself has stressed that the method should not be used for chronological age and thus forensic purposes (21). For adults, although body and sexual growth have terminated, a complete physical examination with perhaps clinical tests, should not be excluded; in females in fact menopause accompanies physical modifications and can be confirmed by hormonal dosage (22) and this may be useful as a general indication—although menopause also is affected by ethnic and inter-individual variability.

However, physical examination do not provide any estimation of age, which is otherwise reached by the application of skeletal and dental methods on X-ray examination; the most commonly used test are Demirjian (23) and Mincer (24) for what concerns dental development, Greulich and Pyle atlas (25) and Tanner-Whitehouse III (3rd Ed.) (26) for skeletal growth. In addition, the fusion of the sternal end of clavicle may be analysed if the subject belongs to the group of young adults, or "transition phase" age. As one can observe, the passage to the living causes a reduction of the number of methods caused by the need for the least invasiveness, and a higher attention to dynamics linked to racial and environmental factors. However, as shown in the next section, most of these method cannot be applied to 2D images.

1.3 Age estimation on 2D images

One of the main problems concerning the aging of living individuals represented in pictures is juvenile pornography. According to the country and legislation involved, the question frequently asked is the age of the child or adolescent (if, for example, under 10, 14, 16 or 18 years). In Italy every image reproducing a subject aged under 18 years in a pronographic context is considered juvenile pornography. A great increase in diffusion of pedo-pornographic material has occurred in the last years, particularly due to the development of web technologies and utilities. Along with the technical progress child pornography has increased proportionally. The misuse of the internet as a (crime) weapon is a serious problem, particularly with regards to an emerging bottomless pit of child abuse material. The demand of pedo-pornographic material determines its supply; every single demand of such material on the internet increases the production. The hideous reality: behind any pornographic graphic material a real child molestation has taken place. This causes a "vicious circle", in which boys are affected as much as girls.
As one can consider, this novel context brings about relevant limits to the age estimation usually performed in the living: in detail, the radiological methods (both skeletal and dental ones) are not applicable. If we consider the problem according to the existing guidelines, the only analysis one can perform on 2D images among those suggested is the physical examination, which in addition is limited to the pure observation of the bodily characteristics without any chance of performing a deeper analysis by palpation (Fig. 5).

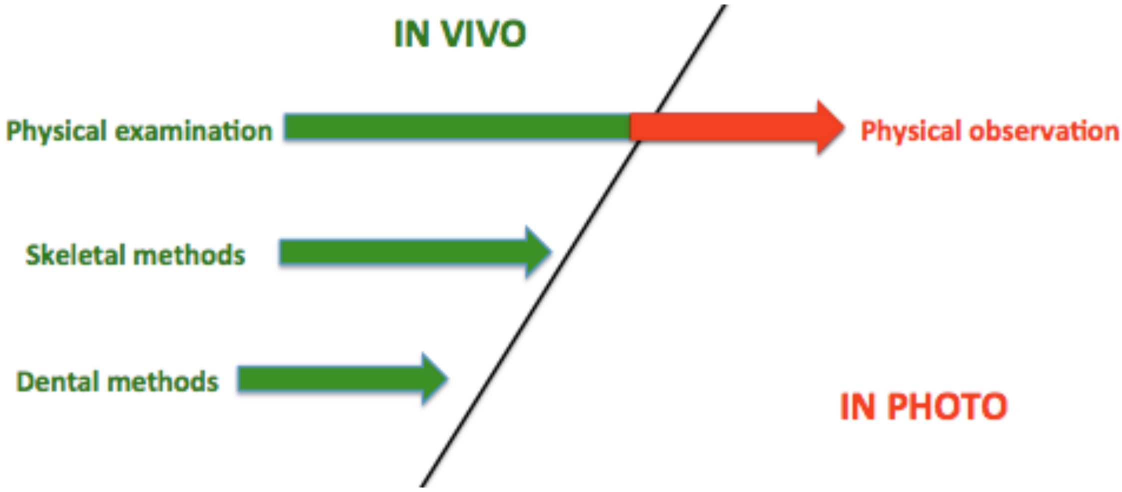


Fig. 5: diagram showing how age estimation is modified by the analysis of photos: skeletal and dental methods are not available, and only the physical examination can be performed, which however is limited to the pure observation

As shown in the previous section, the physical examination in vivo cannot provide an age estimation because of the huge variability of sexual characteristics among different individuals; clearly, the passage from the analysis in vivo to the assessment in photo does not change the situation, but for a lower reliability of the analysis.

First, one should consider that Tanner staging in different cases clearly reports that specific degree of development can be evaluated with difficult in photo; for example, stage 2 of pubic hair is described as "sparse growth of long, slightly pigmented, downy hair, straight or only slightly curved, appearing chiefly along the labia": the authors add that "this stage is difficult to see on photographs". A similar judgment is also shared by the stage 2 of pubic hair in males and stage 4 of penis development.

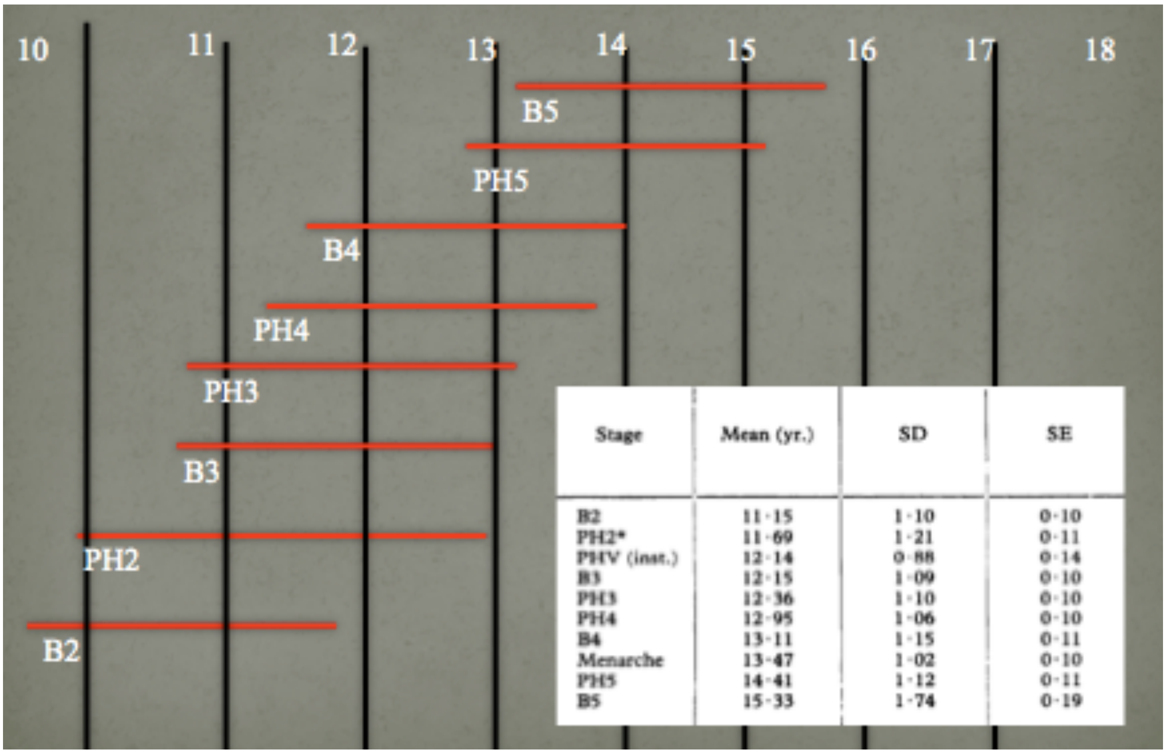
In addition, some stages *cannot* at all be verified in photo, because their description clearly state that the observation should be in three dimensions: for example, stage 4 in breast development of females is characterized by the "projection of areola and papilla", which cannot be evaluated in 2D frontal images.

Another limit of age estimation by sexual characteristics deals with ethnic variability which radically modifies the time of the beginning of each stage (Table 2).

Source	Population	Pubic hair				Breast development			
		PH2	PH3	PH4	PH5	B2	B3	B4	B5
Shumei et al., 2002	**Non-Hispanic White**	10.57 (10.29-10.85)	11.8 (11.54-12.07)	13.00 (12.71-13.30)	16.33 (15.86-16.88)	10.38 (10.11-10.65)	11.75 (11.49-12.02)	13.29 (12.97-13.61)	15.47 (15.04-15.94)
	Non-Hispanic Black	9.43 (9.05-9.74)	10.57 (10.30-10.83)	11.90 (11.38-12.42)	14.7 (14.32-15.11)	9.48 (9.14-9.76)	10.79 (10.50-11.08)	12.24 (11.87-12.61)	13.92 (13.57-14.29)
	Mexican American	10.39	11.7 (11.14-12.27)	13.19 (12.88-13.52)	16.3 (15.9-16.76)	9.8 (0-11.78)	11.43 (8.64-14.5)	13.07 (12.79-13.36)	14.7 (14.37-15.04)
Christensen et al., 2009	**English**	10.19 (9.16-11.22)	11.66 (10.8-12.52)	13.19 (12.2-14.18)		10.95 (9.99-11.91)	11.99 (11.19-12.8)	12.88 (12.04-13.73)	
Hua-Mei et al., 2009	**Chinese**	9.2 (9.06-9.32)	10.37 (11.03-11.29)			11.16 (11.03-11.29)	12.4 (12.25-12.55)		

Table 2: comparison of age of beginning of each stage in various ethnic groups in females according to different authors (26-28)

The third limit takes into consideration the practical point of view of the procedure: age estimation is in fact, as the term itself means, a statistical evaluation of the possible age of the individual, and as all statistical tools it should be, above all, *useful* for the specific purpose. For example, the chosen methods should provide a result which is included within the limits of age the operator is evaluating. A method based on bodily development cannot be applied to adults, and in the same way, methods applied to adults are not expected to give any results if tested on underage subjects. In case of sexual development all the age ranges are limited in a strict interval, and this clearly limits the possible application of sexual analysis, both for children and juvenile adults (Fig. 6).



Stage	Mean (yr.)	SD	SE
B2	11·15	1·10	0·10
PH2*	11·69	1·21	0·11
PHV (inst.)	12·14	0·88	0·14
B3	12·15	1·09	0·10
PH3	12·36	1·10	0·10
PH4	12·95	1·06	0·10
B4	13·11	1·15	0·11
Menarche	13·47	1·02	0·10
PH5	14·41	1·12	0·11
B5	15·33	1·74	0·19

Fig. 6: age interval of breast (B) and pubic hair (PH) development in girls according to Tanner staging

In addition, genitalia of the represented subjects may be affected by modifications (shaving, computer adjustments, etc.).

All these limits led the authors of the method to publish a letter on Pediatrics concerning the worrying increase of cases of application of Tanner stages to expert witness, stating such use as "wholly illegitimate" (29), and defining it as a "misuse". This contribution clearly prevents from any further application of such a method to pornographic images.

The unreliability of sexual assessment in photos was proven also by an article published in 2009 (30): 11 photos of 11 females were taken from official authorised pornographic websites where the "actresses" were known and of adult age. On every photo, the observer/examinee (who was unaware of the girls' age) was asked to establish if each girl was underage (18 years was selected in this trial) or adult, specifying which particular anatomical element suggested the choice (face, breast, pubic hair, other). The photographs were the object of the same study both in Germany and in Italy. In Italy the test was subjected to groups of five observers belonging to three different medical specialist categories: forensic pathologists, paediatricians, gynaecologists, all of experience. Another group, used as a control group, was composed by 13 non-medical specialists (laymen); in total, the subjects who underwent the test were 28. In Germany the exact same study was performed, with the same number of laymen and of forensic pathologists. The number of gynaecologists and paediatricians was slightly lower, for a total of 23 examinees. A very similar outcome can be observed in both countries. All classes performed poorly. The best results were obtained by forensic pathologists who correctly identified the women as being over 18 years of age in 60% and 50% of cases (for Italy and Germany, respectively); laymen (50% and 23%, respectively) performed second best. Paediatricians incorrectly classed the girls as under 18 in 73% and 95% of cases respectively and gynaecologists in 69% and 91% of cases. When asked which were the areas which helped them in their decisions, examinees responded in the following manner: globally forensic pathologists mostly pointed out facial traits (64%) and breast development (23%), whereas pubic hair (2%) and axillary hair (0%) were less frequently observed; paediatricians took into consideration general facial morphology in 41% of cases, breast morphology in 27% of cases, the pubic area in 23%, axillary hair in 4%; gynaecologists indicated the face in 39% of cases, breast morphology in 36% of cases, pubis in 17%, axillary hair in 2%; laymen used the face in 33% of cases, breasts in 29%, pubis in 17%, axillary hair in 10% of cases. It is difficult to explain the better performance of the forensic pathologists compared to the gynaecologists and paediatricians. Perhaps gynaecologists and paediatricians were more greatly influenced by the apparently "juvenile" sexual traits and faces. Another reason may simply be (since most forensic pathologists involved in the study did not have much experience with pedo-pornographic material) the "innate" inclination of forensic pathologists towards criticism and caution in expressing an opinion (Figg. 7,8).

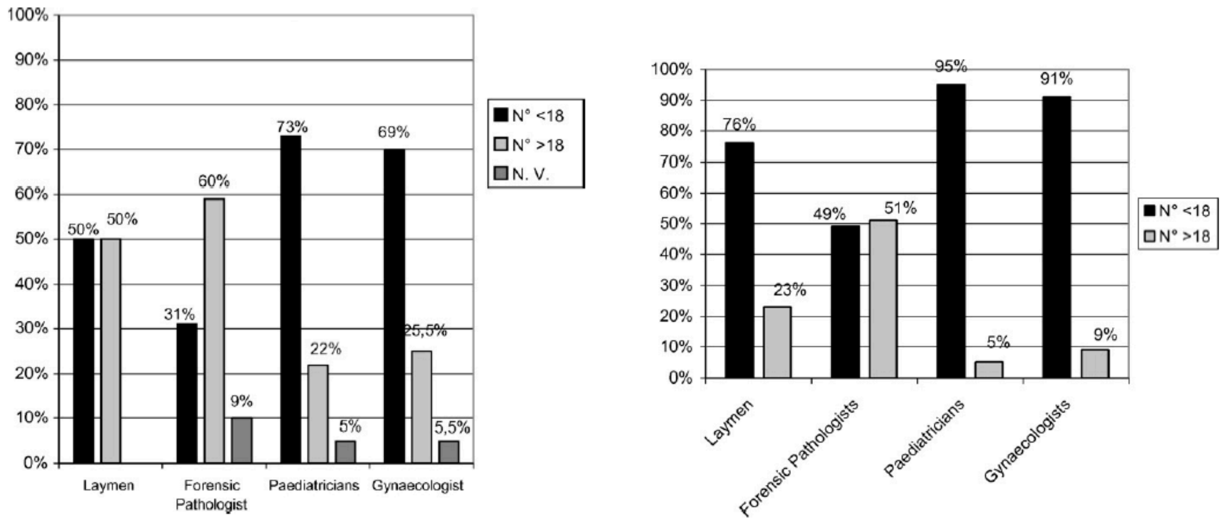
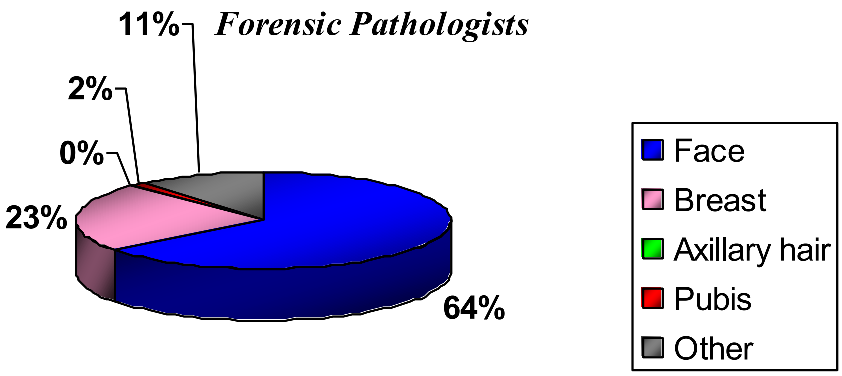
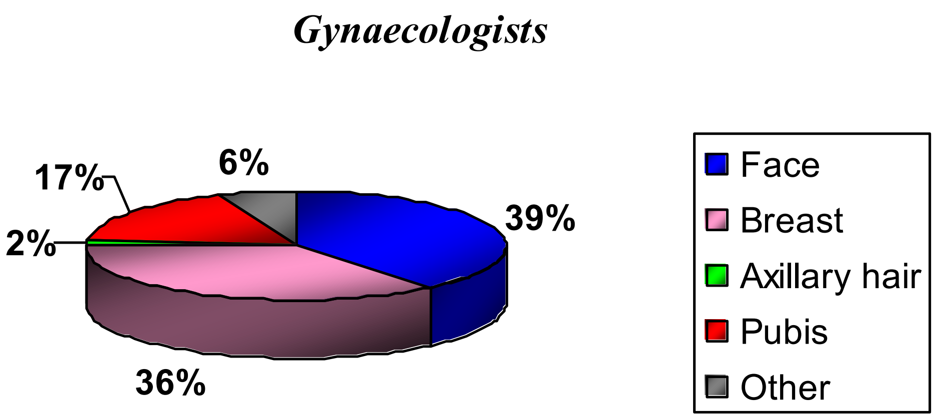


Fig. 7: final results of the study: on the left, the Italian results (NV stands for "not evaluable"), on the right the German ones





Paediatricians

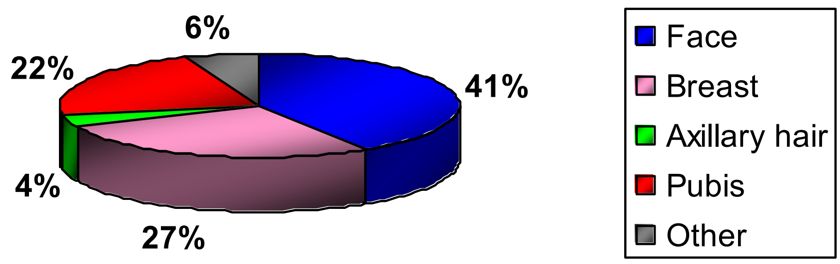


Fig. 8: bodily characteristics used for age estimation by the observers taking part to the experimental project

These results clearly demonstrate that the judgment based on the sexual characteristics is wholly unreliable, and therefore cannot be applied to the ascertainment of juvenile pornographic material. On the other hand, this is the only approach actually existing in this field: no other method is available, and therefore the valuation of sexual characteristics is still applied to forensic experts.

However, in the forensic scenario, the lack of scientific methods usually increase the misuse of the existing ones, or even the application of "tests" without any scientific base. This leads even to more severe consequences of one considers that the crime of juvenile pornography has an important social aspect, which contributes in emarginating the charged subjects. The need for a scientific method is therefore urging; however, new biological characteristics linked with time need to be found.

The study published in 2009 gives some hits concerning these novel characteristics; for example, operators who gave best results declared to have evaluated face: this may be a hint concerning the biological structures which are more truly linked to time in 2D images.

From this indication, the actual experimental project starts; however, before explaing the details of the research, some information are needed: for example, is facial development actually linked to time? And what changeson the other side of the mirror, in other words in photos? These questions will find a partial answer in the following sections.

1.4 The crime of juvenile pornography in the Italian Penal Code

In order to provide the juridical scenario of the crime of juvenile pornography, hereby the specific articles of the Italian Penal Code will be exposed:

Art. 660 ter, Italian Penal Code: "anyone who abuses minors younger than 18 years in pornographic exhibitions or produces pornographic material, or induces minors younger than 18 years to take part to ponographic exhibitions, is punished by imprisonment between 6 and 12 years and sanction between 25.822 and 258.228 €. The same punishment is shared by anyone trading pornographic material previously indicated. Anyone, beyond the conditions indicated in the first and second clause, distribute, spread or publicize, also by data transmission the pornographic material previously indicated in the first clause, or distribute or spread news and information aiming at the enticement or sexual exploitation of minors aged under 18 years, is punished by imprisonment between 1 and 5 years and the sanction between 2.582 and 51.645 €.

Anyone who, beyond the first, second and third clause, offers or transfer to others, also for free, the pornographic material indicated in the first clause, is punished by imprisonment up to 3 years and the sanction between 1.549 and 5.164 €[1].

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[1] Chiunque, utilizzando minori degli anni diciotto, realizza esibizioni pornografiche o produce materiale pornografico ovvero induce minori di anni diciotto a partecipare ad esibizioni pornografiche è punito con la reclusione da sei a dodici anni e con la multa da euro 25.822 a euro 258.228. Alla stessa pena soggiace chi fa commercio del materiale pornografico di cui al primo comma. Chiunque, al di fuori delle ipotesi di cui al primo e al secondo comma, con qualsiasi mezzo, anche per via telematica, distribuisce, divulga, diffonde o pubblicizza il materiale pornografico di cui al primo comma, ovvero distribuisce o divulga notizie o informazioni finalizzate all'adescamento o allo sfruttamento sessuale di minori degli anni diciotto, è punito con la reclusione da uno a cinque anni e con la multa da euro 2.582 a euro 51.645.

Chiunque, al di fuori delle ipotesi di cui ai commi primo, secondo e terzo, offre o cede ad altri, anche a titolo gratuito, il materiale pornografico di cui al primo comma, è punito con la reclusione fino a tre anni e con la multa da euro 1.549 a euro 5.164.

Art. 660 quater, Italian Penal Code: "anyone who, beyond the hypotheses indicated in the art. 600-ter, consciously manages to obtain or holds pornographic material performed by abusing minors younger than 18 years, is punished by imprisonment up to 3 years and a sanction not lower than 1.549 €.

The punishment is increased of not more of two thirds if the held material is huge[2].

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[2] Art. 600 quarter: "Chiunque, al di fuori delle ipotesi previste dall'articolo 600-ter, consapevolmente si procura o detiene materiale pornografico realizzato utilizzando minori degli anni diciotto, è punito con la reclusione fino a tre anni e con la multa non inferiore a euro 1.549.

La pena è aumentata in misura non eccedente i due terzi ove il materiale detenuto sia di ingente quantità**.**

2. Facial growth: state of the art

Facial assessment, performed both from a metrical and morphological point of view, is one of the most ancient and treated issues in science, since face is the main tool for the communication and interaction with the environment (31); pionieristic studies were performed by Leonardo da Vinci and Albrecht Dürer, and deal with the graphical methods useful to describe the facial morphological variation (32). Charles Darwin first analysed the facial expressions and explored the importance of face in interaction between individuals of the same species (33). In the 19th century, with the beginning of the modern forensic anthropology, metrical analysis of face was analysed with identification purposes by Alphonse Bertillon who developed a system of recording called *bertillonage* (34); in the early 20th century, the importance of the face was explored for what concerns the relation between personality, moral behaviour and morphological facial traits, by Lombroso (35).
The revolutionary discovery of X-rays allowed the scientist to perform a more precise analysis of facial morphology, which was one of the main issues of the new technology (36): however, only in the last 30 years the study of the face was developed by an increase of studies published on this topic and the widening of research in the fields, thanks to the introduction of more advanced technologies such as CT scan and NMR (nuclear magnetic resonance), which since the early '80's were widely applied to the 3D study of cranium and facial soft tissues (37), and the use of modern 3D image acquisition systems, both the non contact (laser scanner, stereophotogrammetry) and contact ones (electromagnetic and electromechanical digitizers, ultrasound probes) (38). The use of such technologies allowed the operators to perform an easier recording and quantification of facial metrical parameters, in order to increase data available in literature and to analyse the chances of practical application of the obtained information. Some fields of application are the diagnosis of pathology, especially the chromosomic ones (39,40), such as the relation between ear measurements and Down's Syndrome (41). Other studies deal with ectodermic dysplasia (42) and Moebius' syndrome (43). In the clinical contest the modification of soft facial characteristics seems to be related with the success of dialytic therapy (44), and therefore may provide new tools for the evaluation of health conditions

in patients affected by renal insufficiency. A specific discussion is requested for the wide field of analysis of oral and dental surgery, especially for what concerns the relation between therapy and modification of the face in subjects affected by cleft palate (45) or relevant orthognatic surgery procedures (46), in order to predict the aesthetic result. The relation between age and face is not the only one widely explored by literature: several articles deal with the influence of dental occlusion on facial morphology (47-49). Other fields of application concern the quantification of facial physiological symmetry, or the quantification of attractiveness in males and females (50-53), as well as anatomical differences between males and females (54,55).

For what concerns the relation between craniometric measurements and age, literature provides several articles dealing with the development of different facial traits in children and juvenile adults; Farkas for example analysed the degree of growth of different cranial and facial parameters, pointing out the percentual modification (56). In more recent times, different studies have been published concerning the sectorial development of single facial areas, in detail the lips (57), the ears (58,59), the nose (60) and the orbital region (61,62).

The modification of face with age has been improved by analyses concerning the movement of facial landmarks with time, with consequent modifications of facial profiles (63,64); in detail, between 6 and 11 years vertical diameters of the face increase, especially in the middle and upper thirds of faces: then, at 10 years circa in females and at 13 years circa in males the facial profiles are close to the adult model, with a dislocation of the main landmarks. Up to 11 years the trend is similar in both the genders; then females show a spurt around 11-12 years, followed by a progressive decrease of bodily development. On the other hand males are affected by a delayed growth, which remains constant from 11-12 to 16-17 years. As a consequence, at 14-15 years females have a facial configuration close to the adult one, whereas males of the same age are still developing. In females, the upper and lower thirds have higher degree of development up to 11-12 years; on the other side, males begin to increase the lower third since 12-13 years.

As one can observe, most of the literature actually deals with linear measurements which remain the traditional way to explore the facial morphology: in such cases, the increases are usually analysed as a percentage of the adult measurements. For instance, for what concerns the transversal diameters, head breadth (eu-eu) reaches 83.8% of the adult standard at 1 year, 92.7% at 5 years and then a limited increase up to 18 years in both the genders.

The forehead breadth at 1 year reaches 71.7%, with a different trend in males (where the main increases are recorded between 3 and 4 years, and between 4 and 5 years), and in females (between 2 and 3, and 5 and 6 years). The same difference was observed also for the head height (v-n) and head length (g-op): in both the cases, males and females show different trends (65).

As indicated by these few studies, the cranial development is characterised by a dishomogeneous correlation with time, with periods of higher increase, and a sexual difference, as observed also for other biological parameters such as the height and secondary sexual features. The same analysis, including the facial characteristics, provides additional information: in detail, Farkas et al. verified a similar trend also in facial measurements, although the growth seems to be more limited in the early period of childhood. For example, facial heigth (n-gn) reaches only 67.8% of the adult measurement at 1 year, and 85% at 5 years, both in males and females. In males the higher increase is recorded between 1 and 2 years, and 3 and 4 years, in females between 1 and 2 years, and between 3 and 5 years. Also in this case the development is earlier completed in females (13 years) than in males (15 years). The upper facial height (n-sto) shows modifications related to the total facial height, reaching 67.3% of the adult size in the first year, 82.2% at 5 years. The faster development is observed in males between 1 and 2 years, and between 3 and 4 years, in females between 1 and 4 years. The mandibular height (sto-gn) at 1 year is 67% of the adult measurements, at 5 years 87.8%. The higher increase occurs between 1 and 2 years, and 3 and 4 years in both the genders. The facial breadt (or bizygomatic breadth, zy-zy) at 1 year is 72.1% of the adult measurement, at 5 years 82.9%. The higher increase occurs between 3 and 4 years, and ends at 13 years in females and 15 years in males. The mandibular breadth (or bigonial breadth, go-go) at 1 year is 80.2% of the adult measurement, at 5 years 92% with a higher increase between 3 and 4 years, between 7 and 8 years and 12 and 13 years in males, between 6 and 7 years in females, and ends at 12 years in females, at 13 years in males. Therefore, the longitudinal diameters seem to show a slower increase than the transversal ones which increase faster in the early chidlhood (66). In addition, in males an increase of vertical diameters is observed after 30 years (67).

The linear approach to the facial growth has provided with time epidemiological information concerning the modifications of different parameters; however, although the metrical variations of faces are well known, these data have no forensic application since a statistical study concerns correlation and regression between facial measurements and age has not yet been developed, since most of studies are anatomical analysis, aiming at verifying the metrical characteristics of faces.

In the last years, the research in this field has known a relevant improvement thanks to the advanced 3D image acquisition techniques: the main advantage consists in the chance of measuring dimensional parameters which cannot be evaluated in vivo, for instance areas and volumes. Several studies have appeared concerning the modification of facial areas included within three or more landmarks, and their modifications with age; however, also in these cases, the higher interest deals with the anatomical asset of facial profiles in different ages, rather than in forensic application concerning age estimation.

