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# Role of multi-detector CT in analysis of the greater and lesser palatine foramina

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## Abstract

**Background:** The objective of this study was to assess variation in number, size, shape, and location of greater and lesser palatine foramina using multiple anatomical landmarks through data obtained from adult head CT scans. CT skulls of 200 adult persons were included in this study. There were 100 males and 100 females, aged from 22 to 65 years old. An e-film DICOM viewer version 2 was applied to estimate morphological parameters and to calculate the linear measurements related to the greater palatine foramen.

**Results:** On the basis of CT findings, regarding the position of GPF in relation to maxillary molar teeth, the most frequent location was opposite the third maxillary molar (41%). Regarding the dimensions of the GPF, the mean AP diameter was  $3.94 \pm 1.13$  mm on the right side and  $4.22 \pm 1.21$  mm on the left. The mean LM diameter was  $2.17 \pm 0.59$  mm on the right side and  $2.28 \pm 0.74$  mm on the left. It was concluded that the GPF was AP elongated in 90.5% and circular in 9.5% of the examined CT scans. Linear measurements from the center of GPF to surrounding anatomical landmarks were done and showed no statistically significant difference existed between sides, but a statistically highly significant difference existed between males and females.

**Conclusions:** Proper localization of GPF is important to facilitate therapeutic, local anesthetic, and surgical manipulation in the maxillofacial region. Based on CT findings, we demonstrated that the GPF is most often located opposite the M3 in the majority of the cases. The maxillary molars are the best landmarks for locating the GPF.

**Keywords:** Greater palatine foramen, Location, CT

## Background

The hard palate presents many important features including the greater and lesser palatine foramina. The lesser palatine foramina (LPF) transmit lesser palatine vessels as well as middle and posterior palatine nerves. The greater palatine foramen (GPF) transmits greater palatine nerve and vessels. Greater palatine nerve is a branch of maxillary division of trigeminal nerve supplying mucosa of hard palate, medial wall of maxillary sinus, and posterior aspect of lateral wall of nose [1]. The greater palatine artery originates from descending palatine branch of maxillary artery in the pterygopalatine

fossa, passes through the greater palatine canal, and emerges from GPF in palatal aspect of the third maxillary molar, to reach the hard palate [2]. The palatine crest is a prominent bony ridge extending medially from behind GPF [3].

Locating the greater palatine foramen is of paramount importance for both dentists and oral and maxillofacial surgeons [4]. Furthermore, it is important to determine the location of the GPF for palatal donor tissue and greater palatine nerve block anesthesia. Knowing the exact location of the GPF is essential also for mobilization of the greater palatine artery in closure of oroantral fistula using mucoperiosteal pedicled palatal flaps [5]. It is also reported that stimulation of pterygo-palatine ganglion through this foramen is used for diminishing the effects of paralysis in paralytic patients

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and also in cases of cerebral vasospasm cluster and migraine headache [6].

The objective of this study was to assess variation in number, size, shape, and location of greater and lesser palatine foramina using multiple anatomical landmarks through data obtained from adult head CT scans.

## Methods

CT skulls for examination of the brain or paranasal sinuses of 200 adult persons were included in this study. There were 100 males and 100 females, aged from 22 to 65 years old.

- Inclusion criteria: CT skulls for examination of brain or paranasal sinuses of adult persons of both sexes.
- Exclusion criteria: radiographs showing pathological changes in the region of maxilla (including developmental and traumatic changes).

This study was approved by the Research Ethics Committee. Written informed consent was obtained from all the study patients before any data or scans were gathered or performed.

A high-speed GE FX CT scanner (GE Healthcare) acquired CT images at exposure 120 kV, 74 mA, 60 mAs; rotation time 0.5; and slice thickness 0.5 mm.

Patient's sex and age data were acquired from patient files.

An e-film DICOM viewer version 2, a program for radiograph analysis and measurement, was applied to estimate morphological parameters and to calculate the linear measurements. Images were evaluated in axial, coronal, and sagittal planes.

## Morphological parameters

1. Number of lesser palatine foramina on both sides.
2. Presence of palatine crest on both sides.
3. Location of the GPF in relation to maxillary molar teeth. The location of GPF was described as either opposite the second maxillary molar (M2), between M2 and M3, opposite M3, or behind M3.

