Forensic Science International 204 (2010) 205.e1–205.e9

Contents lists available at ScienceDirect

Forensic Science International

journal homepage: www.elsevier.com/locate/forsciint

Forensic Anthropology Population Data

# Age- and sex-related changes in the normal human external nose

Chiarella Sforza *, Gaia Grandi, Marcio De Menezes, Gianluca M. Tartaglia, Virgilio F. Ferrario

*Functional Anatomy Research Center (FARC), Laboratorio di Anatomia Funzionale dell'Apparato Stomatognatico (LAFAS), Dipartimento di Morfologia Umana e Scienze Biomediche "Città Studi", Facoltà di Medicina e Chirurgia, Università degli Studi di Milano, via Mangiagalli 31, I-20133 Milano, Italy*

ARTICLE INFO

*Article history:*
Received 22 November 2009
Received in revised form 5 June 2010
Accepted 18 July 2010
Available online 21 August 2010

*Keywords:*
Digital anthropometry
Forensic anthropology
Nose
Man
Growth
Aging
Forensic Anthropology Population Data

ABSTRACT

The objective of this study was to measure: (1) normal sex-related dimensions of external nose (linear distances, ratios, angles, volume and surface area); and (2) growth changes between childhood and old age. The three-dimensional coordinates of several soft-tissue landmarks on the external nose were obtained by a non-invasive, computerized digitizer in 519 male and 340 female healthy subjects aged 4–73 years. The subjects were divided into 11 non-overlapping age groups: for children and preadolescent subjects, 2-year spans were used, while larger intervals were used for adolescent and adult subjects. From the landmarks, nasal volume and external surface area; nasal and alar base widths, nasal height, nasal bridge length, philtrum length, nasal tip protrusion, right and left nostril lengths, superior and inferior nostril widths; nasal tip protrusion-to-nasal height, and nasal width-to-nasal height ratios; nasal convexity, alar slope, and nasal tip angles were calculated, and averaged for age and sex. Comparisons were performed by factorial analysis of variance. On average, men had larger nasal external volume and area, linear distances and nasal width-to-height ratio than women ($p < 0.01$); no sex differences were found for the angles and the nasal tip protrusion-to-nasal height ratio. Age significantly influenced all analyzed measurements ($p < 0.001$): nasal volume, area, linear distances increased from childhood to old age, while the nasal tip angle decreased as a function of age. No consistent age related patterns were found for the ratios and the nasal convexity and alar slope angles. Men and women had different age related patterns, with significant sex by age interactions ($p < 0.001$). Overall, in most occasions male increments in nasal dimensions were larger than female ones. Data collected in the present investigation could serve as a database for the quantitative description of human nasal morphology during normal growth, development and aging. Forensic applications (evaluations of traumas, craniofacial alterations, teratogenic-induced conditions, facial reconstruction, aging of living and dead persons, personal identification) may also benefit from age and sex based data banks.



## 1. Introduction

The external nose is one of the body structures that continue to modify and enlarge throughout life, well beyond the attainment of skeletal maturity. As shown by both cross-sectional and longitudinal studies, older people tend to possess bigger noses than younger people of the same sex and ethnic group [1–3].

Pre- and postnatal abnormalities in nose dimensions and shape can be found in several genetic and acquired alterations. Individuals with Down's syndrome have frequent prenatal ultrasonographic findings of nasal bone absence or hypoplasia, coupled with a flat facial profile [4–8]. This underdevelopment of the nasal region remains after birth, and individuals with Down's syndrome are characterized by a hypoplasic maxillary region, with reduced vertical, lateral and anteroposterior dimensions. Their nose is smaller than in reference subjects, and it has a different shape [9–11].

A defective nasal growth, associated with a general underdevelopment of the facial middle third, is also found in individuals with cleft lip [12–14]. Individuals with hypohidrotic ectodermal dysplasia have maxillary hypoplasia and a narrow and short nose [15].

Therefore, knowledge of the normal nasal dimensions and shape is necessary for the timing of surgical reconstructions [13,14,16–20]. Sex, age and ethnicity related data banks may therefore be produced, supplying reference information for multiple diagnostic, clinical and forensic procedures (aging of both living and dead persons, personal identification, facial reconstruction) [21–30].

In the field of facial reconstruction, a good approximation of nasal morphology is particularly important for profile or three-quarter views, even if no current method seems to produce sufficiently accurate estimates [25,31]. From this point of view, knowledge of the developmental patterns of the various nasal

* Corresponding author. Tel.: +39 02 503 15407; fax: +39 02 503 15387.
*E-mail address:* chiarella.sforza@unimi.it (C. Sforza).

0379-0738/$ – see front matter © 2010 Elsevier Ireland Ltd. All rights reserved.
doi:10.1016/j.forsciint.2010.07.027

dimensions, even after the attainment of biological maturity, may provide further help to forensic anthropologists [1,29,30,32,33].

In living persons, personal identification greatly depends on facial characteristics [28]: the definition of age, sex and ethnicity specific data banks for each facial feature is the first step to detect those individual traits that best discriminate between persons [22,24]. Furthermore, age related facial dimensions may help in the aging of victims from pedo-pornography [34].

Sex and age related variations in the nasal region are particularly important when considering the functional, social and esthetic role played by the facial soft tissues [20,23,29,32,35–41]. For instance, reference data are necessary for surgeons treating facial deformities: diagnosis and treatment should obtain harmonious facial characteristics concurring to a sound functionality [12,13,15–20,23,32,39,41,42].

Overall, quantitative data on the age-related changes in nasal dimensions during growth, development and aging have been reported for several Caucasoid subgroups: children, adolescents, and adults of central European descent [3], Dutch children and adolescents [40], English children and adolescents [42], Italian children, adolescents and adults [1,43], North American children, adolescents and young adults [16,29,39,44], and Turkish adults [38,45]. Reports on other ethnic groups can also be found: Afroamerican women [46], Chilean adults [41], Chinese adults [18,36], Indian infant boys and girls [47], Iranian women [23], Japanese children [19], and Malaysian adults [48] have been investigated in the last 10 years.

Despite several studies on the topic, no comprehensive data on Caucasoids exist: the two most complete reports focused only on three linear dimensions measured from birth and 97 years of age [3], or assessed linear distances and angles only for the first three decades of postnatal life [44]. As a matter of fact, in contemporary western society, not only is the number of elderly increasing, but also forensic investigations are currently performed on a wider age range than before, thus needing new reference data on each ethnic group.

In the current study, information about: (1) normal sex-related dimensions of external nose (linear distances, ratios, angles, volume and surface area); and (2) growth changes between childhood and old age, were provided. Data were collected non-invasively using digital anthropometry in healthy Italian Caucasoids aged 4–73 years.

## 2. Materials and methods

### 2.1. Subjects

Data on 859 healthy white Italians (519 men, 340 women) aged 4–73 years were collected. The subjects were divided into several non-overlapping age groups (Table 1): for children and preadolescent subjects, 2-year spans were used, while larger intervals were used for adolescent and adult subjects [26,27].

Subjects with a previous history of craniofacial trauma, congenital anomalies or surgery were not included in the sample. Participants were informed about all the adopted procedures, and provided their consent to the investigation. Informed consent was also obtained from the parents/ legal guardians of the subjects younger than 18 years. The study protocol was approved by the local ethic committee.

The data collection procedure used in the current study is non-invasive, not potentially harmful, do not provoke pain and do not use any instrument or energy currently considered to be potentially dangerous to the present or future health of the subjects or of her/his offspring [49]. Additionally, great care was taken to use procedures provoking the minimal disturbance to the subject.

### 2.2. Collection of three-dimensional facial landmarks

The data collection procedure was previously described in detail [15,26,27,49–51]. In brief, for each subject, a single experienced operator located a set of 50 landmarks and marked them on the cutaneous surface. During landmark marking, the subjects sat relaxed with a natural head position. The complete set of 50 landmarks allowed the quantitative study of head, face, orbits, nose, lips and mouth, ears in the living human subjects [49].