Another point of discussion concerns the type of areas used for facial assessment: the increase of accuracy of facial analysis is necessarily linked to a less standardized model of face, and therefore to a higher risk of low correlation with age, since all variables (both environmental and individual) are included. This is a very relevant point, since the facial assessment with the introduction of modern technology is divided between the traditional approach, based on linear measurements and defined by a standardized, physical context, and the new chances of areas and volume assessment, which are more adherent to reality. The first one is usually affected by a general distance from the real information, since the linear measurements can provide only a simplification of natural growth process: on the other hand, the second approach, although reliable, is more affected by environmental and individual data, and so the metrical modification may be less related with age, and dependant upon other variables. In the last years, literature has begun to search for an adequate balance between these two approaches, for example analyzing the *geometrical* areas and volumes included within facial landmarks. This was an attempt both at applying the 3D image acquisition systems and trying to find a standardization as for linear measurements (60,61,68). However, as one can imagine, the application of *geometrical* measurements provide only an approximation to the *real* face, which is characterized by a physiological curvature, completely ignored by the actual approach. The application of a geometrical points risk losing precious information concerning age which may be included within the surface modification of a face, although somehow "polluted" (Fig. 9).

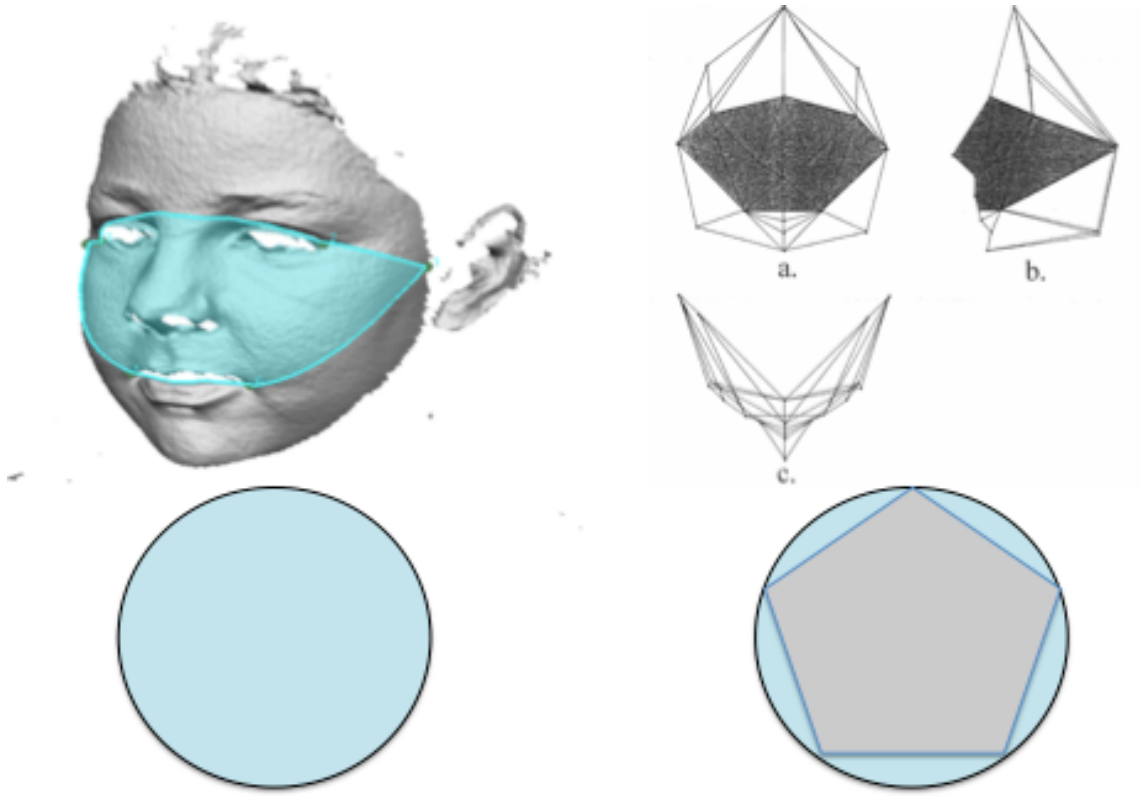

Fig. 9: example of measurements of a facial surface (on the left) and the geometrical area included within the same points (on the right): comparison between the morphological difference of the two approaches

From this point of view, the analysis of real surfaces may provide additional information to the analysis of growth, which is radically influenced by the method of measurement.
Therefore, the surface assessment is worth being analysed in depth, especially for what concerns the relation between facial metrical parameters and age.
However, this is not the only task to achieve for the actual purposes of this study: in detail, the reliability of the correlation of facial measurements with age, even if it is confirmed, needs to find a corresponding significance also in 2D images, on which the age estimation is performed. This is the other part of the problem, the world "across the mirror" which will be treated in detail in the next section.

3. Aim of the study

As previously mentioned, the issue of age estimation on 2D images brings about relevant specific limits, and adds new problems, both from a scientific and practical point of view, to those usually reported in other fields of application. The main issues include the need for finding new biological parameters related with age and for testing them on 2D images. Anatomy has widely analysed in depth modifications of faces with age, especially in minors; however, most of literature deals with linear measurements. Recently the introduction of 3D image acquisition systems has allowed the operators to perform an evaluation of 2D and 3D parameters of faces, but the available literature is limited to geometrical areas, which provide only an approximation to the real facial surfaces which undergo modifications with age. From this point of view the analysis of 3D surfaces may provide additional information to age estimation, especially for what concerns the complex system of individual variabilities which may affect facial growth and may not be traced by geometrical measurements. However, before taking into consideration other new facial parameters, there is the need to verify if there is actually a correlation between facial measurements taken in photos and age.

On the other hand, literature concerning age estimation from photos is very poor, and deals only with linear measurements. However, literature on identification verified that linear measurements may be deceiving, especially if they are few in number. Also from this point of view, the evaluation of surfaces may add new suggestions to the topic of age estimation.

This study aims at exposing the results of different investigations performed during the PhD course, aimed at verifying the relation between facial measurements and age, in vivo and in photo: the line of research followed a project aiming first at ascertaining the reliability of linear measurements in photos, both for subjects aged under and above 18 year threshold, and then at verifying the chance of extrapolating new biological parameters from the face useful for age estimation. The first steps will consist in finding a standardization of facial metrical assessment by an analysis of reliability of collocation of facial landmarks. After this phase, the study will attempt at verifying the reliability of linear measurements for age estimation in photos in subjects aged under 18 years. A similar experiment will be applied as well to young adults aged over 18 years, after a preliminary study of in vivo measurements in order to verify the correlation of such parameters with age. In conclusion, the study will attempt at finding new biological geometrical parameters (in detail, facial surfaces) for age estimation, in vivo and in photo.

4. Analysis of facial parameters in vivo, in photo and 3D model

All the steps preiously indicated will be analysed in detail in the following sections. Every step of the entire experimental project led to a scientific articles, in some cases already published in specific journals, whose references will be indicated. For every step, the single experiment will be described in its materials and methods, results and discussion, in order to render them easily readable, whereas at the end there will be an overall conclusion of information opbtained by the entire path followed during the PhD course.
First of all, the study will start by standardizing the facial assessment by verifying the reliability of the collocation of landmarks, needed for metrical measurements.

4.1 Standardization of facial metrical assessment: quantitative study of accuracy in positioning facial landmarks[3]

Before verify if facial measurements may be useful for age estimation, one should standardize a method for taking such measurements. To be repeatable, all the linear parameters need to be defined by facial landmarks which should be easily identified and collocated on the image. However, no study analysed in depth the reliability in positioning facial landmarks in photos. Whichever the application, the correct positioning of landmarks is the key issue in many fields of research in facial morphology. Literature has defined in

[3] Cummaudo M, Guerzoni M, Marasciuolo L, Gibelli D, Cigada A, Cattaneo C, Pitfalls at the root of facial assessment on photographs: a quantitative study of accuracy in positioning facial landmarks, unpublished data

the years several landmarks, each of them with a specific spatial collocation according to their nature; facial landmarks are divided into anatomical which describe points where two different tissues or phases meet (for instance, the vermilion edge of the lips), geometrical (maximum bending of structures) and extremal ones (belonging to a curve or surface whose position is mathematically defined according to its geometric characteristics) (69). As reported by literature, only anatomical landmarks are actual biological loci (69), and therefore the modification of their position can be interpreted as due to a biological alteration, whereas the change of geometrical and extremal points may be due to numerous variables. In addition, digital anthropometry has introduced in the past year the concept of sliding or interpolated landmarks, usually drawn between other landmarks alongside a curve or a surface according to interpolating functions which optimize their closeness with the other landmarks (70). However, the accuracy in positioning such points depends upon the correct definition of the traditional landmarks within which the curve or surface is limited. Landmarks useful for facial morphology should have the same position in all faces and be identified repeatably with a known accuracy; however, at the moment very few studies have been performed concerning the accuracy in positioning facial landmarks, and mainly deal with advanced radiological methods (71) but take into consideration skeletal landmarks.

The correct position of facial landmarks is fundamental for any further analysis of faces, both from a morphological and metrical point of view; in fact, there are both positive and negative aspects of using indirect methods for facial measurements rather than direct ones. On one hand, during direct measurement of soft tissue features the contact with anthropometric instruments may deform the facial surface and lead to unacceptable inaccuracies. On the other hand, when the same landmark is used for severaldifferent directmeasurements, this has to be repeatedly located. Furthermore, measurements based on soft tissue landmarks might be more suited to indirect methods like photogrammetry, while direct measurements would be preferable for bony landmarks, requiring palpation like the zygion and the gonion (72). When approaching single image photogrammetry for facial and body measurements, the greatest error source seems to be related to the individual pose (73). Farkas et al. (74) underlined that the error magnitude depends on the thickness of the soft tissue covering the bony landmark. Moreover measurements of

some landmarks like alare, superaurale and subaurale may not be precise if photographs are not sharp enough to allow accurate identification of these landmarks.
However, but for general considerations, no indication is actually available in literature concerning the exact quantification of accuracy in positioning facial landmarks, particularly in photographs which are frequently the only existing material in some forensic scenarios.
The present study aims to assess the pitfalls behind the positioning of landmarks on faces in pictures.

Materials and methods

The experimental project includes two phases: during the first one 22 landmarks were placed on frontal view photographs and 11 on lateral view photographs (75); a computer software was specifically developed for this purpose, which allowed the operators to lay down the chosen points, to record them in all the observations and to calculate the distances among all points (Fig. 10).

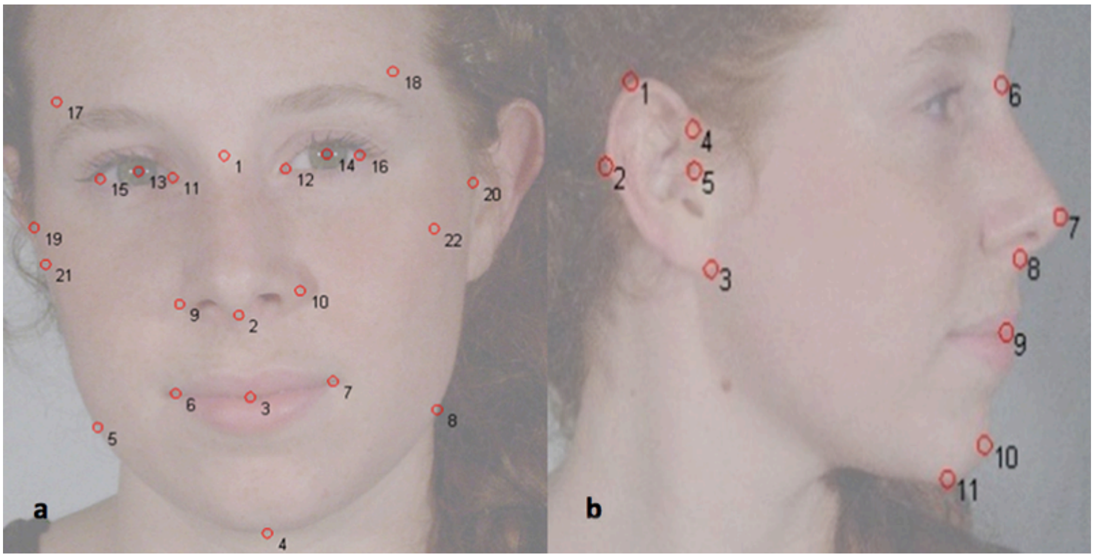

Fig. 10: a) Facial landmarks chosen in frontal view: 1- Sellion (se); 2- Subnasale (sn); 3- Stomion (sto); 4- Gnathion (gn); 5 e 8- Gonion (go); 6 e 7- Cheilion (ch); 9 e 10- Alare (al); 11 e 12- Endocanthion (en); 13 e 14- Pupil (pu); 15 e 16- Exocanthion (ex); 17 e 18- Frontotemporale (ft); 19 e 20- Tragion (t); 21 e 22 Zygion (zy).
b – Facial landmarks chosen in lateral view: 1- Superaurale (sa); 2- Postaurale (pa); 3- Subaurale (sba); 4- Preaurale (pra); 5- Tragion (t); 6- Sellion (se); 7-

Pronasale (prn); 8) Subnasale (sn); 9) Stomion (sto); 10) Pogonion (pg); 11) Gnathion (gn)

The results concerning the dispersion of different observations were stored in array forms. The minimum acceptable photograph resolution was considered 640 X 480 pixels, although higher resolution (in the order of at least 1000 X 700) pixels is recommended (76).

The first step consisted in evaluating the interobserver dispersion and involved 25 operators who were requested to lay down 22 landmarks in the frontal view and 11 landmarks in the lateral view on two photographs of the same person.

Then the intra-observer dispersion was analyzed by 3 operators who were requested to repeat 20 times (each one at distance of 24 hours) the positioning procedure of the same landmarks on the same photograph.

During the second step, 2046 photos in frontal view and 2043 in lateral view were taken from Caucasoid subjects aged between 3 and 32 years without relevant pathologies and facial deformities. The photos underwent analysis on Mathworks Matlab, via the collocation of 22 facial landmarks on faces taken in the frontal view and 11 in the lateral view. The inter- and intra-observer error in definition of each landmark were also evaluated.

The obtained data elaborated by the computer software for each point were the following: the mean coordinates along thex-axis (horizontally) andy-axis (vertically), separately; the mean standard deviation ofx and y data (standard deviation divided by the square root of the number of repeated tests), the mean standard deviation of the dispersion along x and y axis (therefore providing a single spread parameter), and a "weight" associated with these values, which is roughly the inverse of the spread parameter: this means that a point with low dispersion can be trusted more than a higher dispersion one. The "weight" is of particular interest because it providesa numerical value related to each of the 22 points and allows one to identify which ones are those with a lower intra-observer and inter-observer dispersion.

Results

Figure 11 and Table 3 show respectively graphically and numerically the dispersion of the 22 and 11 landmarks placed on the frontal and the lateral view photos of the same individual by the 25 different operators. With regard to the frontal view, the landmarks with the smallest dispersion were the two pupillary, the stomion, the two cheilion; those with a very high dispersion are the two gonion, the two zygion, the two frontotemporal, the two tragion and sellion; with regard to the lateral view the points with the smallest dispersion were stomion and pronasale, those with greater dispersion the anterior auricular and tragion. Furthermore it is evident for most of the points that the dispersion in the positioning mainly regards the y-axis rather than the x-axis. It is also noted that, for some of them, an estimation might both come from the frontal as well as from the lateral view.

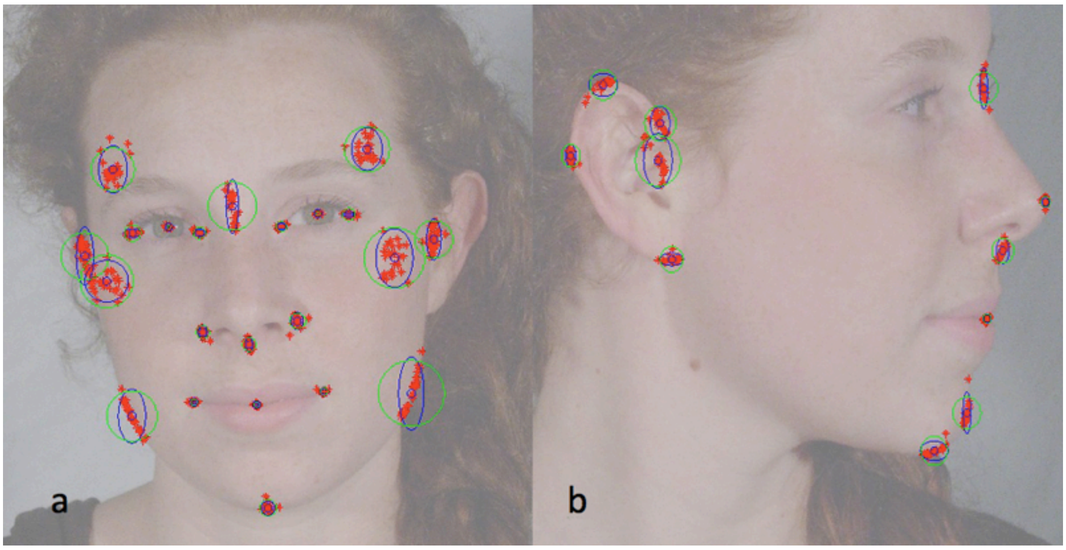

Fig. 11: inter-observer dispersion of the positioning of facial landmarks on the same photograph by 25 operators in frontal (a) and lateral (b) view

FRONTAL VIEW							LATERAL VIEW						
	Mean [px]	Mean y [px]	Std x [px]	Std y [px]	Radius [px]	Weight [px]		Mean [px]	Mean y [px]	Std x [px]	Std y [px]	Radius [px]	Weight [px]
1 (se)	1430	725	1.31	5.88	26.20	0.07	**1 (sa)**	1340	717	3.12	2.18	13.10	0.33
2 (sn)	1470	1030	0.72	1.58	7.22	0.25	**2 (pa)**	1280	841	1.07	2.15	9.53	0.45
3 (sto)	1480	1160	0.51	0.37	2.66	0.67	**3 (sba)**	1480	1020	2.59	1.18	11.80	0.38
4 (gn)	1510	1380	1.46	1.53	8.76	0.20	**4 (pra)**	1450	784	2.08	3.18	15.40	0.28
5 (go)	1210	1180	2.96	5.85	27.30	0.07	**5 (t)**	1450	849	3.08	5.22	22.20	0.19
6 (ch)	1350	1150	0.88	0.28	3.55	0.50	**6 (se)**	2090	723	0.82	3.96	13.70	0.31
7 (ch)	1630	1130	0.94	0.43	3.87	0.46	**7 (prn)**	2220	923	0.66	1.08	4.69	0.91
8 (go)	1820	1130	2.72	7.93	35.70	0.05	**8 (sn)**	2130	1010	1.37	2.44	10.90	0.39
9 (al)	1370	999	0.92	1.48	6.97	0.26	**9 (sto)**	2100	1130	0.82	0.68	4.27	**1.00**
10 (al)	1570	975	1.31	1.85	8.25	0.22	**10 (pg)**	2060	1290	0.85	3.97	13.80	0.31
11 (en)	1360	783	1.39	0.69	6.47	0.28	**11 (gn)**	1990	1360	3.01	1.87	12.90	0.33
12 (en)	1540	769	1.13	0.64	5.52	0.32							
13 (pu)	1290	770	0.50	0.24	1.95	0.91							
14 (pu)	1610	741	0.47	0.24	1.78	**1.00**							
15 (ex)	1210	783	1.87	0.93	8.79	0.20							
16 (ex)	1680	743	1.61	0.40	6.66	0.27							
17 (ft)	1170	645	3.09	5.12	23.30	0.08							
18 (ft)	1720	601	3.30	4.62	24.60	0.07							
19 (t)	1110	833	1.88	6.29	25.70	0.07							
20 (t)	1860	797	1.56	4.43	20.40	0.09							
21 (zy)	1160	888	4.71	4.53	28.70	0.06							
22 (zy)	1780	838	4.03	6.36	32.80	0.05							

Table 3: interobserver dispersion: all the values are expressed in pixels. The positioning of facial landmarks on the photographs of the same person both in the frontal and in the lateral view. The “1.00” value in the weight column points out the landmark with the lower dispersion: this means that values have been normalized to unit

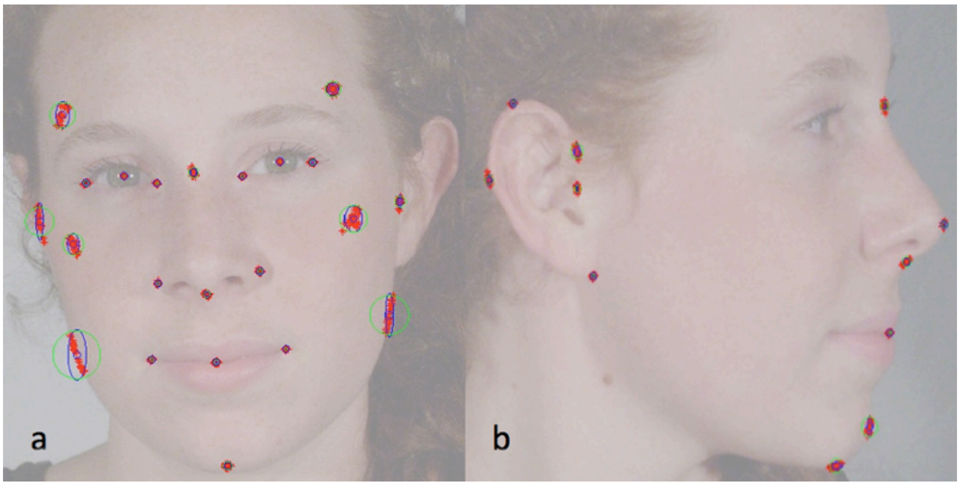

Fig. 12: example of intra-observer dispersion of facial landmarks in frontal (a) and lateral (b) view, according to the twenty repetitions performed by the operator n° 2

	Frontal view			**Lateral view**		
	Operator n° 1	**Operator n° 2**	**Operator n° 3**	**Operator n° 1**	**Operator n° 2**	**Operator n° 3**
1	Pupil (R)	Pupil (R)	Pupil (R)	Tragion	Stomion	Postaurale
2	Pupil (L)	Pupil (L)	Pupil (L)	Pronasale	Subaurale	Pronasale
3	Cheilion (L)	Exocanthion (L)	Cheilion (L)	Stomion	Superaurale	Superaurale
4	Endocanthion (R)	Endocanthion (L)	Exocanthion (R)	Postaurale	Pronasale	Stomion
5	Endocanthion (L)	Cheilion (L)	Exocanthion (L)	Subaurale	Tragion	Sellion
6	Alare (R)	Alare (R)	Endocanthion (L)	Sellion	Sellion	Subnasale
7	Cheilion (R)	Exocanthion (R)	Alare (R)	Superaurale	Postaurale	Subaurale
8	Stomion	Endocanthion (R)	Stomion	Subnasale	Subnasale	Pogonion
9	Exocanthion (L)	Stomion	Cheilion (R)	Preaurale	Gnathion	Gnathion
10	Alare (L)	Cheilion (R)	Endocanthion (R)	Gnathion	Preaurale	Preaurale
11				Pogonion	Pogonion	Tragion

Table 4: ranking of the landmarks with the lowest intra-observer dispersion in frontal and lateral view among the three operators; R indicates the right landmark. L the left one

For what concerns the second step. the following shows the “weights” of the landmarks laid down on 8 photographs in frontal view and 8 in the lateral view of individuals having different sex and age: these landmarks have been positioned by 20 different operators. The dispersion approximately follows the same trend as shown in the test on a single photograph.

Frontal view	Photo A	Photo B	Photo C	Photo D	Photo E	Photo F	Photo G	Photo H
	Weight [px]	Weight [px]	Weight [px]	Weight [px]	Weight [px]	Weight [px]	Weight [px]	Weight [px]
1 (se)	0.02	0.12	0.08	0.10	0.11	0.06	0.09	0.14
2 (sn)	0.10	0.54	0.47	0.75	0.42	0.21	0.19	0.27
3 (sto)	0.21	0.67	0.46	0.95	0.67	0.43	0.54	0.37
4 (gn)	0.05	0.29	0.18	0.27	0.21	0.09	0.36	0.15
5 (go)	0.02	0.09	0.11	0.10	0.09	0.02	0.03	0.06
6 (ch)	0.10	0.66	0.58	0.58	1.00	0.35	0.34	0.30
7 (ch)	0.16	0.79	0.48	0.64	0.54	0.27	0.27	0.36
8 (go)	0.02	0.11	0.07	0.08	0.06	0.02	0.04	0.05
9 (al)	0.08	0.27	0.42	0.36	0.48	0.37	0.25	0.31
10 (al)	0.09	0.35	0.29	0.45	0.48	0.44	0.22	0.33
11 (en)	0.12	0.54	0.44	0.52	0.57	0.19	0.37	0.35
12 (en)	0.12	0.49	0.39	0.38	0.37	0.14	0.23	0.26
13 (pu)	0.74	0.92	1.00	0.90	0.93	1.00	1.00	0.92
14 (pu)	1.00	1.00	0.93	1.00	0.97	0.73	0.42	1.00
15 (ex)	0.08	0.22	0.21	0.31	0.22	0.08	0.13	0.17
16 (ex)	0.10	0.21	0.23	0.32	0.29	0.06	0.17	0.21
17 (ft)	0.03	0.09	0.07	0.09	0.10	0.04	0.10	0.07
18 (ft)	0.02	0.08	0.09	0.09	0.10	0.03	0.10	0.09
19 (t)	0.03	0.10	0.14	0.13	0.09	0.04	0.06	0.04
20 (t)	0.03	0.09	0.08	0.10	0.11	0.05	0.06	0.07
21 (zy)	0.01	0.06	0.05	0.09	0.07	0.03	0.05	0.06
22 (zy)	0.01	0.06	0.05	0.06	0.07	0.03	0.05	0.04
Lateral view	**Photo A**	**Photo B**	**Photo C**	**Photo D**	**Photo E**	**Photo F**	**Photo G**	**Photo H**
	Weight [px]	Weight [px]	Weight [px]	Weight [px]	Weight [px]	Weight [px]	Weight [px]	Weight [px]
1 (sa)	0.18	0.26	0.29	0.13	0.12	0.09	0.22	0.51
2 (pa)	0.19	0.18	0.29	0.15	0.12	0.10	0.17	0.52
3 (sba)	0.41	0.47	0.56	0.25	0.53	0.27	0.37	0.77
4 (pra)	0.32	0.30	0.30	0.14	0.10	0.04	0.12	0.25
5 (t)	0.14	0.14	0.20	0.11	0.09	0.07	0.15	0.27
6 (se)	**1.00**	0.43	0.61	0.50	0.17	0.28	0.60	0.75
7 (prn)	0.79	0.96	**1.00**	0.46	0.47	0.65	**1.00**	0.98
8 (sn)	0.70	**1.00**	0.79	0.43	0.36	0.25	0.26	**1.00**
9 (sto)	0.55	0.38	0.50	**1.00**	**1.00**	**1.00**	0.55	0.38
10 (pg)	0.38	0.49	0.34	0.13	0.10	0.08	0.45	0.33
11 (gn)	0.20	0.21	0.30	0.08	0.15	0.07	0.16	0.26

Table 5: "weights" of the landmarks laid down on 8 photographs in frontal view and 8 in the lateral view of individuals having different sex and age by 20 different operators

In this case too the landmarks showing less dispersion are the two pupillary, the two cheilion, the two endocanthion and stomion. The dispersion was higher for the positioning of the two gonia, the two zygia, the two frontotemporal, the two tragi and sellion in the frontal view; in the lateral view the landmarks with the smallest dispersion were sellion, pronasale, subnasale and stomion; those with the highest dispersion were tragion, preaurale, postaurale and gnathion (Table 6).

