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ORIGINAL RESEARCH

# Morphological types of sella turcica bridging and sella turcica dimensions in relation to palatal canine impaction: a retrospective study

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**Abstract**

The aim of this study was to determine the relationship between the presence of sella turcica bridging and palatal canine impaction (PCI) using several classification methods. In this retrospective study, lateral cephalometric radiographs of 120 subjects with PCI (43 males, 77 females; mean age 18.8 ± 7.8 years) and 120 controls (44 males, 76 females; mean age 18.1 ± 5.6 years) with complete permanent dentition were examined. The extent of sella turcica bridging was assessed using two different methods, and the types of complete sella turcica bridging were evaluated. The sella turcica dimensions were measured and analyzed using the *t*-test, and comparison of the presence of sella turcica bridging was performed using the two-tailed Fisher's exact test. The frequency of complete sella turcica bridging was significantly higher in subjects with PCI (18.3%) than in controls (8.3%, $p = 0.023$) but without significant differences in the occurrence of sella turcica bridging of Type A (ribbon-like fusion) and Type B (extension of clinoid processes). No significant differences in partial bridging were found between patients with PCI and controls according to both methods. The length and the anteroposterior diameter were significantly larger in subjects with PCI and no difference was observed between the groups in the sella turcica depth. Complete sella turcica bridging occurred significantly more frequently in subjects with PCI than in controls. However, the association between partial bridging and PCI was not confirmed, therefore, we do not recommend any classification of partial bridging for clinical practice.

**Keywords**

Palatal canine impaction; Sella turcica bridging; Morphology; Sella dimensions

## 1. Introduction

The maxillary canines are the second most frequently impacted teeth after the third molars [1]. The incidence rate of maxillary impacted canines is approximately 3.5%, and it is more common in females [2]. In general, impaction occurs when the tooth root development is completed but the tooth has not erupted into the oral cavity yet. Impaction of permanent maxillary canines is a frequently encountered clinical problem; its treatment is time-consuming and technically demanding.

Based on the localization, maxillary impacted canines are classified into three categories [3]. The Class I maxillary impacted canine is located palatally and occurs 2 times more frequently than other positions [4]. The Class II maxillary impacted canine is located in the centre of the alveolar crest or labial to the alveolar crest, but not superimposed labially to the root of the adjacent lateral incisor and the Class III impacted maxillary canine is located labial to the root of the adjacent lateral incisor [3].

The aetiology of maxillary canine impaction is multifactorial and the causes are mainly localized, such as tooth-size and arch-length discrepancies, prolonged retention or early loss of the deciduous canine, abnormal position of the tooth bud, alveolar cleft, ankylosis, cystic or neoplastic formation, dilaceration of the root, iatrogenic or idiopathic origin. Palatal canine impaction usually occurs with other dental anomalies, such as a small size of maxillary laterals and infraocclusion of primary molars [5], and therefore a genetic background of this condition is evident. On the other hand, the labial position of maxillary impacted canines is associated with the lack of space in the dental arch as a result of crowding [6].

Sella turcica is a saddle-shaped depression located in a cranial base that contains and protects the pituitary gland. This structure serves as a cephalometric landmark essential for the evaluation of the relationship between craniofacial and dental structures and for evaluation of growth, development and craniofacial changes [7]. It is visible on lateral cephalograms routinely used as a part of the orthodontic examination and therefore its morphological deviations can be encountered. According to Axelsson *et al.* [8], there are five morphological variations of sella turcica: oblique anterior wall, extremely low sella turcica, sella turcica bridging, irregularity (notching) in the posterior part of the dorsum sellae, and pyramidal shape of the dorsum sellae. Sella turcica bridging (also known as interclinoid ICL ossification) is one of the most common developmental variations formed by abnormal fusion of the ligament between the anterior and posterior clinoid processes [9]. The aetiology of the origin is unknown, but the main theories include abnormal embryologic development of the sphenoid bone, ossification of the ligaments between the clinoid processes [9], or infection of the pituitary gland. The literature also suggests that its abnormal morphology is related to genetic syndromes affecting the craniofacial complex, such as Axenfeld-Rieger syndrome, basal cell naevus syndrome, Down's syndrome, William's syndrome, Freeman-Burian syndrome, Focal Dermal Hypoplasia, Osteogenesis imperfecta and Single Maxillary Midline Central Incisor syndrome [10], and genetically determined dental anomalies such as palatal canine impaction (PCI), hypodontia, dental transposition, mandibular second premolar agenesis, and maxillary lateral incisor agenesis [11–19].