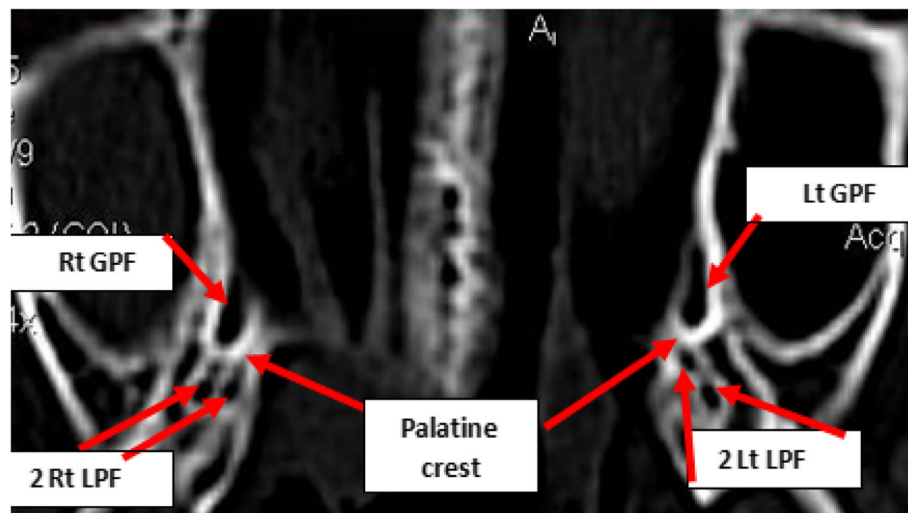
The location of the GPF were determined by the following steps:

- a. The screen was divided on the e-film viewer into two parts (A and B).
- b. The same axial cuts were retrieved in both parts.
- c. A transverse line passing through the center of GPF in image B was drawn.
- d. Another line parallel to the first one was drawn in image A.
- e. A new depth of axial reconstruction demonstrated an overlap between the previous two lines, thus locating the GPF in relation to maxillary molar teeth.

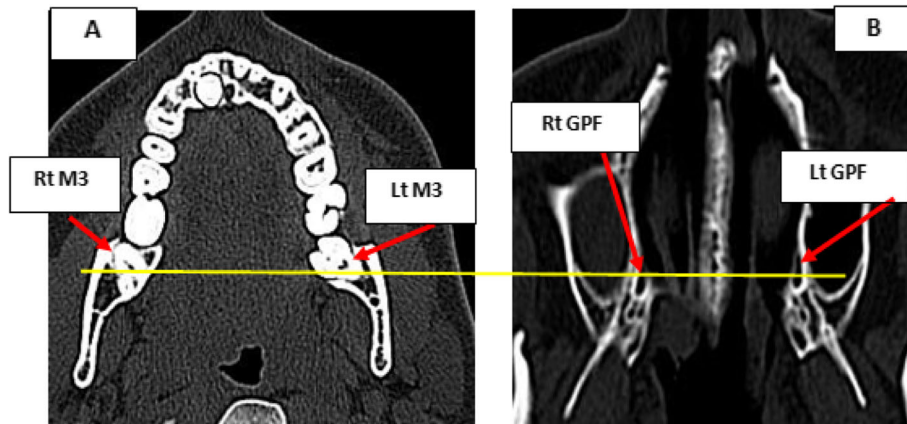
## Morphometric parameters

The dimensions of the GPF were estimated as follows:

- a. The longest anteroposterior (AP) and lateral-medial (LM) dimensions were measured.
- b. The center of GPF was set at the point of intersection of the longest AP and LM dimensions.



**Fig. 1** A CT scan at the region of hard palate illustrating the greater and lesser palatine foramina as well as the presence of palatine crest on both sides



**Fig. 2** A CT scan at the region of hard palate illustrating the right and left greater palatine foramina (b) located opposite the right and left third maxillary molars (M3) (a)

- c. The shape (or form) of GPF was determined by dividing AP by LM dimensions:
- Values equal to one indicate a circular foramen
  - Values greater than one indicate an AP elongated foramen
  - Values less than one indicate a LM elongated foramen

Measurements on CT scans were obtained from the center of GPF to:

1. Posterior border of hard palate (PBHP) (shortest distance).
2. Midline maxillary suture (MMS) (shortest perpendicular distance).
3. Posterior nasal spine (PNS).
4. Center of incisive fossa (IF).