		Photo A	Photo B	Photo C	Photo D	Photo E	Photo F	Photo G	Photo H
FRONTAL VIEW	1	Pupil (L)	Pupil (L)	Pupil (R)	Pupil (L)	Cheilion (R)	Pupil (R)	Pupil (R)	Pupil (L)
	2	Pupil (R)	Pupil (R)	Pupil (L)	Stomion	Pupil (L)	Pupil (L)	Stomion	Pupil (R)
	3	Stomion	Cheilion (L)	Cheilion (R)	Pupil (R)	Pupil (R)	Alare (L)	Pupil (L)	Stomion
	4	Cheilion (L)	Stomion	Cheilion (L)	Subnasale	Stomion	Stomion	Endocanthion (R)	Cheilion (L)
	5	Endocanthion (R)	Cheilion (R)	Subnasale	Cheilion (L)	Endocanthion (R)	Alare (R)	Gnathion	Endocanthion (R)
	6	Endocanthion (L)	Subnasale	Stomion	Cheilion (R)	Cheilion (L)	Cheilion (R)	Cheilion (R)	Alare (L)
	7	Subnasale	Endocanthion (R)	Endocanthion (R)	Endocanthion (R)	Alare (R)	Cheilion (L)	Cheilion (L)	Alare (R)
	8	Cheilion (R)	Endocanthion (L)	Alare (R)	Alare (L)	Alare (L)	Subnasale	Alare (R)	Cheilion (R)
	9	Exocanthion (L)	Alare (L)	Endocanthion (L)	Endocanthion (L)	Subnasale	Endocanthion (R)	Endocanthion (L)	Subnasale
	10	Alare (L)	Gnathion	Alare (L)	Alare (R)	Endocanthion (L)	Endocanthion (L)	Alare (L)	Endocanthion (L)
LATERAL VIEW	1	Sellion	Subnasale	Pronasale	Stomion	Stomion	Pronasale	Pronasale	Subnasale
	2	Pronasale	Pronasale	Subnasale	Sellion	Subaurale	Pronasale	Sellion	Pronasale
	3	Subnasale	Pogonion	Sellion	Pronasale	Pronasale	Sellion	Stomion	Subdurale
	4	Stomion	Subaurale	Subaurale	Subnasale	Subnasale	Subaurale	Pogonion	Sellion
	5	Subaurale	Sellion	Stomion	Subaurale	Sellion	Subnasale	Subaurale	Postaurale
	6	Pogonion	Stomion	Pogonion	Postaurale	Gnathion	Postaurale	Subnasale	Superaurale
	7	Preaurale	Preaurale	Gnathion	Superaurale	Postaurale	Superaurale	Superaurale	Stomion
	8	Gnathion	Superaurale	Preaurale	Preaurale	Superaurale	Pogonion	Postaurale	Pogonion
	9	Postaurale	Gnathion	Superaurale	Pogonion	Preaurale	Gnathion	Gnathion	Tragion
	10	Superaurale	Postaurale	Postaurale	Tragion	Pognonion	Tragion	Tragion	Gnathion
	11	Tragion	Tragion	Tragion	Gnathion	Tragion	Preaurale	Preaurale	Preaurale

Table 6: ranking ofthe landmarks with the lower dispersion based on theinterobserver tests; R indicates the right landmark, L the left one

Discussion

Most experts in the field of anatomy and anthropology applied to the forensic sciences are acquainted with the difficulties in examining the face of an individual by using only two-dimensional images, whether it concerns identifying an individual or trying to verify the age range of a child or adolescent. The study of facial morphology which may involve the application of facial landmarks may bring about relevant advantages for the analysis of 2D images by measuring distances and indices useful for determining identity or an age range. However, the pitfalls behind the very preliminary step of applying such landmarks on photographs have always been underestimated. The present study has the objective to assess whether and in what measure this danger exists.

The first step was to evaluate the interobserver dispersion in positioning facial landmarks on two photographs of the same person, one taken in the frontal view and one in the lateral view. With regard to the frontal view, the landmarks with the least dispersion were the two pupillary, the stomia, the two cheilia; those with a very high dispersion the two gonia, the two zygia, the two frontotemporal, the two tragi and sellion. In the case of gonion, zygion and frontotemporale the high dispersion is due to the fact that these are not easily detectable without palpation expecially when the soft tissue covering the bony landmark is very thick. In the case of tragion and sellion, the high dispersion is due to the fact that these landmarks are more easily detectable in photographs taken in the lateral view. With regard to the lateral view the landmarks which showed the least dispersion were stomion and pronasale, those with the highest dispersion the preaurale and tragion. A subsequent similar test, this time with 8 photos (both in frontal and lateral views) of individuals of different sex and age (5, 10, 15 and 19 years) showed no substantial differences related to sex and age of the analized individuals.

Furthermore it is evident for most of the points that the dispersion in the positioning mainly regards they-axis rather than the x-axis. This was particularly evident in the case of sellion and gonion. In the first case this is probably due to the fact that this landmark is along the mid-sagittal plane and in the case of gonion to the fact that it is located along the lateral edges of the face.

The second step was to evaluate the intraobserver dispersion by letting 3 operators repeat 20 times (each one at a distance of 24 hours) the positioning of the landmarks on the same two photographs, one taken in the frontal view and one in the lateral view: with regard to the frontal view the landmarks which showed the least dispersion were pupillare, cheilion, exocanthion and endocanthion; the points with the highest dispersion gonion, zygion and frontotemporale. In the case of the lateral view the landmarks which showed the least dispersion were pronasale, stomion and superaurale; the points with the highest dispersion pogonion, gnathion and preaurale.

The second step, based on positioning landmarks on faces of different age and sex, substantially confirms the results of the first phase, and in detail underlines the reliability of anatomical landmarks, which seem to be accurately detectable also in children and young adults. This is even more important if one considers that facial assessment may have a relevant influence in age estimation in cases of juvenile pornography, where the represented subjects are usually young adults.

The present study provides the first quantitative results concerning the accuracy in positioning landmarks on photographs. Only very few landmarks seem to be reliable for facial assessment, and this limits the number of information which may be extrapolated.

However, where these facial landmarks prove to be reliable, they can be reproduced also in photos of young subjects. The second step will provide a first attempt at verifying if the facial measurements defined between such landmarks may provide an indication concerning the age of the subject represented in photo.

4.2 Correlation between linear measurements and age in photo: a pilot study[4]

After having analyzed the reliability of facial landmarks, the second steps consists in verifying the correlation between age and linear metrical measurements taken in photo.
The present study, in collaboration of an EU-funded international research group, has studied age-related facial growth and development in children and juveniles in terms of the applicability of facial proportions as an age indicator on images (77,78). In this pilot study, the possibilities of the metric assessment of facial images with respect to age-related changes are addressed.

Material and methods
Standardized facial images of 353 female and 20 male subjects from four different age groups were randomly selected from a data set of 2100 photographs from Germany, Italy and Lithuania. This data set was established during the course of two EU-funded projects STOP II and AGIS between 2002 and 2007. The number of the subjects in each age category was as follows: 89 6-year-olds, 99 10-year-olds, 85 14-year-olds, and 100 18-year-olds. A consent was obtained for the scientific use of the photographs.
The male subjects were included in the category of 6-year-olds because there were not enough German and Lithuanian girls measured in this age group. However, statistical tests showed that there are no significant differences in the selected measurements between boys and girls at this age thus the data could be pooled for further analysis.
For each subject five standardized photographs were acquired with the focus on sellion (the deepest point of the nasal root depression); the distance between sellion and the camera was 1.5 m. The landmark sellion was used instead of nasion since it can be located more precisely on photographs. The head of the test person was oriented in the Frankfurt plain and photographed in the following positions: left lateral (90°), 45° left, frontal, 45° right, right lateral (90°).

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[4] Cattaneo C, Obertovà Z, Ratnayake M, Marasciuolo L, tutkuviene J, Gibelli D, Poppa P, Gabriel P, Ritz-Timme S, Can facial proportions taken from images be of use for ageing in cases of suspected child pornography? A pilot study, Int J Legal Med 2012;126(1):139-44

In addition to photographs the data set also includes the respective "in vivo" measurements of the head and face of each subject. The measurements on living persons were defined according to Martin & Saller (79) (Table 7).

Measurement No. [Martin, Saller 1957]	**Description (Frontal landmarks)**	**Measurement N° [Martin, Saller 1957]**	**Description (Right lateral landmarks)**
12	Interpupillarydistance (pu-pu)	21c*	Nasal height (se-sn)
9	Intercanthalwidth (en-en)	23*	Nasal bridge length (se-prn)
10	Biocularwidth (ex-ex)	19*	Physiognomic upper facial height (se-sto)
13	Nose width (al-al)	22	Nasal depth (prn-sn)
14	Labial width (ch-ch)	29	Physiognomic ear length (sa-sba)
6	Bizygomatic width (zy-zy)	30	Physiognomic ear width (pa-pra)
4	Distance bifronto temporalis (Forehead width) (ft-ft)		
21c*	Nasal height (se-sn)		
19*	Physiognomic upper facial height (se-sto)		

Table 7: definitions of distances measured in living persons

Facial measurements were taken from frontal and right lateral images using the Adobe Photoshop CS4 "Ruler Tool". However the landmarks on a 2D image and a 3D subject cannot be directly comparable since the landmarks on a subject are identified through palpation, whereas on a 2D image this is not possible. Some adjustments were therefore made to the definitions of the landmarks and the distances when applied to photographs. For example the bizygomatic width was defined as the distance between the most laterally visible points of the cheekbones.

Next, 43 indices were calculated from the above measurements. The statistical tests were carried out using IBM SPSS Statistics 18.

Pearson's correlation analysis was used to determine the correlation between the "in vivo" and the "in photo" facial indices. All "in photo" indices were analyzed using ANOVA to determine the differences between the age groups. Twenty three indices taken from photographs were identified through the above statistical procedure to be suitable for further analysis, i.e. they showed continuity (i.e. the index values increased or decreased continuously with age) and significant differences between age groups in the pooled sample. Consequently, 18 indices taken from the frontal images (enen-pupu, pupu-exex, alal-pupu, pupu-ftft, pupu-zyzy, enen-exex, enen-alal, enen-ftft, enen-zyzy, alal-exex, exex-ftft, exex-zyzy, alal-ftft, alal-zyzy, chch-zyzy, chch-sesn, chch-sesto, ftft-zyzy) and two indices taken from lateral images (prnsn-seprn, prnsn-sesn) were excluded.

Finally, a discriminant analysis based on these selected indices was conducted to show if and how precisely the age can be estimated by the calculation of facial indices from the available 373 images.

Results

The following tables show the means for "in vivo" and "in photo" indices with a significantly positive correlation for the pooled sample. These indices also showed continuity and significant differences between the defined age groups, which proved them applicable as indicators for an age assessment (Table 8).

Indices	MEAN in vivo (SD)	MEAN in photo (SD)	CC Pearson
sesn-pupu	81.5 (11.7)	75.3 (6.8)	.393**
pupu-sesto	86.8 (9.8)	91.7 (6.2)	.402**
enen-sesn	68.2 (11.8)	71.6 (9.0)	.423**
enen-sesto	47.2 (6.8)	49.0 (4.9)	.415**
sesn-exex	51.0 (5.8)	50.9 (4.9)	.555**
sesto-exex	73.2 (5.9)	74.1 (5.4)	.512**
alal-sesn	69.6 (10.1)	75.2 (7.9)	.607**
alal-sesto	48.2 (5.1)	51.5 (4.1)	.555**
chch-pupu	81.6 (10.3)	73.5 (6.6)	.500**
chch-exex	51.2 (4.6)	49.7 (4.6)	.458**
enen-chch	67.5 (8.9)	73.2 (8.0)	.497**
alal-chch	68.9 (7.1)	76.9 (7.0)	.615**
chch-ftft	42.3 (4.6)	43.2 (4.7)	.291**
sesn-ftft	42.3 (5.5)	44.3 (4.5)	.590**
sesto-ftft	60.5 (5.7)	64.3 (5.2)	.391**
sesn-zyzy	37.4 (6.4)	35.4 (3.4)	.671**
sesto-zyzy	53.4 (6.9)	51.4 (3.9)	.726**
sesn-sesto	69.7 (5.1)	68.8 (3.6)	.432**
Lateralseprn-sesn	87.4 (6.3)	83.7 (4.5)	.583**
Lateralsesn-sesto	69.7 (5.1)	70.2 (3.5)	.463**
Lateralseprn-sesto	61.0 (6.8)	58.8 (4.7)	.700**
Lateralprnsn-sesto	28.9 (4.9)	28.2 (2.9)	.401**
Lateralprapa-sasba	57.4 (5.6)	57.9 (5.9)	.397**

Table 8: mean and standard deviation of "in vivo" and "in photo" indices with the Pearson correlation coefficient. Two asterisks stand for the level of significance ($p < 0.01$).

Indices	6 years	10 years	14 years	18 years
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
sesn-pupu	70.1 (5.4)	74.8 (6.0)	76.9 (6.1)	79.2 (5.9)
pupu-sesto	94.8 (5.4)	92.4 (6.1)	90.5 (5.5)	89.3 (6.2)
enen-sesn	78.5 (8.0)	71.7 (8.9)	69.7 (7.6)	66.8 (7.3)
enen-sesto	51.8 (4.2)	49.3 (5.5)	48.2 (3.9)	46.9 (4.5)
sesn-exex	47.1 (3.7)	50.8(4.3)	51.9 (4.6)	53.7 (4.4)
sesto-exex	71.1 (3.7)	73.8 (5.1)	74.9 (5.5)	76.3 (5.7)
alal-sesn	81.0 (7.8)	75.7 (6.7)	74.4 (6.7)	70.3 (6.4)
alal-sesto	53.5 (3.9)	51.9 (3.8)	51.4 (3.6)	49.4 (4.1)
chch-pupu	70.3 (6.9)	72.3 (5.5)	75.7 (6.6)	75.8 (5.7)
chch-exex	47.3 (4.9)	49.1 (3.9)	51.1 (4.3)	51.4 (4.0)
enen-chch	78.5 (7.9)	73.9 (6.9)	70.9 (7.5)	69.7 (6.8)
alal-chch	80.9 (7.4)	78.2 (6.5)	75.6 (6.3)	73.4 (5.6)
chch-ftft	40.7 (4.9)	42.5 (4.2)	44.6 (4.5)	45.0 (4.0)
sesn-ftft	40.5 (3.1)	43.9 (3.9)	45.3 (4.3)	47.0 (3.7)
sesto-ftft	61.1 (3.6)	63.8 (4.7)	65.4 (5.8)	66.7 (4.9)
sesn-zyzy	32.5 (2.5)	35.2 (3.1)	36.4 (3.1)	37.3 (2.9)
sesto-zyzy	49.1 (3.0)	51.1 (3.8)	52.5 (4.0)	52.9 (3.9)
sesn-sesto	66.2 (3.1)	68.8 (2.8)	69.3 (3.2)	70.5 (3.7)
Lateralseprn-sesn	80.5 (4.2)	83.0 (3.4)	84.5 (4.0)	86.5 (4.3)
Lateralsesn-sesto	67.8 (2.9)	70.0 (2.5)	71.3 (3.0)	71.8 (3.8)
Lateralseprn-sesto	54.6 (3.7)	58.1 (3.2)	60.2 (3.8)	62.0 (4.5)
Lateralprnsn-sesto	26.8 (2.6)	27.7 (2.3)	29.0 (2.9)	29.3 (3.1)
Lateralprapa-sasba	59.6 (6.0)	58.4 (5.4)	57.3 (6.6)	56.6 (5.1)

Table 9: mean and standard deviation of the selected "in photo" indices for the four different age groups (ANOVA results). All indices showed statistically significant differences ($p < 0.000$) between age groups.

The discriminant analysis based on the 23 indices showed that for the pooled sample 60.3% of the cases were correctly classified into the respective age group. After splitting the sample by country the percentage of correctly classified cases increased as follows: 69.9% for the German sample, 69.4% for the Lithuanian sample, and 80.5% for the Italian sample.

Discussion

The results of this pilot study seem to be promising for two main reasons. The first reason refers to the fact that many indices extracted from the frontal and lateral photographs are closely correlated to their respective indices taken from the living individuals. This means that the age-related changes in facial growth, which can be observed in living individuals, are also reflected in the photographs. The second reason refers to the independent observation that several indices taken from the photographs seem to be closely correlated with age.

However, in the present study only four age groups – 6, 10, 14 and 18 years – were examined. The 373 mostly female facial images were selected randomly for the metric analysis. Therefore, if the sample size was to be enlarged and more age groups were to be included it is possible that the results would differ in terms of accuracy.

The discriminant analysis based on 23 facial indices showed that for the pooled sample 60% of the cases could be correctly classified into the respective age group. After splitting the sample by country the percentage of correctly classified cases increased, reaching 80% for the Italian sample. These differences may be due to different growth rates within these three samples in the four age groups. Thus, Italy may rate best because the differences are more evident for the age groups chosen for this study than is the case in the Lithuanian and German sample. However, this observation needs to be verified on a larger sample.

The present study attempts at pointing a way towards a more accurate age estimation of subjects portrayed on suspected pedo-pornographic material. Nonetheless more work needs to be done in order to verify the reliability of these findings on a large sample including more age categories. The next study aimed at analysing in depth the correlation of such parameters with age, by a test on a larger sample.

4.3 Towards an algorithm for determining age ranges from faces of juveniles on photographs[5]

In order to confirm data reported in the previous study, a wider sample was recruited with a dual purpose: the first consists in verifying whether it is possible to use specific anthropometric indices of the face of an individual to produce an age estimation; the second task consists in creating a database of official measurements on a population of children in order to improve face aging techniques; these data may allow the operator to modify the photographs of missing children according to time in order to predict their facial morphology after years.

Materials and methods

The study was made on 1924 standardized photographs in frontal view and 1921 in lateral view taken from Caucasoid subjects aged between 3 and 24 years without relevant pathologies and facial deformities (Table 10). A consent was obtained for the scientific use of the photographs.

Age ranges (years)	Frontal view		Lateral view	
	Males	Females	Males	Females
3-5	92	64	92	62
6-8	20	21	20	21
9-11	86	98	86	98
12-14	261	154	261	155
15-17	163	119	164	117
18-20	211	416	210	417
21-24	27	192	27	191
Total	860	1064	860	1061

Table 10: distribution of the chosen sample within the different age ranges

[5] Cummaudo M, Guerzoni M, Marasciuolo L, Gibelli D, Cigada A, Cattaneo C, Towards an algorithm for determining age ranges from faces of juveniles on photographs, unpublished data

For each subject, standardized photographs were taken at 1.5 m distance with the head oriented in the Frankfurt plain. The minimum acceptable photographs resolution was 640 X 480 pixels. The photographs underwent analysis through the mathematical processing software "Mathworks Matlab", via the collocation of 22 landmarks on faces taken in the frontal view and 11 in the lateral view (Figure 13).

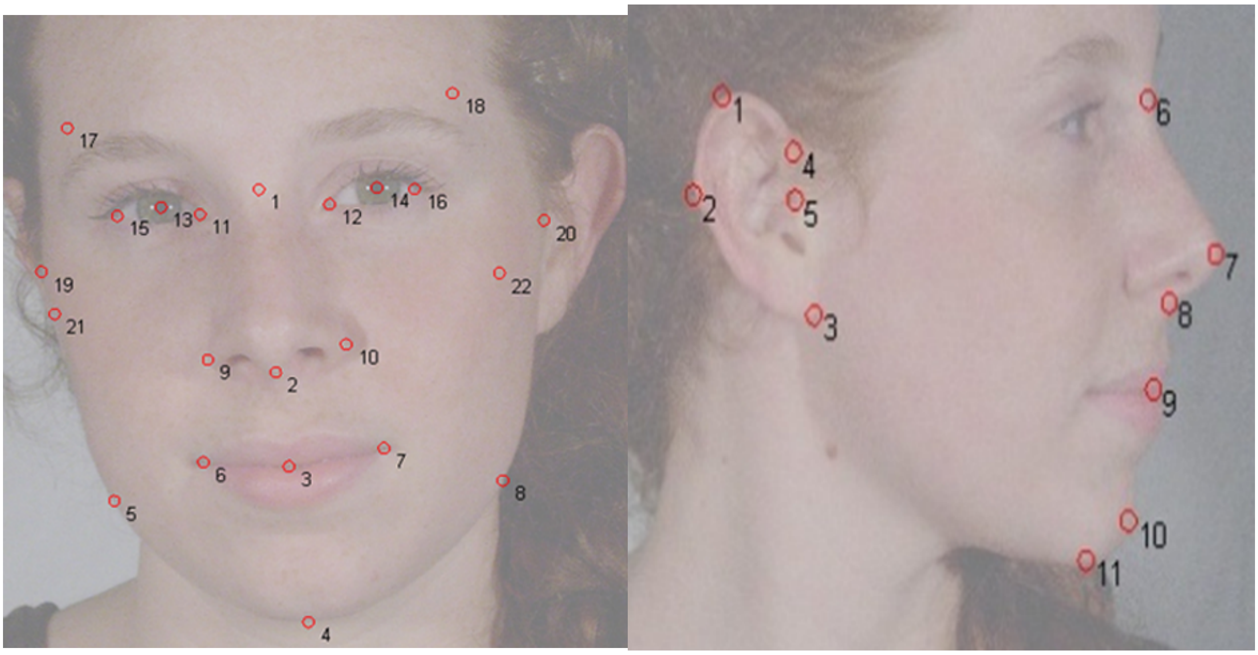


Fig. 13: frontal view: 1- Sellion (se); 2- Subnasale (sn); 3- Stomion (sto); 4- Gnathion (gn); 5 e 8- Gonion (go); 6 e 7- Cheilion (ch); 9 e 10- Alare (al); 11 e 12- Endocanthion (en); 13 e 14- Pupil (pu); 15 e 16- Exocanthion (ex); 17 e 18- Frontotemporale (ft); 19 e 20- Tragion (t); 21 e 22 Zygion (zy).
Lateral view: 1- Superaurale (sa); 2- Postaurale (pa); 3- Subaurale (sba); 4- Preaurale (pra); 5- Tragion (t); 6- Sellion (se); 7- Pronasale (prn); 8) Subnasale (sn); 9) Stomion (sto); 10) Pogonion (pg); 11) Gnathion (gn)

Then 18 anthropometrical indices for the frontal view (al-al/ch-ch, al-al/se-sn, al-al/se-sto, ch-ch/ex-ex, ch-ch/ft-ft, ch-ch/pu-pu, en-en/ch-ch, en-en/se-sn, en-en/se-sto, pu-pu/se-sto, se-sn/ex-ex, se-sn/ft-ft, se-sn/pu-pu, se-sn/se-sto, se-sn/zy-zy, se-sto/ex-ex, se-sto/ft-ft, se-sto/zy-zy) and 5 for the lateral view (prn-sn/se-sto, se-prn/se-sn, se-prn/se-sto, se-sn/se-sto) were calculated by distances between different landmarks; the correlation with age was then evaluated.

Results

After positioning facial landmarks on the entire database of photographs and calculating distances between each of them, 18 anthropometric indices for the frontal view and 5 for the lateral view were extracted and rendered graphically.

Indices showing a possible correlation with age were in number of 8, 5 in frontal view (ch-ch/ex-ex, ch-ch/pu-pu, ch-ch/ft-ft, en-en/ch-ch and se-sto/ex-ex) and 3 in lateral view (se-prn/se-sn, se-prn/se-sto and se-sn/se-sto).

In frontal view ch-ch/ex-ex shows a constant increase from 3-5 years (mean 0.49) and 21-24 years (mean 0.58), both in males and females; the same trend was reported for ch-ch/pu-pu (ranging between 0.71 and 0.80 in mean in males, 0.70 and 0.81 in females) and se-sto/ex-ex (ranging between 0.83 and 0.90 in mean in males, 0.80 and 0.88 in females) (Fig. 14).

In lateral view se-prn/se-sn shows a constant increase from 3-5 years (mean 0.82 in males, 0.83 in females) and 21-24 years (mean 0.91 in males, 0.90 in females) and the same is valid also for se-prn/se-sto (ranging between 0.54 and 0.64 in males, 0.55 and 0.65 in females) and se-sn/se-sto (ranging between 0.66 and 0.71 in males, 0.67 and 0.71 in females) (Fig. 15).

FRONTAL VIEW

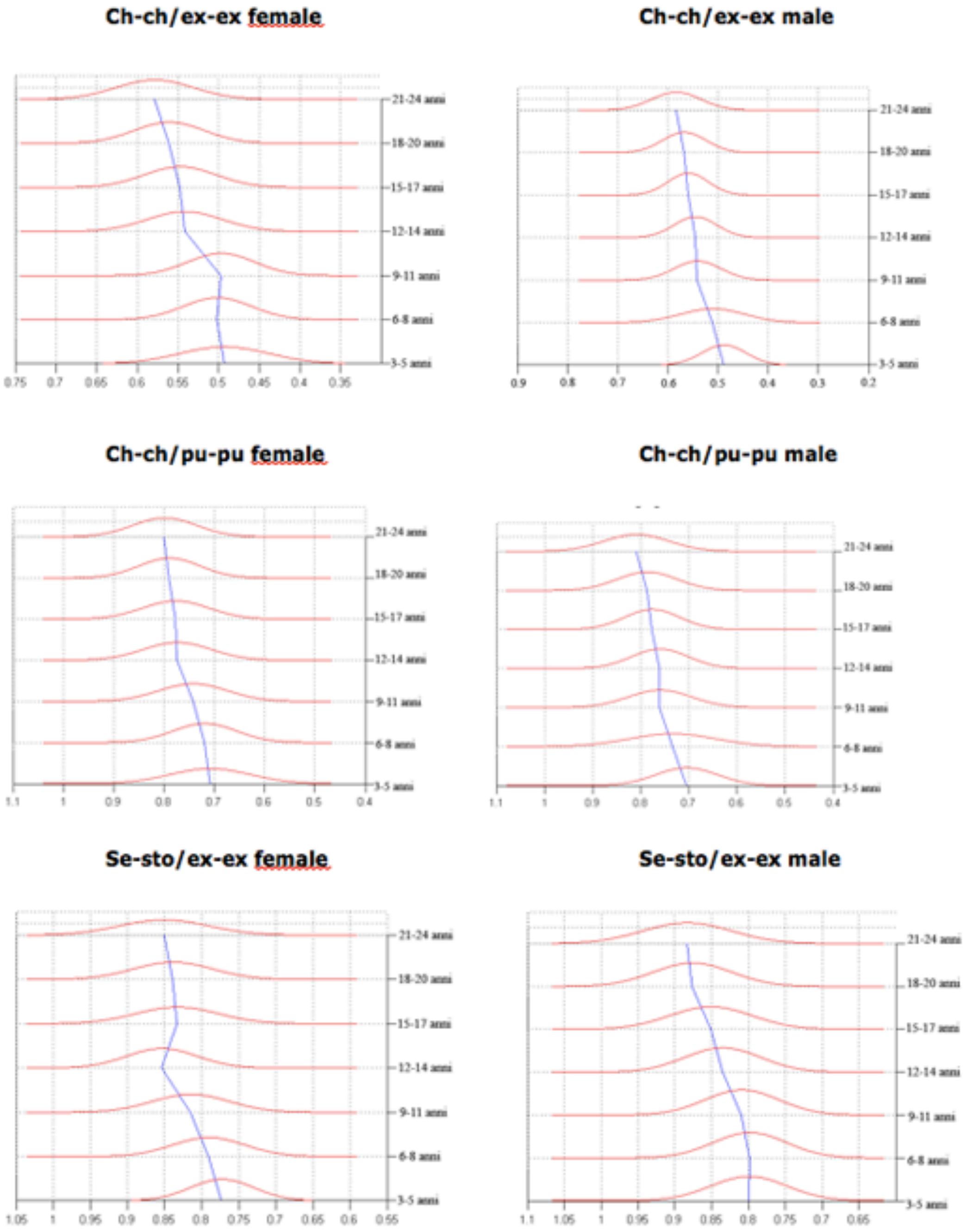


Fig. 14: indices related to age in frontal view: in blue the trend of the mean of the indices in each age group, in red the Gaussian curve within which the mean falls.

LATERAL VIEW

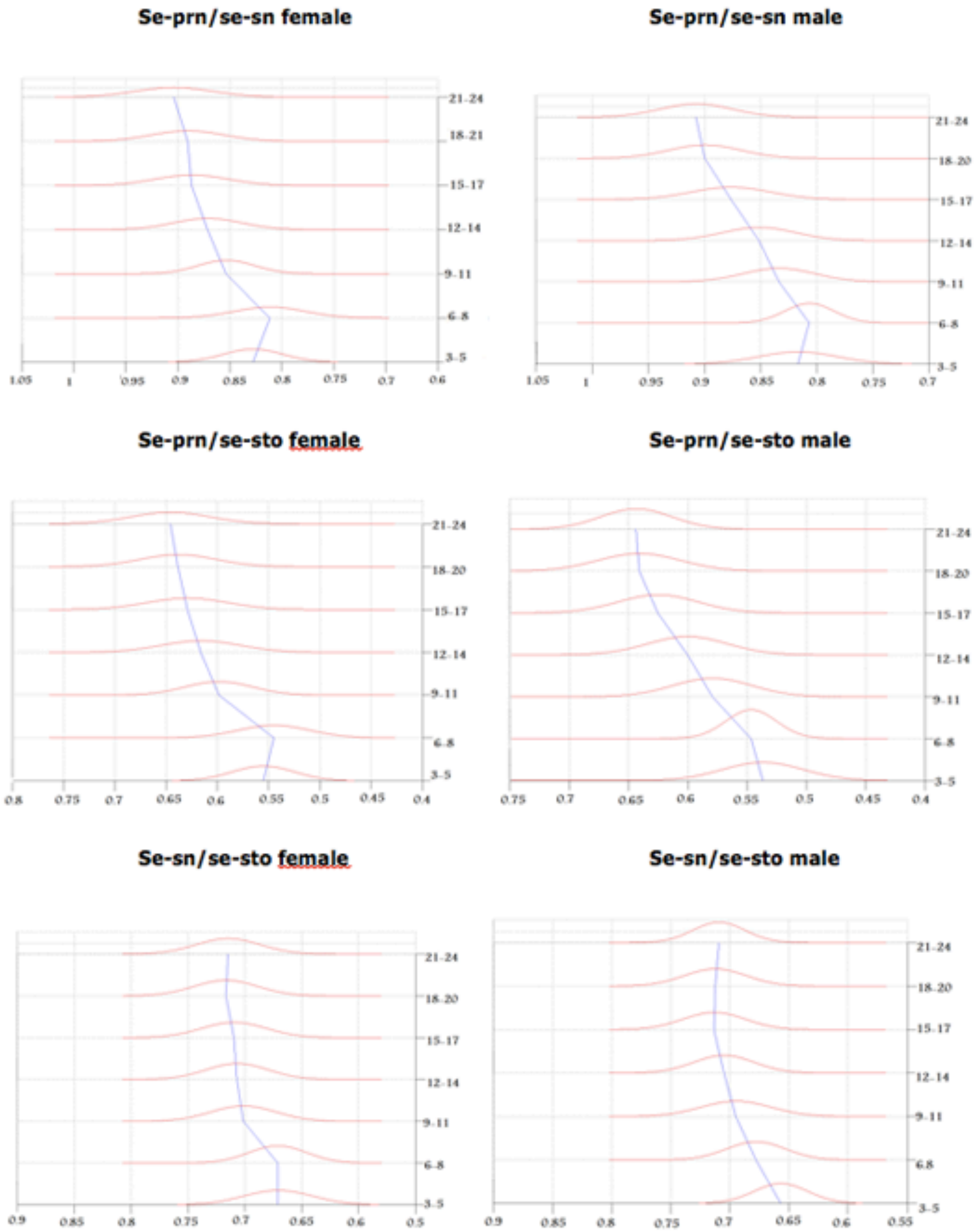


Fig. 15: indices related to age in frontal view: in blue the trend of the mean of the indices in each age group, in red the Gaussian curve within which the mean falls.