Sella turcica, dental epithelial progenitor cells and maxillary, palatal and frontonasal areas share a common embryologic origin, the neural crest cells [20]. The anterior and posterior wall of sella turcica has different embryologic origin, neural crest cells and the para-axial mesoderm [21]. Kjær [21] suggests that mostly the anterior wall of sella turcica is probably associated with deviations in the frontonasal and maxillary fields. The higher prevalence of sella turcica bridging in subjects with PCI is usually connected with a shared embryological basis of craniofacial and dental structures. It is hypothesized that any disturbances in the gene expression such as homeobox or hox genes [22] in the neural crest cells can lead to errors in these areas. This can lead to many genetically determined dental anomalies such as PCI connected to the abnormal shape of sella turcica.

Clinically, if future development of PCI is suspected, orthodontists may recommend extraction of the deciduous canine or space expansion. The presence of specific factors is the most crucial key to the indication of treatment. These factors may include the side asymmetry in eruption of the permanent maxillary canine, the inappropriate position of the canine crown on the panoramic radiograph, or congenitally missing, size-reduced or a peg-shaped lateral incisor. Some researchers have also addressed the issue of the presence of sella turcica bridging as a predictive factor for PCI [11–17, 19, 22–25].

Previous studies have focused on determining the type of sella turcica bridging based on the sella turcica dimensions. The dimensions measured and the scoring scale varied, and the studies showed inconsistent results. In particular, interclinoid distance is often confused with length. No studies on subjects with PCI evaluating the distance between the anterior and posterior clinoid processes were found. Radiologic images of sella turcica bridging (Types A and B) obtained through lateral cephalogram have not yet been evaluated in relation to the development of impacted canines [26]. The question is whether the proper assessment of the morphological variation of sella turcica could be helpful for clinical practice.

This study aimed to investigate the association between morphological types of sella turcica bridging in subjects with PCI and healthy controls using conventional imaging methods in orthodontic practice, cephalometric radiography. Several methods evaluating sella turcica bridging for partial and complete bridging based on the sella turcica dimensions were assessed for clinical relevance. The null hypothesis states that there is no significant difference between subjects with palatally impacted canines and controls in terms of the presence of Type A and Type B sella turcica bridging and the sella turcica dimensions.

## 2. Materials and methods

### 2.1 Subjects

Treatment records of 120 subjects (43 males, 77 females; mean age 18.8 ± 7.8 years) with unilateral or bilateral PCI were collected retrospectively from patients who had visited the Orthodontic Department of Clinic of Stomatology, Faculty of Medicine, Masaryk University and St. Anne's University Hospital Brno, Czech Republic. The palatal position of canine was identified by an experienced clinician (AO) using dental panoramic radiographs, anterior occlusal radiographs, and computed tomography/cone-beam computed tomography (CBCT) and later confirmed during surgery. The data of subjects were collected blindly, without any analysis of the lateral cephalometric radiograph. The exclusion criteria included a low-quality or missing lateral cephalometric radiograph, the presence of craniofacial anomalies, a cleft lip or palate, a trauma or previous orthodontic treatment.

The controls consisted of the same number of healthy individuals (44 males, 76 females; mean age 18.1 ± 5.6 years) with erupted canines in the dental arch and complete permanent dentition. The exclusion criteria were the same as for the subjects with PCI.

### 2.2 Data collection

Lateral cephalometric radiographs were taken in a standardized manner using the same cephalostat and X-ray device (PM 2002 CC Proline, Planmeca OY, Helsinki, Finland) in the Department of Dental Radiology. The cephalometric radiographs were scanned using a scanner (Epson Perfection V700, Epson Portland Inc., Portland, OR, USA) and then measured with imaging software (PicPick, Version 4.0.0, NTeWORKS, Daejeon, Republic of Korea). The actual size of each image was calibrated based on the known distance on the cephalometric radiograph.

### 2.3 Definition of measurement

Fig. 1 illustrates the linear dimensions of the sella turcica in the sagittal plane. The length, depth and anteroposterior diameter were measured according to the study of Silverman [27] and Kisling [28], and the interclinoid distance was measured by the method used by Sundareswaran and Nipun [29]. The definition of the parameters is as follows:

- Length (L): the distance from the tip of the dorsum sellae to that of the tuberculum sellae.
- Depth (D): the line's distance dropped perpendicularly

from the line above to the deepest point of the sella floor.

• Anteroposterior diameter (APD): the distance from the tip of the tuberculum sellae to the farthest point on the inner wall of the sella turcica.