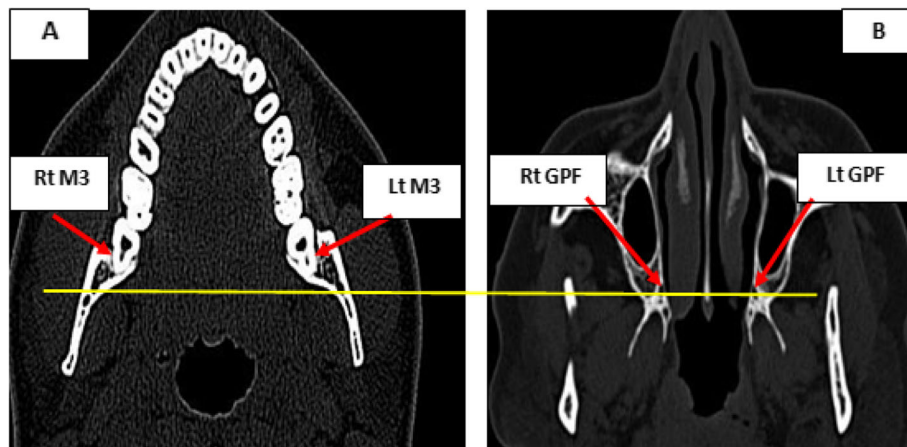
5. Center of opposite GPF.

**Statistical study**

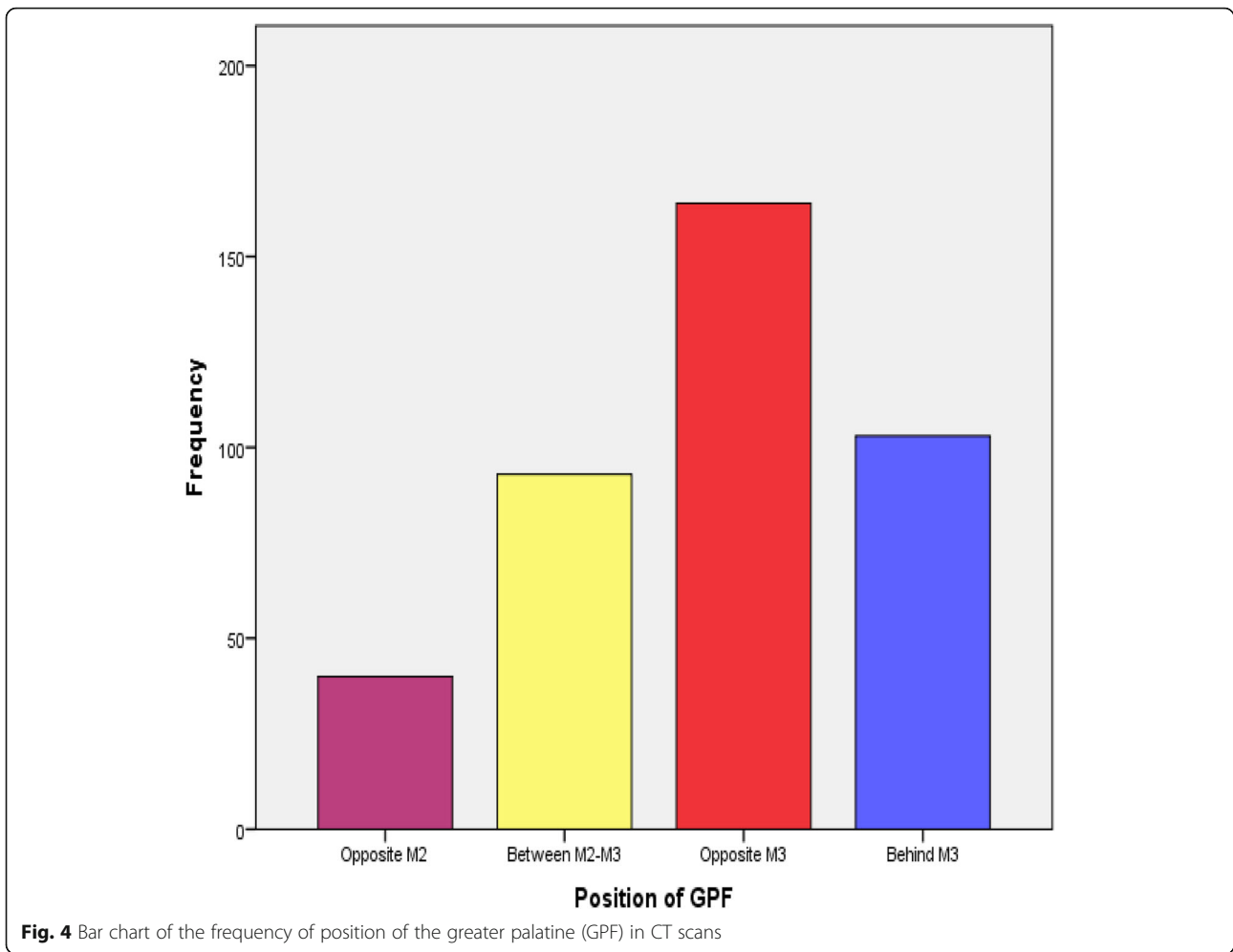
Statistical analysis was performed using statistical package for social sciences (SPSS) version 21.0 (IBM corporation, Somers, NY, USA) statistical software. The frequency of nominal data was done. The association among the different nominal variables regarding side and gender was explored using Chi square ( $X^2$ ) tests.