Discussion

This study confirmed previous findings on the chances of using facial anthropometric indices as age indicator. The previous study (Section 4.2 of this thesis) underlined the possible correlation between the variation of these indices and the age in a sample of 373 individuals. In the present study indices that confirm this correlation with age were ch-ch/ex-ex, ch-ch/pu-pu, ch-ch/ft-ft, en-en/ch-ch and se-sto/ex-ex in the frontal view, se-prn/se-sn, se-prn/se-sto and se-sn/se-sto in the lateral view.

On one hand this technique has proven to be easy to use and quite fast. On the other hand the error associated with this procedure is in order of 3-4 years and maybe it is still too high to be used for forensic purposes. Nevertheless, this technique may be improved after a careful evaluation of all its possible weaknesses.

Another possible limit of this technique is related to the posing of the subject depicted on the photograph. Tanner and Weiner (80) pointed out that when approaching to single photogrammetry for facial and body measurements the greatest single source of error seems to be attributable to posing. Currently there are not morphometric studies helping in assessing in which measure the pose of the individual depicted in a photograph can affect the measurements of 2D images but further studies will be conducted to fill this lack. This will clarify the circumstances in which an image can be used for age estimation.

Finally, an aspect to take into account is definitely the quality of the photographs. The minimum acceptable photographs resolution is 640 X 480 pixels since lower resolution make it very difficult to detect facial landmarks.

These results require further statistical study to see if and how the trends identified can be used to develop an algorithm to properly correlate the values of these indices with age.

In addition the database of metrical data derived from the experiment may provide interesting insight for refining the techniques of face aging, with which, starting from a photo of an individual, it is possible to predict the facial morphology after many years.

As one can observe, the evaluation of linear parameters in photos seems to be promising; one may wonder if some of such parameters may be of some interest for age estimation also in adults. As underlined in the introduction, age estimation in adults may be of some importance; after verifying the reliability of linear measurements in minors, the experimental study took into consideration juvenile adults, i.e. the individuals who are at the end of the growth. The following step consisted in ascertaining if some facial parameters actually show a correlation with age in adults, too. The analysis of adults starts from the measurements in vivo.

4.4 Age changes of facial measurements in European young adult males: implications for the identification of the living[6]

Age changes in facial soft tissues in these developmental periods principally trace skeletal and dental growth patterns, which have been known in forensic practice for decades. However, little information is available on soft tissue facial changes in young adults after skeletal growth had ceased. No detailed information concerning the modification with age of facial traits year by year in the early adult age is actually available. This may be explained by the usual supposition that body growth is no longer recognizable after the crucial threshold of 18-19 years; hence, the residual facial modifications in this sensitive age interval are often ignored.

The interest in facial assessment is therefore clear, as shown by the numerous fields of application in forensic and clinical contexts; for example personal identification is usually performed without precise information concerning changes which may affect facial traits in the early adult age. The need for a precise analysis of facial modifications in the age range between 20 and 30 years is therefore obvious.

This study aims at analysing facial metric characteristics of Caucasian males aged between 20 and 30 years, in order to identify if changes occur in this age range and how these changes may influence personal identification in forensic practice.

Materials and methods

The study is based on a sample of 404 Caucasian males, aged between 20 and 30 years, recruited in Dusseldorf (Germany), Milan (Italy) and Vilnius (Lithuania), within a EU-funded project. All the subjects were Caucasoid, born in the respective countries as were their parents and all relatives of more distant degrees (i.e. grand parents, great grandparents). Recruitment was made from undergraduate and postgraduate Universities, military schools, gymnasiums and general social get-togethers. The age of each subject was reported in decimals, approximated to 0.01 years. The mean age was 24.20 years. All

[6] Gibelli D, Mapelli A, Obertovà Z, Poppa P, Gabriel P, Ratnayake M, Tutkuviene J, Sforza C, Ritz-Timme S, Cattaneo C, Age changes of facial measurements in European young adult males: implications for the identification of the living, Homo 2012;63(6):451-8

the subjects were healthy; individuals with craniofacial trauma, congenital anomalies or surgery were excluded. The tested persons consented to their participation after being informed of the procedure used in this study. The study design was approved by local ethic committees within each participating country.

Sixteen facial landmarks were identified. Fourteen facial measurementswere obtained, as more representative of the middle and lower thirds of face, following the method by Martin and Saller (79) (Fig. 16), according to the experimental project established by the EU-funded committee. The forehead width (ft-ft) and bizygomatic width (zy-zy) were evaluated by the use of a spreading caliber, whereas for all the other measurements (se-gn, pu-pu, en-en, ex-en, ala-ala, ch-ch, se-sto, se-sn, se-prn, prn-sn, sa-sba, pra-pa) a sliding caliper was used (Table 11). For both the calipers the accuracy was 0.1 mm. Data were collected and inserted within an EXCEL© sheet. For each measurement, means and standard deviations (SD) were computed for each age group.

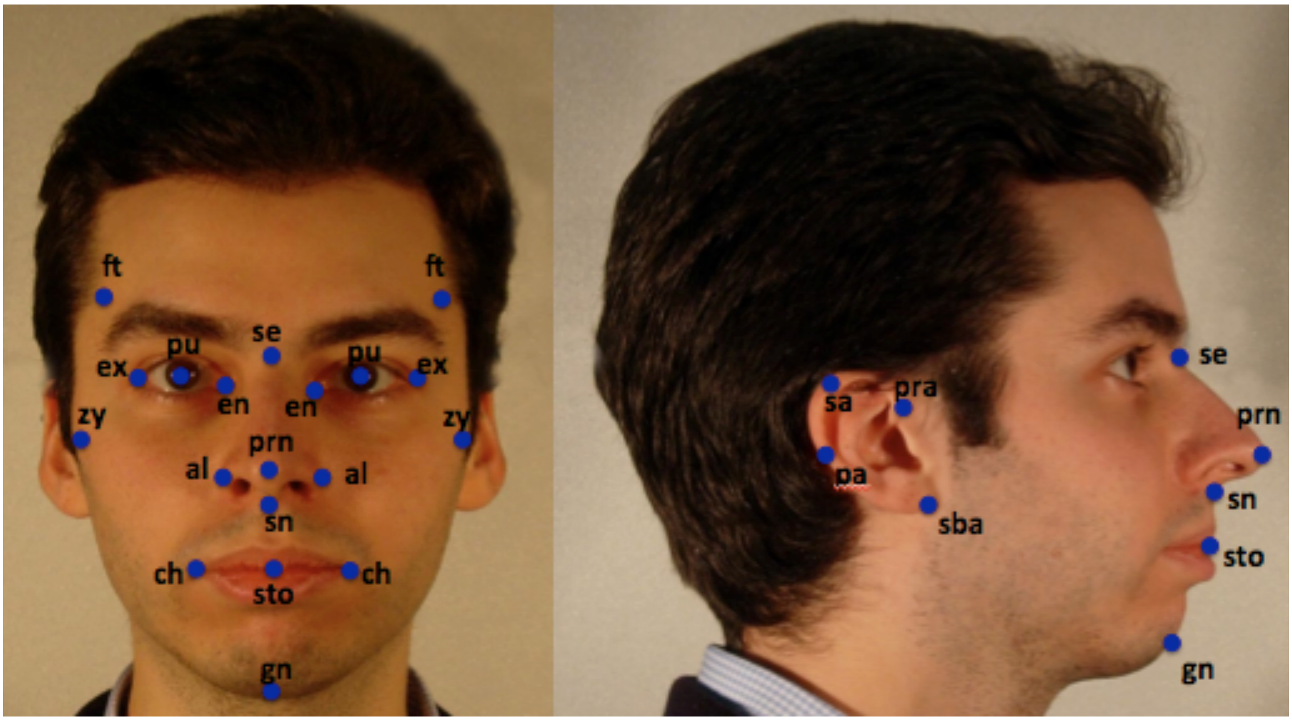


Fig. 16: landmarks used for facial measurements (ft: frontotemporale; ex: exocanthion; en: endocanthion; pu: pupillare; se: sellion; zy: zygion; al: ala; prn: pronasale; sn: subnasale; ch: cheilion; sto: stomion; gn: gnathion; sa: superaurale; pra: preaurale; pa: postaurale; sba: subaurale)

Cranial measurements	Abbreviation	Tool
Forehead width	ft-ft	Spreading caliper
Bizygomatic width	zy-zy	Spreading caliper
Morphological face height	se-gn	Sliding caliper
Interpupillary distance	pu-pu	Sliding caliper
Intercanthal width	en-en	Sliding caliper
Biocular width	ex-ex	Sliding caliper
Nose width	al-al	Sliding caliper
Labial width	ch-ch	Sliding caliper
Physiognomic upper facial height	se-sto	Sliding caliper
Nasal height	se-sn	Sliding caliper
Nasal bridge length	se-prn	Sliding caliper
Nasaldepth	prn-sn	Sliding caliper
Physiognomic ear length	sa-sba	Sliding caliper
Physiognomic ear width	pra-pa	Sliding caliper

Table 11: facial measurements (according to Martin &Saller, 1957) and corresponding abbreviations

The correlation index (C.I. index) which measures the correlation between different variables, was computed between pairs of linear distances. In addition, correlation between each facial measurement and age in decimals was evaluated as well. Values above the 0.7 threshold were considered indicative of high correlation.

The ANOVA test was used to verify if differences between age groups for individual measurements, and correlations as well between facial measurements and age are significant. For all analyses, the significance level was set at 5% ($p<0.05$).

Results

Means and standard deviations of fourteen facial measurements for individual age groups are shown in the following table (Table 12).

Age (years)		pu-pu	en-en	ex-ex	al-al	ch-ch	ft-ft	zy-zy	se-sn	se-sto	se-gn	se-prn	prn-sn	sa-sba	pra-pa
20	**Mean**	59.4	31.8	97.6	36.0	52.1	125.9	122.0	55.1	75.1	118.6	49.2	22.2	61.9	35.9
(N° 45)	**SD**	4.6	3.7	5.3	2.3	3.7	9.3	10.4	3.8	4.4	6.3	4.9	3.3	4.1	3.6
21	**Mean**	60.7	31.5	94.9	36.0	51.5	119.3	130.9	54.0	75.1	116.4	49.5	22.7	63.0	36.6
(N° 35)	**SD**	5.4	4.4	6.0	3.1	3.3	11.2	12.4	4.1	5.1	6.2	3.5	4.0	4.1	3.7
22	**Mean**	59.0	31.8	96.6	35.9	51.9	119.3	125.4	54.8	75.6	118.9	49.9	21.4	62.7	36.4
(N° 50)	**SD**	6.6	3.1	5.1	3.4	4.4	10.1	11.5	4.6	4.2	7.3	4.6	3.1	4.2	3.2
23	**Mean**	60.1	31.7	97.7	36.4	52.0	124.3	123.1	55.9	75.5	118.2	50.1	21.7	62.7	36.4
(N° 52)	**SD**	4.4	3.5	4.6	2.9	4.3	10.3	9.8	5.0	4.9	6.3	5.1	3.1	4.3	4.0
24	**Mean**	60.5	31.6	97.7	36.7	52.1	124.9	127.0	55.8	76.3	120.1	50.1	23.4	63.3	36.5
(N° 64)	**SD**	4.3	3.2	4.9	3.2	3.7	10.9	11.1	4.7	4.3	7.5	4.9	3.4	4.1	3.8
25	**Mean**	60.6	31.4	95.8	34.8	52.9	121.9	129.2	55.4	74.6	118.3	49.8	22.3	62.8	37.2
(N° 30)	**SD**	3.5	3.9	4.9	3.1	4.3	11.7	13.8	4.4	4.9	4.9	3.7	2.8	4.3	3.5
26	**Mean**	59.7	31.8	96.9	36.3	51.8	118.9	132.1	54.8	75.9	121.1	49.9	22.3	65.2	38.1
(N° 27)	**SD**	5.1	2.7	5.2	2.2	3.7	13.5	12.7	5.4	4.9	7.6	4.4	4.0	4.9	3.7
27	**Mean**	61.1	32.2	97.0	36.1	52.2	122.5	128.5	55.0	74.7	120.7	49.6	22.8	65.0	36.9
(N° 26)	**SD**	5.6	3.5	4.5	2.8	5.4	12.7	12.7	4.0	3.8	9.4	4.8	2.6	3.8	3.5
28	**Mean**	61.6	32.9	96.3	36.4	53.4	119.1	128.8	52.9	74.9	118.2	48.4	21.2	64.9	35.9
(N° 30)	**SD**	5.3	3.7	5.1	3.1	3.9	12.0	13.6	5.2	5.8	7.0	5.6	2.9	4.2	3.3
29	**Mean**	61.0	32.6	99.1	36.4	55.6	117.8	125.9	54.2	75.8	117.1	51.0	22.4	65.7	35.8
(N° 30)	**SD**	5.2	3.2	5.4	3.0	5.4	9.4	11.9	4.5	4.8	6.9	4.8	2.5	4.4	4.4
30	**Mean**	60.4	32.1	99.5	36.6	53.8	123.0	128.0	53.4	75.3	118.4	48.1	21.5	67.2	38.1
(N° 15)	**SD**	7.7	4.5	3.4	2.7	4.4	13.2	11.5	4.1	5.2	8.5	6.5	3.0	4.7	3.5

Table 12: mean and SD of facial measurements for each age (mm)

The results of correlation analysis between each of the measurements and age groups revealed a positive statistically significant correlation ($p<0.05$) for labial width ($r = 0.171$) and physiognomic ear length ($r = 0.280$), although in these cases the correlation is limited (Table 13).

Facial measurements	Correlation with age
pu-pu	.085
en-en	.072
ex-ex	.078
al-al	.031
ch-ch	.171*
ft-ft	-.083
zy-zy	.092
se-sn	-.092
se-sto	-.016
se-gn	.004
se-prn	-.0.17
prn-sn	-.024
sa-sba	.280*
pra-pa	.048

Table 13: correlations between facial measurements and age (values with asterisk are significant for p<0.05)

Facial measurements which showed the highest correlation with age are zy-zy, se-sn, pu-pu and ft-ft, but in all these cases the significance is low (p>0.05).

Results of ANOVA test are shown in the following table: concerning the interrelations between the different facial measurements, only few significant correlations were observed at p<0.05. Correlation coefficients higher than 0.5 and significant for p<0.05 were found between pu-pu and en-en (0.562), between se-sto and se-sn (0.621), se-prn and se-sn (0.808) and se-prn and se-sto (0.574). The other correlations, where statistically significant, are in all cases lower than 0.47 (Table 14).

pu-pu														
en-en	***.562***													
ex-ex	**.215**	**.308**												
al-al	**.158**	**.169**	**.313**											
ch-ch	**.145**	**.210**	**.217**	**.202**										
ft-ft	**.116**	.075	**.435**	**.306**	**-.132**									
zy-zy	**.287**	.063	**-.139**	-.059	.046	**-.285**								
se-sn	.030	.026	**.248**	**.142**	-.028	**.474**	**-.322**							
se-sto	**.164**	**.158**	**.154**	.064	-.017	**.266**	-.050	***.621***						
se-gn	.042	**.160**	**.127**	.017	.066	.052	-.021	**.350**	**.481**					
se-prn	.045	.051	**.180**	**.143**	-.017	**.343**	**-.273**	***.808***	***.574***	**.252**				
prn-sn	.045	-.031	**-.102**	.089	.059	-.022	.081	**.162**	**.243**	.055	**.157**			
sa-sba	**.104**	**147**	**.252**	**.148**	**.104**	**.208**	-.019	**.197**	**.153**	**.163**	**.166**	.044		
pra-pa	**-.165**	**-.130**	**.147**	.032	.072	.096	**-.171**	**.144**	.058	.028	**.137**	.096	**.240**	
	pu-pu	en-en	ex-ex	al-al	ch-ch	ft-ft	zy-zy	se-sn	se-sto	se-gn	se-prn	prn-sn	sa-sba	pra-pa

Table 14: relationships between facial measurements. Values in bold are statistically significant ($p<0.05$), values in italics show also a correlation coefficient higher than 0.5

The facial measurements affected by less significant correlation with other measurements are mainly the horizontal ones (ch-ch, al-al, zy-zy). Ex-ex instead shows significant correlation with all the other measurements, although the correlation index is always between -0.139 and 0.435.

Discussion

Surprisingly, the impact of facial changes with age is often underestimated for young adults. This study aimed at verifying the correlation between the facial morphology and age of a European population belonging to three different countries; the actual target does not consist in verifying ethnic differences between the three populations, widely assessed in a previous publication (81), but only in evaluating the influence of age in determination of the facial structure between 20 and 30 years of age.

The statistical analysis in the present study showed a limited correlation of facial measurements with age in early adulthood. This implies that most measurements should be reliable in time. These findings are in accordance with the available literature on cranial growth, which states that facial growth ceases around the age of 20 years, and are

confirmed by the existing literature which states that facial measurements are substantially constant after the end of growth (82,83).
However, a positive significant correlation with age was observed for labial width and physiognomic ear length; at the moment most of literature mainly deals with facial growth during childhood and does not take into consideration early adulthood. For adulthood in general, particularly later adulthood, for what concerns ear length, only one study has pointed out that the ear shows independent and specific age changes (59). Furthermore the only existing study in this sense on mouth measurements during adulthood shows a significant effect of age for labial thickness and area even after 20 years (84). Nonetheless no one has so far confirmed and assessed these changes as significant even between 20 and 30 years of age as well as their importance for forensic identification.
The occurrence of facial changes during early adulthood may have crucial implications for personal identification. For example, the ear has frequently been used for personal identification because of its unique shape and metrics (85). However, the present study showed that ear dimensions may change in a relatively short period of time in young adults. Therefore, when two images of a person are compared, the time factor may be of consequence for assessing facial features, such as the ear.
For what concerns the interrelation between the facial measurements, most of the correlations which were verified can be easily explained as one of the measurements is included within the other (as observed for pu-pu and en-en, and se-sn and se-sto); in addition, the study pointed out a correlation between se-sn and se-prn, and between se-sto and se-prn, which suggests a harmonic proportion of the nasal and oral districts between 20 and 30 years.
For a correct evaluation of the present results, one should also take into consideration the limits of the study, especially for what concerns the experimental project which is cross sectional: in other words, the modification of each facial measurement with age is evaluated by the mean values of each parameter. From this point of view, the study provides only a general indication concerning the mean differences of facial measurements, according to the population group belonging to each age range. The same experimental project within a longitudinal study, where the same individual is analysed after a period of time, is being at the present performed in order to ascertain the real modification of the face within the same subject and to verify the correspondence with the

cross-sectional study. Finally, gender may have an influence in determining the modifications of facial measurements with age; further studies are needed in order to verify the same relations in a female population.

In conclusion, this study showed that some changes still occur in dimensions of the face, particularly mouth and ear, in young adult males aged between 20 and 30 years. These findings need to be considered in cases of personal identification of the living in forensic scenarios.

5.5 Age changes of ear measurements in subjects aged between 12 and 19 years

The previous study points out that ear and mouth measurement show a correlation with age also in juvenile adults; among these values, mouth is highly influenced by variables linked to the facial expression, weight, etc. On the other hand, ear may be useful for age estimation, if their parameters prove to show the same reliability also in photos: the following study will attempt at providing the reliability of ear measurements.

Materials and methods

The study analyzed 356 individuals aged between 12 and 19 years, recruited in Dusseldorf (Germany), Milan (Italy) and Vilnius (Lithuania), within an EU-funded project. All the subjects were Caucasoid, born in the respective countries as were their parents and all relatives of more distant degrees (i.e. grand parents, great grandparents). A consent was obtained for the scientific use of the photographs. The age of each subject was reported in months.

The mean age was 183.5 months (SD 34 months). All the subjects were healthy; individuals with craniofacial trauma, congenital anomalies or surgery were excluded. The subjects underwent photography in right lateral view: then length and breadth of the right ear were measured, as well as the area in pixel.

Data were collected and inserted within an EXCEL© sheet. For each measurement, correlation with age was evaluated.

Results

Results are shown in the following tables (Table 15).

Age (months)	Ratio length/ breadth	Area (pixel)	Age (months)	Ratio length/ breadth	Area (pixel)	Age (months)	Ratio length/ breadth	Area (pixel)	Age (months)	Ratio length/ breadth	Area (pixel)
121	1.96	39726	151	1.88	13659	194	1.49	35587	217	1.62	29286
121	1.33	35505	152	1.61	35411	194	1.57	15233	217	1.47	36159
122	1.54	28685	152	1.48	45782	195	1.52	12669	217	1.50	12479
123	1.51	46131	152	1.55	34601	195	1.51	21022	217	1.48	13906
123	1.61	30461	152	1.46	42368	196	1.51	32762	217	1.83	17794
123	1.77	45639	153	1.70	41004	196	1.47	21663	218	1.83	46885
125	1.52	26531	153	1.40	36767	196	1.56	16619	218	1.66	47129
125	1.63	32304	154	1.47	12113	196	1.48	13746	218	1.68	19107
126	1.53	40205	155	1.74	24631	197	1.53	58622	218	1.60	21691
127	1.42	28100	155	1.37	39719	197	1.69	11725	218	1.55	19920
128	1.45	54253	155	1.44	18931	197	1.56	20187	218	1.47	26012
129	1.28	35334	155	1.58	22610	197	1.55	16429	218	1.58	15981
130	1.46	29727	155	1.27	21827	198	1.54	18166	218	1.59	23589
131	1.54	15405	155	1.51	22563	198	1.36	13854	219	1.46	49869
131	1.65	14643	156	1.54	13651	199	1.59	44989	219	1.42	17499
131	1.50	12411	156	1.69	16737	199	1.85	24084	219	1.42	11550
131	1.94	17098	157	1.45	21020	199	1.47	26041	219	1.50	13542
132	1.52	35157	157	1.74	11843	199	1.43	18157	219	1.53	12710
132	1.68	13809	158	1.72	29749	199	1.56	14212	220	1.37	66702
133	1.52	52473	158	1.62	40329	199	1.45	11046	220	1.43	16862
133	1.51	10261	158	1.53	46802	200	1.50	60418	221	1.43	32608
133	1.23	21472	158	1.44	18622	200	1.55	50717	221	1.28	31376
134	1.46	37948	158	1.62	17473	200	1.46	14761	221	1.85	63905
134	1.69	19998	158	1.57	9967	201	1.66	59806	221	1.53	35938
134	1.55	20810	159	1.53	49760	201	1.38	54361	222	1.50	54054
135	1.49	24860	159	1.60	48784	201	1.69	33871	222	1.40	23421
135	1.72	13730	159	1.57	40281	201	1.59	25672	223	1.58	69921
135	1.66	22982	159	1.71	17067	201	2.10	15643	223	1.47	59360
135	1.57	11995	160	1.39	18067	202	1.33	48596	223	1.38	40348
136	1.25	27293	160	1.60	19112	202	1.57	17040	223	1.56	84212
136	1.54	12718	161	1.43	28957	202	1.66	16889	223	1.77	67806
136	1.56	14657	162	1.70	21642	203	1.75	52338	223	1.62	17700
136	1.45	27422	162	1.75	16576	203	1.35	42372	223	1.49	22397
136	1.43	26220	162	1.37	12645	203	1.67	9513	223	1.21	12899
136	1.56	17324	162	1.51	13879	204	1.54	71843	223	1.83	18525
137	1.47	42740	163	1.74	38042	204	1.74	45631	224	1.48	50823
137	1.67	38575	163	1.61	36471	205	1.55	51643	224	1.43	43953
137	1.58	49377	163	1.58	37143	205	1.74	54847	224	1.39	17931
137	1.44	17439	164	1.59	53873	205	1.44	58108	224	1.37	16839
137	2.22	9735	164	1.54	13271	205	1.32	18459	224	1.49	15719
137	2.08	18251	164	1.76	16083	205	1.67	16162	224	1.75	17906
137	1.68	15626	165	1.50	28347	205	1.53	22808	224	1.51	16979
137	1.62	21842	165	1.54	23945	206	1.64	58154	224	1.40	20197
138	1.39	27362	165	1.43	11100	207	1.74	53850	224	1.60	12416
138	1.35	42676	165	1.66	16729	207	1.35	30022	224	1.84	17568

Age (months)	Ratio length/ breadth	Area (pixel)	Age (months)	Ratio length/ breadth	Area (pixel)	Age (months)	Ratio length/ breadth	Area (pixel)	Age (months)	Ratio length/ breadth	Area (pixel)
138	1.74	20418	151	1.79	39022	192	1.44	20881	216	1.65	53526
138	1.89	22273	151	1.54	17686	192	1.55	18933	216	1.39	21572
139	1.52	39607	166	1.69	46302	193	1.44	20944	216	1.56	14444
139	1.44	15499	166	1.50	20306	193	1.41	11151	216	1.48	14956
139	1.62	22218	166	1.74	13851	207	1.62	10442	217	1.97	53349
139	1.48	20436	166	1.51	13763	208	1.57	31361	217	1.77	61524
139	1.54	20705	167	1.62	20722	208	1.56	16877	225	1.41	20833
140	1.80	13317	167	1.66	41152	209	1.73	59691	225	1.31	52938
140	0.07	15804	167	1.92	39663	209	1.39	24572	225	1.35	62269
140	1.71	12813	167	1.49	31797	209	1.42	12154	225	1.57	60318
140	1.66	16487	167	1.62	17173	210	1.72	56114	225	1.43	35440
140	1.65	17339	170	1.68	37865	210	1.40	20070	225	1.97	13726
140	1.52	21585	170	1.64	50002	210	1.62	12952	225	1.42	14718
141	1.48	46135	171	1.55	40812	211	1.77	46661	225	1.62	13530
141	1.75	16365	179	1.55	16442	211	1.51	50976	225	1.38	18491
141	1.62	10888	180	1.62	35222	211	1.41	40885	225	1.47	21369
142	1.72	50769	180	1.50	17633	211	1.59	28353	226	1.38	48895
142	1.46	12853	180	1.59	17228	211	1.56	11538	226	1.52	63175
142	1.35	12685	180	1.81	16481	211	1.50	21017	226	2.46	62318
142	1.70	12029	181	1.52	25154	211	1.40	18141	226	1.76	43979
142	1.62	23821	181	1.41	46064	211	1.71	18420	226	1.41	54529
144	1.43	36489	181	1.45	16366	211	1.51	17279	226	1.42	41291
144	1.80	33755	182	1.51	21765	212	1.46	42592	226	1.42	68854
144	1.54	31515	182	1.77	16534	212	1.46	33300	226	1.35	40399
144	1.60	13985	183	1.38	17423	212	1.32	26034	226	1.44	60164
144	1.41	12501	183	1.37	14068	212	1.56	18571	226	1.42	18473
145	1.70	28397	184	1.78	16545	213	1.86	45967	226	1.38	13570
146	1.52	35614	185	1.50	55350	213	1.52	49125	226	1.59	26348
146	1.52	33528	185	1.41	30954	213	1.44	39001	226	1.33	19556
146	1.68	45994	185	1.56	14844	213	1.52	38414	226	1.43	18752
146	1.65	15471	185	1.55	16095	213	1.38	34508	226	1.59	15023
146	1.61	16454	186	1.63	29837	213	1.76	33279	226	1.56	13801
146	1.82	17643	186	1.52	15898	213	1.75	17860	226	1.28	16512
147	1.43	22943	187	1.43	77870	214	1.48	44250	226	1.48	10293
147	1.47	14106	187	1.58	18126	214	1.65	39497	227	1.33	28595
147	1.49	18434	187	1.38	18151	214	1.41	35823	227	1.68	67182
148	1.31	45150	187	1.47	15920	214	1.52	39484	227	1.47	36554
148	1.37	40579	188	1.70	16571	214	1.26	34536	216	1.56	14444
148	1.66	17450	188	1.56	18070	214	1.53	33209	216	1.48	14956
149	1.51	50080	189	1.48	39562	215	1.47	54469	217	1.97	53349
149	1.73	38284	189	1.42	16073	215	1.51	40560	217	1.77	61524
150	1.43	13050	190	1.53	16741	215	1.34	26440	225	1.41	20833
151	1.39	42834	190	1.63	14019	215	1.37	36641	225	1.31	52938
151	1.71	43410	191	1.59	30691	216	1.57	44084			

Fig. 15: results of ear measurements in all the subjects recruited in the experiment

The correlation values with age were low for both the measurements (length/breadth ratio and area); in detail, considering the entire age range between 10 and 19 years, the correlation index (C.I.) of the ratio between length and breadth, and age was -0.07, whereas area reached the value of 0.17. If we consider the different age groups (10-13 years, 14-17 years, 18-19 years), the ratio between length and breadth was always below 0.1, whereas for what concerns area the highest correlation index was observed between 14 and 17 years (0.11) (Table 16).

