A cephalometric morphometric study of the sella turcica

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SUMMARY The purpose of this study was to use quantitative methods to measure the size and shape of the sella turcica and thus establish normative reference standards that could assist in a more objective evaluation and detection of pathological conditions.

Standardized lateral cephalograms of 184 healthy Greeks (91 males and 93 females) were used. The age range was between 6 and 17 years. Conventional measurements included three different heights of the sella turcica (anterior, posterior, median), its length, and width, measured in relation to the Frankfort reference line. In addition, the area of sella turcica was calculated. Morphometric methods were used to assess shape. The tracings were superimposed using the Procrustes method, and the average shape was computed. Principal component analysis (PCA) was used to assess shape variability. The data were correlated with centroid size, age, and gender. Unpaired *t*-tests were used to determine gender differences.

Sella height anteriorly was the only variable found to be significantly different between the genders, being larger in females by 0.5 mm. Linear and area measurements were found to be significantly correlated with age, but all correlations were low (r^2 below 8 per cent). Sella turcica shape, as described by PCA, was different between males and females, mainly at the posterior aspect of the sella outline. However, although there was an extensive overlap between the genders, and differences were minimal. Age was not found to be correlated with the shape coefficients, although, in the female group, the first principal component of shape was marginally not significant. Allometry was observed in both genders, the sella showing a tendency towards a flatter and wider shape with increase in size.

The results of this study constitute quantitative reference data that could be used for objective evaluation of sella shape.

Introduction

The sella turcica is a structure readily recognized on lateral cephalometric radiographs and routinely traced for cephalometric analysis. This makes it a good source of additional diagnostic information related to pathology of the hypophysis, or to various syndromes that affect the craniofacial region. Clinicians should be familiar with the normal radiographic anatomy and morphologic variability of this area, in order to recognize and investigate deviations that may reflect pathological situations, even before these become clinically apparent (Friedland and Meazzini, 1996; Feldkamp *et al.*, 1999; Alkofide, 2001).

Normative data on the size of the sella turcica have been reported in the literature and typically range from 4 to 12 mm for the vertical and 5 to 16 mm for the antero-posterior dimension (Camp, 1924; Silverman, 1957; Chilton *et al.*, 1983; Choi *et al.*, 2001; Axelsson *et al.*, 2004a; Jones *et al.*, 2005). Changes in size of the sella turcica are frequently related to pathology; enlargement is the most frequent finding but is usually not accompanied by bone erosion. The most common causes are the presence of intrasellar adenomas (e.g. prolactinomas; Weisberg *et al.*, 2003) and empty sella syndrome (intrasellar herniation of the suprasellar subarachnoid space; Weisberg *et al.*, 1976; Ammar *et al.*, 1999; Sage and Blumbergs, 2000; De Marinis

et al., 2005). Other more rare conditions may also cause enlargement, such as Rathke's cleft cysts and aneurysms (Swallow and Osborn, 1998). An abnormally small sella is less likely to occur and is seen in primary hypopituitarism, growth hormone deficiency, and Williams syndrome (Axelsson *et al.*, 2004b). Sheehan's syndrome, the necrosis of the pituitary from infarction after a complicated delivery, may also result in a small sella turcica (Dejager *et al.*, 1998; Kelestimur, 2003). Most of these conditions are not immediately life threatening but some can lead to pituitary apoplexy (necrosis and haemorrhage), which requires urgent management.

In addition to size, the shape of the sella may also be affected by pathological conditions, such as Down syndrome (Russell and Kjær, 1999), Williams syndrome (Axelsson *et al.*, 2004b), Seckel syndrome (Kjær *et al.*, 2001), and lumbosacral myelomeningocele (Kjær *et al.*, 1999). In previous studies, the morphology of the sella was described subjectively and qualitatively, and variations were categorized into different types such as circular, oval, flat, shallow, and J-shaped. Regional assessment of sella has identified the following morphological variants: oblique anterior wall, sella turcica bridge, double contour of the floor, irregularities of the posterior part of the dorsum sella, and pyramidal shape of the dorsum sella (Camp, 1924; Choi *et al.*, 2001; Axelsson *et al.*, 2004a). Sella bridging has been found to occur more

frequently in patients with severe craniofacial anomalies requiring combined surgical–orthodontic treatment than those requiring orthodontics alone (Becktor *et al.*, 2000; Jones *et al.*, 2005).