The quantitative data were expressed as means  $\pm$  standard deviation (SD). The data were examined by Kolmogorov Smirnov test for normality. Independent *t* test was performed to compare between the different variables regarding side and gender.

The results were considered significant at *p* value  $\leq$  0.05 and highly significant at *p* value  $\leq$  0.01.



**Fig. 3** A CT scan at the region of hard palate illustrating the right and left greater palatine foramina (b) located behind the right and left third maxillary molars (M3) (a)



**Table 1** Frequency and percent of position of the GPF based on side

| Position of GPF   | Side   |        | Total  | p value |
|-------------------|--------|--------|--------|---------|
|                   | Right  | Left   |        |         |
| Opposite M3       | 80     | 84     | 164    | 0.2(NS) |
|                   | 40.0%  | 42.0%  | 41.0%  |         |
| Opposite M2       | 20     | 20     | 40     | 10.0%   |
|                   | 10.0%  | 10.0%  | 10.0%  |         |
| Between M2 and M3 | 48     | 45     | 93     | 23.2%   |
|                   | 24.0%  | 22.5%  | 23.2%  |         |
| Behind M3         | 52     | 51     | 103    | 25.8%   |
|                   | 26.0%  | 25.5%  | 25.8%  |         |
| Total             | 200    | 200    | 400    |         |
|                   | 100.0% | 100.0% | 100.0% |         |