• Interclinoid distance (ID): the shortest distance between the anterior clinoid and posterior clinoid processes of the sella turcica.

The length-to-diameter ratio according to Leonardi *et al.* [19], the ratio between the interclinoid distance and length according to Sundareswaran and Nipun [29] and the area size (the product of length and depth) were also calculated.

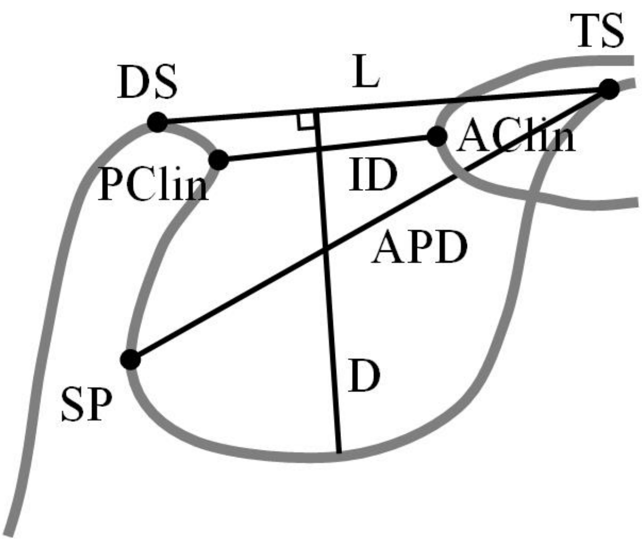


**FIGURE 1. The contour of a sella turcica with landmarks and linear dimensions.** TS: tuberculum sellae; DS: dorsum sellae; PClin: posterior clinoid; AClin: anterior clinoid; SP: sella posterior; L: length; ID: interclinoid distance; APD: anteroposterior diameter; D: depth.

## 2.4 Measurement

The subjects with PCI and the controls were divided into two groups: sella turcica with no fusion (Fig. 2a) and sella turcica with a bridge. These groups were classified using three methods. In the group with no fusion, the level of calcification was assessed based on the length and anteroposterior (AP) diameter of the sella turcica as suggested by Leonardi *et al.* [19], method 1:

• Class I (no bridging): length >3/4 of the AP diameter.

• Class II (partial sella turcica bridging): length ≤3/4 of the AP diameter.

However, method 1 does not consider the distance between the clinoid processes, therefore, this study used an additional method according to Sundareswaran and Nipun [29], described as method 2:

• Class I (no bridging): interclinoid distance >1/3 of the length of the sella turcica.

• Class II (partial sella turcica bridging): interclinoid distance <1/3 of the length of the sella turcica.

In the group with complete sella turcica bridging, the morphology of the bridge according to Becktor *et al.* [26] was evaluated and classified into two subgroups:

• Type A: ribbon-like fusion (Fig. 2b).

• Type B: extension of the anterior and/or posterior clinoid process, where these two meet anteriorly, posteriorly or in the middle, with a thinner fusion (Fig. 2c).

The cephalograms were randomly numbered and then assigned to the subjects with PCI or controls after the sella turcica bridging was evaluated and measured. The jaws and teeth were not visible due to the use of an opaque card in the computer screen. Classification of sella turcica bridging was determined independently by two experienced clinicians (AO, PV) who were blinded to the treatment assignment of individual images. There was 100% agreement between the clinicians on the incidence and type of complete sella bridging. Measurements of linear dimensions were performed by one of them (AO). The same investigator re-evaluated 30 randomly selected lateral cephalometric radiographs two weeks after the first analysis to establish the error of linear measurements. The method error of linear measurements was calculated according to Dahlberg's formula [30]. The errors of duplicate measurements were generally small with a standard deviation of 0.26 mm for the length, 0.23 mm for the diameter and 0.26 mm for the depth.

## 2.5 Statistical analysis

Power of the study was calculated as a component of a-priori designed study protocol. The sample size was optimized to account for the relatively wide range of comparisons performed, where the outcome depends on the stratified subsamples and the occurrence of the analyzed endpoints. In the case of binary and ordinary endpoints (Fisher's exact test, goodness-of-fit test) the achieved sample size is sufficient to detect differences ranging from 10% to approximately 21% in all comparisons performed with a power of 80%, overall tests working with the whole sample ($2 \times N = 120$) are powerful to detect a 10% difference in these endpoints. For the quantitative parameters, the sample size was optimized to detect as statistically significant difference of 0.4–0.5 times the standard deviation, also with 80% power. These effect size ranges appear to be clinically relevant and consistent with the results and designs of other already published studies (cited in discussion). The analysis was computed using IBM SPSS Statistics 29 Software (IBM Corp, Armonk, NY). The two-tailed Fisher's exact test with a significance level of 0.05 was used to compare the presence of sella turcica bridging between the subjects with PCI and the control group. The cephalometric data were analysed using Student's *t*-test (two-tailed, unequal variance) to determine the differences between the two groups, also with a significance level of 0.05. Statistical analysis was conducted using Microsoft Office Excel 2016 (Microsoft Corporation, Redmond, Washington, United States).