The evaluations described above are subjective, do not provide quantitative data, and thus do not facilitate definitive diagnostic conclusions. The purpose of this study was to use quantitative methods to measure the shape of the sella turcica and establish normative reference standards of sella morphology that could assist in a more objective evaluation and detection of pathological conditions.

Materials and methods

The sample consisted of cephalograms of patients who consecutively presented at a private orthodontic office for treatment. Only radiographs of good quality, depicting a reference ruler on the cephalostat for exact measurement of the magnification factors, were included. Patient age was restricted to between 6 and 17 years. All subjects were clinically healthy with no syndromes, clefts, or other malformations. Malocclusion type was not a criterion for sample selection. However, no severe malformations were present and all subjects were treated by orthodontics alone without surgical intervention. The final sample consisted of 184 cephalometric radiographs of 91 males and 93 females of Greek ethnic origin.

The radiographs were scanned at 150 dpi and the points shown in Figure 1 were digitized with Viewbox 3 software (dHAL Software, Kifissia, Greece).

The contour of the sella turcica was traced between points tuberculum sella (TS) and posterior clinoid (PClin), and nine additional equally spaced points along this contour were located by the computer software. The total of these 11 points defined a smooth curve that represented the outline



Figure 1 The following points were digitized: porion (Po) and orbitale (Or); tuberculum sella (TS), the most anterior point of the contour of the sella turcica; posterior clinoid (PClin), the most anterior point of the PClin process.

of the sella turcica from TS to PClin, and these points were used for shape analysis. Furthermore, the outline was used to calculate the position of the most posterior point (sella posterior), the most anterior point (sella anterior), and the deepest point of the sella (sella floor), using the Frankfort plane (FH) as the horizontal reference direction.

The following measurements were computed:

- 1. Sella width: the largest antero-posterior dimension, as measured parallel to the FH plane, from sella posterior to sella anterior.
- 2. Sella length: the distance from TS to PClin.
- 3. Sella height anterior: The vertical distance, as measured perpendicular to the FH plane, from TS to the sella floor.
- 4. Sella height posterior: The vertical distance, as measured perpendicular to the FH plane, from PClin to the sella floor.
- 5. Sella height median: The vertical distance, as measured perpendicular to the FH plane, from the sella floor to a point midway between PClin and TS.
- Sella area: the area included by the outline of the sella and capped by a line joining PClin to TS.

In addition to the conventional linear and area measurements, the 11 points defining the outline of the sella were used in a morphometric analysis (Dryden and Mardia, 1998; Halazonetis, 2004). All tracings were registered using Procrustes superimposition on the 11 outline points and the average shape was calculated. Principal component analysis (PCA) was applied to the residuals of the points coordinates and the principal components (PCs) of shape were extracted. Centroid size was also calculated for each tracing.

All measurements were taken after adjusting for the magnification of the radiographs. The conventional measurements and the morphometric analysis were performed using Viewbox 3 (dHAL Software) and statistical tests were run using StatsDirect (StatsDirect Ltd, Altrincham Cheshire, UK) and PAST (Hammer *et al.*, 2001).

To calculate the error of the method, 20 radiographs were randomly selected and re-digitized. Paired *t*-tests were employed to evaluate the systematic error. Random error was calculated using the method of Houston (1983).

Results

Error

No systematic error was detected between duplicate measurements of the conventional variables. Differences between duplicate measurements (in absolute values) ranged from 0 to 0.7 mm for the linear measurements and from 0 to 4.4 mm² for the sella area. The coefficient of reliability ranged from 95.8 to 98.5 per cent. The random error (Houston, 1983); the square root of half of the variance of the difference between duplicate measurements), ranged from 0.17 to 0.24 mm.

Descriptive data and size

Descriptive statistics for the measured variables are shown in Table 1. Unpaired *t*-tests were used to assess differences between the genders. Sella height anterior was the only variable found to be significantly different, being larger in females than males by 0.5 mm.

Age correlations

Several linear measurements were found to be significantly correlated with age (Table 2), but all correlations were low (r^2 , the square of the correlation coefficient, did not exceed 8 per cent).

Shape

PCA produced 18 PCs of shape for the 11 data points. The first two PCs were the most significant, accounting for 85 per cent of the total shape variance (Table 3). For the purposes of this study, the first four PCs were retained, which accounted for approximately 95 per cent of the total variance. A graphical depiction of these components is shown in Figure 2.