**Results**

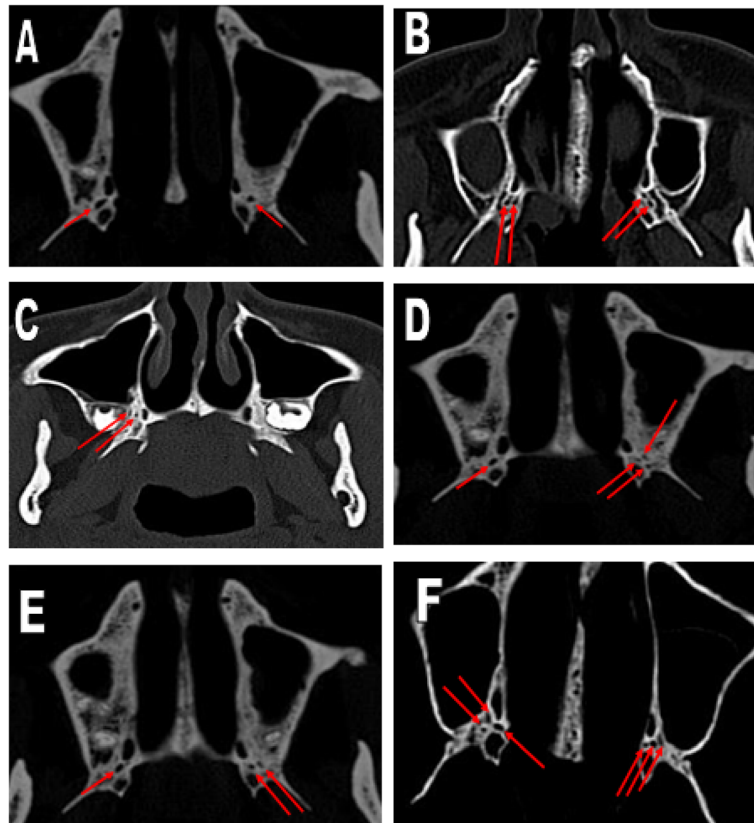
**Morphological parameters**

**Location of GPF in relation to maxillary molar teeth**

The presence of one GPF on both sides was a constant finding (Fig. 1). The GPF was most frequently located opposite M3 (41%) (Fig. 2). It was found behind M3 in 25.8% (Fig. 3), between M2 and M3 in 23.3%, and opposite M2 in 10% (Fig. 4). Regarding the side, on the right side, the GPF was located opposite M3 in 40%, behind

**Table 2** Frequency and percent of position of the GPF based on gender

| Gender | Position of GPF |                   |             |           | Total  | p value  |
|--------|-----------------|-------------------|-------------|-----------|--------|----------|
|        | Opposite M2     | Between M2 and M3 | Opposite M3 | Behind M3 |        |          |
| Male   | 8               | 54                | 95          | 43        | 200    | 0.3 (NS) |
|        | 4.0%            | 27.0%             | 47.5%       | 21.5%     |        |          |
| Female | 32              | 39                | 69          | 60        | 200    | 100.0%   |
|        | 16.0%           | 19.5%             | 34.5%       | 30.0%     |        |          |
| Total  | 40              | 93                | 164         | 103       | 400    |          |
|        | 10.0%           | 23.2%             | 41.0%       | 25.8%     | 100.0% |          |



**Fig. 5** A CT scan at the region of the hard palate in different patients. **a** Single LPF on both sides. **b** Two LPF on both sides. **c** Two right LPF and absent left. **d** Single LPF on the right side and 3 LPF on left side. **e** Single LPF on the right and two LPF on left side. **f** Three LPF on both sides

M3 in 26%, between M2 and M3 in 24%, and opposite M2 in 10%. On the left side, it was located opposite M3 in 42%, behind M3 in 25.5%, between M2 and M3 in 22.5%, and opposite M2 in 16%. *p* value = 0.2 is statistically non-significant using Chi square tests (Table 1).

**Table 3** Number, frequency, and percent of lesser palatine foramina

| Frequency of lesser palatine foramina | Side   |        | Total  | <i>p</i> value |
|---------------------------------------|--------|--------|--------|----------------|
|                                       | Right  | Left   |        |                |
| No foramina                           | 0      | 2      | 2      | 0.5 (NS)       |
|                                       | 0.0%   | 1.0%   | 0.5%   |                |
| One foramen                           | 152    | 150    | 302    | 75.5%          |
|                                       | 76.0%  | 75.0%  | 75.5%  |                |
| Two foramina                          | 46     | 42     | 88     | 22.0%          |
|                                       | 23.0%  | 21.0%  | 22.0%  |                |
| Three foramina                        | 2      | 6      | 8      | 2.0%           |
|                                       | 1.0%   | 3.0%   | 2.0%   |                |
| Total                                 | 200    | 200    | 400    |                |
|                                       | 100.0% | 100.0% | 100.0% |                |