**Table 1**
Three-dimensional external nasal morphometry in 519 healthy men.

| Measurement | Unit | Age (years) | 4–5 | 6–7 | 8–9 | 10–11 | 12–13 | 14–16 | 18–30 | 31–40 | 41–50 | 51–64 | 65–80 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. subjects | | | 11 | 47 | 55 | 44 | 82 | 55 | 126 | 66 | 11 | 15 | 7 |
| Nasal volume | $mm^3$ | Mean | 1.55 | 2.07 | 2.07 | 3.13 | 3.46 | 4.32 | 4.32 | 4.95 | 5.43 | 5.57 | 5.18 |
| | | SD | 0.58 | 1.28 | 1.90 | 0.82 | 0.84 | 0.94 | 4.15 | 2.39 | 3.46 | 4.59 | 1.33 |
| Nasal area | $mm^2$ | Mean | 735.00 | 848.00 | 973.00 | 1194.00 | 1327.00 | 1522.00 | 1643.00 | 1822.00 | 1873.00 | 1866.00 | 1874.00 |
| | | SD | 164.40 | 96.50 | 162.40 | 181.70 | 180.50 | 189.10 | 185.80 | 182.80 | 132.70 | 162.70 | 188.80 |
| Nasal width | mm | Mean | 23.75 | 25.67 | 26.65 | 26.40 | 28.73 | 31.10 | 32.31 | 33.86 | 34.10 | 35.76 | 37.10 |
| | | SD | 5.53 | 2.46 | 2.90 | 2.55 | 2.29 | 3.29 | 3.10 | 2.36 | 1.97 | 2.56 | 2.31 |
| Alar base width | mm | Mean | 24.88 | 26.90 | 27.45 | 25.98 | 27.40 | 29.23 | 31.48 | 33.21 | 35.24 | 35.00 | 37.77 |
| | | SD | 4.85 | 2.46 | 3.42 | 2.40 | 2.56 | 3.68 | 3.31 | 2.74 | 2.93 | 3.09 | 1.58 |
| Height of the nose | mm | Mean | 34.50 | 40.04 | 43.03 | 46.83 | 49.00 | 50.53 | 55.65 | 57.30 | 58.68 | 54.79 | 57.36 |
| | | SD | 3.20 | 2.13 | 3.08 | 2.35 | 3.32 | 2.84 | 3.31 | 4.17 | 4.04 | 3.28 | 3.93 |
| Nasal bridge length | mm | Mean | 27.58 | 32.49 | 34.79 | 39.70 | 41.75 | 44.36 | 51.00 | 52.52 | 52.34 | 49.34 | 51.98 |
| | | SD | 2.77 | 2.65 | 3.44 | 2.48 | 3.67 | 2.68 | 3.91 | 4.82 | 4.38 | 3.86 | 3.81 |
| Philtrum length | mm | Mean | 11.84 | 13.62 | 13.50 | 14.25 | 14.91 | 15.58 | 17.04 | 18.52 | 19.79 | 19.51 | 19.05 |
| | | SD | 2.29 | 1.93 | 2.00 | 1.79 | 2.11 | 1.69 | 2.24 | 2.32 | 2.23 | 2.54 | 2.56 |
| Nasal tip protrusion | mm | Mean | 14.16 | 15.89 | 16.95 | 16.86 | 18.30 | 18.91 | 19.17 | 20.24 | 22.65 | 23.15 | 22.57 |
| | | SD | 0.92 | 1.46 | 1.74 | 1.83 | 1.74 | 1.93 | 2.15 | 2.16 | 3.26 | 1.93 | 1.68 |
| Right nostril length | mm | Mean | 12.31 | 12.11 | 13.33 | 14.98 | 15.59 | 17.96 | 18.18 | 18.73 | 19.38 | 20.85 | 21.45 |
| | | SD | 1.24 | 1.47 | 2.01 | 1.58 | 2.06 | 1.64 | 1.98 | 2.01 | 1.89 | 2.53 | 3.19 |
| Left nostril length | mm | Mean | 11.39 | 12.39 | 13.08 | 14.59 | 15.30 | 16.69 | 18.47 | 18.92 | 19.28 | 21.12 | 21.06 |
| | | SD | 0.82 | 1.72 | 1.62 | 1.32 | 1.72 | 2.33 | 2.05 | 1.89 | 1.97 | 2.48 | 4.01 |
| Superior nostril width | mm | Mean | 6.28 | 6.16 | 6.61 | 6.30 | 6.47 | 8.25 | 8.93 | 10.12 | 10.09 | 8.52 | 10.41 |
| | | SD | 4.72 | 1.45 | 2.18 | 2.38 | 2.25 | 3.57 | 2.07 | 1.77 | 2.95 | 2.06 | 2.88 |
| Inferior nostril width | mm | Mean | 17.16 | 19.23 | 19.99 | 17.94 | 18.82 | 20.44 | 22.57 | 24.46 | 23.71 | 28.36 | 30.91 |
| | | SD | 5.06 | 1.79 | 3.21 | 2.75 | 2.21 | 2.90 | 3.15 | 2.64 | 2.99 | 2.37 | 4.12 |
| Tip protrusion to height | % | Mean | 48.35 | 36.35 | 37.53 | 42.75 | 41.55 | 44.31 | 37.61 | 39.89 | 39.02 | 43.59 | 37.69 |
| | | SD | 7.94 | 6.51 | 8.37 | 6.71 | 6.41 | 4.93 | 4.84 | 4.39 | 5.33 | 5.23 | 3.83 |
| Width to height | % | Mean | 68.47 | 64.33 | 62.20 | 59.59 | 58.83 | 61.74 | 58.26 | 59.42 | 58.39 | 65.40 | 65.02 |
| | | SD | 14.05 | 7.37 | 7.69 | 6.71 | 5.47 | 7.59 | 6.49 | 6.13 | 5.61 | 4.77 | 6.91 |
| Nasal convexity | deg | Mean | 23.21 | 22.31 | 22.06 | 20.35 | 21.40 | 21.76 | 20.06 | 20.67 | 22.54 | 25.01 | 22.99 |
| | | SD | 1.86 | 2.59 | 2.58 | 1.88 | 2.53 | 2.04 | 2.54 | 2.68 | 3.09 | 2.73 | 1.91 |
| Alar slope angle | deg | Mean | 64.49 | 82.83 | 79.68 | 66.53 | 70.84 | 69.61 | 75.43 | 73.15 | 73.66 | 73.86 | 81.11 |
| | | SD | 14.44 | 10.82 | 14.13 | 9.10 | 8.54 | 7.66 | 7.91 | 6.05 | 5.55 | 5.85 | 5.58 |
| Nasal tip angle | deg | Mean | 106.85 | 106.70 | 107.41 | 104.36 | 102.47 | 97.78 | 93.84 | 92.86 | 94.70 | 90.88 | 92.10 |
| | | SD | 3.81 | 5.92 | 5.40 | 4.32 | 5.51 | 3.54 | 6.33 | 5.77 | 6.49 | 5.27 | 7.87 |

Three-dimensional ($x$, $y$, $z$) coordinates of the facial landmarks were obtained with a three-dimensional computerized electromagnetic digitizer (3Draw, Polhemus Inc., Colchester, VT). The system has an accuracy of 0.25 mm, a resolution of 0.13 mm/mm of range, and it supplies actual metric data independent from external reference systems. Digitization of landmarks was performed by a single operator.

The reproducibility of landmark identification, marker positioning and the reproducibility of the data collection procedure were previously reported, and found to be reliable, with Dahlberg's errors on 50 landmarks of 1.20 mm (males) and 0.95 mm (females), corresponding to 1.04 and 1.05% of the relevant nasion–mid-tragion distances [50].

In the present study, from the complete set of 50 landmarks the following soft-tissue landmarks were further considered (Fig. 1):

- midline landmarks: n, nasion; sn, subnasale; prn, pronasale; ls, labiale superius;
- paired landmarks (right and left side noted r and l): $al_r$, $al_l$, alare; $ac_r$, $ac_l$, nasal alar crest; $itn_r$, $itn_l$, inferior point of the nostril axis; $stn_r$, $stn_l$, superior point of the nostril axis.