## 3. Results

Table 1 summarizes the prevalence of sella turcica bridging in the subjects with PCI and the control group. Complete sella turcica bridging occurred significantly more frequently in subjects with PCI (18.3%) than in controls (8.3%, $p$ = 0.0355). A high prevalence was observed in both sexes, but the difference was found to be significant only in the male

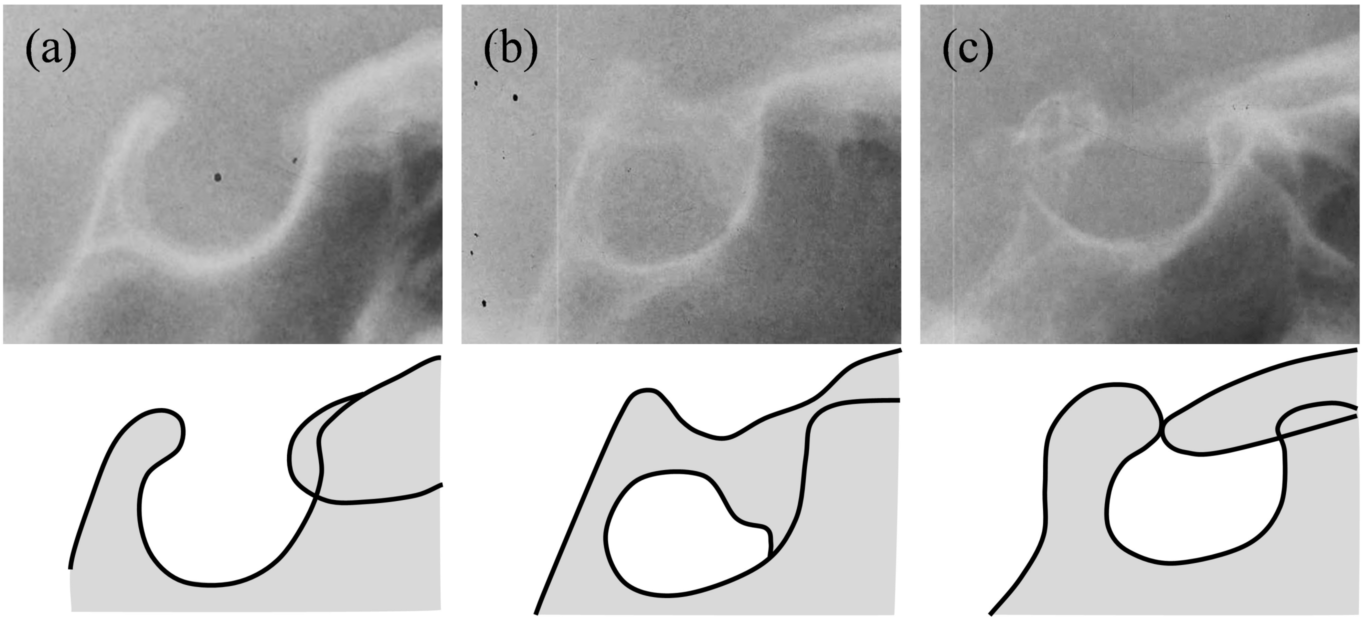


**FIGURE 2. Radiographic image obtained from the lateral cephalogram and a corresponding contour of a sella turcica.** (a) no bridging; (b) Type A sella bridging; (c) Type B sella bridging.

group ($p = 0.0264$). Partial sella turcica bridging was not more frequent in subjects with PCI according to method 1 (16.7%) and method 2 (35.0%) than in controls (19.2% and 35.0%, respectively, $p > 0.05$). No significant differences were also found in the male and female subgroups. In addition, there were no significant differences found between subjects with PCI and controls without bridging ($p > 0.05$).