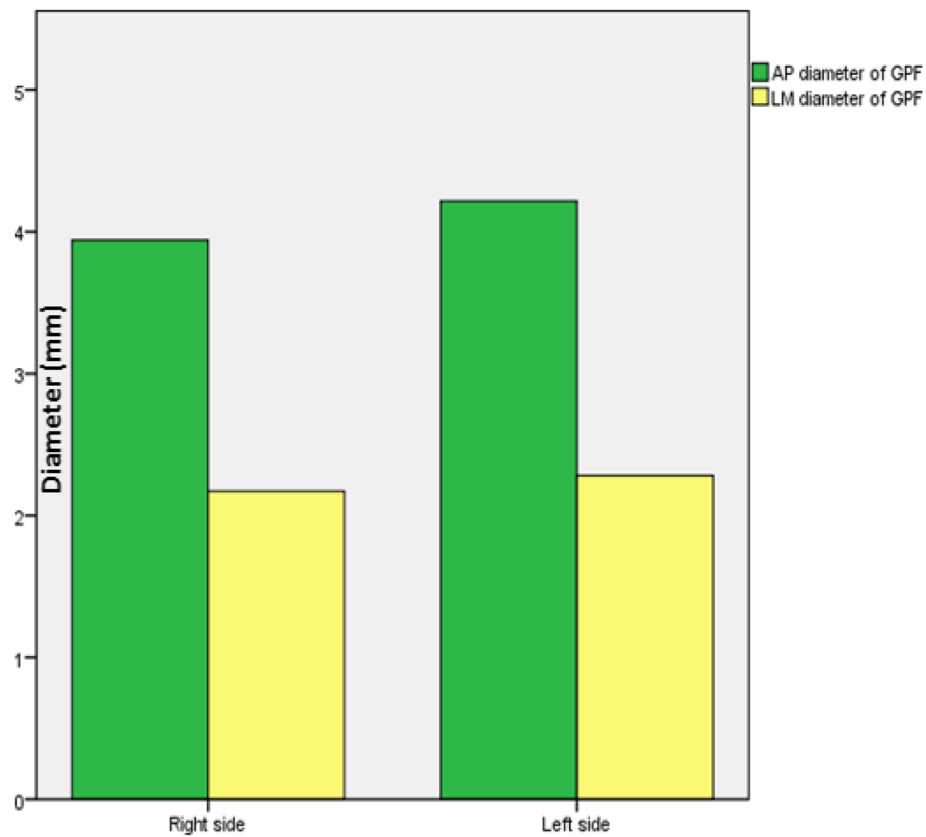
Regarding the location of GPF in relation to maxillary molars in both males and females, several locations were encountered, opposite M3 in 47.5% of males and 34.5% of females, between M2 and M3 in 27% of males and 19.5% of females, behind M3 in 21.5% of males and 30% of females, and opposite M2 in 4% of males and 16% of females. *p* value = 0.3 is statistically non-significant using Chi square tests (Table 2).

**Table 4** Number, frequency, and percent of lesser palatine foramina based on gender

| Gender | Number of lesser palatine foramina |       |       |       | Total  |
|--------|------------------------------------|-------|-------|-------|--------|
|        | No                                 | One   | Two   | Three |        |
| Male   | 2                                  | 152   | 46    | 0     | 200    |
|        | 1.0%                               | 76.0% | 23.0% | 0.0%  | 100.0% |
| Female | 0                                  | 150   | 42    | 8     | 200    |
|        | 0.0%                               | 75.0% | 21.0% | 4.0%  | 100.0% |
| Total  | 2                                  | 302   | 88    | 8     | 400    |
|        | 0.5%                               | 75.5% | 22.0% | 2.0%  | 100.0% |



**Fig. 6** A CT scan at the region of hard palate illustrating the dimensions of the greater palatine foramina (GPF)



**Fig. 7** Bar chart of the dimensions of the greater palatine foramen (GPF) in CT scans based on side

**Table 5** The dimensions of the GPF based on side

| Dimensions of GPF     | Side  | N   | Mean ± SD   | p value |
|-----------------------|-------|-----|-------------|---------|
| AP dimension-GPF (mm) | Right | 200 | 3.94 ± 1.13 | 0.02    |
|                       | Left  | 200 | 4.22 ± 1.21 |         |
| LM dimension-GPF (mm) | Right | 200 | 2.17 ± 0.59 | 0.09    |
|                       | Left  | 200 | 2.28 ± 0.74 |         |