### 2.3. Data analysis

The $x$, $y$, $z$ coordinates of the landmarks obtained on each subject were used to calculate the following measurements [11,13,43,49,51,52]:

- volume (unit: $mm^3$): nasal volume, approximated from the volumes of two tetrahedra: the first tetrahedron had the plane $ac_r$, $ac_l$, prn as its base and vertex in n, the second had the same base and vertex in sn;
- area (unit: $mm^2$): external nasal surface, computed as the sum of the areas of the triangles n–prn–$ac_r$, n–prn–$ac_l$, prn–sn–$ac_r$, and prn–sn–$ac_l$;
- linear distances (unit: mm): nasal width ($al_r$–$al_l$); alar base width ($ac_r$–$ac_l$); height of the nose (n–sn); length of the nasal bridge (n–prn); philtrum length (sn–ls); nasal tip protrusion (prn–sn); right and left length of the nostrils (stn–itn); superior width of the nostrils ($stn_r$–$stn_l$); inferior width of the nostrils ($itn_r$–$itn_l$);

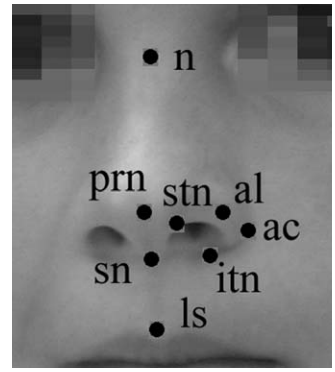


**Fig. 1.** Digitized three-dimensional soft-tissue nasal landmarks used in the current study: n, nasion; sn, subnasale; prn, pronasale; ls, labiale superius; $al_r$, $al_l$, alare; $ac_r$, $ac_l$, nasal alar crest; $itn_r$, $itn_l$, inferior point of the nostril axis; $stn_r$, $stn_l$, superior point of the nostril axis.

- ratios (unit: percentage): nasal tip protrusion-to-nasal height (prn–sn/n–sn $\times$ 100); nasal width-to-nasal height (al–al/n–sn $\times$ 100);
- angles (unit: degrees): nasal convexity or nasal prominence (sn–n–prn); alar slope or inter-alar angle ($al_r$–prn–$al_l$); nasal tip angle (n–prn–sn) (Fig. 2).

All measurements were performed in the three-dimensional space, *i.e.*, the position of landmarks relative to all the three planes (frontal, lateral and horizontal) was considered at the same time (no projections).

Descriptive statistics (mean and standard deviation) for each measurement were computed within sex and age group. Statistics of the angular measurements were computed by using the rectangular components of each angle.

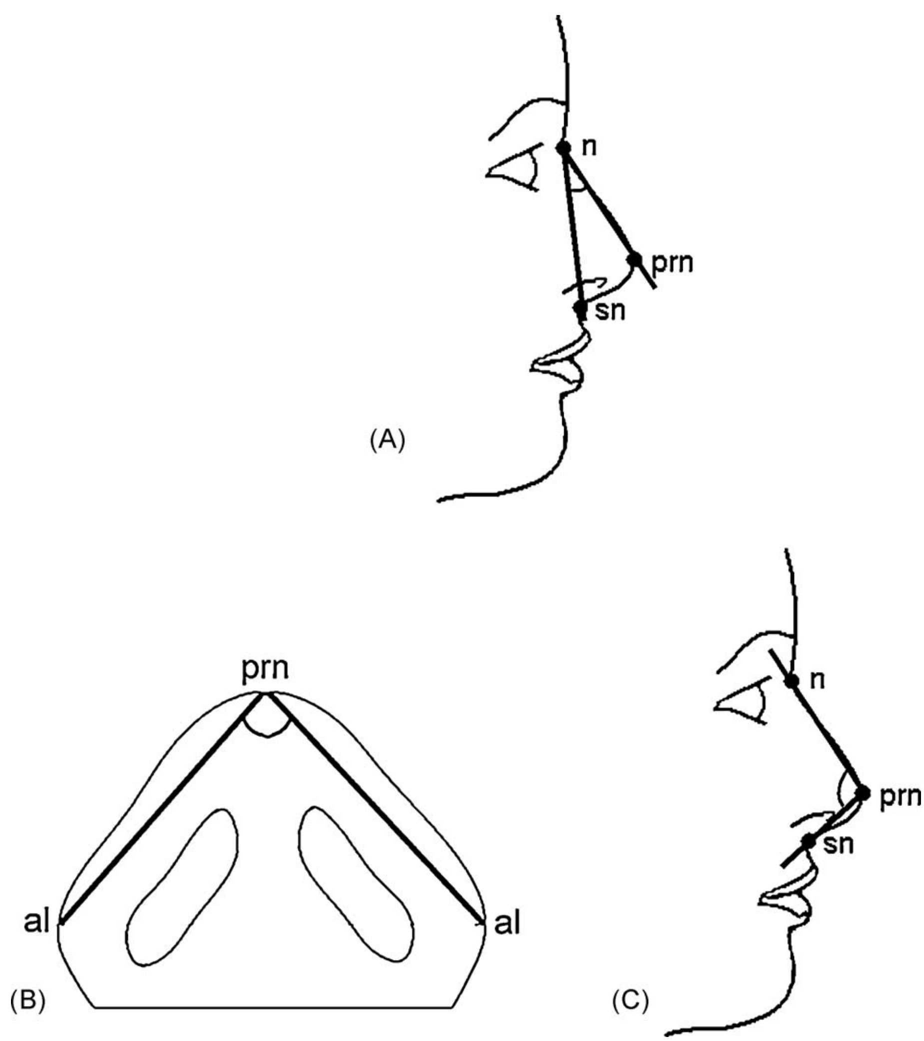


**Fig. 2.** Analyzed angles: (A) nasal convexity or nasal prominence (sn–n–prn); (B) alar slope or inter-alar angle ($al_r$–prn–$al_l$); (C) nasal tip angle (n–prn–sn)