The data describing the presence of the types of complete bridging are summarized in Table 2. Type A sella turcica bridging showed no significant difference between the two groups, and no sexual dimorphism was detected ($p = 0.6218$). Type B complete sella turcica bridging was present in 18.6% of male subjects compared to 2.4% of male controls ($p = 0.0149$). No significant differences were found among women ($p = 0.6251$). Similarly, Type B total bridging did not occur significantly more often in patients with PCI.

A comparison of sella turcica linear dimensions between the two groups is shown in Table 3. Besides the basic linear dimensions referred to in the Materials and methods section, some combinations thereof are also presented. The ratio between the sella length and diameter was used according to Leonardi *et al.* [19] in classifying partial bridging. Similarly, the ratio between the interclinoid distance and length was used according to Sundareswaran and Nipun [29]. The length and depth were multiplied to calculate the area of the sella turcica on cephalometric radiographs. The data showed that the mean values of the linear dimensions were higher in subjects with PCI than in controls, regardless of sex, except for the interclinoid distance that was smaller in subjects with PCI. The difference was statistically significant ($p < 0.05$) only for length, diameter and area. In the case of the interclinoid distance, the difference was not statistically significant. A statistically significant increase in length ($p < 0.05$) and area ($p < 0.05$) was observed in the male group, but no statistically significant difference was observed in any parameter in the female group.

The last two rows of Table 3 show the level of statistical significance when comparing the previously mentioned parameters between the male and female subgroups. The male population showed a significantly increased length and length-to-AP diameter ratio in both groups and an increased interclinoid distance in the controls ($p < 0.05$).

## 4. Discussion

### 4.1 Main observations

This study confirmed previous findings of a significantly higher occurrence of complete sella turcica bridging in subjects with PCI. In addition, the effect of the type of complete bridging according to Becktor *et al.* [26] for PCI was assessed for the first time and found to be insignificant. Partial bridging was classified according to Leonardi *et al.* [19] (method 1), which is a relatively common method; however, it often exhibits confusion between the interclinoid distance and the sella turcica length. Therefore, the method of Sundareswaran and Nipun [29] (method 2), which works with the interclinoid distance as the shortest distance between clinoid processes and which has not been previously reported for PCI subjects, was also used. Both methods for the identification of partial bridging showed a non-significant association with PCI. Finally, several parameters characterizing the sella turcica dimensions were tested for the association with PCI. Controversially, the length, AP diameter and area were found to be higher for subjects with PCI and in the male population.

### 4.2 Sella turcica bridging

In most relevant studies, a higher prevalence of sella bridging was observed in the subjects with PCI. The highest prevalence in subjects (25.8%) was found by Ali *et al.* [23]. Moder-

**TABLE 1. Comparison of sella turcica bridging between the subjects with PCI and the controls.**

| Sex | Group | Complete sella bridging | Partial bridging | | No bridging | |
|---|---|---|---|---|---|---|
| | | Total | Method 1‡ | Method 2§ | Method 1‡ | Method 2§ |
| Male | | | | | | |
| | Subjects (n = 43) | 9 (20.9%) | 4 (9.3%) | 13 (30.2%) | 30 (69.8%) | 21 (48.8%) |
| | Controls (n = 44) | 2 (4.8%) | 6 (13.6%) | 15 (34.1%) | 36 (81.8%) | 27 (61.4%) |
| | *p*-value | 0.0264* | 0.7387 | 0.8193 | 0.2179 | 0.2844 |
| Female | | | | | | |
| | Subjects (n = 77) | 13 (16.9%) | 16 (20.8%) | 29 (37.7%) | 48 (62.3%) | 35 (45.5%) |
| | Controls (n = 76) | 8 (10.5%) | 17 (22.3%) | 28 (36.8%) | 51(67.1%) | 40 (52.6%) |
| | *p*-value | 0.3479 | 0.8462 | 1.0000 | 0.6126 | 0.4204 |
| Total | | | | | | |
| | Subjects (n = 120) | 22 (18.3%) | 20 (16.7%) | 42 (35.0%) | 78 (65.0%) | 56 (46.7%) |
| | Controls (n = 120) | 10 (8.3%) | 23 (19.2%) | 43 (35.8%) | 87 (72.5%) | 67 (55.8%) |
| | *p*-value | 0.0355* | 0.7367 | 1.0000 | 0.2652 | 0.1965 |

‡: *According to Leonardi et al. [19]*; §: *According to Sundareswaran and Nipun [29]; *: p-value < 0.05.*