	Length/breadth ratio	Area
10-13 years	0.05	-0.03
14-17 years	0.03	0.11
18-19 years	-0.04	0.01
10-19 years	-0.07	0.17

Table 16: correlation index (C.I.) of the ratio between length and breadth, and area with age

In no case the correlation index was higher then 0.7, a threshold commonly indicated for a high (or at least, biologically and clinically significant) correlation.

Discussion

The study shows that the modifications of ear morphology, although observed both in minors and adults, does not show a similar correlation also in photos: the ear assessment therefore fails in being considered a useful tool for age estimation from photos.

The real role of the ear morphology needs therefore to being ascertained in depth, especially if one considers that ear is usually considered as an important structure also for personal identification. However, for what concerns the age estimation from 2D images, the ear measurements seem not to be enough reliable for providing a scientifically based method.

***

The previous studies point out relevant information: first, linear measurements seem to be a useful method for age estimation from photos; in addition, if a parameter is related with age in vivo, not necessarely such relation is verified in photo. From this point of view, photograph may be considered rather than the modification of the real image, a different method for its acquisition, where the relation with age may be different than that observed in vivo; in other words, if a parameter in vivo is related with age, not necessarely such relation is demonstrated also in photo. However, also the contrary may be verified: some parameters may not be related with age in vivo, but in photos. The need for finding new facial measurements useful for age estimation is therefore urgent. The next study will ascertain if assessment of facial surfaces may add some new information to the issue of age estimation in photos.

4.6 Searching for a new methods of age estimation in 3D models and photos: assessment of facial surfaces in subjects aged between 6 and 10 years

As reported in the previous section, the issue of age estimation from photos is more complex than in vivo: in detail, photograph can be considered a method of image acquisition where the correlation with age of facial parameters observed in vivo may not be observed. Linear measurements seem to be a useful method for age estimation in photos, but they are not reliable enough to produce a scientifically sound method with the limited error range requested by the forensic practice. One may therefore wonder if facial parameters other than the linear measurements may give a help, i.e. facial surfaces. At the moment no study is available concerning this topic: the next step will be based on the analysis of facial surfaces in order to verify their correlation with age, and their applicability to 2D images.

Materials and methods

The experimental project is divided in two phases, concerning first the acquisition of photos and 3D scans and the facial metrical assessment. The two different methods are better described in the following sections. For the purposes of the current study, the 3D scans were considered "in vivo" assessments.

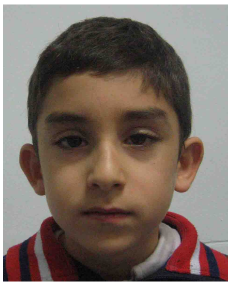
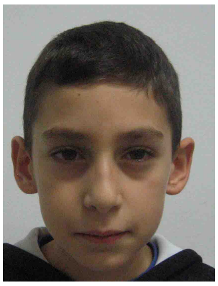
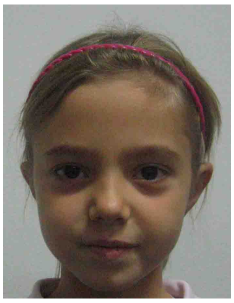
Recruitment and acquisition of 2D and 3D images

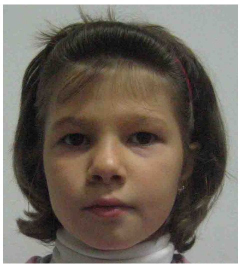
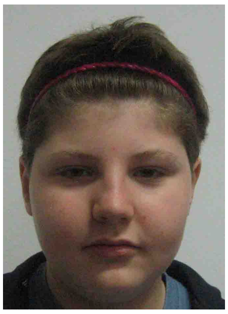
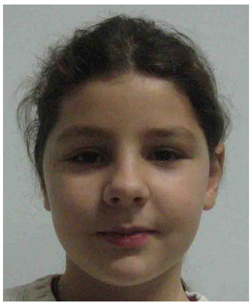
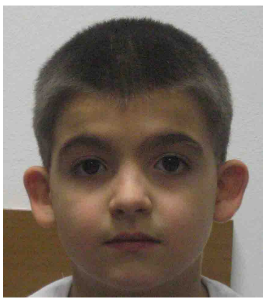
Eight children were recruited, aged between 6 and 10 years, 4 males and 4 females: subjects affected by facial pathologies and deformities were excluded. All the following analyses were performed after signature of a specific consent by the parents.

In December 2010 the eight children underwent the following analyses:

- Photographs in five position (frontal view, right and left profile, right and left ¾ position);

- 3D scan by laser scanner Vivid 910 (Konica Minolta, Osaka, Giappone); the 3D model was built by five scans obtained in five positions (frontal view, right and left profile, right and left ¾ position) (Table 17);

N° subject	**Gender**	**Photograph**	**Age at the beginning of the experiment (month)**	**Age at the end of the experiment (month)**	**3D scan**
1	M		80	101	
2	M		123	144	
3	F		86	107	

4	F		108	129	
5	M		131	152	
6	F		119	140	
7	M		102	123	

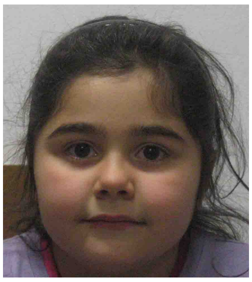
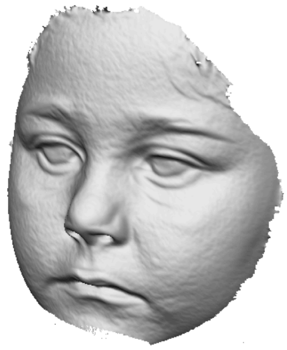
8	F		72	93	

Table 17: details of sex and age of the eight children taking part to the experiment with 3D scan performed in December 2010

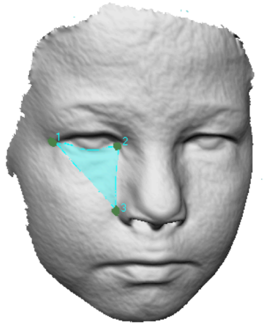
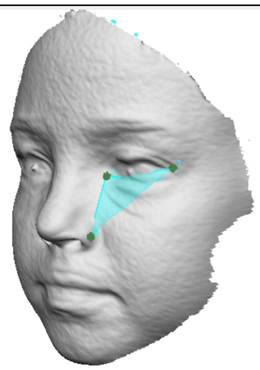
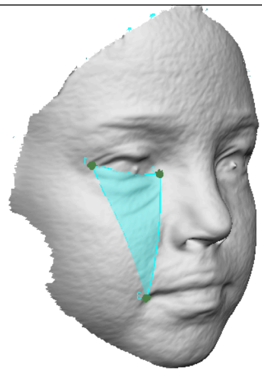
The same procedures were performed other 5 times, in June 2011, Spetember 2011, January 2012 and September 2012; in total 6 analyses were performed on the same subjects in a time span of 21 months.

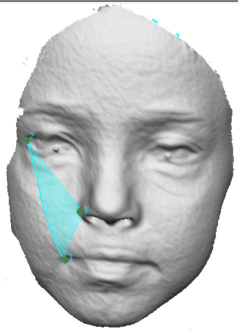
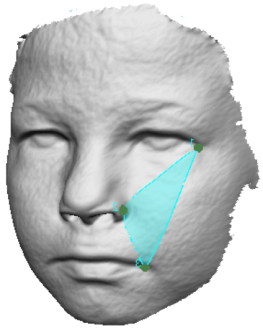
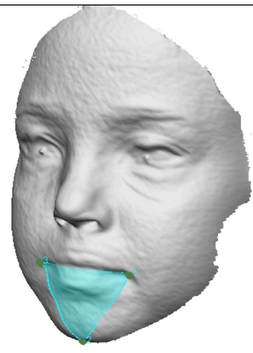
Metrical assessment of facial sufaces

On the three-dimensional scans from the eight individuals 8 different facial triangular surfaces were measured, defined by three facial landmarks, among which three paired and symmetrical, for a total of 11 surfaces:

a) right ex-en-ala;
a’) left ex-en-ala;
b) right ex-en-ch;
b’) left ex-en-ch;
c) right ex-ch-ala;
c’) left ex-ch-ala;
d) ala-ala-se;
e) ch-ch-sn;
f) ch-ch-gn;
g) ex-ex-gn;
h) ex-ex-t.

Definition and measurement of facial surfaces were performed by the image elaboration software VHAM©; in detail, first the three chosen landmarks were put on each model, then the included area was defined by the comand “extend using landmark”. The area of the surface was measured in cm^2. In the following table the chosen surfaces are shown (Table 18).

Reference landmark	Analysed surface
Right ex-en-ala	
Left ex-en-ala	
Right ex-en-ch	
Left ex-en-ch sinistro	

Right ex-ch-ala	
Left ex-ch-ala sinistro	
ala-ala-se	
ch-ch-sn	
ch-ch-gn	

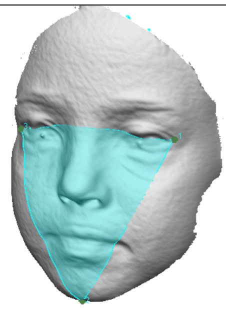
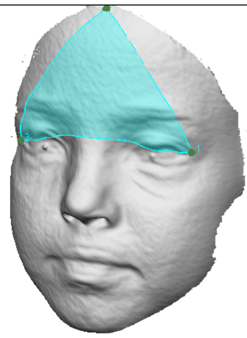
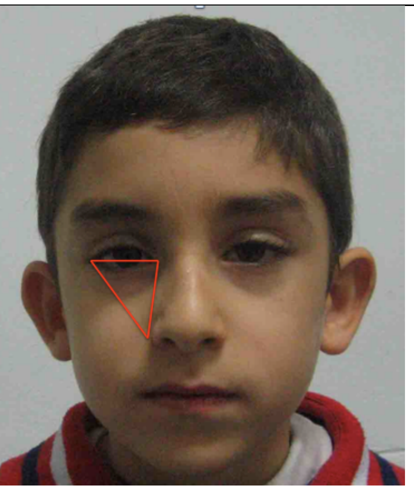
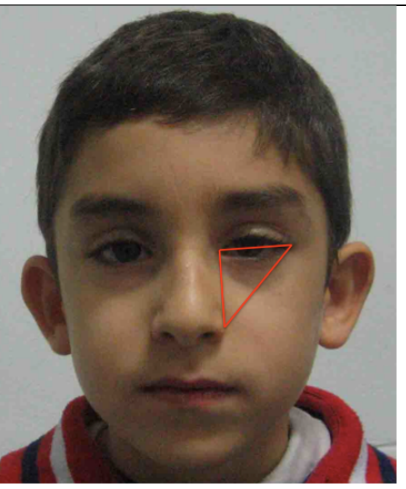
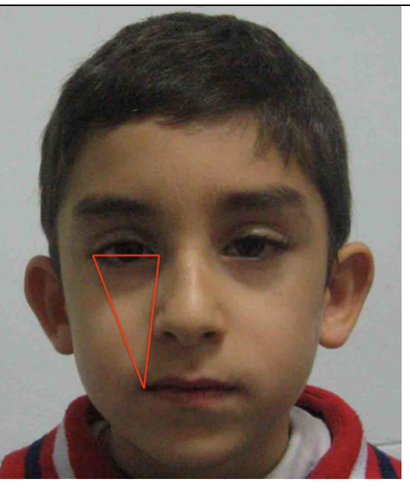
ex-ex-gn	
ex-ex-t	

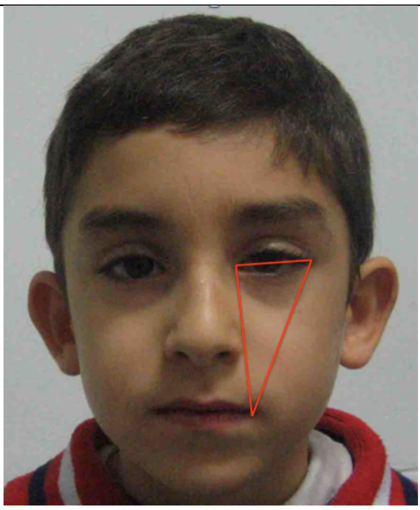
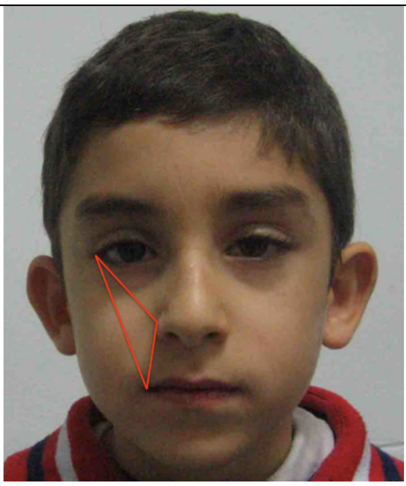
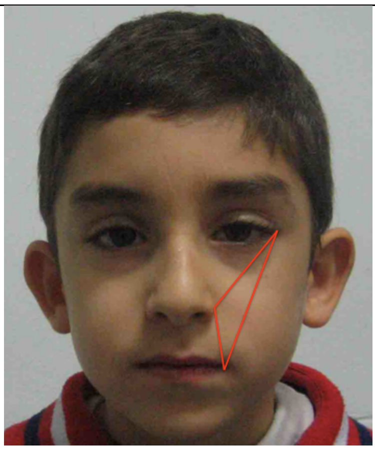
Table 18: details of analysed surfaces included in the experiment

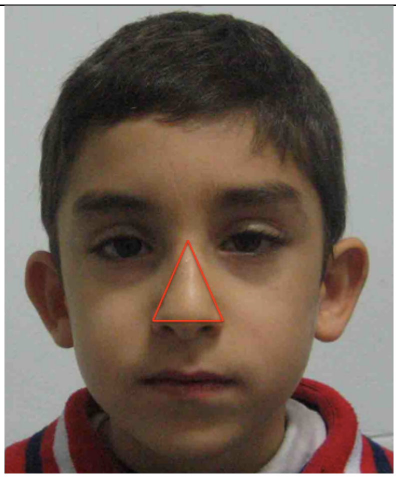
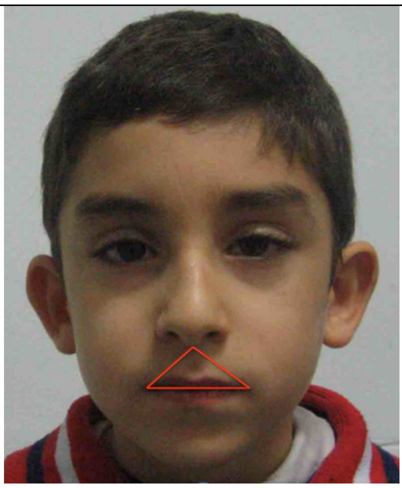
The metrical analysis was performed for all the 48 scans obtained by the eigth children in the six different time periods.

The metrical measurements were repeated by the same operator 7 days after the first analysis in order to evaluate the intra-observer error; in addition, the same surfaces were measured by a second operator in order to estimate the inter-observer error.

For what concerns the photographs, a similar study was performed, based on the same triangular surfaces taken on the 3D scans; in detail, the surfaces with all the three defining landmarks visible were measured. In the frontal position, all the 11 surfaces were measured as indicated in Table 19.

Reference landmarks	Analysed surface
Right ex-en-ala	
Left ex-en-ala	
Right ex-en-ch	

Left ex-en-ch	
Right ex-ch-ala	
Left ex-ch-ala	

<table>
<tr><td>ala-ala-se</td><td></td></tr>
<tr><td>ch-ch-sn</td><td></td></tr>
<tr><td>ch-ch-gn</td><td></td></tr>
</table>

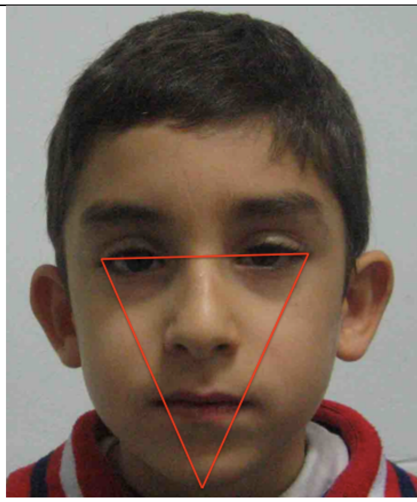
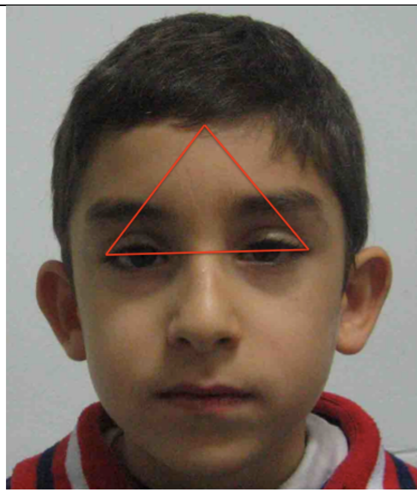
ex-ex-gn	
ex-ex-t	

Table 19: details of surfaces measured in frontal position

In ¾ position, surfaces defined by the triangles ex-en-ala, ex-en-ch, ex-ch-ala were analysed (Table 20).

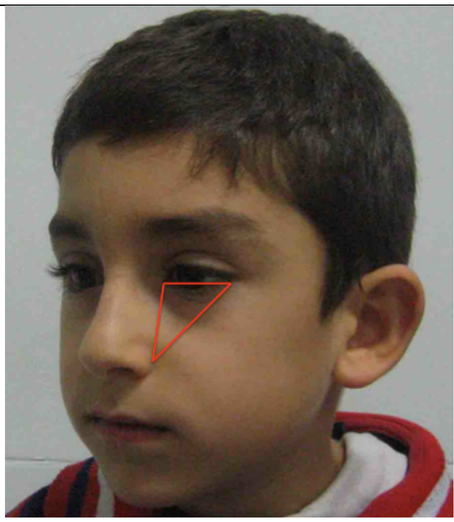
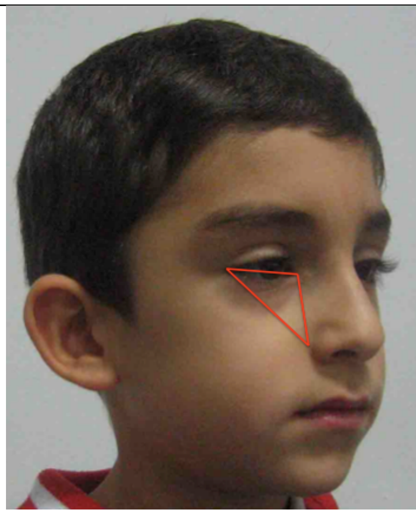
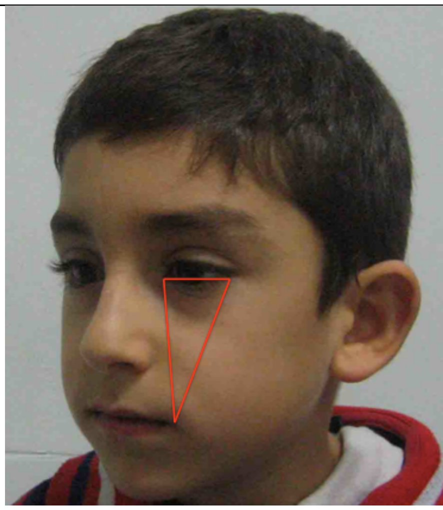
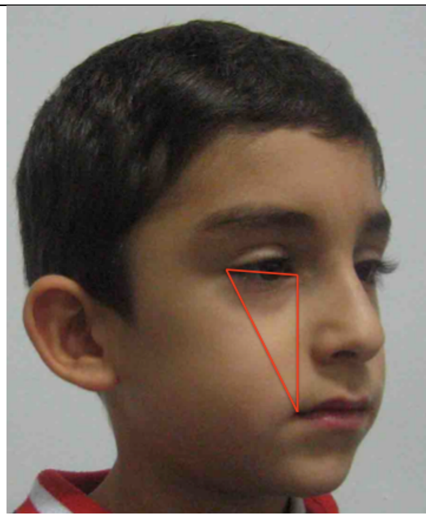
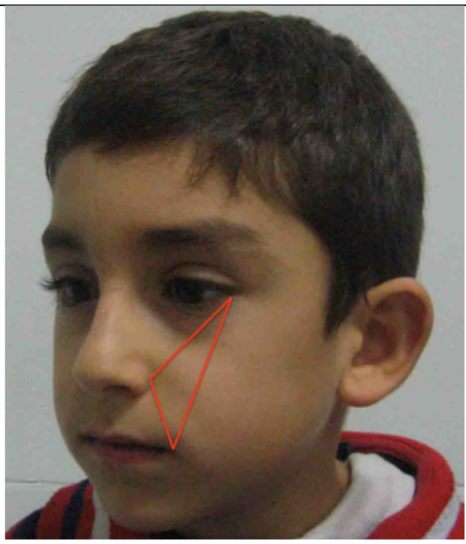
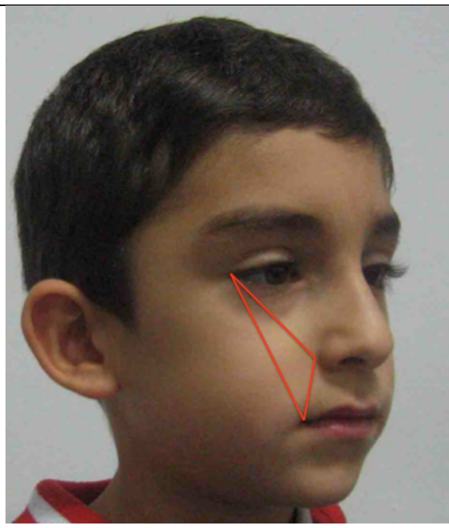
	Right ¾ position	Left ¾ position
ex-en-ala		
ex-en-ch		
ex-ch-ala		

Table 20 : details of surfaces measured in right and left ¾ positions

Measurements taken in photo were performed by Photoshop© software, defining the surfaces by straight lines and taken the measures in pixels. All the measurements on the same photo were taken at the same magnification degree.

In order to have an objective indication concerning facial growth in vivo and in photo, specific indices were evaluated, by the ratios between measurements of facial surfaces. In this way pure numbers were obtained, independent from the magnification factors, both in vivo and in photo. A total of 17 indices were evaluated, as indicated by the following list:

- right and left ex-en-ala/ex-en-ch
- right and left ex-en-ala/ex-ch-ala
- right and left ex-en-ch/ex-ch-ala
- right and left ex-en-ala/ex-ex-gn
- right and left ex-en-ch/ex-ex-gn
- right and left ex-ch-ala/ex-ex-gn
- ala-ala-se/ex-ex-gn
- ch-ch-sn/ex-ex-gn
- ch-ch-gn/ex-ex-gn
- ex-ex-t/ex-ex-gn
- ch-ch-sn/ch-ch-gn.

Finally, the following statistical analyses were performed:

1) evaluation of correlation index (C.I.) between facial measurements taken on 3D scan and indices taken on 3D scan and in photo with time;
2) evaluation of regression between each index on 3D scan and in photo and age, with corresponding r^2 value.

In conclusion, the modification of facial morphology on 3D scan was evaluated by a qualitative point of view following a protocol of facial comparison. In detail, 11 facial landmarks (right and left: en, ex, ala, ch: midline: se, gn, sn) were identified on two 3D scans from the same individual by software VHAM. The system was required to superimpose the two images in order to reduce the distance between the corresponding points (Fig. 17).

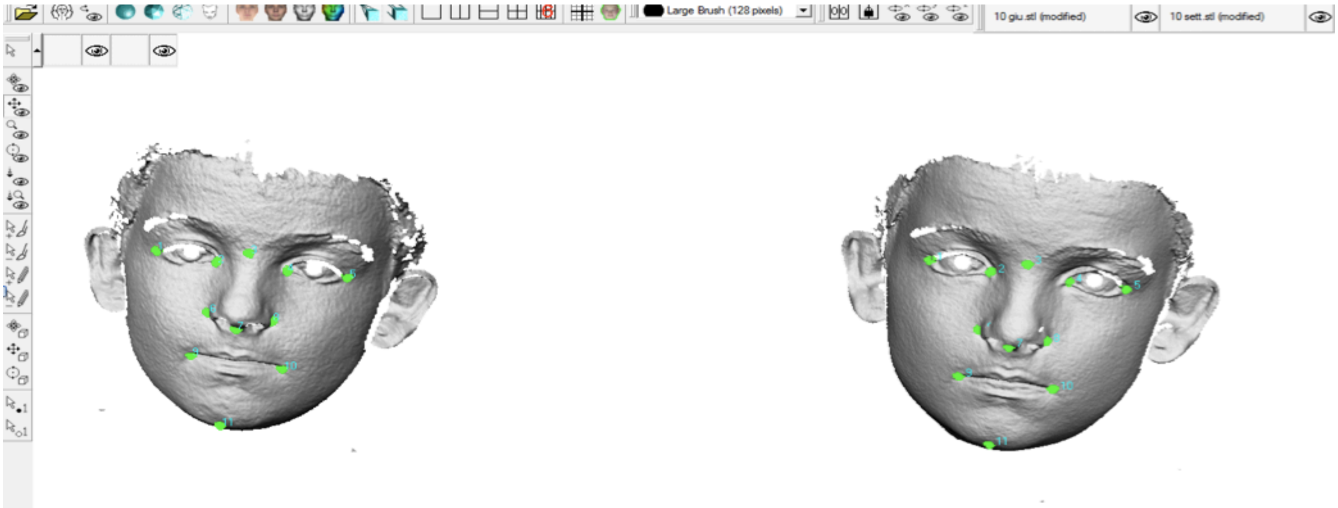


Fig. 17: definition of 11 landmarks for facial superimposition

This procedure allowed the operator to obtain a chromatic sheet of the face, where in blue are colored the growing zones and in red the zones which showed a decrease. In green the immutated areas are indicated (Fig. 18).

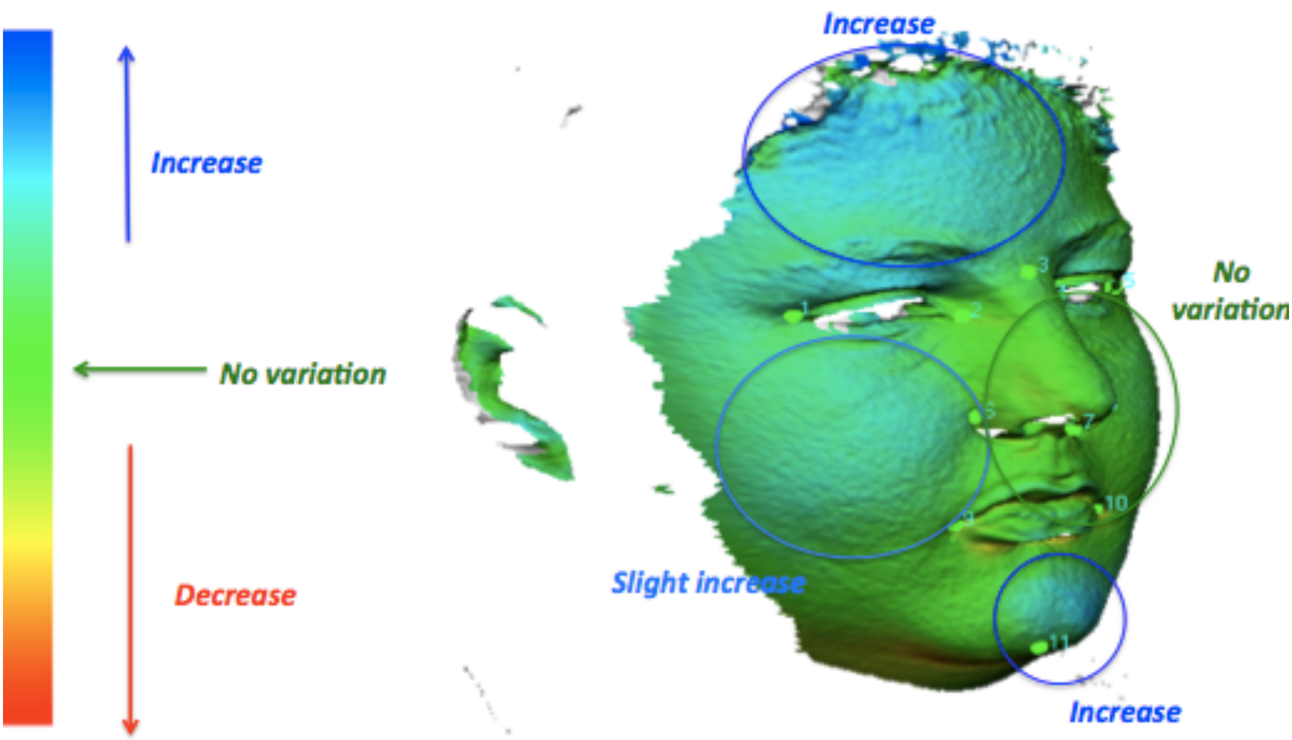


Fig. 18: example of chromatic sheet of comparison between two 3D models from the same individual

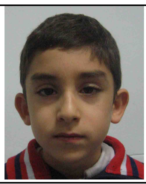
In order to follow the facial growth, three comparison were performed for each individual, referring to the period between December 2010 and June 2011, between June 2011 and January 2012 and between January and September 2012.