**Table 2**
Three-dimensional external nasal morphometry in 340 healthy women.

| Measurement | Unit | Age (years) | 4–5 | 6–7 | 8–9 | 10–11 | 12–13 | 14–16 | 18–30 | 31–40 | 41–50 | 51–64 | 65–80 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. subjects | | | 11 | 29 | 42 | 48 | 68 | 12 | 66 | 28 | 11 | 18 | 7 |
| Nasal volume | $mm^3$ | Mean | 1.50 | 1.35 | 1.27 | 1.45 | 2.54 | 3.52 | 3.60 | 4.33 | 4.54 | 4.18 | 4.25 |
| | | SD | 0.55 | 1.87 | 2.06 | 2.85 | 4.02 | 0.93 | 3.34 | 1.01 | 1.05 | 3.22 | 0.96 |
| Nasal area | $mm^2$ | Mean | 706.00 | 843.00 | 916.00 | 1070.00 | 1322.00 | 1430.00 | 1361.00 | 1487.00 | 1524.00 | 1629.00 | 1648.00 |
| | | SD | 138.00 | 107.20 | 125.10 | 177.10 | 180.40 | 202.10 | 197.20 | 175.00 | 154.20 | 142.20 | 319.60 |
| Nasal width | mm | Mean | 20.64 | 25.10 | 25.83 | 26.78 | 28.22 | 31.25 | 28.90 | 30.29 | 32.31 | 32.42 | 31.37 |
| | | SD | 3.53 | 1.82 | 2.13 | 2.38 | 3.22 | 2.92 | 3.30 | 2.52 | 2.97 | 3.08 | 3.07 |
| Alar base width | mm | Mean | 22.37 | 26.04 | 26.84 | 26.99 | 27.98 | 29.97 | 28.70 | 29.66 | 33.47 | 32.75 | 32.79 |
| | | SD | 2.15 | 2.39 | 2.29 | 2.47 | 2.94 | 3.86 | 3.51 | 2.46 | 2.09 | 3.07 | 2.17 |
| Height of the nose | mm | Mean | 34.08 | 40.22 | 42.71 | 44.38 | 50.12 | 49.95 | 51.17 | 52.69 | 53.02 | 53.18 | 53.48 |
| | | SD | 3.51 | 2.91 | 2.92 | 3.29 | 3.60 | 3.94 | 3.57 | 3.64 | 3.92 | 3.15 | 4.50 |
| Nasal bridge length | mm | Mean | 26.84 | 32.33 | 34.50 | 36.82 | 43.68 | 43.50 | 46.46 | 47.90 | 48.21 | 48.60 | 47.32 |
| | | SD | 2.58 | 2.95 | 3.16 | 3.36 | 3.65 | 3.94 | 3.99 | 4.38 | 4.44 | 3.48 | 5.62 |
| Philtrum length | mm | Mean | 10.98 | 12.64 | 12.51 | 13.27 | 14.52 | 15.02 | 15.40 | 15.13 | 16.95 | 17.17 | 16.03 |
| | | SD | 2.10 | 2.19 | 2.02 | 1.60 | 1.64 | 1.90 | 2.21 | 2.38 | 2.33 | 2.21 | 2.54 |
| Nasal tip protrusion | mm | Mean | 14.06 | 15.61 | 17.00 | 17.89 | 18.17 | 19.06 | 17.69 | 18.78 | 19.26 | 20.85 | 22.26 |
| | | SD | 1.87 | 1.81 | 1.89 | 1.75 | 2.10 | 1.84 | 1.92 | 2.35 | 1.59 | 3.34 | 2.28 |
| Right nostril length | mm | Mean | 11.89 | 12.20 | 12.69 | 14.27 | 15.24 | 18.16 | 16.05 | 16.73 | 18.10 | 18.32 | 19.69 |
| | | SD | 1.09 | 1.45 | 1.77 | 1.72 | 1.93 | 1.39 | 1.69 | 1.60 | 2.03 | 2.09 | 2.29 |
| Left nostril length | mm | Mean | 10.64 | 12.00 | 12.40 | 14.00 | 15.09 | 16.67 | 16.39 | 16.74 | 18.17 | 18.56 | 18.73 |
| | | SD | 1.66 | 1.35 | 1.63 | 1.78 | 1.50 | 1.32 | 1.94 | 1.97 | 1.26 | 2.51 | 2.21 |
| Superior nostril width | mm | Mean | 6.93 | 6.26 | 5.99 | 6.19 | 6.88 | 6.98 | 8.47 | 9.62 | 9.25 | 8.73 | 6.29 |
| | | SD | 2.29 | 1.69 | 1.50 | 1.76 | 2.18 | 2.96 | 1.98 | 1.97 | 2.42 | 2.16 | 1.50 |
| Inferior nostril width | mm | Mean | 14.76 | 18.52 | 19.74 | 20.17 | 18.79 | 21.16 | 19.95 | 21.72 | 24.17 | 24.81 | 24.88 |
| | | SD | 2.17 | 2.20 | 2.48 | 2.70 | 2.74 | 3.27 | 3.12 | 3.40 | 2.97 | 3.46 | 4.58 |
| Tip protrusion to height | % | Mean | 55.33 | 37.48 | 38.03 | 38.99 | 38.95 | 40.64 | 37.16 | 38.30 | 37.03 | 40.75 | 41.23 |
| | | SD | 12.89 | 8.56 | 8.59 | 7.34 | 6.14 | 3.75 | 4.58 | 4.79 | 5.71 | 5.01 | 3.46 |
| Width to height | % | Mean | 61.28 | 62.83 | 60.55 | 60.58 | 56.48 | 62.66 | 56.55 | 57.73 | 61.33 | 61.23 | 58.82 |
| | | SD | 12.96 | 7.50 | 8.39 | 6.33 | 6.73 | 7.50 | 6.00 | 6.03 | 7.72 | 7.37 | 5.59 |
| Nasal convexity | deg | Mean | 23.00 | 21.59 | 22.26 | 23.06 | 20.91 | 22.16 | 20.19 | 20.87 | 21.27 | 23.06 | 24.39 |
| | | SD | 2.33 | 3.10 | 2.19 | 2.28 | 2.51 | 1.36 | 2.68 | 3.23 | 2.08 | 3.69 | 1.36 |
| Alar slope angle | deg | Mean | 56.35 | 80.45 | 82.66 | 76.14 | 72.00 | 74.87 | 74.45 | 73.92 | 79.05 | 73.55 | 69.98 |
| | | SD | 10.65 | 14.04 | 10.54 | 11.76 | 9.21 | 7.83 | 6.91 | 6.02 | 6.92 | 8.97 | 7.47 |
| Nasal tip angle | deg | Mean | 108.69 | 109.00 | 107.27 | 103.13 | 100.00 | 98.27 | 94.99 | 93.82 | 93.49 | 90.62 | 94.03 |
| | | SD | 4.23 | 4.75 | 4.94 | 5.64 | 5.19 | 3.70 | 5.01 | 6.05 | 5.10 | 5.02 | 6.11 |

Mean values between sexes and age groups were compared using two-way factorial analyses of variance (ANOVA). Significance was set at 1% ($p \leq 0.01$), with two-tail statistical tests used in all analyses. To identify different growth patterns before and after the attainment of skeletal maturity, and to compute the developmental level of each measurement, data at each age group were expressed as a percentage of the value recorded in the 18–30-year-old subjects [26,53,54].

## 3. Results

On average, a significant sexual dimorphism was found for nasal external volume and area, all linear distances (two-way ANOVA, 1;837 degrees of freedom, $p < 0.001$ for all measurements) and the nasal width-to-height ratio ($p = 0.004$) (all measurements larger in men than in women of corresponding age), while no differences were found for the angles and the nasal tip protrusion-to-nasal height ratio ($p > 0.01$) (Tables 1 and 2). Age significantly influenced all analyzed measurements (ANOVA, 10;837 degrees of freedom, $p < 0.001$ for all measurements): nasal volume, area, linear distances increased from childhood to old age, while the nasal tip angle (n–prn–sn) decreased as a function of age (more prominent nasal tip). No consistent age related patterns were found for the ratios and the nasal convexity or nasal prominence angle (sn–n–prn) and the alar slope or inter-alar angle ($al_r$–prn–$al_l$). In all occasions, men and women had different age related patterns, with significant sex by age interactions (ANOVA, 10;837 degrees of freedom, $p < 0.001$ for all measurements). Overall, in most occasions male increments in nasal dimensions were larger than those observed in females.

At 3–4 years of age, external nasal volume was approximately 42% (girls) and 36% (boys) of the relevant values recorded in the 18–30 years old subjects; hereafter, the age related increment was gradual in both sexes (Fig. 3). During adult aging, further gradual age related increments were observed, and external nasal volume reached 129% (51–64 years old men) and 118% (65–80 years old women) of the relevant mean value of the 18–30 years old subjects. Similar age related variations were observed for external nasal area: from 45% (boys) and 52% (girls) of the relevant young adult value in the first age group, to 114% (men) and 121% (women) in the last age group.

In the first age group, nasal width was 71–74% of the value recorded in the reference "adult" group, with subsequent increments up to 115% (65–80 years old men) and 112% (51–64 years old women) (Figs. 4 and 5). Similar trends were found for the height of the nose (n–sn), that started from 62% (boys) and 67% (girls), and reached 105% of its values recorded in the 18–30 years old subjects.

At 3–4 years of age the length of the nasal bridge (n–prn) was the least developed linear nasal dimension, being 54% (boys) and

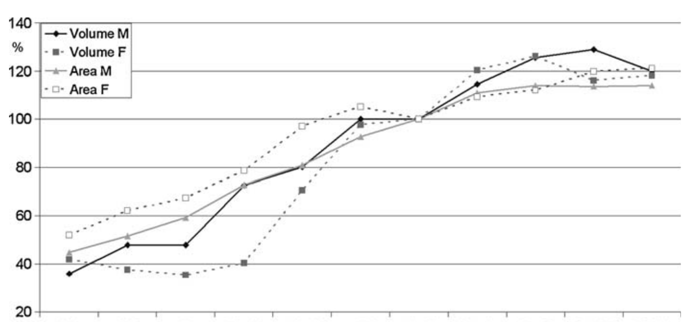


**Fig. 3.** Age related modifications in external nasal volume and area in men (continuous lines) and in women (interrupted lines). All values are expressed as a percentage of the mean value in the 18–30 years age group.

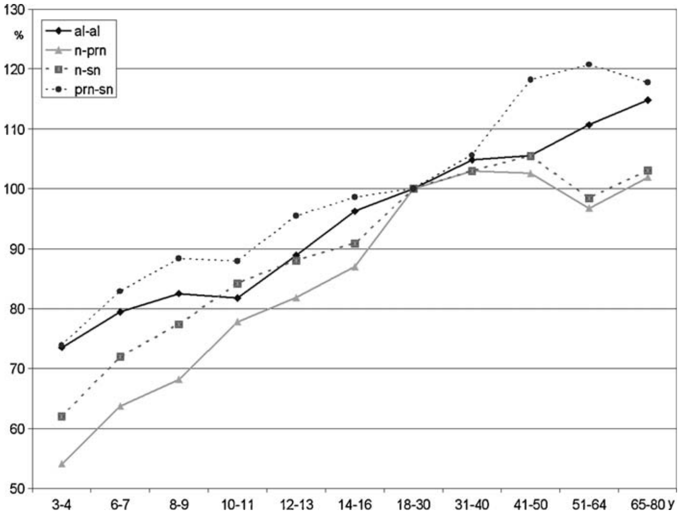


**Fig. 4.** Age related modifications in male nasal linear distances. All values are expressed as a percentage of the mean value in the 18–30 years age group.