**TABLE 2. Comparison of Type A and Type B complete sella turcica bridging between the subjects with PCI and the controls.**

| Sex | Group | Complete sella bridging | | |
|---|---|---|---|---|
| | | Type A† | Type B† | Total |
| Male | | | | |
| | Subjects (n = 43) | 1 (2.3%) | 8 (18.6%) | 9 (20.9%) |
| | Controls (n = 44) | 1 (2.4%) | 1 (2.4%) | 2 (4.8%) |
| | *p*-value | 1.0000 | 0.0149* | 0.0264* |
| Female | | | | |
| | Subjects (n = 77) | 2 (2.6%) | 11 (14.3%) | 13 (16.9%) |
| | Controls (n = 76) | 0 (0.0%) | 8 (10.5%) | 8 (10.5%) |
| | *p*-value | 0.4967 | 0.6251 | 0.3479 |
| Total | | | | |
| | Subjects (n = 120) | 3 (2.5%) | 19 (15.8%) | 22 (18.3%) |
| | Controls (n = 120) | 1 (0.8%) | 9 (7.5%) | 10 (8.3%) |
| | *p*-value | 0.6218 | 0.0688 | 0.0355* |

†: *According to Becktor et al. [26]; *: p-value < 0.05.*

**TABLE 3. Comparison of linear dimensions of sella turcica between the subjects with PCI and the controls.**

| Sex | Group | Variable (mean ± standard deviation) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Length (mm) | Depth (mm) | Anteroposterior diameter (mm) | Interclinoid distance (mm) | Length/anteroposterior diameter (-) | Interclinoid distance/length (-) | Area ($mm^2$) |
| Male | | | | | | | | |
| | Subjects | 11.25 ± 2.62 | 8.21 ± 1.69 | 12.02 ± 2.47 | 3.48 ± 2.76 | 0.94 ± 0.16 | 0.31 ± 0.24 | 93.23 ± 35.35 |
| | Controls | 10.26 ± 1.89 | 7.85 ± 1.48 | 11.53 ± 1.63 | 4.13 ± 2.28 | 0.89 ± 0.15 | 0.40 ± 0.19 | 80.10 ± 20.26 |
| | *p*-value | 0.050* | 0.297 | 0.285 | 0.238 | 0.149 | 0.078 | 0.040* |
| Female | | | | | | | | |
| | Subjects | 9.80 ± 1.73 | 8.45 ± 1.33 | 11.82 ± 1.69 | 3.05 ± 2.23 | 0.83 ± 0.13 | 0.30 ± 0.20 | 83.34 ± 23.42 |
| | Controls | 9.44 ± 1.63 | 8.31 ± 1.22 | 11.37 ± 1.58 | 3.15 ± 1.85 | 0.83 ± 0.12 | 0.33 ± 0.19 | 78.68 ± 19.43 |
| | *p*-value | 0.194 | 0.486 | 0.090 | 0.755 | 0.990 | 0.415 | 0.185 |
| Total | | | | | | | | |
| | Subjects | 10.32 ± 2.21 | 8.37 ± 1.47 | 11.89 ± 2.01 | 3.20 ± 2.44 | 0.87 ± 0.15 | 0.31 ± 0.22 | 86.89 ± 28.68 |
| | Controls | 9.74 ± 1.77 | 8.14 ± 1.34 | 11.43 ± 1.60 | 3.51 ± 2.07 | 0.86 ± 0.14 | 0.35 ± 0.19 | 79.20 ± 19.75 |
| | *p*-value | 0.027* | 0.216 | 0.049* | 0.293 | 0.368 | 0.076 | 0.017* |
| M *vs.* F | | | | | | | | |
| | Subjects | 0.002** | 0.431 | 0.640 | 0.390 | 0.000*** | 0.846 | 0.109 |
| | Controls | 0.020* | 0.090 | 0.593 | 0.019* | 0.025* | 0.071 | 0.711 |

**: p-value < 0.05; **: p-value < 0.01; ***: p-value < 0.001; M: Male; F: Female.*

ate prevalence, consistent with this work, was reported by Leonardi *et al.* [19] (16.7%), Leonardi *et al.* [22] (18.4%), Haji *et al.* [24] (14.3%) and Divya *et al.* [16] (17.9%). Al-Nakib and Najim [25], Amelinda *et al.* [11], Dadgar *et al.* [12], and Kaya *et al.* [17] showed a relatively low presence of complete sella turcica bridging in subjects with PCI (5.0%, 5.9%, 4.4% and 6.3%, respectively), but still higher than controls. Although these results differ, all findings were statistically significant, except those by Kaya *et al.* [17]. The differences may be due to the variance in age and genetic background between the samples. It is not clear from the literature whether these studies were blinded or open. Typically, dental structures and the sella turcica are visible together on a lateral cephalometric radiograph, leading to a potential bias. Only four studies [17, 19, 22, 23] described the diagnostic method of PCI. All studies reported PCI except for that of Al-Nakib and Najim [25]. They included maxillary palatal and buccal impacted canines, which could affect their results.