Hotelling's multivariate T^2 test on the four PCs showed that the sella turcica shape was different between males and females (P = 0.0007, 64 per cent correctly classified). This finding was corroborated by a permutation test (2000 permutations, P = 0.0015). In order to assess separation between the two groups, a canonical variates analysis was performed and the samples were plotted along the first two canonical axes (Figure 3). It can be seen that there was an extensive overlap. Unpaired *t*-tests showed that the components that differed were PC2 and PC3 (Table 4). The average shape of each group is depicted in Figure 4, which shows that the differences were located in the posterior part of the sella outline and were minor.

Allometry within the sample was investigated by calculating the correlation between centroid size and the PCs. Both the female and the male groups showed significant

correlations. In the female group, multiple regression of centroid size on PC1, PC2, PC3, and PC4 resulted in an r^2 of 19.9 per cent (P = 0.0006). PC1 and PC2 were the influential variables, producing an r^2 of 15.0 per cent (P = 0.0007). In the male group, only PC1 was found to be related to centroid size ($r^2 = 15.1$ per cent, P = 0.0001; Table 5).

Age was not found to be correlated with the shape coefficients (PC1 to PC4), although, in the female group, PC1 was marginally not significant ($r^2 = 4.0$ per cent, P = 0.0547).

Discussion

Reference normative data for the sella turcica already exist but they are mainly restricted to conventional linear measurements, such as height and length. The recent dissemination of geometric morphometrics in the field of orthodontics (Halazonetis, 2004) was an incentive to apply quantitative, and therefore objective, methods for assessment of shape normality of the sella.

The normal shape variability was described by decomposing the sample variation into the PCs, as undertaken routinely in geometric morphometrics (Dryden and Mardia, 1998; Slice, 2005). A major advantage of this method is its comprehensive nature. The percentage of shape variability explained by each PC is calculated, allowing retention of the most significant components for analysis. In this study, four PCs, out of 18, were sufficient to describe 94.9 per cent of shape variability. As illustrated in Figure 2, the first component (PC1) was related to the overall height/width ratio, representing shape variability ranging from vertically elongated with a narrow opening, to wide-open flat structures. This shape variation accounted for approximately 60 per cent of the overall variance (Table 3). The second component (PC2) described the position and orientation of the deepest part of the sella relative to the overlying opening. Components PC3 and PC4 were less significant and described relative width between the centre of the sella and

	Female group $(n = 93)$				Male group $(n = 91)$			
	Mean (SD)	Maximum	Median	Minimum	Mean (SD)	Maximum	Median	Minimum
Age	11.8 (2.0)	16.7	11.8	6.4	11.4 (1.8)	16.1	11.4	6.9
Sella length (mm)	7.0 (1.7)	10.7	7.0	3.6	7.1 (1.6)	11.8	7.2	3.3
Sella height FH-anterior (mm)*	7.2 (1.3)	9.9	7.1	3.8	6.7 (1.0)	10.1	6.6	4.1
Sella height FH-midpoint (mm)	6.8 (1.0)	8.9	6.9	4.6	6.6 (0.8)	8.6	6.6	4.2
Sella height FH-posterior (mm)	6.5 (1.0)	8.7	6.4	3.9	6.6 (1.0)	9.1	6.6	4.4
Sella width FH (mm)	9.1 (1.2)	11.6	9.2	6.2	8.9 (1.2)	12.0	8.9	5.8
Sella area (mm ²)	48.4 (12.4)	77.3	48.6	25.6	46.1 (10.7)	72.1	45.7	22.3
Centroid size (mm)	138.7 (17.1)	173.4	140.2	101.2	135.0 (15.0)	170.2	135.1	95.9

 Table 1
 Descriptive statistics.

SD, standard deviation.

*Significantly different between genders, as determined by unpaired *t*-test (t = 2.91, P = 0.004).

Table 2Correlations of variables with age.

	Femal	e group $(n = 93)$	Male group $(n = 91)$		
	r^2	Р	r^2	Р	
Sella length (mm)	0.01	0.345 (NS)	0.00	0.8591 (NS)	
Sella height	0.04	0.0523 (NS)	0.08	0.0068	
FH-anterior (mm)		× ,			
Sella height	0.07	0.0118	0.05	0.0296	
FH-midpoint (mm)					
Sella height	0.07	0.0101	0.01	0.3606 (NS)	
FH-posterior (mm)				× ,	
Sella width FH (mm)	0.01	0.2767 (NS)	0.05	0.0366	
Sella area (mm ²)	0.04	0.0488	0.08	0.0086	
Centroid size (mm)	0.03	0.0919 (NS)	0.07	0.0145	

NS, not significant.