58% (girls) of its adult dimensions; during adult aging only minor modifications were seen. In the analyzed age span, nasal tip protrusion (prn–sn) increased from 74% (boys) and 78% (girls) to 121% (51–64 years old men) and 126% (65–80 years old women) of its mean value at 18–30 years of age.

In both sexes, the nasal tip angle decreased during the analyzed time span, starting at 3–4 years from 114% of the relevant adult "reference" value, and reaching 98–99% in the most elderly (Fig. 5).

## 4. Discussion

Actual and virtual reconstructions of facial characteristics in the three spatial dimensions are currently performed in a variety of clinical and basic fields: plastic and maxillofacial surgeons should re-establish the hard- and soft-facial tissues for the corrections of deformities, traumas, mal-development [13,14,17–20,23,32,45]. Orthodontists should try to predict the growth patterns to better their orthodontic and orthopedic interventions [2,15,16,39,40,42]. Forensic anthropologists sometimes reconstruct the global facial appearance starting from skeletal remnants [25,29–31,33], or try

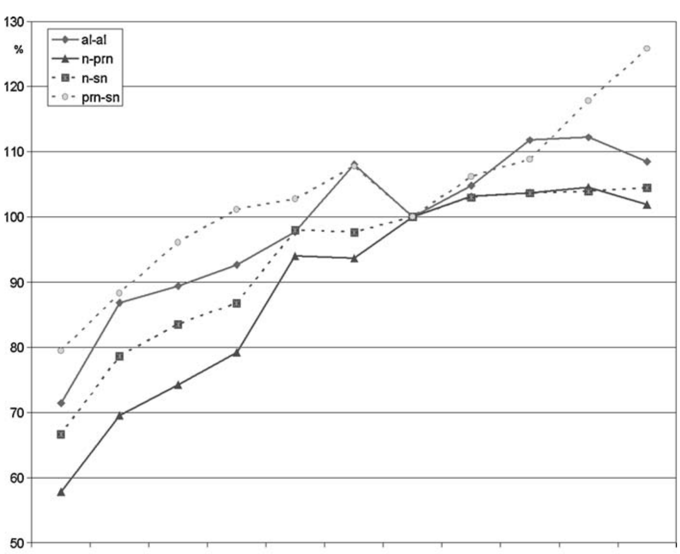


**Fig. 5.** Age related modifications in female nasal linear distances. All values are expressed as a percentage of the mean value in the 18–30 years age group.

to predict growth- and aging-related modifications of facial structures [34,49].

Therefore, a detailed knowledge of the dimensions and relative positions of facial structures in the different age and ethnic groups, as well as in the two sexes, is preferable [1,19,26,27,44].

In the present study, nasal dimensions and shape have been found to be sexually dimorphic, and to modify between childhood, adolescence and young adulthood, and even after young adulthood into the eighth decade of life.

In children, the current linear dimensions were similar to previous literature reports, also considering ethnic related variations [3,16,19,40,42–44].

In young adults, the current nasal dimensions were sufficiently well comparable to those recorded both in Caucasoids and in other ethnic groups (Tables 3 and 4). Overall, measurements were obtained with various methods, and different geometric approximations were used for the estimation of nasal volume and area [42]. Indeed, when comparing measurements obtained in different studies the effect of the measurement protocols should always be considered: for instance, optical instruments (stereo-photogrammetric digitizers, laser scans) do not compress facial skin during landmark collection, while this may occur with callipers and contact digitizers similar to the one used in the current investigation [51]. The differences arising from the use of two- (photographs, radiographs) vs. three-dimensional measurements (anthropometry, computerized digitizers) are also to be taken into account [51]. Furthermore, intra- and inter-observer errors may also be possible sources of measurement variability. These errors may be of larger importance in direct anthropometry, where each measurement is taken individually, thus possibly incrementing their variability (landmark identification, calliper positioning, measurement reading and recording). In contrast, the use of computerized digitizers reduces the method error to landmark identification and digitization [51].

Boys and men had larger noses than girls and women, a finding in accord with the previous studies [1,3,16,18,36–39,41–44,48]. The sexual dimorphism in nasal dimensions appears to begin at different ages depending on the measurement: for instance, nasal bridge length (n–prn) becomes larger in boys than in girls only with postnatal growth: at birth, and in the first months of life, it was similar in infant boys and girls [47]. In contrast, philtrum length was significantly larger in newborn boys than in girls of the same age [47].

The growth patterns of these two vertical dimensions were also different: according to Agnihotri and Singh [47], in the first 4 months of postnatal life philtrum length increased 1.18 (boys)–1.27 (girls) times, while nasal bridge length increased only 1.14–15 times. This increment in philtrum length was larger than any other increment observed in the current study between subsequent age groups (for instance, between 4–5 and 6–7 years of age the increment was 1.15 times). In contrast, the growth of nasal bridge length was faster between 4–5 and 6–7 years of age (1.18 times in boys, 1.20 in girls) than in the first months of postnatal life.

Growth in the nasal soft tissues was larger and earlier in adolescent girls than in boys of the same age, in accord with literature reports [14,16,29,30,40,42,43], with trends similar to those reported for white American Caucasoids [44] and for white Caucasoids of central European descent [3]. In both sexes, nasal height had the fastest growth, and it doubled its value from birth to young adulthood. A large increment was observed also for nasal tip protrusion. The smallest age related increments were found for nasal width.

Posen [39] analyzed longitudinal nasal growth and development between 6 months and 18 years of postnatal life. Child and adolescent growth patterns were consistent with the current ones, with approximately 81% of the adult dimensions of nasal bridge

**Table 3**
Three-dimensional external nasal morphometry in healthy young adult men.

| Measurement | Unit | | Current | Italian [43] | Central European [3] | North American Caucasoid [16] | North American Caucasoid [44] | Chilean [41] | Turkish [38] | Turkish [45] | Malaysian [48] | Chinese [36] | Han Chinese [18] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Instrument | | | a | b | c | d | c | e | e | c | c | f | c |
| No. subjects | | | 126 | 57 | 50 | 16 | 42–109[a] | 90 | 149 | 108 | 50 | 45 | 56 |
| Nasal volume | $mm^3$ | Mean | 4.32 | 11.16 | | | | | | | | | |
| | | SD | 4.15 | 1.33 | | | | | | | | | |
| Nasal area | $mm^2$ | Mean | 1643 | 2200.6 | | | | | | | | | |
| | | SD | 185.8 | 215 | | | | | | | | | |
| Nasal width | mm | Mean | 32.31 | | | | 34.9 | 37.3 | 38.4 | 33.63 | 41 | 39.49 | 39.3 |
| | | SD | 3.10 | | | | 2.1 | 5.05 | 4.4 | 0.27 | 2 | 2.95 | 2.23 |
| Alar base width | mm | Mean | 31.48 | 37.13 | | | 32.8 | | | 23.14 | | | 39.23 |
| | | SD | 3.31 | 2.51 | | | 2.3 | | | 0.28 | | | 2.39 |
| Height of the nose | mm | Mean | 55.65 | 57.59 | | 55.7 | 54.8 | | 51.9 | 56.92 | | 50.15 | 60.33 |
| | | SD | 3.31 | 4.01 | | 5.8 | 3.3 | | 7.5 | 0.44 | | 4.16 | 4.25 |
| Nasal bridge length | mm | Mean | 51 | 49.89 | 52.5 | | 50 | 50.09 | 40.3 | 55.26 | | 43.65 | 51.8 |
| | | SD | 3.91 | 4.81 | 5 | | 3.6 | 5.88 | 7.1 | 0.36 | | 4.50 | 3.94 |
| Philtrum length | mm | Mean | 17.04 | | 18.5 | | | | 24.4 | | | | |
| | | SD | 2.24 | | 2.3 | | | | 3.9 | | | | |
| Nasal tip protrusion | mm | Mean | 19.17 | | 22 | 16 | 19.5 | | | | 18.1 | 17.68 | 18.24 |
| | | SD | 2.15 | | 2 | 2 | 1.9 | | | | 1.4 | 1.66 | 2.33 |
| Tip protrusion to height | % | Mean | 37.61 | | | | | | | | | 35.25 | |
| | | SD | 4.84 | | | | | | | | | 4 | |
| Width to height | % | Mean | 58.26 | | | | | 76 | | 59.4 | | 79 | 65.46 |
| | | SD | 6.49 | | | | | 7.22 | | 6.44 | | 7 | 6.03 |
| Nasal convexity | deg | Mean | 20.06 | 22.37 | | | | | | | | | |
| | | SD | 2.54 | 2.22 | | | | | | | | | |
| Alar slope angle | deg | Mean | 75.43 | 61.07 | | | 63.9 | 67.84 | | | | 89.07 | |
| | | SD | 7.91 | 5.33 | | | 5.8 | 11.14 | | | | 9.89 | |
| Nasal tip angle | deg | Mean | 93.84 | 79.84 | | | 71.7 | | | | | 82.55 | 77.11 |
| | | SD | 6.33 | 4.49 | | | 7.4 | | | | | 9.19 | 7.09 |