The prevalence of Type A and Type B complete sella bridging according to Becktor *et al.* [26] has not yet been reported in subjects with PCI. Becktor *et al.* [26] found complete sella turcica bridging in 18.6% of subjects, with 5.6% being Type A and 13% Type B. All subjects had severe craniofacial deviation and underwent combined orthodontic and surgical treatment. Although Becktor *et al.* [26] used a sample population with different pathology, these values correlate with those of our results.

More pronounced differences between published studies were in the classification of partial bridging. All the authors who studied canine impaction used the method proposed by Leonardi *et al.* [19], which involves the sella length-to-diameter ratio (method 1). Except for the study by Majeed *et al.* [14], the prevalence of partial bridging was higher in subjects with impacted canines. The difference was statistically significant in seven studies [12, 13, 16, 19, 22–24] and insignificant in two studies [14, 17]. Nevertheless, this study showed contradictory results.

The clinical significance of the classification according to method 1 is questionable for several reasons. Firstly, the exact definition of the “tip of the dorsum sellae”, as one of the points defining the length, differs across the above mentioned studies. Some studies define the tip as the most superior tip of the dorsum sellae, as in our work, while other studies consider the sella length as the closest distance between the tuberculum sellae and dorsum sellae. The latter method underestimates the length, resulting in the overestimation of the occurrence of partial bridging. This may lead to a relatively high prevalence of partial bridging in both groups (>50%), making the classification less valuable from a clinical point of view. Secondly, the distance from the tip of the dorsum sellae to the tuberculum sellae does not reflect in all respects the degree of calcification that occurs between the anterior and posterior clinoid processes.

Hence, a method according to Sundareswaran and Nipun [29] (method 2) was used in the current study. This method is based on the interclinoid distance, which reflects the variable extent of calcification of the clinoid processes. Nevertheless, no significant differences in groups with partial and without sella turcica bridging between the subjects with PCI and the controls were found.

## 4.3 Sella turcica dimensions

The length of the sella turcica was significantly higher in subjects with PCI. The difference was higher in males. A higher length in subjects with PCI is inconsistent with data reported in previous studies [14, 15, 23, 25]. An in-depth review of the studies revealed that their results differed from each other in terms of length, even in the controls.

There is an apparent discrepancy in the graphic interpretation of the "length", although the definition is the same, *i.e.*, the distance from the tuberculum sellae to the tip of the dorsum sellae. As already mentioned, some authors consider the tip to be the most superior tip of the dorsum sellae [25, 29], while others consider the tip as the point closest to the tuberculum sellae [13–15, 17, 23, 24]. In our opinion, the first definition is considerably more appropriate because it corresponds better to measurements from CBCT or directly on the skull, where the length is evaluated in the midsagittal plane and is not affected by the lateral clinoid processes.

Moreover, according to the second definition, the authors confuse the length with the sagittal interclinoid distance [12, 14, 15, 17, 23]. This is inaccurate since the interclinoid distance connects to the anterior clinoid process rather than the tuberculum sellae. Therefore, the definition of "interclinoid distance" varies across studies.

The AP diameter is used to describe the size of the sella turcica, and thus, its definition is more straightforward and should not lead to misinterpretation. The other studies have shown a relatively large variance in mean values. The discrepancies are usually attributed to the differences in the sample population. However, significant differences can also be found between studies with the same population [13–15, 23]. Our results correspond well with those of Ali *et al*. [23], Al-Nakib and Najim [25] and Axelsson *et al*. [8]. The differences between the subjects and controls are mostly inconclusive. In this study, the mean AP diameter increased significantly in subjects with PCI, but the difference is on the border of statistical significance.

Considering the length-to-AP diameter ratio in Table 3, we can observe that the difference between the groups is practically negligible, although the parameters were calculated with the inclusion of patients with sella turcica bridging. Thus, the ratio used by Leonardi *et al*. [19] shows an insignificant difference in the occurrence of partial bridging. Interclinoid distance seems to be a much more appropriate parameter. In our study, this is the only parameter that is smaller in subjects with PCI. However, it shows a very high standard deviation which makes the difference statistically insignificant. For the same reason, the difference in the interclinoid distance-to-length ratio is not significant.