Table 3 Percentage variance and cumulative variance explained by the first 10 principal components (PCs) of shape. Only the first four were used in the statistical evaluations.

PC	Variance (%)	Cumulative variance (%)
PC1	59.8	59.8
PC2	25.2	85.0
PC3	7.4	92.4
PC4	2.5	94.9
PC5	1.3	96.2
PC6	1.1	97.3
PC7	0.6	97.9
PC8	0.4	98.3
PC9	0.4	98.7
PC10	0.3	99.0

the opening, as well as skewness of the shape in the anteroposterior direction, respectively.

Morphometric analysis offers quantitative objective criteria of what is to be considered as a deviation from the norm concerning sella turcica shape, perhaps leading to greater specificity and sensitivity in detecting sella shape abnormalities. Previous studies have used various descriptive terms to evaluate sella shape and have presented examples of shape aberrations (Camp, 1924; Choi et al., 2001; Axelsson et al., 2004a). It is interesting to note that Axelsson et al. (2004a) attributed 'normal' sella shape to less than 70 per cent of the sample, even though individuals with no clinically apparent pathology were investigated. It is believed that the remaining 30 per cent should not be considered dysmorphological, but within the normal variability of the population. These high percentages of assumed aberration probably stem from deficiencies of subjective evaluation, such as assignment to shape groups using subjective and arbitrary cut off criteria. In contrast, the present data showed a uniform distribution of shapes in the shape space, with no clear-cut boundaries or group formation (Figure 5). Such a distribution, common to



Figure 2 The principal components (PCs) of shape. The rows show the effect of each PC on the average shape by warping the average shape (middle column) by three standard deviations of the PC in each direction (left and right columns).



Figure 3 Canonical variates analysis showing the female (crosses) and male (dots) patients and the 95 per cent ellipses (female: broken line, male: solid line).

biological structures, lends itself better to quantitative methods. However, the need for specific software to perform morphometric analysis makes clinical application difficult. Until such software becomes ubiquitous, representative shapes, at two standard deviation (SD) distances from the

Table 4Comparison of principal components (PCs) of shapebetween the genders.

	Female group $(n = 93)$		Male group $(n = 91)$		t-test		
	Mean	SD	Mean	SD	t	Р	
PC1	-0.011	0.106	0.010	0.104	1.36	0.1753 (NS)	
PC2	0.014	0.058	-0.014	0.075	2.81	0.0056	
PC3	-0.008	0.036	0.009	0.037	3.06	0.0026	
PC4	0.000	0.022	0.000	0.021	0.13	0.895 (NS)	

NS, not significant; SD, standard deviation.



Figure 4 Average shapes of the female (solid line) and male (broken line) groups.

average along the two most significant shape space axes, were constructed to be used as templates for assessing shape normality (Figure 5).

It should be pointed out that the shape studied in the present research included only the interior outline of the sella turcica and did not extend to the posterior side of the PClin processes because this structure may be affected by factors unrelated to intrafossa pathology. Therefore, variation in the shape of the entire clinoid process was not investigated and morphological types such as 'pyramidal shape of the dorsum sellae' (Axelsson *et al.*, 2004a) were not assessed.

In addition to morphometric evaluation, conventional linear and area measurements were included. The literature contains an abundance of such data but methods of measurement differ widely. Following the concerns expressed by Silverman (1957), it was decided to use the FH as the reference plane, so that antero-posterior and vertical measurements would be related to an external reference system and not be dependent on sella shape. This is a problem in studies where the antero-posterior diameter of sella is measured from TS to the most distant point on the opposite side of the outline (Axelsson *et al.*, 2004a) because the orientation of the measurement depends on the shape

 Table 5
 Correlation between shape and centroid size.

	Female group $(n = 93)$		Male $(n = 9)$	group 91)
	r^2	Р	r^2	Р
PC1 (simple regression) PC2 (simple regression) PC1, PC2 (multiple regression)	0.07 0.08 0.15	0.0118 0.0067 0.0007	0.15 0.00	0.0001 0.7171 (NS)

NS, not significant; PC, principal component.