Instrument used for data collection: (a) electromagnetic; (b) stereo-photogrammetry; (c) anthropometry; (d) cephalometry; (e) photography; (f) laser scan.
[a] The number of subjects in [44] depends on the measurement.

**Table 4**
Three-dimensional external nasal morphometry in healthy young adult women.

| Measurement | Unit | | Current | Italian [43] | Central European [3] | N American Caucasoid [16] | N American Caucasoid [44] | Chilean [41] | Turkish [38] | Iranian Sistani [23] | Iranian Baluch [23] | Malaysian [48] | Chinese [36] | Han Chinese [18] | Afroamerican [46] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Instrument | | | a | b | c | d | c | e | e | c | c | c | f | c | c |
| No. subjects | | | 66 | 44 | 50 | 16 | 45–200[a] | 90 | 281 | 200 | 200 | 50 | 45 | 63 | 107 |
| Nasal volume | $mm^3$ | Mean | 3.6 | 8.64 | | | | | | 4.79 | 5.23 | | | | |
| | | SD | 3.34 | 1.28 | | | | | | 0.36 | 0.45 | | | | |
| Nasal area | $mm^2$ | Mean | 1361 | 2260 | | | | | | 1752 | 1894.7 | | | | |
| | | SD | 197.2 | 215 | | | | | | 212.8 | 186.5 | | | | |
| Nasal width | mm | Mean | 28.9 | | | | 31.4 | 35.17 | 34.8 | | | 37.3 | 37.63 | 34.75 | 37.98 |
| | | SD | 3.3 | | | | 2.0 | 5.54 | 2.9 | | | 2.6 | 3.47 | 2.22 | 2.96 |
| Alar base width | mm | Mean | 28.7 | | | | 30.5 | | | 32.3 | 31.4 | | | 35.14 | |
| | | SD | 3.51 | | | | 2.2 | | | 1.3 | 1.5 | | | 2.57 | |
| Height of the nose | mm | Mean | 51.17 | 54.33 | | 53 | 50.6 | | 51.7 | 46.5 | 53.0 | | 46.93 | 58.23 | |
| | | SD | 3.57 | 4.23 | | 2.7 | 3.1 | | 5.8 | 1.8 | 1.3 | | 3.30 | 3.73 | |
| Nasal bridge length | mm | Mean | 46.46 | 46.37 | 50 | | 44.7 | 46.86 | 40.1 | 44.0 | 49.5 | | 40.04 | 50.54 | |
| | | SD | 3.99 | 4.04 | 5 | | 3.4 | 6.62 | 5.6 | 2.2 | 1.3 | | 3.62 | 3.87 | |
| Philtrum length | mm | Mean | 15.4 | | 16.3 | | | | 2.24 | | | | | | |
| | | SD | 2.21 | | 2.5 | | | | 2.7 | | | | | | |
| Nasal tip protrusion | mm | Mean | 17.69 | | 21 | 14.6 | 19.7 | | | | | 17.5 | 16.69 | 16.54 | |
| | | SD | 1.92 | | 2.5 | 2.1 | 1.6 | | | | | 1.5 | 2.01 | 1.75 | |
| Tip protrusion to height | % | Mean | 37.16 | | | | | | | | | | 36 | | 33.8 |
| | | SD | 4.58 | | | | | | | | | | 5 | | 4.2 |
| Width to height | % | Mean | 56.55 | | | | | 74 | | 69.7 | 59.2 | | 81 | 59.9 | 79.7 |
| | | SD | 6 | | | | | 6.36 | | 3.5 | 3.3 | | 9 | 5.17 | 9.0 |
| Nasal convexity | deg | Mean | 20.19 | 20.95 | | | | | | | | | | | |
| | | SD | 2.68 | 2.83 | | | | | | | | | | | |
| Alar slope angle | deg | Mean | 74.45 | 66.16 | | | 59.4 | 68.62 | | | | | 90.89 | | |
| | | SD | 6.91 | 5.71 | | | 5.3 | 9.08 | | | | | 12.55 | | |
| Nasal tip angle | deg | Mean | 94.99 | 77.18 | | | 67.4 | | | | | | 83.87 | 78.36 | |
| | | SD | 5.01 | 4.87 | | | 7.4 | | | | | | 7.39 | 8.5 | |

Instrument used for data collection: (a) electromagnetic; (b) stereo-photogrammetry; (c) anthropometry; (d) cephalometry; (e) photography; (f) laser scan.
[a] The number of subjects in [44] depends on the measurement.

length obtained at 13 years, and 91% at 16 years of age (male and female pooled values). At 15 years of age, adolescents gained 95% of adult dimensions in nasal depth. At the same age, Prahl-Andersen et al. [40] found that girls had obtained 98% of their adult dimension, while boys only 89%. Genecov et al. [16] and Ferrario et al. [43] reported that girls had ended a large part of their soft-tissue nasal growth at 12 years of age, while boys continued to growth until 17 years of age: similar trends can be observed in the current adolescents. In boys, Burke and Hughes-Lawson [42] found a growth spurt in nasal width between 11 and 13 years of age, well paralleling current findings.

Increments in nasal dimensions continued after 20 years of age; modifications went on with reduced speed, as found in previous cross-sectional anthropometric studies [3,44]. The trends for adult aging of vertical and horizontal nasal dimensions were in good accord with those reported in longitudinal studies ranging from late adolescence to late adulthood [1,2]. In particular, aging differences were larger in men than in women [1], as shown by the significant age by sex interactions found in the current and in previous investigations on other facial soft tissues [26,27].

All over the world, nasal dimensions have been investigated in several ethnic groups [1–3,16,18,19,23,29,36,32–48]. Overall, notwithstanding ethnical variations in actual nasal dimensions and proportions [18,19,23,36,45,46,48], all investigations found that the human facial soft tissues continue to modify well beyond the attainment of skeletal maturity. With aging, modifications of the microscopic structure of facial soft tissues, with alterations of cartilages, muscles, skin elasticity and resilience, have been reported [32,55–57]. Overall, the microscopic modifications may explain the macroscopic increments in nasal dimensions, especially in those more determined by muscles and cartilages (nasal width, nasal tip protrusion), observed after the attainment of skeletal maturity.

The number of subjects examined in the present investigation is comparable to that analyzed in several cross-sectional [18,19,23,36,38,41,43,45–48] and longitudinal [1,2,16,29 ,39,40,42] investigations, even if some studies analyzed one or two thousands of individuals [3,44]. It has to be mentioned that in some of those investigations only selected linear distances were measured [3], and only some age groups were analyzed [44].

The current study has two principal limitations: its cross-sectional nature, and the instrument used for data collection. Cross-sectional studies assess different individuals in the various age classes, and do not estimate actual growth or aging, but can only suggest trends for the age related variations: the possible presence of secular trends, with individuals with different craniofacial characteristics examined in the various age groups, should be considered. Nonetheless, the current data for both growth [16,29,39,40,42] and aging [1,2,29] are in good accord with those obtained by longitudinal records. Another limitation is the reduced number of subjects in the first and last age groups, that should be implemented with new healthy children and older adults.