Results

In the following sections the results of metrical and morphological assessment will be exposed.

Metrical assessment of facial surfaces

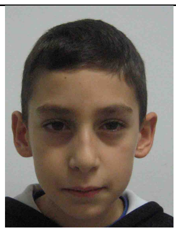
For what concerns the male subjects, the results of surface assessment with corresponding ratios are shown in the following tables (Tables 21-24).

	Dec. 2010	June 2011	Sept. 2011	Jan. 2012	June 2012	Sept. 2012
ex-en-ala R (a)	7.22	4.97	4.99	4.76	4.81	4.6
ex-en-ala L (a')	6.57	4.59	4.92	5.54	5.21	5.4
ex-en-ch R (b)	11.5	8.78	10.24	8.79	9.39	9.6
ex-en-ch L (b')	11.93	8.64	7.97	9.72	8.39	9.5
ex-ala-ch R (c)	9.32	5.75	6.18	7.93	8.58	8.58
ex-ala ch L (c')	9.2	5.86	7.19	7.49	7.48	7.6
ala-ala-se (d)	15.3	13.36	15.95	14.37	13.82	13.2
ch-ch-sn (e)	9.62	10.5	5.24	5.4	5.29	7.4
ch-ch-gn (f)	13.11	9.82	9.83	9.81	9.9	9.5
ex-ex-gn (g)	72.89	68.25	65.6	82.48	70.22	68.4
t-ex-ex (h)	30.38	31.25	33.2	32.03	35.39	36.4
Age (months)	**80**	**86**	**89**	**93**	**98**	**101**

Results are reported in cm^2

	Dec. 2010	June 2011	Sept. 2011	Jan. 2012	June 2012	Sept. 2012
a/b	0.63	0.57	0.49	0.54	0.51	0.48
a/c	0.77	0.86	0.81	0.60	0.56	0.54
b/c	1.23	1.53	1.66	1.11	1.09	1.12
a'/b'	0.55	0.53	0.62	0.57	0.62	0.57
a'/c'	0.71	0.78	0.68	0.74	0.70	0.71
b'/c'	1.30	1.47	1.11	1.30	1.12	1.25
a/g	0.10	0.07	0.08	0.06	0.07	0.07
b/g	0.16	0.13	0.16	0.11	0.13	0.14
c/g	0.13	0.08	0.09	0.10	0.12	0.13
a'/g	0.09	0.07	0.08	0.07	0.07	0.08
b'/g	0.16	0.13	0.12	0.12	0.12	0.14
c'/g	0.13	0.09	0.11	0.09	0.11	0.11
d/g	0.21	0.20	0.24	0.17	0.20	0.19
e/g	0.13	0.15	0.08	0.07	0.08	0.11
f/g	0.18	0.14	0.15	0.12	0.14	0.14
h/g	0.42	0.46	0.51	0.39	0.50	0.53
e/f	0.73	1.07	0.53	0.55	0.53	0.78

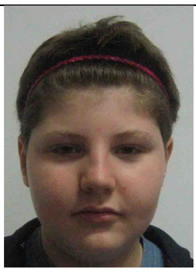
Table 21: results of surface assessment from individual number 1

	Dec. 2010	June 2011	Sept. 2011	Jan. 2012	June 2012	Sept. 2012
ex-en-ala R (a)	7	9.79	5.74	6.3	6.77	7.3
ex-en-ala L (a')	6.85	6.33	6.22	6.8	7.45	7.7
ex-en-ch R (b)	12.47	14.41	10.44	11.3	12.11	12.4
ex-en-ch L (b')	12.23	12.21	11.05	11.56	11.94	13.1
ex-ala-ch R (c)	9.54	9.16	8.76	11.46	8.94	9.3
ex-ala ch L (c')	6.93	7.94	7.77	8.78	5.83	6.3
ala-ala-se (d)	19.22	18.16	18.92	19.2	20.42	21.2
ch-ch-sn (e)	8.04	13.86	9.25	11.95	9.19	10.3
ch-ch-gn (f)	12	11.42	11.12	12.3	12.59	13.2
ex-ex-gn (g)	79.05	90.49	83.16	86.4	95.17	97.3
t-ex-ex (h)	31.2	32.33	38.92	36.76	37.8	38.3
Age (months)	**123**	**129**	**132**	**136**	**141**	**144**

Results are reported in cm^2

	Dec. 2010	June 2011	Sept. 2011	Jan. 2012	June 2012	Sept. 2012
a/b	0.56	0.68	0.55	0.56	0.56	0.59
a/c	0.73	1.07	0.66	0.55	0.76	0.78
b/c	1.31	1.57	1.19	0.99	1.35	1.33
a'/b'	0.56	0.52	0.56	0.59	0.62	0.59
a'/c'	0.99	0.80	0.80	0.77	1.28	1.22
b'/c'	1.76	1.54	1.42	1.32	2.05	2.08
a/g	0.09	0.11	0.07	0.07	0.07	0.08
b/g	0.16	0.16	0.13	0.13	0.13	0.13
c/g	0.12	0.10	0.11	0.13	0.09	0.10
a'/g	0.09	0.07	0.07	0.08	0.08	0.08
b'/g	0.15	0.13	0.13	0.13	0.13	0.13
c'/g	0.09	0.09	0.09	0.10	0.06	0.06
d/g	0.24	0.20	0.23	0.22	0.21	0.22
e/g	0.10	0.15	0.11	0.14	0.10	0.11
f/g	0.15	0.13	0.13	0.14	0.13	0.14
h/g	0.39	0.36	0.47	0.43	0.40	0.39
e/f	0.67	1.21	0.83	0.97	0.73	0.78

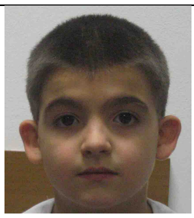
Table 22: results of surface assessment from individual number 2

	Dec. 2010	June 2011	Sept. 2011	Jan. 2012	June 2012	Sept. 2012
ex-en-ala R (a)	7.31	7.16	6.71	6.12	8.14	8.74
ex-en-ala L (a')	6.3	6.5	7.31	6.83	7.79	9.73
ex-en-ch R (b)	12.69	13.3	13.97	11.31	14.72	12.42
ex-en-ch L (b')	14.47	14.6	14	14.81	14.23	16.44
ex-ala-ch R (c)	11.31	11.25	11.07	13.54	8.99	11.95
ex-ala ch L (c')	9.17	9.6	9.99	8.69	11.43	12.5
ala-ala-se (d)	20.56	22.5	23.72	22.5	19.76	25.82
ch-ch-sn (e)	11.57	10.4	9.07	13.5	7.53	10.73
ch-ch-gn (f)	9.95	10.2	9.42	14.63	13.25	14.68
ex-ex-gn (g)	88.68	94.5	114.89	114.64	99.45	111.94
t-ex-ex (h)	36	35.8	39.3	34.03	31.76	33.29
Age (months)	**131**	**137**	**140**	**144**	**149**	**152**

Results are reported in cm^2

	Dec. 2010	June 2011	Sept. 2011	Jan. 2012	June 2012	Sept. 2012
a/b	0.58	0.54	0.48	0.54	0.55	0.70
a/c	0.65	0.64	0.61	0.45	0.91	0.73
b/c	1.12	1.18	1.26	0.84	1.64	1.04
a'/b'	0.44	0.45	0.52	0.46	0.55	0.59
a'/c'	0.69	0.68	0.73	0.79	0.68	0.78
b'/c'	1.58	1.52	1.40	1.70	1.24	1.32
a/g	0.08	0.08	0.06	0.05	0.08	0.08
b/g	0.14	0.14	0.12	0.10	0.15	0.11
c/g	0.13	0.12	0.10	0.12	0.09	0.11
a'/g	0.07	0.07	0.06	0.06	0.08	0.09
b'/g	0.16	0.15	0.12	0.13	0.14	0.15
c'/g	0.10	0.10	0.09	0.08	0.11	0.11
d/g	0.23	0.24	0.21	0.20	0.20	0.23
e/g	0.13	0.11	0.08	0.12	0.08	0.10
f/g	0.11	0.11	0.08	0.13	0.13	0.13
h/g	0.41	0.38	0.34	0.30	0.32	0.30
e/f	1.16	1.02	0.96	0.92	0.57	0.73

Table 23: results of surface assessment from individual number 5



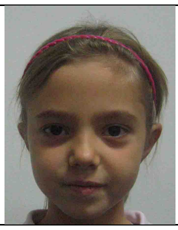
	Dec. 2010	June 2011	Sept. 2011	Jan. 2012	June 2012	Sept. 2012
ex-en-ala R (a)	3.14	3.79	5.88	5	5.74	5.72
ex-en-ala L (a')	7.4	4.48	4.81	5	5.52	5.9
ex-en-ch R (b)	8.58	7.89	11.29	10.85	10.03	9.99
ex-en-ch L (b')	8.6	7.99	9.49	10.22	9.91	8.21
ex-ala-ch R (c)	6.42	7.21	8.31	9.52	10.03	10.16
ex-ala ch L (c')	6.5	6.23	8.42	7.58	7.34	10.3
ala-ala-se (d)	17.59	15.69	14.5	12.54	11.4	14.51
ch-ch-sn (e)	5.77	6.24	7.2	7.28	5.8	6.2
ch-ch-gn (f)	9.57	10.86	11.3	13.03	9.76	10.85
ex-ex-gn (g)	72.23	79.06	82.3	73.18	86.11	75.41
t-ex-ex (h)	28.22	24.93	22.5	35.05	20.39	18.95
Age (months)	**102**	**108**	**111**	**115**	**120**	**123**

Results are reported in cm^2

	Dec. 2010	June 2011	Sept. 2011	Jan. 2012	June 2012	Sept. 2012
a/b	0.37	0.48	0.52	0.46	0.57	0.57
a/c	0.49	0.53	0.71	0.53	0.57	0.56
b/c	1.34	1.09	1.36	1.14	1.00	0.98
a'/b'	0.86	0.56	0.51	0.49	0.56	0.72
a'/c'	1.14	0.72	0.57	0.66	0.75	0.57
b'/c'	1.32	1.28	1.13	1.35	1.35	0.80
a/g	0.04	0.05	0.07	0.07	0.07	0.08
b/g	0.12	0.10	0.14	0.15	0.12	0.13
c/g	0.09	0.09	0.10	0.13	0.12	0.13
a'/g	0.10	0.06	0.06	0.07	0.06	0.08
b'/g	0.12	0.10	0.12	0.14	0.12	0.11
c'/g	0.09	0.08	0.10	0.10	0.09	0.14
d/g	0.24	0.20	0.18	0.17	0.13	0.19
e/g	0.08	0.08	0.09	0.10	0.07	0.08
f/g	0.13	0.14	0.14	0.18	0.11	0.14
h/g	0.39	0.32	0.27	0.48	0.24	0.25
e/f	0.60	0.57	0.64	0.56	0.59	0.57

Table 24: results of surface assessment from individual number 7

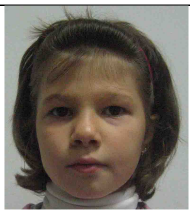
For what concerns female subjects, results are shown in Tables (25-28).

	Dec. 2010	June 2011	Sept. 2011	Jan. 2012	June 2012	Sept. 2012
ex-en-ala R (a)	4.79	3.69	3.37	3.94	4.1	6.4
ex-en-ala L (a')	4.56	4.01	4.1	4.82	4.86	6.53
ex-en-ch R (b)	7.84	7.89	8.37	8.54	9	8.86
ex-en-ch L (b')	9.2	8.88	7.7	9.37	9.5	10.65
ex-ala-ch R (c)	6.07	6.7	7.17	6.57	7.65	9.31
ex-ala ch L (c')	6.57	6.92	6.74	7.42	7.54	8.37
ala-ala-se (d)	13.58	14.16	13.46	11.46	13	11.92
ch-ch-sn (e)	6.27	5.24	6.03	5.8	5.23	5.66
ch-ch-gn (f)	10.08	11.74	8.22	9.77	9.77	10.45
ex-ex-gn (g)	57.27	65.14	64.8	65.76	63.91	64.24
t-ex-ex (h)	39.76	37.32	36.79	41.11	39.63	40.2
Age (months)	**86**	**92**	**95**	**99**	**104**	**107**

Results are reported in cm^2

	Dec. 2010	June 2011	Sept. 2011	Jan. 2012	June 2012	Sept. 2012
a/b	0.61	0.47	0.40	0.46	0.46	0.72
a/c	0.79	0.55	0.47	0.60	0.54	0.69
b/c	1.29	1.18	1.17	1.30	1.18	0.95
a'/b'	0.50	0.45	0.53	0.51	0.51	0.61
a'/c'	0.69	0.58	0.61	0.65	0.64	0.78
b'/c'	1.40	1.28	1.14	1.26	1.26	1.27
a/g	0.08	0.06	0.05	0.06	0.06	0.10
b/g	0.14	0.12	0.13	0.13	0.14	0.14
c/g	0.11	0.10	0.11	0.10	0.12	0.14
a'/g	0.08	0.06	0.06	0.07	0.08	0.10
b'/g	0.16	0.14	0.12	0.14	0.15	0.17
c'/g	0.11	0.11	0.10	0.11	0.12	0.13
d/g	0.24	0.22	0.21	0.17	0.20	0.19
e/g	0.11	0.08	0.09	0.09	0.08	0.09
f/g	0.18	0.18	0.13	0.15	0.15	0.16
h/g	0.69	0.57	0.57	0.63	0.62	0.63
e/f	0.62	0.45	0.73	0.59	0.54	0.54

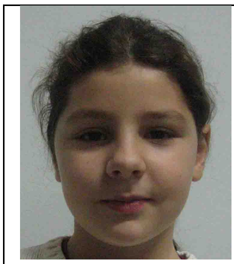
Table 25: results of surface assessment from individual number 3

	**Dec. 2010**	**June 2011**	**Sept. 2011**	**Jan. 2012**	**June 2012**	**Sept. 2012**
ex-en-ala R (a)	4.6	4.74	4.9	5.1	6.03	6.67
ex-en-ala L (a')	6.91	5.4	5.17	5.44	6.22	4.89
ex-en-ch R (b)	11.65	9.9	9.01	10.31	10.18	9.84
ex-en-ch L (b')	13.71	11.5	10.16	11.95	11.47	10.03
ex-ala-ch R (c)	9.31	8.23	7.56	7.86	9.79	6.91
ex-ala ch L (c')	8.61	7.5	7.75	8.5	8.85	7.93
ala-ala-se (d)	15.29	15.85	16.12	13.84	18.76	13.04
ch-ch-sn (e)	7.36	7.64	7.24	6.53	6.34	7.49
ch-ch-gn (f)	10.48	10.67	12.59	10.01	12.43	11.6
ex-ex-gn (g)	65.56	67.46	68.4	68.41	78.07	79
t-ex-ex (h)	35.97	28.12	30.23	32.1	28.36	26.5
Age (months)	**108**	**114**	**117**	**121**	**126**	**129**

Results are reported in cm^2

	Dec. 2010	June 2011	Sept. 2011	Jan. 2012	June 2012	Sept. 2012
a/b	0.39	0.48	0.54	0.49	0.59	0.68
a/c	0.49	0.58	0.65	0.65	0.62	0.97
b/c	1.25	1.20	1.19	1.31	1.04	1.42
a'/b'	0.50	0.47	0.51	0.46	0.54	0.49
a'/c'	0.80	0.72	0.67	0.64	0.70	0.62
b'/c'	1.59	1.53	1.31	1.41	1.30	1.26
a/g	0.07	0.07	0.07	0.07	0.08	0.08
b/g	0.18	0.15	0.13	0.15	0.13	0.12
c/g	0.14	0.12	0.11	0.11	0.13	0.09
a'/g	0.11	0.08	0.08	0.08	0.08	0.06
b'/g	0.21	0.17	0.15	0.17	0.15	0.13
c'/g	0.13	0.11	0.11	0.12	0.11	0.10
d/g	0.23	0.23	0.24	0.20	0.24	0.17
e/g	0.11	0.11	0.11	0.10	0.08	0.09
f/g	0.16	0.16	0.18	0.15	0.16	0.15
h/g	0.55	0.42	0.44	0.47	0.36	0.34
e/f	0.70	0.72	0.58	0.65	0.51	0.65

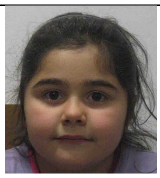
Table 26: results of surface assessment from individual number 4

	Dec. 2010	June 2011	Sept. 2011	Jan. 2012	June 2012	Sept. 2012
ex-en-ala R (a)	5.9	6.3	6.5	7.81	8.3	8.6
ex-en-ala L (a')	7.27	6.18	5.06	7.63	6.62	5.07
ex-en-ch R (b)	11.07	12.47	10.51	11.56	11.29	9.52
ex-en-ch L (b')	14.2	11.73	11.35	13.3	12.42	10.4
ex-ala-ch R (c)	9.49	11.67	9	11	11.54	7.29
ex-ala ch L (c')	11.22	9.17	7.86	12.06	7.6	7.5
ala-ala-se (d)	16.85	19.17	17.6	15.7	22.88	15.5
ch-ch-sn (e)	11.99	10.9	11.5	8.83	7.94	7.58
ch-ch-gn (f)	15.89	11.38	11.58	12.17	10.45	9.6
ex-ex-gn (g)	106.8	90.7	77.95	84.36	87.72	88.5
t-ex-ex (h)	30.88	33.98	32.4	41.85	23.48	30.5
Age (months)	**119**	**125**	**128**	**132**	**137**	**140**

Results are reported in cm^2

	Dec. 2010	June 2011	Sept. 2011	Jan. 2012	June 2012	Sept. 2012
a/b	0.53	0.51	0.62	0.68	0.74	0.90
a/c	0.62	0.54	0.72	0.71	0.72	1.18
b/c	1.17	1.07	1.17	1.05	0.98	1.31
a'/b'	0.51	0.53	0.45	0.57	0.53	0.49
a'/c'	0.65	0.67	0.64	0.63	0.87	0.68
b'/c'	1.27	1.28	1.44	1.10	1.63	1.39
a/g	0.06	0.07	0.08	0.09	0.09	0.10
b/g	0.10	0.14	0.13	0.14	0.13	0.11
c/g	0.09	0.13	0.12	0.13	0.13	0.08
a'/g	0.07	0.07	0.06	0.09	0.08	0.06
b'/g	0.13	0.13	0.15	0.16	0.14	0.12
c'/g	0.11	0.10	0.10	0.14	0.09	0.08
d/g	0.16	0.21	0.23	0.19	0.26	0.18
e/g	0.11	0.12	0.15	0.10	0.09	0.09
f/g	0.15	0.13	0.15	0.14	0.12	0.11
h/g	0.29	0.37	0.42	0.50	0.27	0.34
e/f	0.75	0.96	0.99	0.73	0.76	0.79

Table 27: results of surface assessment from individual number 6

	Dec. 2010	June 2011	Sept. 2011	Jan. 2012	June 2012	Sept. 2012
ex-en-ala R (a)	3.53	3.9	4.19	4.48	4.77	4.47
ex-en-ala L (a')	3.6	3.8	3.89	4.19	4.84	4.74
ex-en-ch R (b)	8.48	9.1	9.35	10.79	8.83	9.24
ex-en-ch L (b')	8.6	9.4	8.66	9.82	8.44	9.17
ex-ala-ch R (c)	6.8	7.3	6.59	8.15	6.42	6.91
ex-ala ch L (c')	6.41	7.2	6.49	7.42	6.68	6.65
ala-ala-se (d)	14.79	14.9	13.34	13.79	15.72	13.94
ch-ch-sn (e)	7.58	8.3	7.02	6.91	7.91	5.81
ch-ch-gn (f)	9.2	10.2	10.84	9.89	9.27	10.3
ex-ex-gn (g)	72	75.4	59.2	60.49	67.69	72.3
t-ex-ex (h)	33.2	35.3	35.35	34.47	35.29	36.5
Age (months)	**72**	**78**	**81**	**85**	**90**	**93**

Results are reported in cm^2

	Dec. 2010	June 2011	Sept. 2011	Jan. 2012	June 2012	Sept. 2012
a/b	0.42	0.43	0.45	0.42	0.54	0.48
a/c	0.52	0.53	0.64	0.55	0.74	0.65
b/c	1.25	1.25	1.42	1.32	1.38	1.34
a'/b'	0.42	0.40	0.45	0.43	0.57	0.52
a'/c'	0.56	0.53	0.60	0.56	0.72	0.71
b'/c'	1.34	1.31	1.33	1.32	1.26	1.38
a/g	0.05	0.05	0.07	0.07	0.07	0.06
b/g	0.12	0.12	0.16	0.18	0.13	0.13
c/g	0.09	0.10	0.11	0.13	0.09	0.10
a'/g	0.05	0.05	0.07	0.07	0.07	0.07
b'/g	0.12	0.12	0.15	0.16	0.12	0.13
c'/g	0.09	0.10	0.11	0.12	0.10	0.09
d/g	0.21	0.20	0.23	0.23	0.23	0.19
e/g	0.11	0.11	0.12	0.11	0.12	0.08
f/g	0.13	0.14	0.18	0.16	0.14	0.14
h/g	0.46	0.47	0.60	0.57	0.52	0.50
e/f	0.82	0.81	0.65	0.70	0.85	0.56

Table 28: results of surface assessment from individual number 6

Age-related correlations were evaluated for all the facial surfaces and ratios, and are shown in the following table. As one can observe, all parameters show a correlation with age only in specific age ranges: in detail, the measurements more related to age are t-ex-ex both in males and females, whereas the others show less continuity and differences among the two genders. The parameters relative to the malar zone (ex-en-ala) are more related with age in females, whereas the nose (ala-ala-se) grows more in males. This difference is even more evident in case of indices: a/b and a/c (both related to the malar zone) are more related with age in females. On the other hand, males show a different trend: in some cases, the correlation is observed in the latest age ranges (123-144 and 131-152 months), whereas in females the same trend is evident in the first age groups. In addition, in some age ranges males and females show a different evolution: it is the case of ch-ch-gn which decreases in age range of 80-101 years in males, whereas it does not change in females. Some other parameters (for instance, the right ex-en-ala) decreases in males between 80 and 101 months and increase in females between 72 and 93 months. However, the most interesting indication is the limited simmetry between different parameters: although the right and left measurements and indices show a similar evolution, they differ according the correlation, and so indicate a differential growth between the right and left side of the face (Table 29).

		Males				Females			
	Age (months)	80-101	102-123	123-144	131-152	72-93	86-107	108-129	119-140
Surface	ex-en-ala dx (a)	**-0.79**	-0.17	-0.22	0.53	**0.92**	0.43	-0.03	**0.97**
	ex-en-ala sin (a')	-0.34	-0.28	0.61	**0.85**	**0.96**	**0.72**	-0.54	-0.36
	ex-en-ch dx (b)	-0.53	0.50	-0.21	0.06	0.29	**0.95**	-0.46	-0.49
	ex-en-ch sin (b')	-0.48	0.26	0.30	0.55	0.12	0.58	-0.68	-0.60
	ex-ala-ch dx (c)	0.19	**0.97**	0.02	-0.08	-0.05	**0.85**	-0.32	-0.23
	ex-ala ch sin (c')	-0.22	**0.73**	-0.40	**0.77**	0.11	**0.92**	0.11	-0.55
	ala-ala-se (d)	-0.56	**-0.76**	**0.70**	0.39	-0.04	-0.67	-0.07	0.11
	ch-ch-sn (e)	-0.59	0.06	0.05	-0.26	-0.55	-0.50	-0.40	**-0.94**
	ch-ch-gn (f)	**-0.74**	0.20	0.52	**0.82**	0.16	-0.08	0.43	**-0.86**
	ex-ex-gn (g)	-0.02	0.33	**0.70**	0.60	-0.14	0.60	**0.91**	-0.55
	t-ex-ex (h)	**0.93**	-0.45	**0.80**	-0.64	**0.78**	0.38	**-0.75**	-0.23
Area	a/b	**-0.82**	**0.88**	-0.18	0.49	**0.72**	0.20	**0.93**	**0.92**
	a/c	**-0.85**	0.23	-0.18	0.41	**0.75**	-0.26	**0.80**	**0.75**
	b/c	-0.50	**-0.78**	-0.15	0.15	0.57	-0.67	0.15	0.08
	a'/b'	0.46	-0.33	**0.70**	**0.86**	**0.79**	**0.70**	0.15	0.05
	a'/c'	-0.29	-0.69	0.60	0.52	**0.83**	0.44	**-0.81**	0.47
	b'/c'	-0.41	-0.51	0.49	-0.59	0.00	-0.41	**-0.89**	0.42
	a/g	**-0.76**	**0.85**	-0.58	-0.03	0.62	0.26	**0.90**	**0.95**
	b/g	-0.37	0.34	**-0.79**	-0.39	0.21	0.43	**-0.84**	0.05
	c/g	0.24	**0.88**	-0.46	-0.65	0.06	**0.73**	**-0.75**	0.05
	a'/g	-0.33	-0.35	-0.16	0.55	**0.81**	0.55	**-0.83**	-0.02
	b'/g	-0.51	0.02	**-0.75**	-0.38	0.16	0.23	**-0.87**	-0.10
	c'/g	-0.18	0.60	-0.63	0.26	0.16	0.65	**-0.71**	-0.28
	d/g	-0.36	**-0.71**	-0.42	-0.39	0.15	**-0.79**	-0.60	0.34
	e/g	-0.54	-0.09	-0.24	-0.61	-0.37	-0.62	**-0.85**	-0.62
	f/g	-0.68	0.04	-0.40	0.59	0.14	-0.33	-0.38	**-0.73**
	h/g	0.58	-0.44	0.07	**-0.91**	0.34	-0.23	**-0.87**	0.02
	e/f	-0.31	-0.34	-0.14	**-0.92**	-0.48	-0.20	-0.58	-0.28

Table 29: correlation index (C.I.) observed in the study

The metrical results, both for what concerns the correlation with age and differences between sex and facial side, are confirmed by the morphological analysis, whose results are shown in the following figures.

The subject n° 1 (male, analysed between 80 and 101 months) showed between December 2010 and June 2011 an increase in the lower third of the face: limited areas of increase are observed also in the palpebral regions, although they may be due to the different position of the eyelids during the second scanning (the child had the eyes closed during the second scan, whereas they were open at the first one). At January 2012 there is an increase of the entire face, but only on the left side, the perioral region and the nose, whereas the right side did not show modifications. At the end of the experiment, the same region was affected by a slight decrease (Fig. 19).

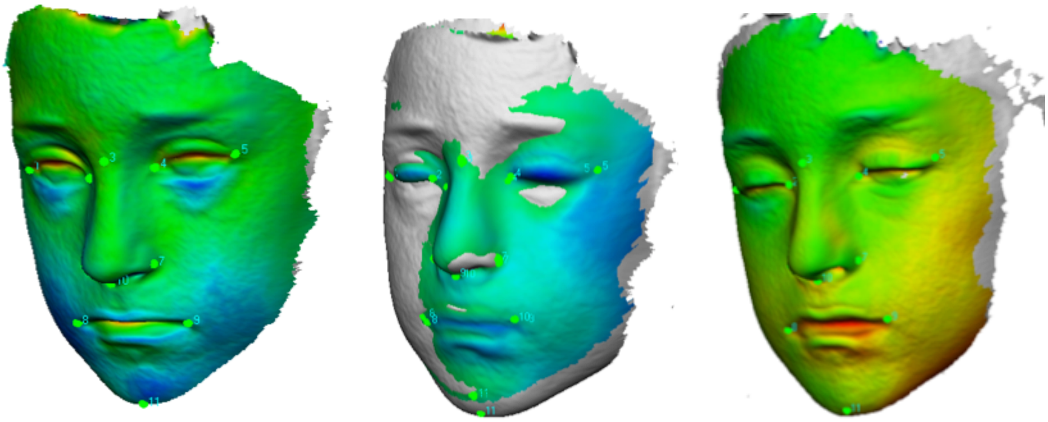


Fig. 19: chromatic figures of growth in child n° 1

The child n° 2 (male, analysed between 123 and 144 months) first showed an increase in the frontal area, and at the secon comparison an increase in the malar region, bilaterally. However, also in this case, the increase may be due to the smiling expression of the child. At the end of the experiment, the areas with an increase were the nose and the perioral region (Fig. 20).