The mean of the area increased significantly in subjects with PCI. However, in contrast to recent studies by Sato and Endo [31] and Antonarakis *et al*. [32], no detailed evaluation of the sella surface area, was performed in this study. No other studies investigated sexual dimorphism in subjects with PCI.

When comparing linear dimensions of sella turcica between sexes, we found a significantly higher length in males compared to females. This difference was reflected in the length-to-diameter ratio, which was also significant. Greater length in males compared to females was found only in the 18-year-old age group in the study by Axelsson *et al*. [8], which corresponds to the mean age in this study. Nevertheless, no significant sex-related differences were reported more frequently [14, 23, 25, 37]. Previous studies have suggested that the change in size with age and sex reflects the adolescent growth spurt in females 2–3 years earlier [27, 35, 36]. Silverman [27] and Axelsson *et al*. [8] also agreed that both depth and diameter increase during puberty, while the length remains the same.

## 4.4 Clinical relevance

Both classifications of partial bridging appear to be inappropriate for everyday orthodontic practice. Although there are significant differences in dimensions, these differences are clinically insignificant and not useful for the classification of partial bridging. Correct evaluation of the linear dimensions of the sella turcica in the midsagittal plane requires some training, and one may encounter an unclear definition of cephalometric landmarks, which significantly affects the resulting prevalence. Moreover, the cephalometric radiograph should be of good quality, and irregularities in the sella shape can make the classification process difficult. On the other hand, complete sella turcica bridging was observed twice as often in subjects with PCI and we therefore recommend careful monitoring of the eruption of permanent canines in cases of complete sella turcica bridging, as mentioned by Jankowski *et al*. [33].

## 4.5 Limitation

Limitations must be considered when evaluating the results from cephalometric studies. Measurements of sagittal dimensions on the lateral cephalometric radiograph may be misleading due to the superimposition of structures. In particular, in the case of the interclinoid distance, the measurement may be performed between the opposite left and right structures. The most accurate assessment of sella turcica bridging and dimensions has been reported in CBCT studies [34–39]. The cephalometric evaluation was found to be a suitable diagnostic method for diagnosing complete sella turcica bridging but it overestimates partial bridging [37]. Acevedo *et al*. [37] found that lateral cephalogram could reveal all cases of complete bridging, but in addition, the same number of pseudo bridges was classified. CBCT did not show any association between sella turcica bridging and canine impaction [38], and there was no difference between the two groups in terms of sella dimensions. Although these conclusions enhance the diagnostic accuracy of CBCT imaging, it has limited relevance in orthodontic practice. CBCT scans usually display dentition and the surrounding jaws, and the cranial base with sella turcica is usually not visible. CBCT scans showing the entire craniofacial region require a high radiation dose compared to conventional radiography, and they are not necessary for a regular orthodontic visit. For this reason, the CBCT examination of the sellar area is not usually indicated, and a lateral cephalometric radiograph is still preferred.

Future studies should focus on the appropriate definition of measurement points and dimensions in terms of their clinical relevance. CBCT evaluation of the relationship between the presence of sella turcica bridging and other genetically determined dental anomalies should be also considered. In addition, a more detailed comparison of the cephalometric and CBCT results could contribute to the development of an appropriate classification.

## 5. Conclusions

This study found a higher prevalence of complete sella turcica bridging in subjects with PCI, which may support the theory of the same embryological origin of these structures. Nevertheless, we conclude with several new findings:

1. There were no significant differences in complete sella turcica bridging of Type A and Type B between controls and subjects with PCI.

2. Method 1 and method 2 did not find any significant difference in partial bridging.

3. Linear measurements of sella turcica in subjects with PCI revealed increased length and AP diameter and depth, whereas the interclinoid distance showed no statistical difference, in contrast to previous findings.

4. Classification methods based on the sella turcica dimensions appear to be inappropriate for clinical practice. Therefore, we recommend careful follow-up only in subjects with PCI and complete sella turcica bridging with a clearly visible connection between the clinoid processes.

### AVAILABILITY OF DATA AND MATERIALS

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

### AUTHOR CONTRIBUTIONS

AO—designed the research study; AO and PV—performed the research; LD—performed statistical analysis; AO, PC and LIH—analyzed the data, wrote the manuscript. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

### ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The study protocol was approved by the Ethical Committee at St. Anne's University Hospital in Brno, Czech Republic (Approval no. 01G/2020). Subjects' anonymity was maintained and therefore informed consent was not required.


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### CONFLICT OF INTEREST

The authors declare no conflict of interest.

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