Figure 5 Scatter plot of the sample on the first two principal components. The sella outlines around the graph correspond to the shape at the points marked with open circles, positioned at two standard deviations from the average.

being measured and is not directionally consistent between subjects.

Due to differences in the methods of measurement, width and height results in the present investigation should be compared with other studies with caution. Camp (1924) reported higher values for these measurements (width 10.6 mm, height 8.1 mm) but that sample was mostly adults and the magnification of the radiographs was not given. Tetradis and Kantor (1999) reported measurements for four age groups ranging from 6 to over 21 years. For comparison purposes, average values from the present sample were calculated using the same age ranges, but due to very few subjects in the oldest groups, only average values for the 6-10 and 11-15 groups could be reliably calculated. Table 6 shows that values for the investigated subjects were smaller by approximately 10 per cent, but this was probably due to the magnification adjustment applied, whereas Tetradis and Kantor (1999) do not report such a correction. Axelsson et al. (2004a) studied a longitudinal sample and used magnification adjustment. The median sella height measurement in the present study is almost comparable

methodologically to that measured by Axelsson et al. (2004a) and not statistically different, as evaluated by t-tests (Table 6). Their values for width were larger by approximately 1 mm, which could be explained by the differences in the method of measurement. However, sella length, although measured in a comparable manner, was also found smaller in the present study, a discrepancy that could be attributed to other factors, such as ethnicity. Choi et al. (2001) studied 200 orthodontic patients and used a similar method of measurement to that in the present investigation. They reported slightly higher values, but no SDs were given and statistical comparisons with that investigation could not be performed.

Although cross-sectional in nature, statistically significant correlations were found between age and several measurements (Table 2). In another cross-sectional investigation, Tetradis and Kantor (1999) reported a trend of increased size with age but this was not consistent between all successive age groups. Choi et al. (2001) measured volume in addition to width and height in a cross-sectional sample of orthodontic patients. They, too, found an increase in sella dimensions with age, from the 6-10 to the 21-25 age group. However, the change in height was minimal and probably not statistically significant (no SD values were given). Chilton et al. (1983) reported on volume of the sella turcica, as calculated from cephalometric radiographs, and found an increase with age, as well as larger volumes in males than in females.

It should be noted that an age-related increase of sella turcica size is expected because its contents, i.e. the hypophysis, have been shown to increase in size with age (Argyropoulou et al., 1991). Indeed, longitudinal studies of sella size have provided clearer results. Silverman (1957) reported that sella area increases steadily with age and follows the somatic growth pattern, possibly related to the function of the anterior lobe. Correlation of size to stature was higher than to age. Axelsson et al. (2004a) also showed a steady increase in size for both genders during growth.

The present study would appear to be the first that reports allometry in sella shape. PC1 was significantly correlated with centroid size in both genders, the coefficient of determination (r^2) reaching 15 per cent for the male group (Table 5). This signifies that as sella increases in size, it also becomes flatter and wider (see Figure 2). This relationship should be investigated further, preferably in a longitudinal sample.

Another finding of this study, that should not be overlooked, is the large intersubject variability. Size and shape variability have been noted before, but this is probably the first that permits quantitative assessment of sella shape variability. The search for establishment of normative values is based on the assumption that pathological conditions will be identified with sufficient sensitivity once such values are available. However, it is becoming more evident that what appear to be 'abnormalities' in shape may not always reflect underlying pathology. For example, although asymmetry [able 6] Comparison of the results with other studies (average \pm standard deviation and sample size are given). Age groups 9 and 12 span from 8.5 to 9.5 and 11.5 to 12.5 years, 2 6 11-15 Age group (years) Sella height 6-10 2 6 espectively. Axelsson et al. (2004a) had a slightly larger age range 11 - 15Age group (years) Sella width 6 - 10Study

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 $6.7 \pm 1.1 \ (n = 7)$ $6.7 \pm 0.9 \ (n = 3)$