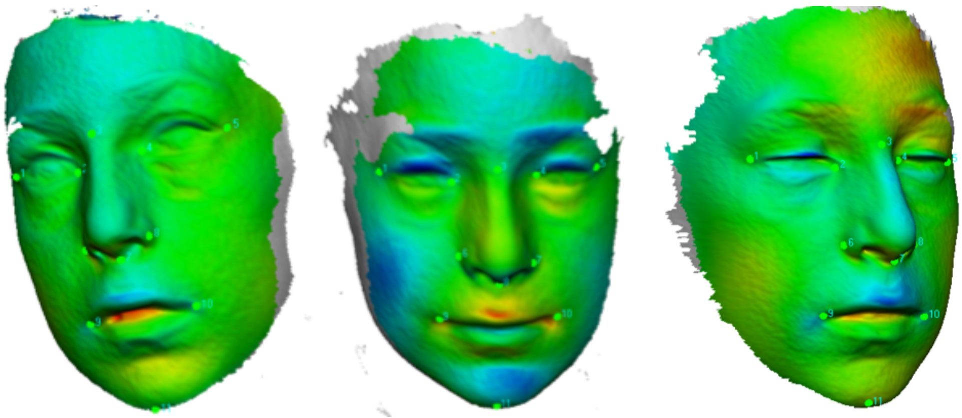


Fig. 20: chromatic figures of growth in child n° 2

Subject n° 5 (male, analysed between 131 and 152 months) showed an increase first limited to the left side of the face, whereas in the second comparison the entire face was affected by a decrease of size. A the end of the experiment, the nose and the right and left malar zones showed an increase (Fig. 21).

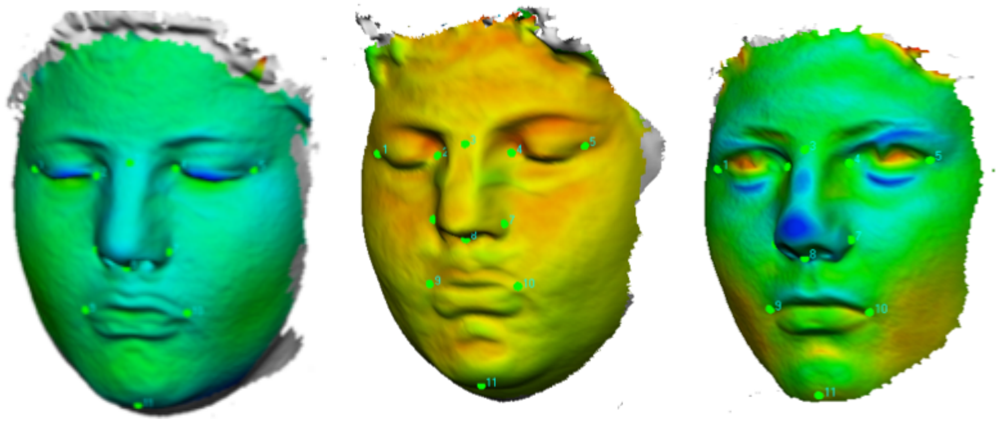


Fig. 21: chromatic figures of growth in child n° 5

Subject n° 7 (male, analysed between 102 and 123 months) showed an increase at the nose, bilateral malar zone and perioral region. However, since the second comparison, the entire face was affected by a strong decrease, first limited to the left side of the face, and then extended to the right side (Fig. 22).

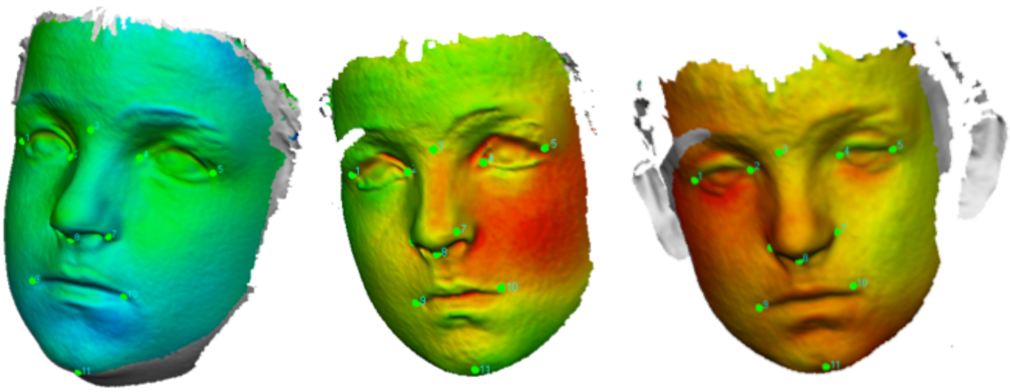


Fig. 22: chromatic figures of growth in child n° 7

The females individuals on the other hand were affected by different modification: the subject n° 3 (analysed between 86 and 107 months) in all the comparisons pointed out an increase of the oral region, with limited modifications (more prone to the decrease) in the rest of the face (Fig. 23).

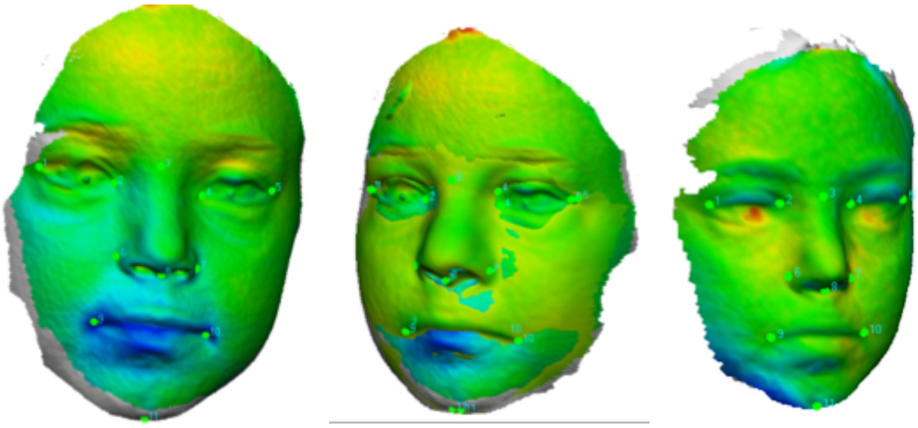


Fig. 23: chromatic figures of growth in child n° 3

However, also in case of the females, strong differences between age ranges within the same individual; subject n° 4 (analysed between 108 and 129 months) both at the first and second comparison was affected by a decrease of facial areas, followed by an increase of the entire facial zone at the end of the experiment (Fig. 24).

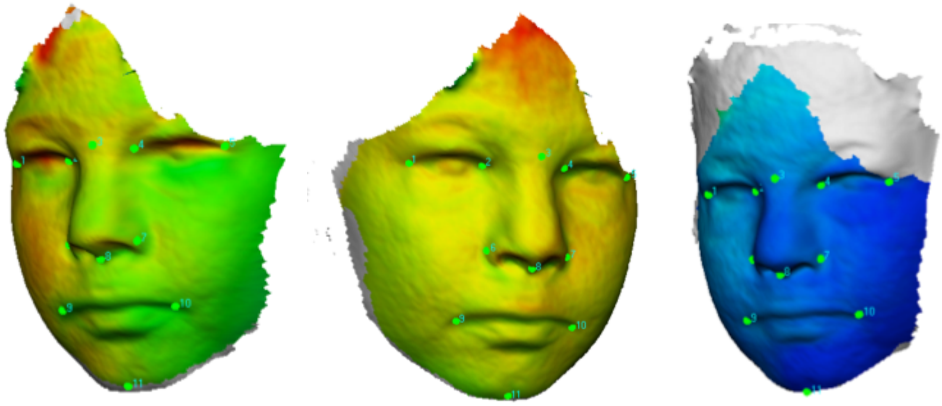


Fig. 24: chromatic figures of growth in child n° 4

The same differences, although with a stronger trend to the increase, is shown by the three comparison of subject n° 6 (analysed between 119 and 140 months) (Fig. 25).

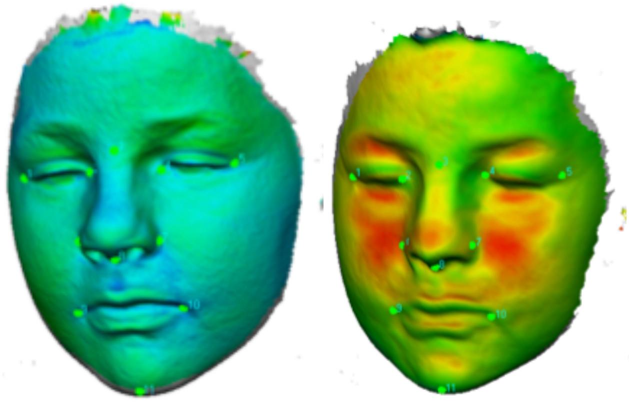


Fig. 25: chromatic figures of growth in child n° 6

Subject n° 8 (analysed between 72 and 93 months) showed an increase at left malar zone; at the second and third comparison, an increase was observed at the cheek: however, also in this case, the different expression of the child may have had a role (Fig. 26).

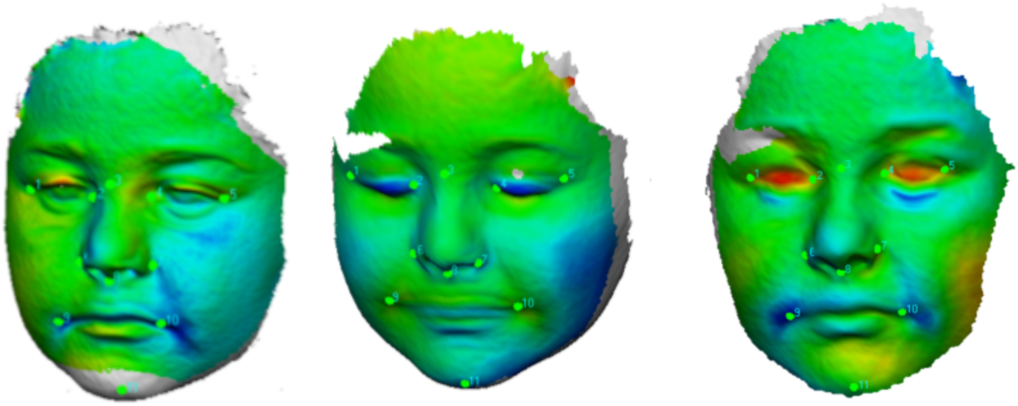


Fig. 26: chromatic figures of growth in child n° 8

In the following figures, the chromatic trends of the male and female subjects are put in comparison (Figg. 27,28).

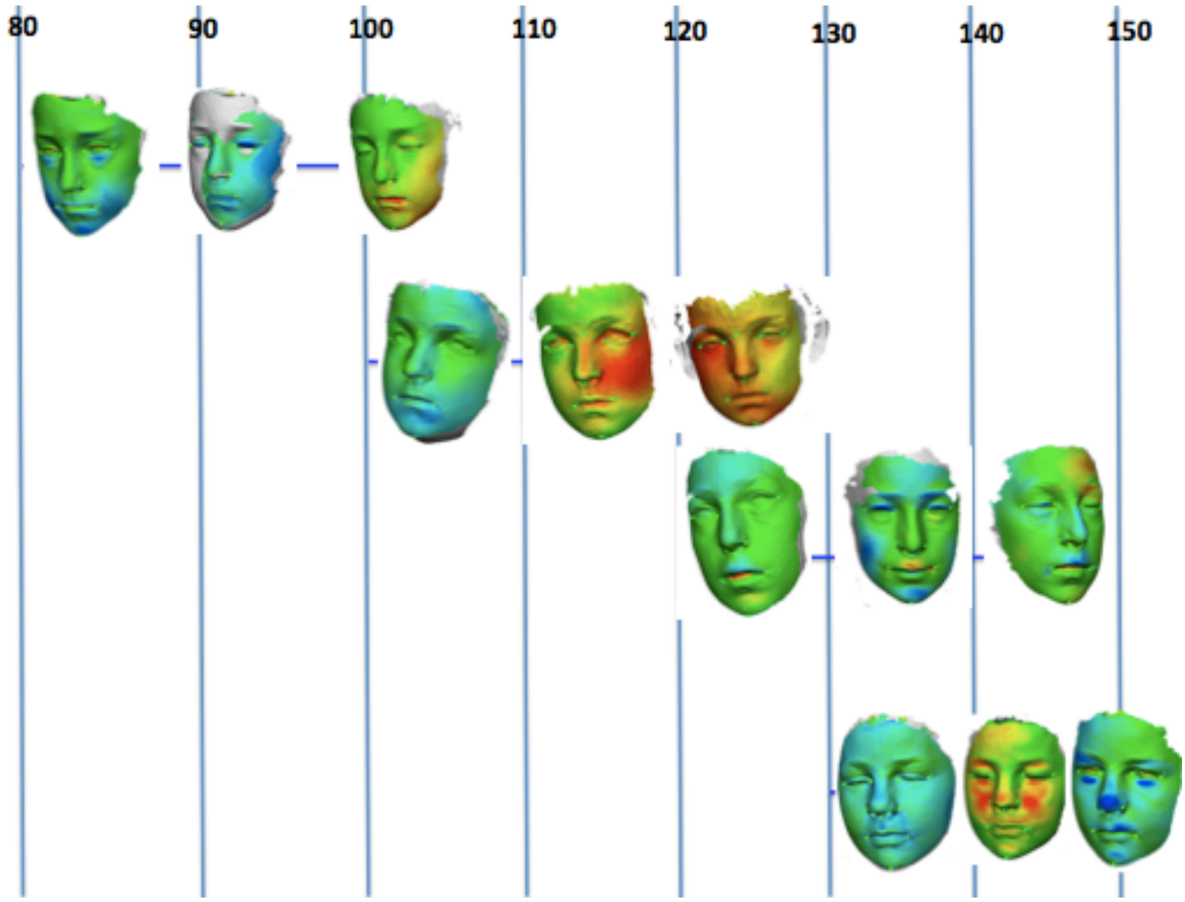


Fig. 27: comparison of growth modifications in male subjects

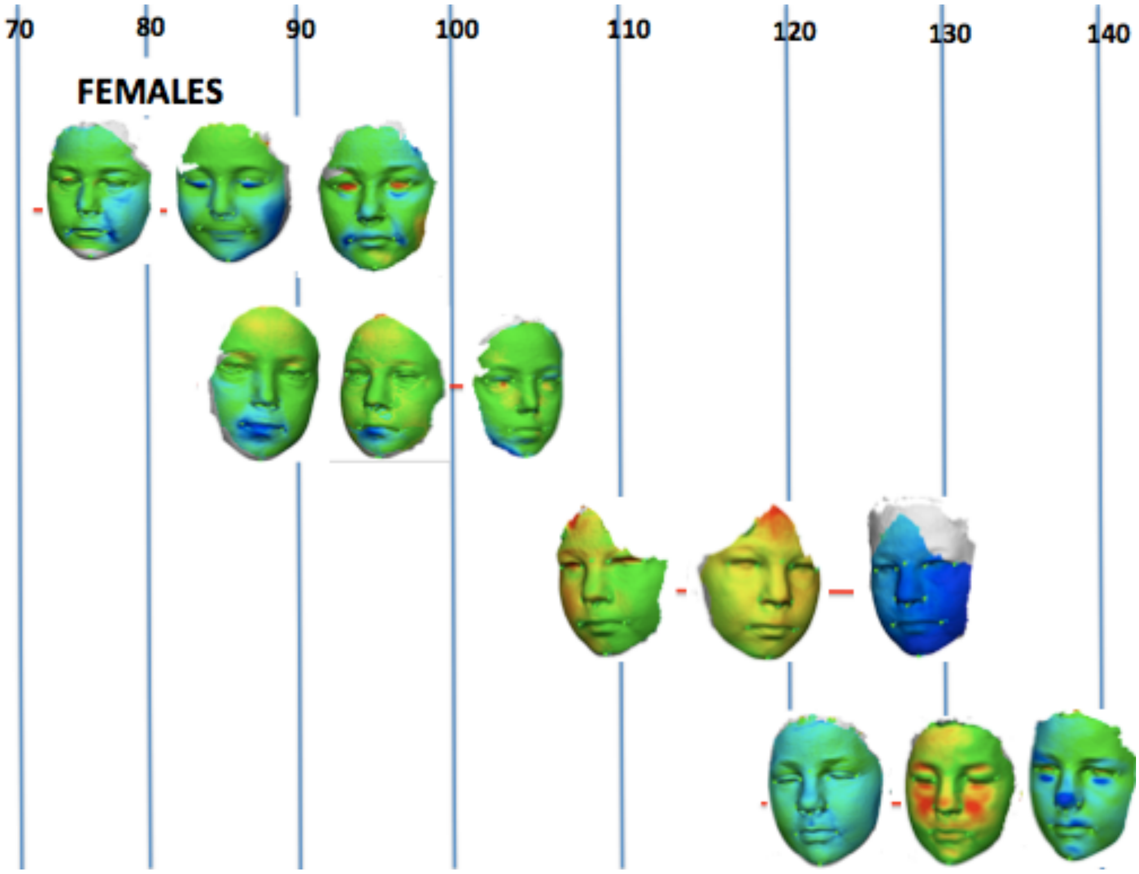


Fig. 28: comparison of growth modifications in female subjects

As observed, there are important differences not only between the growth trend of males and females, but also between subjects of the same sex and similar age.

The metrical measurements taken on 3D scans were statistically analysed in order to draw regression equations, with correspondant r^2 value. Males show low r^2 values; only b′/c′, f/g and h/g seem to have a significance for age estimation from 3D scans. On the other hand, modifications of facial surface seem to be more related with age, especially a/b, a/g and h/g; in these cases, r^2 is higher than 0.40 (Table 30).

Males	m	b	r^2
a/b	102.70	64.21	0.11
a/c	8.93	114.19	0.00
b/c	-16.76	140.76	0.03
a'/b'	-55.96	151.87	0.05
a'/c'	27.44	98.51	0.06
b'/c'	32.55	74.44	0.19
a/g	104.11	112.66	0.00
b/g	-219.15	149.09	0.03
c/g	50.22	114.68	0.00
a'/g	-120.41	129.08	0.00
b'/g	272.72	84.24	0.04
c'/g	-313.19	150.41	0.07
d/g	143.04	90.63	0.03
e/g	31.12	117.02	0.00
f/g	-480.51	184.86	0.21
h/g	-115.25	164.48	0.19
e/f	32.00	95.77	0.10

Females	m	b	r^2
a/b	108.29	48.73	0.47
a/c	64.13	65.46	0.25
b/c	-65.40	186.91	0.18
a'/b'	147.71	33.84	0.14
a'/c'	112.97	32.38	0.20
b'/c'	26.93	71.41	0.03
a/g	864.47	44.94	0.40
b/g	-199.07	134.29	0.03
c/g	200.12	84.98	0.03
a'/g	416.09	77.35	0.08
b'/g	93.90	93.81	0.01
c'/g	63.53	100.51	0.00
d/g	-80.28	124.26	0.01
e/g	-77.12	115.29	0.00
f/g	-302.98	152.68	0.09
h/g	-116.29	163.59	0.45
e/f	22.53	91.78	0.02

Table 30: regression formulae concerning relation between facial indices and age in males and females

Metrical assessment of 2D images

For what concerns the male subjects, the results of surface assessment with corresponding ratios are shown in Tables 31-34; for females, the results are shown in Tables 35-38.

Child n° 1 (pixels)	Dec. 2010	June 2011	Sept. 2011	Jan. 2012	June 2012	Sept. 2012
ex-en-ala dx (a)	12140	12635	24656	22602	5222	5468
ex-en-ala sin (a')	13040	13123	21480	26186	5400	6028
ex-en-ch dx (b)	21452	23494	39380	37296	8894	8936
ex-en-ch sin (b')	25659	22804	38138	39604	8252	9887
ex-ala-ch dx (c)	11499	13537	21629	23064	5949	5495
ex-ala ch sin (c')	12131	14394	24748	24694	5967	5913
ala-ala-se (d)	18042	20621	30850	28828	7000	7145
ch-ch-sn (e)	11317	16287	22036	22656	4269	4672
ch-ch-gn (f)	20496	29154	43264	46112	9460	9624
ex-ex-gn (g)	109332	138338	201379	200989	48230	48531
t-ex-ex (h)	67158	81701	143858	142640	28588	29484
¾ right profile						
ex-en-ala sin	15541	1158	21397	21658	6181	6716
ex-en-ch sin	28067	18329	37706	34828	11354	10318
ex-ala ch sin	21587	12795	29696	29568	8426	7946
¾ left profile						
ex-en-ala dx	12894	15940	31041	30279	6856	6494
ex-en-ch dx	25377	31754	45166	53994	10675	11374
ex-ala-ch dx	16532	19569	40238	37789	7266	8234

Results are in pixels

Frontal view	Dec. 2010	June 2011	Sept. 2011	Jan. 2012	June 2012	Sept. 2012
a/b	0.57	0.54	0.63	0.61	0.59	0.61
a/c	1.06	0.93	1.14	0.98	0.88	1.00
b/c	1.87	1.74	1.82	1.62	1.50	1.63
a'/b'	0.51	0.58	0.56	0.66	0.65	0.61
a'/c'	1.07	0.91	0.87	1.06	0.90	1.02
b'/c'	2.12	1.58	1.54	1.60	1.38	1.67
a/g	0.11	0.09	0.12	0.11	0.11	0.11
b/g	0.20	0.17	0.20	0.19	0.18	0.18
c/g	0.11	0.10	0.11	0.11	0.12	0.11
a'/g	0.12	0.09	0.11	0.13	0.11	0.12
b'/g	0.23	0.16	0.19	0.20	0.17	0.20
c'/g	0.11	0.10	0.12	0.12	0.12	0.12
d/g	0.17	0.15	0.15	0.14	0.15	0.15
e/g	0.10	0.12	0.11	0.11	0.09	0.10
f/g	0.19	0.21	0.21	0.23	0.20	0.20
h/g	0.61	0.59	0.71	0.71	0.59	0.61
e/f	0.55	0.56	0.51	0.49	0.45	0.49
¾ right profile						
a'/b'	0.72	0.09	0.72	0.73	0.73	0.85
a'/c'	0.72	0.09	0.72	0.73	0.73	0.85
b'/c'	1.30	1.43	1.27	1.18	1.35	1.30
¾ left profile						
a/b	0.51	0.50	0.69	0.56	0.64	0.57
a/c	0.78	0.81	0.77	0.80	0.94	0.79
b/c	1.54	1.62	1.12	1.43	1.47	1.38

Fig. 31: results of surface assessment from individual number 1

Child n° 2	Dec. 2010	June 2011	Sept. 2011	Jan. 2012	June 2012	Sept. 2012
ex-en-ala dx (a)	13011	15333	32330	27312	7002	7120
ex-en-ala sin (a')	12068	16929	30276	25670	6403	6475
ex-en-ch dx (b)	21305	27288	54550	46642	12404	11845
ex-en-ch sin (b')	19141	26608	51760	46237	12287	12160
ex-ala-ch dx (c)	12072	17814	32479	23133	7065	7831
ex-ala ch sin (c')	11393	14916	28256	24714	6479	6911
ala-ala-se (d)	17192	22202	41424	32662	8483	8000
ch-ch-sn (e)	7909	13966	25520	21461	6751	7268
ch-ch-gn (f)	18835	25840	45990	40292	12570	13209
ex-ex-gn (g)	101328	140191	266575	220933	61284	60806
t-ex-ex (h)	59946	70396	167411	146342	40604	41438
¾ right profile						
ex-en-ala sin	12847	14059	30564	28902	7596	7690
ex-en-ch sin	20666	25773	50570	56019	13187	13384
ex-ala ch sin	15556	19414	45932	45326	8807	9395
¾ left profile						
ex-en-ala dx	15379	14846	25711	27489	9231	10707
ex-en-ch dx	23889	26693	49140	54297	16407	17179
ex-ala-ch dx	15867	18156	48455	49542	12697	12413

Results are in pixels

Frontal view	Dec. 2010	June 2011	Sept. 2011	Jan. 2012	June 2012	Sept. 2012
a/b	0.61	0.56	0.59	0.59	0.56	0.60
a/c	1.08	0.86	1.00	1.18	0.99	0.91
b/c	1.76	1.53	1.68	2.02	1.76	1.51
a'/b'	0.63	0.64	0.58	0.56	0.52	0.53
a'/c'	1.06	1.13	1.07	1.04	0.99	0.94
b'/c'	1.68	1.78	1.83	1.87	1.90	1.76
a/g	0.13	0.11	0.12	0.12	0.11	0.12
b/g	0.21	0.19	0.20	0.21	0.20	0.19
c/g	0.12	0.13	0.12	0.10	0.12	0.13
a'/g	0.12	0.12	0.11	0.12	0.10	0.11
b'/g	0.19	0.19	0.19	0.21	0.20	0.20
c'/g	0.11	0.11	0.11	0.11	0.11	0.11
d/g	0.17	0.16	0.16	0.15	0.14	0.13
e/g	0.08	0.10	0.10	0.10	0.11	0.12
f/g	0.19	0.18	0.17	0.18	0.21	0.22
h/g	0.59	0.50	0.63	0.66	0.66	0.68
e/f	0.42	0.54	0.55	0.53	0.54	0.55
¾ right profile						
a'/b'	0.83	0.72	0.67	0.64	0.86	0.82
a'/c'	0.83	0.72	0.67	0.64	0.86	0.82
b'/c'	1.33	1.33	1.10	1.24	1.50	1.42
¾ left profile						
a/b	0.64	0.56	0.52	0.51	0.56	0.62
a/c	0.97	0.82	0.53	0.55	0.73	0.86
b/c	1.51	1.47	1.01	1.10	1.29	1.38

Fig. 32: results of surface assessment from individual number 2

Child n° 5	Dec. 2010	June 2011	Sept. 2011	Jan. 2012	June 2012	Sept. 2012
ex-en-ala dx (a)	7089	8123	51860	14432	5060	6727
ex-en-ala sin (a')	6332	7234	55082	13952	5815	6805
ex-en-ch dx (b)	11982	12123	95024	29264	9551	11557
ex-en-ch sin (b')	11510	12321	98938	28456	9478	11432
ex-ala-ch dx (c)	8059	9056	55846	16077	4630	6390
ex-ala ch sin (c')	6662	7200	55786	16489	5519	6302
ala-ala-se (d)	8810	89124	81546	18657	7276	10181
ch-ch-sn (e)	6957	7124	54529	18030	5579	7015
ch-ch-gn (f)	14216	15234	114861	32534	10317	11473
ex-ex-gn (g)	68095	69012	539192	153533	51191	62918
t-ex-ex (h)	38165	39234	238007	84732	25821	33748
¾ right profile						
ex-en-ala sin	8325	9243	50726	17704	6630	5852
ex-en-ch sin	16158	17132	101609	33136	12312	13212
ex-ala ch sin	10854	11233	72896	22864	9043	9500
¾ left profile						
ex-en-ala dx	6211	7245	66686	19756	6369	5751
ex-en-ch dx	11175	12045	121464	34035	12642	9452
ex-ala-ch dx	8383	9034	105732	22960	9524	7243

Results are in pixels

Frontal view	Dec. 2010	June 2011	Sept. 2011	Jan. 2012	June 2012	Sept. 2012
a/b	0.59	0.67	0.55	0.49	0.53	0.58
a/c	0.88	0.90	0.93	0.90	1.09	1.05
b/c	1.49	1.34	1.70	1.82	2.06	1.81
a'/b'	0.55	0.59	0.56	0.49	0.61	1.01
a'/c'	0.95	1.00	0.99	0.85	1.05	1.83
b'/c'	1.73	1.71	1.77	1.73	1.72	1.81
a/g	0.10	0.12	0.10	0.09	0.10	0.11
b/g	0.18	0.18	0.18	0.19	0.19	0.10
c/g	0.12	0.13	0.10	0.10	0.09	0.10
a'/g	0.09	0.10	0.10	0.09	0.11	0.18
b'/g	0.17	0.18	0.18	0.19	0.19	0.18
c'/g	0.10	0.10	0.10	0.11	0.11	0.10
d/g	0.13	1.29	0.15	0.12	0.14	0.16
e/g	0.10	0.10	0.10	0.12	0.11	0.11
f/g	0.21	0.22	0.21	0.21	0.20	0.18
h/g	0.56	0.57	0.44	0.55	0.50	0.54
e/f	0.49	0.47	0.47	0.55	0.54	0.61
¾ right profile						
a'/b'	0.77	0.82	0.70	0.77	0.73	0.62
a'/c'	0.77	0.82	0.70	0.77	0.73	0.62
b'/c'	1.49	1.53	1.39	1.45	1.36	1.39
¾ left profile						
a/b	0.56	0.60	0.55	0.58	0.50	0.61
a/c	0.74	0.80	0.63	0.86	0.67	0.79
b/c	1.33	1.33	1.15	1.48	1.33	1.30

Fig. 33: results of surface assessment from individual number 5

Child n° 7	Dec. 2010	June 2011	Sept. 2011	Jan. 2012	June 2012	Sept. 2012
ex-en-ala dx (a)	6475	5624	5720	24554	6173	6232
ex-en-ala sin (a')	8112	6200	7340	27120	6229	6412
ex-en-ch dx (b)	14746	10197	11022	44925	11256	12345
ex-en-ch sin (b')	12396	9614	10112	46242	11077	12342
ex-ala-ch dx (c)	9665	5759	5967	30063	5825	6213
ex-ala ch sin (c')	9938	7198	8123	28115	6997	7112
ala-ala-se (d)	12125	8378	8541	35664	8851	8923
ch-ch-sn (e)	8394	5511	6512	32052	4642	5231
ch-ch-gn (f)	15357	9566	10002	44400	9217	10123
ex-ex-gn (g)	78729	53496	54963	245267	60549	61232
t-ex-ex (h)	32053	33737	35434	130362	30829	31256
¾ right profile						
ex-en-ala sin	8022	5940	6120	26324	6289	6800
ex-en-ch sin	16005	11996	12324	48528	11722	12324
ex-ala ch sin	12420	10215	11236	43703	8839	91201
¾ left profile						
ex-en-ala dx	9893	5303	5600	25377	6782	7120
ex-en-ch dx	15688	9469	10213	44214	12381	13214
ex-ala-ch dx	13665	9394	10234	36831	8739	89123