Data collection was made with an electromagnetic digitizer, and the procedure was longer than with optical instruments. Movement artifacts may also alter this procedure; nevertheless, the carefully controlled protocol limited this problem [50,58]. Note here that this study's data were in close agreement with those collected by optical instruments [19,36,42,43] and conventional anthropometry [3,23,44,45,48].

Recent investigations compared the performance of contact and optical instruments for the assessment of soft-tissue facial characteristics, and found their use satisfactory from the clinical point of view [59,60]. Contact instruments can be easily used within clinical units, even with the patient in a dental chair [58,60], while optical instruments usually need dedicated locations. Furthermore, the instrument is low cost, when compared to optical devices [51,58–60]. The use of these instruments may help in widespread data collection, allowing the definition of ethnic specific databases that take into account individual characteristics [34].

## 5. Conclusion

In the present investigation, detailed information about the normal sex and age related nasal dimensions in healthy Italian Caucasoids was provided. The analyzed age interval covered eight decades of life, being the first three-dimensional study reporting a global set of linear, angular, surface and volumetric nasal data for Caucasoids.

When compared to data from the literature, some differences were found, underlining the necessity of data collected on each ethnic group. The age related trends for linear dimensions were similar to those found in most previous studies, showing progressive increments of nasal dimensions with advancing age.

Data collected in the present investigation could serve as a database for the quantitative description of human nasal morphology during normal growth, development and aging, also considering sex and ethnic related variations. In living subjects, soft-tissue facial characteristics are among those most used for personal identification, and a deep understanding of their age related modifications is necessary to build data banks for forensic purposes [3,24,26,27,44,55]. Among the others, one application may be the estimation of the age of both living and dead persons, using direct measurements as well as photographic records of those characteristics that show the largest age related variations. The same data may enter into simulations of facial growth and aging, helping in personal identification [21,22,34]. In particular, a correct approximation of soft-tissue nasal morphology may contribute to a better reconstruction of facial characteristics from skeletal remnants [25,29–31,33]: forensic anthropologists may largely benefit from sex and ethnic specific developmental and aging patterns of the various nasal dimensions.

Furthermore, the detection of facial dimensions that remain stable over time (or that have reduced age related variations after the attainment of maturity) may help in personal identification years after the actual crime [24].

## Conflict of interest statement

The authors have no conflict of interest related to the current investigation.

## Acknowledgements

The authors are grateful to all the subjects who volunteered for the study. The precious secretarial assistance of Ms Cinzia Lozio is gratefully acknowledged.

## References

[1] E. Gualdi-Russo, Longitudinal study of anthropometric changes with aging in an urban Italian population, Homo 49 (1998) 241–259.
[2] N.G. Pecora, T. Baccetti, J.A. McNamara Jr., The aging craniofacial complex: a longitudinal cephalometric study from late adolescence to late adulthood, Am. J. Orthod. Dentofacial Orthop. 134 (2008) 496–505.
[3] A. Zankl, L. Eberle, L. Molinari, A. Schinzel, Growth charts for nose length, nasal protrusion, and philtrum length from birth to 97 years, Am. J. Med. Genet. 111 (2002) 388–391.
[4] M. Borenstein, N. Persico, K.O. Kagan, A. Gazzoni, K.H. Nicolaides, Frontomaxillary facial angle in screening for trisomy at 11 + 0 to 13 + 6 weeks, Ultrasound Obstet. Gynecol. 32 (2008) 5–11.
[5] S. Cicero, D. Longo, G. Rembouskos, C. Sacchini, K.H. Nicolaides, Absent nasal bone at 11–14 weeks of gestation and chromosomal defects, Ultrasound Obstet. Gynecol. 22 (2003) 31–35.