 $6.7 \pm 0.9 \ (n = 72)$ $6.4 \pm 0.6 \ (n = 10)$

 $7.5 \pm 1.7 \ (n = 211)$ $6.8 \pm 1.0 \ (n = 132)$

 6.4 ± 0.6 (n = 1

 $6.4 \pm 0.7 \ (n = 46)$ $7.2 \pm 1.6 \ (n = 43)$

 $10.6 \pm 1.2 \ (n = 72)$ $8.9 \pm 1.1 \ (n = 38)$

 $10.1 \pm 1.2 \ (n = 72)$ $9.3 \pm 1.1 \ (n = 10)$

 $9.0 \pm 1.2 \ (n = 132)$ $7.5 \pm 1.7 \ (n = 211)$

9.6 ± 2.0 (*n* = 43) 8.9 ± 1.2 (n = 46)

Tetradis and Kantor (1999)

Axelsson et al. (2004)

Present study

(double outline) and cortical erosion of the sella floor are often considered signs of increased pathological significance (Cook, 1980), this is debatable (Kricheff, 1979) because such signs have been observed in a relatively large percentage of asymptomatic subjects (Swanson and Du Boulay, 1975) and autopsy material (Muhr *et al.*, 1981), without being related to the presence of pituitary tumours.

Conversely, pathology may exist without osseous manifestations. The largest percentage of intrasellar tumours is microadenomas (adenomas smaller than 10 mm in diameter), often too small to cause sella enlargement or shape change. In fact, it is estimated that 10–20 per cent of the population may harbour microadenomas, most often asymptomatic (Hall *et al.*, 1994, Turner *et al.*, 1998). Moreover, even considerable enlargement of the pituitary gland may not produce osseous changes evident on routine films of the skull because the pituitary gland occupies only part (approximately 80 per cent) of the volume of the sella turcica (Chang *et al.*, 2005).

Further studies are needed to assess the sensitivity and specificity of cephalograms for detection of pituitary pathology. Of course, cephalograms do not constitute the radiological method of choice for diagnosis of a suspected pituitary tumour. Computed tomography and magnetic resonance imaging provide much greater sensitivity (Kricheff, 1979). However, incidental findings noted by the orthodontist may lead to further investigation of undiagnosed or subclinical conditions (Friedland and Meazzini, 1996; Feldkamp *et al.*, 1999; Alkofide, 2001).

Conclusions

Several linear measurements were found to be correlated with age, but to a low extent, due to the cross-sectional nature of the study and the large intersubject variability.

The average shape of sella turcica was slightly different between males and females, especially at the posterior part of the outline.

Sella shape was not found to be significantly correlated with age. However, sella allometry was noted in both the male and the female groups.

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References

- Alkofide E 2001 Pituitary adenoma: a cephalometric finding. American Journal of Orthodontics and Dentofacial Orthopedics 120: 559–562
- Ammar A, Al-Sultan A, Al Mulhim F, Al Hassan A Y 1999 Empty sella syndrome: does it exist in children? Journal of Neurosurgery 91: 960–963
- Argyropoulou M, Perignon F, Brunelle F, Brauner R, Rappaport R 1991 Height of normal pituitary gland as a function of age evaluated by magnetic resonance imaging in children. Pediatric Radiology 21: 247–249
- Axelsson S, Storhaug K, Kjær I 2004a Post-natal size and morphology of the sella turcica—longitudinal cephalometric standards for Norwegians between 6 and 21 years of age. European Journal of Orthodontics 26: 597–604
- Axelsson S, Storhaug K, Kjær I 2004b Post-natal size and morphology of the sella turcica in Williams syndrome. European Journal of Orthodontics 26: 613–621
- Becktor J P, Einersen S, Kjær I 2000 A sella turcica bridge in subjects with severe craniofacial deviations. European Journal of Orthodontics 22: 69–74
- Camp J 1924 Normal and pathological anatomy of the sella turcica as revealed by roentgenograms. American Journal of Roentgenology 12: 143–155
- Chang H P, Tseng Y C, Chou T M 2005 An enlarged sella turcica on cephalometric radiograph. Dentomaxillofacial Radiology 34: 308–312
- Chilton L A, Dorst J P, Garn S M 1983 The volume of the sella turcica in children: new standards. American Journal of Roentgenology 140: 797–801
- Choi W J, Hwang E H, Lee S E 2001 The study of shape and size of normal sella turcica in cephalometric radiographs. Korean Journal of Oral and Maxillofacial Radiology 31: 43–49
- Cook D M 1980 Pituitary tumors—current concepts of diagnosis and therapy. Western Journal of Medicine 133: 189–196
- Dejager S, Gerber S, Foubert L, Turpin G 1998 Sheehan's syndrome: differential diagnosis in the acute phase. Journal of Internal Medicine 244: 261–266
- De Marinis L, Bonadonna S, Bianchi A, Maira G, Giustina A 2005 Primary empty sella. Journal of Clinical Endocrinology and Metabolism 90: 5471–5477
- Dostalova S, Sonka K, Smahel Z, Weiss V, Marek J 2003 Cephalometric assessment of cranial abnormalities in patients with acromegaly. Journal of Cranio-Maxillo-Facial Surgery 31: 80–87
- Dryden I L, Mardia K V 1998 Statistical shape analysis. John Wiley & Sons, Chichester
- Feldkamp J, Santen R, Harms E, Aulich A, Mödder U, Scherbaum W A 1999 Incidentally discovered pituitary lesions: high frequency of macroadenomas and hormone-secreting adenomas—results of a prospective study. Clinical Endocrinology 51: 109–113
- Friedland B, Meazzini M C 1996 Incidental finding of an enlarged sella turcica on a lateral cephalogram. American Journal of Orthodontics and Dentofacial Orthopedics 110: 508–512
- Halazonetis D J 2004 Morphometrics for cephalometric diagnosis. American Journal of Orthodontics and Dentofacial Orthopedics 125: 571–581
- Hall W A, Luciano M G, Doppman J L, Patronas N J, Oldfield E H 1994 Pituitary magnetic resonance imaging in normal human volunteers: occult adenomas in the general population. Annals of Internal Medicine 120: 817–820
- Hammer Ø, Harper D A T, Ryan P D 2001 PAST: Paleontological statistics software package for education and data analysis. Palaeontologia Electronica 4: 9. (http://palaeo-electronica.org/2001_1/past/issue1_01.htm)
- Houston W J B 1983 The analysis of errors in orthodontic measurements. American Journal of Orthodontics 83: 382–389
- Jones R M, Faqir A, Millett D T, Moos K F, McHugh S 2005 Bridging and dimensions of sella turcica in subjects treated by surgical-orthodontic means or orthodontics only. Angle Orthodontist 75: 714–718