Results are in pixels

Frontal view	Dec. 2010	June 2011	Sept. 2011	Jan. 2012	June 2012	Sept. 2012
a/b	0.44	0.55	0.52	0.55	0.55	0.50
a/c	0.67	0.98	0.96	0.82	1.06	1.00
b/c	1.53	1.77	1.85	1.49	1.93	1.99
a'/b'	0.65	0.64	0.73	0.59	0.56	0.52
a'/c'	0.82	0.86	0.90	0.96	0.89	0.90
b'/c'	1.25	1.34	1.24	1.64	1.58	1.74
a/g	0.08	0.11	0.10	0.10	0.10	0.10
b/g	0.19	0.19	0.20	0.18	0.19	0.20
c/g	0.12	0.11	0.11	0.12	0.10	0.10
a'/g	0.10	0.12	0.13	0.11	0.10	0.10
b'/g	0.16	0.18	0.18	0.19	0.18	0.20
c'/g	0.13	0.13	0.15	0.11	0.12	0.12
d/g	0.15	0.16	0.16	0.15	0.15	0.15
e/g	0.11	0.10	0.12	0.13	0.08	0.09
f/g	0.20	0.18	0.18	0.18	0.15	0.17
h/g	0.41	0.63	0.64	0.53	0.51	0.51
e/f	0.55	0.58	0.65	0.72	0.50	0.52
¾ right profile						
a'/b'	0.65	0.58	0.54	0.60	0.71	0.07
a'/c'	0.65	0.58	0.54	0.60	0.71	0.07
b'/c'	1.29	1.17	1.10	1.11	1.33	0.14
¾ left profile						
a/b	0.63	0.56	0.55	0.57	0.55	0.54
a/c	0.72	0.56	0.55	0.69	0.78	0.08
b/c	1.15	1.01	1.00	1.20	1.42	0.15

Fig. 34: results of surface assessment from individual number 7

Child n° 3	Dec. 2010	June 2011	Sept. 2011	Jan. 2012	June 2012	Sept. 2012
ex-en-ala dx (a)	6507	5880	21292	22300	16590	9604
ex-en-ala sin (a')	6647	5465	20864	21060	19992	9270
ex-en-ch dx (b)	12156	10276	39699	38777	32736	16614
ex-en-ch sin (b')	12613	9708	39858	36888	34794	16580
ex-ala-ch dx (c)	5882	6343	21833	21855	16716	9695
ex-ala ch sin (c')	7599	5510	24660	26000	20104	9339
ala-ala-se (d)	10393	7460	27295	28675	24918	13966
ch-ch-sn (e)	5635	4266	19504	20045	18749	9314
ch-ch-gn (f)	13497	8993	34963	36045	31608	15480
ex-ex-gn (g)	68391	54580	210576	221056	180576	87188
t-ex-ex (h)	56644	41092	155597	164822	136964	63257
¾ right profile						
ex-en-ala sin	7216	8017	18680	19004	14825	9653
ex-en-ch sin	13503	15214	34743	35762	33602	18275
ex-ala ch sin	10260	9935	27685	28635	22898	15038
¾ left profile						
ex-en-ala dx	7060	10662	21550	22542	18896	9551
ex-en-ch dx	12409	16542	44880	45823	35120	16700
ex-ala-ch dx	12196	11477	27632	29211	20729	10407

Results are in pixels

Frontal view	Dec. 2010	June 2011	Sept. 2011	Jan. 2012	June 2012	Sept. 2012
a/b	0.54	0.57	0.54	0.58	0.51	0.58
a/c	1.11	0.93	0.98	1.02	0.99	0.99
b/c	2.07	1.62	1.82	1.77	1.96	1.71
a'/b'	0.53	0.56	0.52	0.57	0.57	0.56
a'/c'	0.87	0.99	0.85	0.81	0.99	0.99
b'/c'	1.66	1.76	1.62	1.42	1.73	1.78
a/g	0.10	0.11	0.10	0.10	0.09	0.11
b/g	0.18	0.19	0.19	0.18	0.18	0.19
c/g	0.09	0.12	0.10	0.10	0.09	0.11
a'/g	0.10	0.10	0.10	0.10	0.11	0.11
b'/g	0.18	0.18	0.19	0.17	0.19	0.19
c'/g	0.11	0.10	0.12	0.12	0.11	0.11
d/g	0.15	0.14	0.13	0.13	0.14	0.16
e/g	0.08	0.08	0.09	0.09	0.10	0.11
f/g	0.20	0.16	0.17	0.16	0.18	0.18
h/g	0.83	0.75	0.74	0.75	0.76	0.73
e/f	0.42	0.47	0.56	0.56	0.59	0.60
¾ right profile						
a'/b'	0.70	0.81	0.67	0.66	0.65	0.64
a'/c'	0.70	0.81	0.67	0.66	0.65	0.64
b'/c'	1.32	1.53	1.25	1.25	1.47	1.22
¾ left profile						
a/b	0.57	0.64	0.48	0.49	0.54	0.57
a/c	0.58	0.93	0.78	0.77	0.91	0.92
b/c	1.02	1.44	1.62	1.57	1.69	1.60

Fig. 35: results of surface assessment from individual number 3

Child n° 4	Dec. 2010	June 2011	Sept. 2011	Jan. 2012	June 2012	Sept. 2012
ex-en-ala dx (a)	6042	4484	21406	22354	12600	18363
ex-en-ala sin (a')	7299	3885	18983	19456	11360	18096
ex-en-ch dx (b)	12238	7957	36988	37643	22776	33345
ex-en-ch sin (b')	12289	7128	35601	36022	21945	32115
ex-ala-ch dx (c)	5839	4009	19339	20122	12244	16641
ex-ala ch sin (c')	6733	3456	20965	21365	11062	16860
ala-ala-se (d)	9317	5831	27591	28655	20301	27165
ch-ch-sn (e)	7190	4553	23241	24231	12428	19341
ch-ch-gn (f)	11738	6355	35927	36743	22890	38031
ex-ex-gn (g)	61812	38409	202445	210122	119866	167982
t-ex-ex (h)	41063	23603	136773	143022	80392	85980
¾ right profile						
ex-en-ala sin	6296	6294	21260	22345	11735	15651
ex-en-ch sin	11931	10709	34433	35467	21713	28951
ex-ala ch sin	8161	6895	31806	32023	15773	24012
¾ left profile						
ex-en-ala dx	7711	5529	17386	18523	10337	18854
ex-en-ch dx	13938	8262	36256	37623	20589	35486
ex-ala-ch dx	8647	5675	26688	27823	14726	25309

Results are in pixels

Frontal view	Dec. 2010	June 2011	Sept. 2011	Jan. 2012	June 2012	Sept. 2012
a/b	0.49	0.56	0.58	0.59	0.55	0.55
a/c	1.03	1.12	1.11	1.11	1.03	1.10
b/c	2.10	1.98	1.91	1.87	1.86	2.00
a'/b'	0.59	0.55	0.53	0.54	0.52	0.56
a'/c'	1.08	1.12	0.91	0.91	1.03	1.07
b'/c'	1.83	2.06	1.70	1.69	1.98	1.90
a/g	0.10	0.12	0.11	0.11	0.11	0.11
b/g	0.20	0.21	0.18	0.18	0.19	0.20
c/g	0.09	0.10	0.10	0.10	0.10	0.10
a'/g	0.12	0.10	0.09	0.09	0.09	0.11
b'/g	0.20	0.19	0.18	0.17	0.18	0.19
c'/g	0.11	0.09	0.10	0.10	0.09	0.10
d/g	0.15	0.15	0.14	0.14	0.17	0.16
e/g	0.12	0.12	0.11	0.12	0.10	0.12
f/g	0.19	0.17	0.18	0.17	0.19	0.23
h/g	0.66	0.61	0.68	0.68	0.67	0.51
e/f	0.61	0.72	0.65	0.66	0.54	0.51
¾ right profile						
a'/b'	0.77	0.91	0.67	0.70	0.74	0.65
a'/c'	0.77	0.91	0.67	0.70	0.74	0.65
b'/c'	1.46	1.55	1.08	1.11	1.38	1.21
¾ left profile						
a/b	0.55	0.67	0.48	0.49	0.50	0.53
a/c	0.89	0.97	0.65	0.67	0.70	0.74
b/c	1.61	1.46	1.36	1.35	1.40	1.40

Fig. 36: results of surface assessment from individual number 4

Child n° 6	Dec. 2010	June 2011	Sept. 2011	Jan. 2012	June 2012	Sept. 2012
ex-en-ala dx (a)	6174	6342	45992	14958	8228	7312
ex-en-ala sin (a')	6417	6645	44102	14084	7864	8054
ex-en-ch dx (b)	12505	13245	88869	25191	14476	14436
ex-en-ch sin (b')	11816	12832	90720	27243	13143	15016
ex-ala-ch dx (c)	6466	6503	62440	14257	11452	7412
ex-ala ch sin (c')	7578	7623	60582	15978	8446	8282
ala-ala-se (d)	9583	9623	71634	22000	13323	12170
ch-ch-sn (e)	6306	6593	59526	14810	9711	9151
ch-ch-gn (f)	12377	13245	99900	24638	15157	14281
ex-ex-gn (g)	62820	63452	512562	143354	83404	76261
t-ex-ex (h)	40830	41234	319017	91728	51592	49932
¾ right profile						
ex-en-ala sin	7564	8023	57831	15026	8412	9473
ex-en-ch sin	15308	16309	102096	31184	19037	17813
ex-ala ch sin	13556	14324	68946	24234	13530	15702
¾ left profile						
ex-en-ala dx	7250	8234	73194	17824	11169	10730
ex-en-ch dx	14292	15342	128043	33836	18393	19168
ex-ala-ch dx	9630	9760	100969	33121	15274	13983

Results are in pixels

Frontal view	Dec. 2010	June 2011	Sept. 2011	Jan. 2012	June 2012	Sept. 2012
a/b	0.49	0.48	0.52	0.59	0.57	0.51
a/c	0.95	0.98	0.74	1.05	0.72	0.99
b/c	1.93	2.04	1.42	1.77	1.26	1.95
a'/b'	0.54	0.52	0.49	0.52	0.60	0.54
a'/c'	0.85	0.87	0.73	0.88	0.93	0.97
b'/c'	1.56	1.68	1.50	1.71	1.56	1.81
a/g	0.10	0.10	0.09	0.10	0.10	0.10
b/g	0.20	0.21	0.17	0.18	0.17	0.19
c/g	0.10	0.10	0.12	0.10	0.14	0.10
a'/g	0.10	0.10	0.09	0.10	0.09	0.11
b'/g	0.19	0.20	0.18	0.19	0.16	0.20
c'/g	0.12	0.12	0.12	0.11	0.10	0.11
d/g	0.15	0.15	0.14	0.15	0.16	0.16
e/g	0.10	0.10	0.12	0.10	0.12	0.12
f/g	0.20	0.21	0.19	0.17	0.18	0.19
h/g	0.65	0.65	0.62	0.64	0.62	0.65
e/f	0.51	0.50	0.60	0.60	0.64	0.64
¾ right profile						
a'/b'	0.56	0.56	0.84	0.62	0.62	0.60
a'/c'	0.56	0.56	0.84	0.62	0.62	0.60
b'/c'	1.13	1.14	1.48	1.29	1.41	1.13
¾ left profile						
a/b	0.51	0.54	0.57	0.53	0.61	0.56
a/c	0.75	0.84	0.72	0.54	0.73	0.77
b/c	1.48	1.57	1.27	1.02	1.20	1.37

Fig. 37: results of surface assessment from individual number 6

Child n° 8	Dec. 2010	June 2011	Sept. 2011	Jan. 2012	June 2012	Sept. 2012
ex-en-ala dx (a)	7772	7821	7901	29129	4947	10313
ex-en-ala sin (a')	7932	8013	8103	31654	5855	10916
ex-en-ch dx (b)	14737	15323	16241	56990	9315	20046
ex-en-ch sin (b')	14797	15342	16243	55194	10030	20624
ex-ala-ch dx (c)	8131	8234	8521	30045	5605	10253
ex-ala ch sin (c')	10219	11254	12315	36192	5403	11701
ala-ala-se (d)	12313	13125	14127	43879	7654	15076
ch-ch-sn (e)	10502	11254	12832	33993	5593	12813
ch-ch-gn (f)	19945	20154	21011	53346	10231	18996
ex-ex-gn (g)	78740	80364	81046	281306	48668	101178
t-ex-ex (h)	56808	57213	58143	204563	30767	72983
¾ right profile						
ex-en-ala sin	5774	5921	6032	34044	5326	7664
ex-en-ch sin	11718	12612	13912	64257	9677	14860
ex-ala ch sin	11553	12514	13100	51121	7155	13030
¾ left profile						
ex-en-ala dx	7871	7912	8013	40692	7077	6446
ex-en-ch dx	12556	13712	14701	65058	13032	13744
ex-ala-ch dx	8656	9012	9102	43101	7791	10319

Results are in pixels

Frontal view	Dec. 2010	June 2011	Sept. 2011	Jan. 2012	June 2012	Sept. 2012
a/b	0.53	0.51	0.49	0.51	0.53	0.51
a/c	0.96	0.95	0.93	0.97	0.88	1.01
b/c	1.81	1.86	1.91	1.90	1.66	1.96
a'/b'	0.54	0.52	0.50	0.57	0.58	0.53
a'/c'	0.78	0.71	0.66	0.87	1.08	0.93
b'/c'	1.45	1.36	1.32	1.53	1.86	1.76
a/g	0.10	0.10	0.10	0.10	0.10	0.10
b/g	0.19	0.19	0.20	0.20	0.19	0.20
c/g	0.10	0.10	0.11	0.11	0.12	0.10
a'/g	0.10	0.10	0.10	0.11	0.12	0.11
b'/g	0.19	0.19	0.20	0.20	0.21	0.20
c'/g	0.13	0.14	0.15	0.13	0.11	0.12
d/g	0.16	0.16	0.17	0.16	0.16	0.15
e/g	0.13	0.14	0.16	0.12	0.11	0.13
f/g	0.25	0.25	0.26	0.19	0.21	0.19
h/g	0.72	0.71	0.72	0.73	0.63	0.72
e/f	0.53	0.56	0.61	0.64	0.55	0.67
¾ right profile						
a'/b'	0.50	0.47	0.46	0.67	0.74	0.59
a'/c'	0.50	0.47	0.46	0.67	0.74	0.59
b'/c'	1.01	1.01	1.06	1.26	1.35	1.14
¾ left profile						
a/b	0.63	0.58	0.55	0.63	0.54	0.47
a/c	0.91	0.88	0.88	0.94	0.91	0.62
b/c	1.45	1.52	1.62	1.51	1.67	1.33

Fig. 38: results of surface assessment from individual number 8

The values of correlation index for all the ratios are shown in Table 39.

	Males				Females			
Frontal	**80-101**	**102-123**	**123-144**	**131-152**	**72-93**	**86-107**	**108-129**	**119-140**
a/b	0.54	0.50	-0.22	-0.42	0.07	0.09	0.45	0.48
a/c	-0.42	0.71	-0.17	**0.84**	0.07	-0.37	0.12	-0.14
b/c	**-0.84**	0.66	-0.10	**0.80**	0.02	-0.30	-0.56	-0.34
a'/b'	**0.80**	**-0.76**	**-0.93**	0.63	0.38	0.63	-0.52	0.35
a'/c'	-0.13	0.62	**-0.80**	0.63	**0.72**	0.40	-0.18	0.62
b'/c'	-0.66	**0.88**	0.56	0.48	**0.79**	0.14	0.11	0.49
a/g	0.19	0.59	-0.39	-0.24	0.69	0.21	0.27	0.00
b/g	-0.22	0.26	-0.40	-0.49	0.49	0.28	-0.24	-0.53
c/g	**0.74**	-0.67	-0.01	**-0.75**	0.35	0.28	0.30	0.22
a'/g	0.35	-0.22	**-0.87**	**0.70**	**0.71**	**0.70**	-0.43	-0.02
b'/g	-0.36	**0.88**	**0.70**	**0.77**	**0.90**	0.28	-0.30	-0.27
c'/g	**0.71**	-0.55	0.07	0.41	-0.63	0.06	-0.37	**-0.87**
d/g	**-0.79**	**-0.81**	**-1.00**	-0.31	-0.42	0.15	0.45	0.54
e/g	-0.57	-0.48	**0.93**	0.66	-0.50	0.91	-0.53	**0.78**
f/g	0.11	-0.86	**0.73**	**-0.72**	**-0.82**	-0.35	0.59	-0.60
h/g	-0.06	0.52	**0.73**	-0.23	-0.39	-0.75	-0.47	-0.21
e/f	**-0.87**	-0.20	0.69	**0.83**	0.64	**0.95**	-0.67	**0.91**
3/4 right								
a'/b'	0.43	-0.53	0.19	-0.65	0.69	-0.64	-0.54	0.09
a'/c'	0.43	-0.53	0.19	-0.65	0.69	-0.64	-0.54	0.09
b'/c'	-0.16	-0.60	0.45	**-0.76**	**0.72**	-0.21	-0.45	0.24
3/4 left								
a/b	0.45	**-0.79**	-0.14	-0.01	**-0.73**	-0.22	-0.41	0.68
a/c	0.43	-0.49	-0.26	0.05	-0.55	**0.70**	-0.60	-0.20
b/c	-0.26	-0.40	-0.28	0.09	-0.06	**0.82**	**-0.70**	-0.50

Table 39: values of correlation index (C.I.) shown by the ratios between facial surfaces taken in photos

The following tables show the regression formulae and correspondent r^2 values for ratios between surfaces measured on photo; both the number and the r^2 values decrease in comparison with the same parameters measured on 3D scans. For males, a′/c′, b′/c′ and c′/g show the highest values, although in all cases r^2 values are lower than 0.3. For females, h/g preserves the higher r^2 value, followed by c′/g.

Males	m	b	r^2
a/b	102.70	64.21	0.11
a/c	8.93	114.19	0.00
b/c	-16.76	140.76	0.03
a'/b'	-55.96	151.87	0.05
a'/c'	27.44	98.51	0.06
b'/c'	32.55	74.44	0.19
a/g	104.11	112.66	0.00
b/g	-219.15	149.09	0.03
c/g	50.22	114.68	0.00
a'/g	-120.41	129.08	0.00
b'/g	272.72	84.24	0.04
c'/g	-313.19	150.41	0.07
d/g	143.04	90.63	0.03
e/g	31.12	117.02	0.00
f/g	-480.51	184.86	0.21
h/g	-115.25	164.48	0.19
e/f	32.00	95.77	0.10

Females	m	b	r^2
a/b	108.29	48.73	0.47
a/c	64.13	65.46	0.25
b/c	-65.40	186.91	0.18
a'/b'	147.71	33.84	0.14
a'/c'	112.97	32.38	0.20
b'/c'	26.93	71.41	0.03
a/g	864.47	44.94	0.40
b/g	-199.07	134.29	0.03
c/g	200.12	84.98	0.03
a'/g	416.09	77.35	0.08
b'/g	93.90	93.81	0.01
c'/g	63.53	100.51	0.00
d/g	-80.28	124.26	0.01
e/g	-77.12	115.29	0.00
f/g	-302.98	152.68	0.09
h/g	-116.29	163.59	0.45
e/f	22.53	91.78	0.02

Table 40: regression formulae concerning relation between facial indices and age in males and females on 2D images

Discussion

The present study first aimed at verifying the correlation between facial surfaces and age in vivo (using 3D facial scans as a proxy) and in photos, but the experimental project provided relevant information concerning different aspects of facial anatomy and forensic anthropology.

First, the results of metrical assessment in vivo need to be adequately discussed; the analysis of facial surfaces pointed out that the increase of surfaces do not show a progressive trend with time. In detail, every metrical parameter show a correlation with age only in specific ages. This indicates that the modification of facial surfaces is affected by other variables in specific periods; in other words, the same trend observed in the case of linear measurements which are characterized by limited periods of time where the growth increases. However, for what concerns linear measurements, a genetic program probably causes these irregular trends, whereas in the case of facial surfaces the existence of a rationale is still to explore. In detail, the observed modifications may be due to the influence of the environmental and individual factors, whose influence is still to study.

Another interesting information deriving from the analysis of facial surfaces in vivo is the general lack of symmetry in growth both for males and females: in detail, the paired metrical parameters do not show a parallel modification, and the chromatic analysis of facial modifications clearly shows that children faces change asymmetrically. This is a relevant information, since it confirms the general knowledge concerning the asymmetry of facial measurements (86,87). The asymmetry was face is well known, and is observed both in adults and children: the actual study points out indication that also the facial growth follows the same asymmetry. As a consequence, the asymmetry of facial measurements may include also the growth processes, with relevant consequences from a forensic point of view, since this means that the left and right parameters may differ, as well as the final age estimation. From this point of view, the actual study points out important indications for a deeper analysis of the phenomenon of the facial growth.

For what concerns the general correlation of facial indices with age, a strong difference was observed between males and females: in detail, in males only one parameter (f/g) shows a r^2 higher than 0.2, whereas in females three characteristics are between 0.4 and 0.47 (a/b, a/g and h/g); this seems to suggest that the female faces between 6 and 10 years show a higher correlation with age than the male ones. However, also for females the r^2 value is limited and does not reach 0.5. These data clearly indicates that only a part of the entire surface modification is due to age, whereas the larger part is caused by other variables, not completely unknown.

The passage to the 2D images provides the most interesting information: in most of cases, the facial parameters with a correlation with age in vivo do not show the same relation in photo; it is the case of a/b, f/g, h/g and e/f in males, and a/b, a/c, a'/b', a/g and a'/c' in females. For other parameters, the correlation decreases passing from the analysis in vivo to the photos (b'/c' in males, a'/c' in females). These two situations are expected, since the photograph adds a number of variables which partecipate in reducing the correlation between the measurement and the age. However, the most interesting data concern some parameters which conserve a similar relation with age in vivo and in photo, i.e. h/g and a'/c' in females; in addition, some characteristics show a higher r^2 value in photos than in vivo (for example, a'/c' in males, and b'/c', c'/g and f/g in females. In other words, some facial parameters are more easily related with age in photo than in vivo. This is an interesting phenomenon, not observed in linear measurements, which opens new perspectives to age estimation on 2D images. In detail, the results of the study seem to show that some parameters are more related with age if measured in photo than in vivo; from a general point of view, the correlation between measurements taken in vivo and in photo is secondary, since in both the case such measurements show a variable relation with age.

However, the correlation of such measurements with age is limited: the highest values of r^2 amounts up to 0.40, i.e. the age explains only 40% of the modifications shown by the chosen parameter. This values are far from those shown by other biological data in forensic anthropology (for example, the relation between height and long bones length), and even lower than the indications shown by the analysis of linear parameters in photos. This clearly shows that the analysis of facial surfaces does not provide enough reliability for an age estimation procedure in comparison with linear measurements: the low values of regression may be explained by the limited number of partecipant to the experiment, and therefore the widening of the sample may give more precise information. On the other hand the real facial surfaces may be influenced by different variables than age: for example, the chromatic analysis pointed out that even limited modifications of the facial expression may radically influence the facial surfaces; this clearly means that more research is needed in order to ascertain the importance of facial surfaces assessment, which may be useful in other fields.

From this point of view, further studies are needed in order to ascertain the importance of facial surfaces in the forensic field.

5. Discussion of the results

The research field of age estimation from 2D images brings about relevant problems, both from a practical and methodological point of view. The practical limits deal with the scarce data which can be obtained by the 2D image, where only the planar projections of 3D structure can be defined. This necessarily requires a correction which takes the modification of metrical characteristics of face with the variable positions in consideration. This means that very few biological markers can be used for age estimation; face may provide useful information, but the potential of facial assessment has still to explore, although different articles show that it is a promising method. The lack of a scientifically valid method is the real limit affecting the issue of age estimation from photos, since this gap allows different professional figures (sometimes without any scientific background) to provide expert witness concerning this sensitive topic, with obvious consequences on the ascertainment of the crime and the charged subject. This is a different and somehow new situation in forensic anthropology, which is to become more and more frequent in the future, with the widening of applications on the living.

This thesis aimed at exposing different studies, performed in vivo, in photos and in 3D models (that mimic in vivo assessments), which focus on the common attempt at verifying the existence of the correlation between different types of facial measurements and age. This path led to interesting results which may be sumed up in the following points:

1) the study performed on facial landmarks showed that not all the points are reliable for a standardized procedure of facial assessment: in detail, the anatomical landmarks are the most trustable, probably because are defined by anatomical structures which can be easily detected, and are consequently less subjective. More interestingly, such landmarks show the same reliability in photos taken from subjects with different ages, and this means that anatomical points are crucial also for the issue of age estimation from 2D images;
2) the second study pointed out that ratios between linear measurements show a correlation with age also in photos, and therefore may be used for age estimation,

although with a high error range, and only taking into consideration the main age thresholds; from this point of view, such parameters may provide a method for verifying if a subject is close to one of the chosen age limits, but data are too limited to provide adequate regression formulae useful to put in relation age and measurements. However, these results represent the first step for the development of an age estimation method useful for reconstructing age with higher precision;

3) the third study confirmed that some linear measurements show a correlation with age which may be promising for the development of regression formulae useful for age estimation in photos; however, the error range is estimated in 3-4 years, which means that age may be reconstructed in an interval of several years: however, this error range matches with difficulties to the actual forensic purposes, where an age estimation with a more limited error is often requested; the need for the search for new facial parameters is therefore even more evident;
4) the fourth study attempted at verifying the modifications of facial parameters in juvenile adults and subjects in transition phase, and pointed out that ear and mouth show a constant increase also after 18 years; from a general point of view, the parameters which are related with age in vivo should show the same relation also in photos, and therefore may be useful for age estimation;
5) the fifth study focused on verifying the applicability of ear characteristics to age estimation in photos: results show that neither the ratios between linear measurements nor the areas show a correlation with age; these results therefore confirm that photograph is an independent manner of acquisition of reality, with its own rules and relations between facial parameters and age, which not necessarily correspond to those observed in vivo. These results mean that the relation of facial parameters should be verified directly in photos, and underline the need for determining new facial measurements useful for forensic purposes;
6) the last study aimed at verifying the relation of a novel facial parameter (in detail, facial surfaces) with age; results show that the correlation are lower than those showed by linear measurements: the analysis performed in photos confirmed the independence of measurements taken in photos and in vivo (actually, on the digital 3D models of the face), since some parameters are related with age in vivo, not in photos, and vice versa. Anyway, facial surfaces are too variable and are influenced

by too many environmental and individual factors to be usable for the development of an age estimation method.

In conclusion, facial metrical assessment actually cannot be considered a scientifically valid method for forensic purposes: in detail, linear measurements have been widely explored by past literature which showed their constant modification with age. However, this information finds a limited importance in forensic practice, and is affected by a relevant limit in 2D images, which deals with the distorsion of measurements in two dimensions. The introduction of the new 3D acquisition systems now allows the operators to perform a more detailed analysis of face by the measurements of surfaces and volumes; however, literature concerning this topic is still at the beginning, and mainly deals with geometrical measurements which are more standardized, but also more influenced by other variability factors than age, such as the weight, etc. From this point of view, the analysis of surfaces and volumes adds precious information to the morphology of face, and it will be one of the main field of research of the modern anatomy.

6. Conclusions

The studies performed in this PhD courses underline relevant information for what concerns the issues of age estimation and give some useful suggestion for analysis of facial anatomy; from a forensic point of view, the age estimation on photo proved to be possible, although there is need for further research concerning the relation between linear and surface parameters, and age. In detail, for the forensic purposes the photographs seem to be a different method of acquisition of the image, and therefore the relations of facial parameters with age are different from those observed in vivo. This means that there is no need to ascertain the existence of such relation in vivo, since the same measurements may show a different trend. This opens new chances to the attempts at standardizing new method based on photos. From a practical point of view, linear measurements are more reliable for age estimation than surface assessment; this may prove that the geometrical faces are more related with age, whereas the characteristics of facial surfaces are more influenced by environmental variables (for example, the facial expression, the weight, and so on). From this point of view, the facial surfaces do not show to be useful for age estimation, although a limited relation with age was ascertained. More research are needed in order to verify further chances for such parameters to be applied to the forensic context.

From the anatomical point of view, the experimental project pointed out relevant suggestions for different issues: in detail, the chromatic analysis of facial modifications may provide a new useful tool for standardizing and quantifiying variables such as increasing or decreasing of weight, the influence of facial expressions, the resemblance of children with their parents. The application of modern 3D image acquisition system may therefore radically improve the anatomical study of faces, adding new information potentially useful also for clinical purposes.

7. References

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