[6] S. Minderer, K.P. Gloning, W. Henrich, H. Stoger, The nasal bone in fetuses with trisomy 21: sonographic versus pathomorphological findings, Ultrasound Obstet. Gynecol. 22 (2003) 16–21.
[7] F. Orlandi, C.M. Bilardo, M. Campogrande, D. Krantz, T. Hallahan, C. Rossi, E. Viora, Measurement of nasal bone length at 11–14 weeks of pregnancy and its potential role in Down syndrome risk assessment, Ultrasound Obstet. Gynecol. 22 (2003) 36–39.
[8] J.D. Sonek, Nasal bone evaluation with ultrasonography: a marker for fetal aneuploidy, Ultrasound Obstet. Gynecol. 22 (2003) 11–15.
[9] L.G. Farkas, M.J. Katic, C.R. Forrest, L. Litsas, Surface anatomy of the face in Down's syndrome: linear and angular measurements in the craniofacial regions, J. Craniofac. Surg. 12 (2001) 373–379.
[10] A. Tuxen, J.W. Keeling, I. Reintoft, B. Fischer Hansen, D. Nolting, I. Kjaer, A histological and radiological investigation of the nasal bone in fetuses with Down syndrome, Ultrasound Obstet. Gynecol. 22 (2003) 22–26.
[11] V.F. Ferrario, C. Dellavia, A. Colombo, C. Sforza, Three-dimensional assessment of nose and lip morphology in subjects with Down syndrome, Ann. Plast. Surg. 53 (2004) 577–583.
[12] L. Breitsprecher, J. Fanghanel, H.-R. Metelmann, G. Mlynski, F. Wurfel, K. Freise, U. Knape, The influence of the muscles of facial expression on the development of the midface and the nose in cleft lip and palate patients. A reflection of functional anatomy, facial esthetics and physiology of the nose, Ann. Anat. 181 (1999) 19–25.
[13] V.F. Ferrario, C. Sforza, C. Dellavia, L. Vizzotto, A. Carù, Three-dimensional nasal morphology in cleft lip and palate operated adult patients, Ann. Plast. Surg. 51 (2003) 390–397.
[14] P. Van der Heijden, A.G. Korsten-Meijer, B.F. van der Laan, H.P. Wit, S.M. Goorhuis-Brouwer, Nasal growth and maturation age in adolescents: a systematic review, Arch. Otolaryngol. Head Neck Surg. 134 (2008) 1288–1293.
[15] C. Dellavia, F. Catti, C. Sforza, G. Grandi, V.F. Ferrario, Noninvasive longitudinal assessment of facial growth in children and adolescents with Hypohidrotic Ectodermal Dysplasia, Eur. J. Oral Sci. 116 (2008) 305–311.
[16] J.S. Genecov, P.M. Sinclair, P.C. Dechow, Development of the nose and soft tissue profile, Angle Orthod. 60 (1990) 191–198.
[17] M.Y. Hajeer, Z. Mao, D.T. Millett, A.F. Ayoub, J.P. Siebert, A new three-dimensional method of assessing facial volumetric changes after orthognathic treatment, Cleft Palate Craniofac. J. 42 (2005) 113–120.
[18] Z.J. He, X.C. Jian, X.S. Wu, X. Gao, S.-H. Zhou, X.H. Zhong, Anthropometric measurement and analysis of the external nasal soft tissue in 119 young Han Chinese adults, J. Craniofac. Surg. 20 (2009) 1347–1351.
[19] A. Mori, T. Nakajima, T. Kaneko, H. Sakuma, Y. Aoki, Analysis of 109 Japanese children's lip and nose shapes using 3-dimensional digitizer, Br. J. Plast. Surg. 58 (2005) 318–329.
[20] C. Sforza, R. Peretta, G. Grandi, G. Ferronato, V.F. Ferrario, Soft tissue facial planes and masticatory muscle function in skeletal class III patients before and after orthognathic surgery treatment, J. Oral Maxillofac. Surg. 66 (2008) 691–698.
[21] D. De Angelis, R. Sala, A. Cantatore, M. Grandi, C. Cattaneo, A new computer-assisted technique to aid personal identification, Int. J. Legal Med. 123 (2009) 351–356.
[22] N.L. Fraser, M. Yoshino, K. Imaizumi, S.A. Blackwell, C.D. Thomas, J.G. Clement, A Japanese computer-assisted facial identification system successfully identifies non-Japanese faces, Forensic Sci. Int. 135 (2003) 122–128.
[23] H. Heidari, H. Mahmoudzadeh-Sagheb, T. Khammar, M. Khammar, Anthropometric measurements of the external nose in 18–25-year-old Sistani and Baluch aborigine women in the southeast of Iran, Folia Morphol. 68 (2009) 88–92.
[24] M.M. Roelofse, M. Steun, P.J. Becker, Photo identification: facial metrical and morphological features in South African males, Forensic Sci. Int. 177 (2008) 168–175.
[25] C. Rynn, C.M. Wilkinson, Appraisal of traditional and recently proposed relationships between the hard and soft dimensions of the nose in profile, Am. J. Phys. Anthropol. 130 (2006) 364–373.
[26] C. Sforza, G. Grandi, M. Binelli, D.G. Tommasi, R. Rosati, V.F. Ferrario, Age- and sex-related changes in the normal human ear, Forensic Sci. Int. 187 (2009), 110.e1–110.e7.
[27] C. Sforza, G. Grandi, F. Catti, D.G. Tommasi, A. Ugolini, V.F. Ferrario, Age- and sex-related changes in the soft tissues of the orbital region, Forensic Sci. Int. 185 (2009), 115.e1–115.e8.
[28] J. Shi, A. Samal, D. Marx, How effective are landmarks and their geometry for face recognition? Comput. Vis. Image Understand. 102 (2006) 117–133.
[29] S.L. Smith, P.H. Buschang, Midsagittal facial soft-tissue growth of French Canadian adolescents, Am. J. Hum. Biol. 14 (2002) 457–467.
[30] C.N. Stephan, M. Henneberg, Predicting mouth width from inter-canine width—a 75% rule, J. Forensic Sci. 48 (2003) 725–727.
[31] C.N. Stephan, Position of superciliare in relation to the lateral iris: testing a suggested facial approximation guideline, Forensic Sci. Int. 130 (2002) 29–33.
[32] S.R. Coleman, R. Grover, The anatomy of the aging face: volume loss and changes in 3-dimensional topography, Aesthetic Surg. J. 26 (2006) S4–S9.
[33] C.N. Stephan, M. Henneberg, W. Sampson, Predicting nose projection and pronasale position in facial approximation: a test of published methods and proposal of new guidelines, Am. J. Phys. Anthropol. 122 (2003) 240–250.
[34] C. Cattaneo, S. Ritz-Timme, P. Gabriel, D. Gibelli, E. Giudici, P. Poppa, D. Nohrden, S. Assmann, R. Schmitt, M. Grandi, The difficult issue of age assessment on pedo-pornographic material, Forensic Sci. Int. 183 (2009) e21–e24.
[35] A.A. Akgül, T.U. Toygar, Natural craniofacial changes in the third decade of life: a longitudinal study, Am. J. Orthod. Dentofacial Orthop. 122 (2002) 512–522.
[36] S.C. Aung, C.L. Foo, S.T. Lee, Three dimensional laser scan assessment of the Oriental nose with a new classification of Oriental nasal types, Br. J. Plast. Surg. 53 (2000) 109–116.
[37] R.L. Hall, Energetics of nose and mouth breathing, body size, body composition, and nose volume in young adult males and females, Am. J. Hum. Biol. 17 (2005) 321–330.
[38] S.T. Ozdemir, D. Sigirli, I. Ercan, N.S. Cankur, Photographic facial soft tissue analysis of healthy Turkish young adults: anthropometric measurements, Aesthetic Plast. Surg. 33 (2009) 175–184.
[39] J.M. Posen, A longitudinal study of the growth of the nose, Am. J. Orthod. 53 (1967) 746–756.
[40] B. Prahl-Andersen, A.S. Ligthelm-Bakker, E. Wattel, R. Nanda, Adolescent growth changes in soft tissue profile, Am. J. Orthod. Dentofacial Orthop. 107 (1995) 476–483.
[41] P.J.A. Troncoso, G.I.C. Suazo, L.M. Cantin, M.D.A. Zavando, Sexual dimorphism in the nose morphology in adult Chilean, Int. J. Morphol. 26 (2008) 537–542.
[42] P.H. Burke, C.A. Hughes-Lawson, Stereophotogrammetric study of growth and development of the nose, Am. J. Orthod. Dentofacial Orthop. 96 (1989) 144–151.
[43] V.F. Ferrario, C. Sforza, C.E. Poggio, J.H. Schmitz, Three-dimensional study of growth and development of the nose, Cleft Palate Craniofac. J. 34 (1997) 309–317.
[44] L.G. Farkas, T.A. Hreczko, M.J. Katic, Craniofacial norms in North American Caucasians from birth (one year) to young adulthood, in: L.G. Farkas (Ed.), Anthropometry of the Head and Face, Raven Press, New York, 1994, pp. 285–301.
[45] A. Uzun, H. Akbas, S. Bilgic, M. Emirzeoglu, O. Bostanci, B. Sahin, Y. Bek, The average values of the nasal anthropometric measurements in 108 young Turkish males, Auris Nasus Larynx 33 (2006) 31–35.
[46] J.P. Porter, K.L. Olson, Analysis of the African American female nose, Plast. Reconstr. Surg. 111 (2003) 620–626.
[47] G. Agnihotri, D. Singh, Craniofacial anthropometry in newborns and infants, Iran. J. Pediatr. 17 (2007) 332–338.
[48] W.C. Ngeow, S.T. Aljunid, Craniofacial anthropometric norms of Malays, Singapore Med. J. 50 (2009) 525–528.
[49] V.F. Ferrario, C. Sforza, G. Serrao, V. Ciusa, C. Dellavia, Growth and aging of facial soft-tissues: a computerised three-dimensional mesh diagram analysis, Clin. Anat. 16 (2003) 420–433.
[50] V.F. Ferrario, C. Sforza, C.E. Poggio, M. Cova, G. Tartaglia, Preliminary evaluation of an electromagnetic three-dimensional digitizer in facial anthropometry, Cleft Palate Craniofac. J. 35 (1998) 9–15.
[51] C. Sforza, V.F. Ferrario, Soft-tissue facial anthropometry in three dimensions: from anatomical landmarks to digital morphology in research, clinics and forensic anthropology, J. Anthropol. Sci. 84 (2006) 97–124.
[52] V.F. Ferrario, F. Mian, R. Peretta, R. Rosati, C. Sforza, Three-dimensional computerized anthropometry of the nose: landmark representation compared to surface analysis, Cleft Palate Craniofac. J. 44 (2007) 278–285.
[53] C. Niemitz, M. Nibbrig, V. Zacher, Human ears grow throughout the entire lifetime according to complicated and sexually dimorphic patterns—conclusions from a cross-sectional analysis, Anthrop. Anz. 65 (2007) 391–413.
[54] L.G. Farkas, J.C. Posnick, Growth and development of regional units in the head and face based on anthropometric measurements, Cleft Palate Craniofac. J. 29 (1992) 301–302.
[55] L.G. Farkas, O.G. Eiben, S. Sivkov, B. Tompson, M.J. Katic, C.R. Forrest, Anthropometric measurements of the facial framework in adulthood: age-related changes in eight age categories in 600 healthy white North Americans of European ancestry from 16 to 90 years of age, J. Craniofac. Surg. 15 (2004) 288–298.
[56] I. Ito, M. Imada, M. Ikeda, K. Sueno, T. Arikuni, A. Kida, A morphological study of age changes in adult human auricular cartilage with special emphasis on elastic fibers, Laryngoscope 111 (2001) 881–886.
[57] V. Penna, G.B. Stark, S.U. Eisenhardt, H. Bannasch, N. Iblher, The aging lip: a comparative histological analysis of age-related changes in the upper lip complex, Plast. Reconstr. Surg. 124 (2009) 624–628.
[58] S. Nagasaka, T. Fujimura, K. Segoshi, Development of a non-radiographic cephalometric system, Eur. J. Orthod. 25 (2003) 77–85.
[59] M. de Menezes, R. Rosati, V.F. Ferrario, C. Sforza, Accuracy and reproducibility of a 3D stereophotogrammetric imaging system, J. Oral Maxillofac. Surg., in press, doi:10.1016/j.joms.2009.09.036.
[60] U. Ozsoy, B.M. Demirel, F.B. Yildirim, O. Tosun, L. Sarikcioglu, Method selection in craniofacial measurements: advantages and disadvantages of 3D digitization method, J. Craniomaxillofac. Surg. 37 (2009) 285–290.