Kelestimur F 2003 Sheehan's syndrome. Pituitary 6: 181-188

- Kjær I, Fischer Hansen B, Reintoft I, Keeling J W 1999 Pituitary gland and axial skeletal malformations in human fetuses with spina bifida. European Journal of Pediatric Surgery 9: 354–358
- Kjær I, Hansen N, Becktor K B, Birkebæk N, Balslev T 2001 Craniofacial morphology, dentition, and skeletal maturity in four siblings with Seckel syndrome. Cleft Palate-Craniofacial Journal 38: 645–651
- Kricheff I I 1979 The radiologic diagnosis of pituitary adenoma: an overview. Radiology 131: 263–265
- Muhr C, Bergström K, Grimelius L, Larsson S G 1981 A parallel study of the roentgen anatomy of the sella turcica and the histopathology of the pituitary gland in 205 autopsy specimens. Neuroradiology 21: 55–65
- Russell B G, Kjær I 1999 Postnatal structure of the sella turcica in Down syndrome. American Journal of Medical Genetics 87: 183–188
- Sage M R, Blumbergs P C 2000 Primary empty sella turcica: a radiologicalanatomical correlation. Australasian Radiology 44: 341–348

- Silverman F N 1957 Roentgen standards for size of the pituitary fossa from infancy through adolescence. American Journal of Roentgenology 78: 451–460
- Slice D E 2005 Modern morphometrics in physical anthropology. Kluwer Academic/Plenum Publishers, New York
- Swallow C E, Osborn A G 1998 Imaging of sella and parasellar disease. Seminars in Ultrasound, CT, and MRI 19: 257–271
- Swanson H A, Du Boulay G 1975 Borderline variants of the normal pituitary fossa. British Journal of Radiology 48: 366–369
- Tetradis S, Kantor M L 1999 Prevalence of skeletal and dental anomalies and normal variants seen in cephalometric and other radiographs of orthodontic patients. American Journal of Orthodontics and Dentofacial Orthopedics 116: 572–577
- Turner H E, Moore N R, Byrne J V, Wass J A H 1998 Pituitary, adrenal and thyroid incidentalomas. Endocrine-Related Cancer 5: 131–150
- Weisberg L A, Zimmerman E A, Frantz A G 1976 Diagnosis and evaluation of patients with an enlarged sella turcica. American Journal of Medicine 61: 590–596

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