**Number of lesser palatine foramina (LPF) (Fig. 5)**

The presence of one lesser palatine foramen (LPF) was most frequent (75.5%). Two LPF were observed in 22% and three foramina in 22%. Absent foramina were encountered in 0.5%. Regarding the side, on the right side, one foramen existed in 76%, two foramina in 23%, and three in 1%. On the left side, one foramen existed in 75%, two foramina in 21%, and three in 3%, and absent foramina were encountered in 1%. *p* value = 0.5 is statistically non-significant using Chi square tests (Table 3).

Regarding the gender, males showed absent LPF in 1%, one foramen in 76%, and two foramina in 23%. Females showed one LPF in 75%, two foramina in 21%, and three foramina in 4% (Table 4).

**Presence of palatine crest**

The presence of palatine crest has been a constant finding in all examined CT scans (Fig. 1).

**Morphometric parameters**

**The dimensions of the greater palatine foramen (GPF)**

On the right side, the mean AP diameter of GPF was 3.94 ± 1.13 mm, and LM diameter was 2.17 ± 0.59 mm. On the left side, mean AP diameter was 4.22 ± 1.21 mm, and LM diameter was 2.28 ± 0.74 mm (Figs. 6 and 7). *p* value = 0.02 is statistically significant using independent *t* test (Table 5).

In males, the mean AP diameter of the GPF was 4.39 ± 1.2 mm, and the mean LM diameter was 2.47 ± 0.70 mm. In females, the mean AP diameter was 3.77 ± 1.07 mm, and the mean LM diameter was 1.98 ± 0.53 mm. *P* value less than 0.01 is statistically highly significant using independent *t* test (Table 6).

The GPF was AP elongated in 90.5% and circular in 9.5%. Regarding the side, on the right side, the GPF was AP elongated in 90% and circular in 10%. On the left

**Table 6** The dimensions of the GPF based on gender

| Dimensions of GPF     | Gender | N   | Mean ± SD   | p value |
|-----------------------|--------|-----|-------------|---------|
| AP dimension-GPF (mm) | Male   | 200 | 4.39 ± 1.20 | 0.000   |
|                       | Female | 200 | 3.77 ± 1.07 |         |
| LM dimension-GPF (mm) | Male   | 200 | 2.47 ± 0.70 | 0.000   |
|                       | Female | 200 | 1.98 ± 0.53 |         |

side, it was AP elongated in 91% and circular in 9%. *p* value = 0.1 is statistically non-significant using Chi square tests (Table 7 and Fig. 8).

In males, GPF was AP elongated in 94% and circular in 6%. In females, it was AP elongated in 87% and circular in 13%. *p* value = 0.02 is statistically significant using Chi square tests (Table 8).

**Measurements from the center of GPF to surrounding anatomical landmarks**

On the right side, the GPF was positioned 3.9 ± 1.21 mm from PBHP (Fig. 9), 14.95 ± 1.3 mm from MMS (Fig. 10), 16.55 ± 1.61 mm from PNS (Fig. 11), and 38.06 ± 3.10 mm from IF (Fig. 12). On the left side, the GPF was positioned 3.93 ± 1.13 mm from PBHP, 14.99 ± 1.24 mm from MMS, 16.48 ± 1.6 mm from PNS, and 37.96 ± 3.17 mm from IF. *P* value ranges from 0.66 to 0.8 which is statistically non-significant using independent *t* test (Table 9 and Fig. 13).

The mean distance from the center of GPF to the center of opposite GPF was 30.38 ± 2.36 mm (Fig. 14).

In males, the GPF was positioned 4.22 ± 1.21 mm from PBHP, 15.37 ± 1.21 mm from MMS, 17.13 ± 1.54 mm from PNS, and 38.89 ± 3.28 mm from IF. In females, the GPF was positioned 3.61 ± 1.04 mm from PBHP, 14.57 ± 1.21 mm from MMS, ± 1.42 mm from PNS, and 37.13 ± 2.70 mm from IF. *P* value less than 0.01 indicates statistically highly significant using independent *t* test (Table 10).

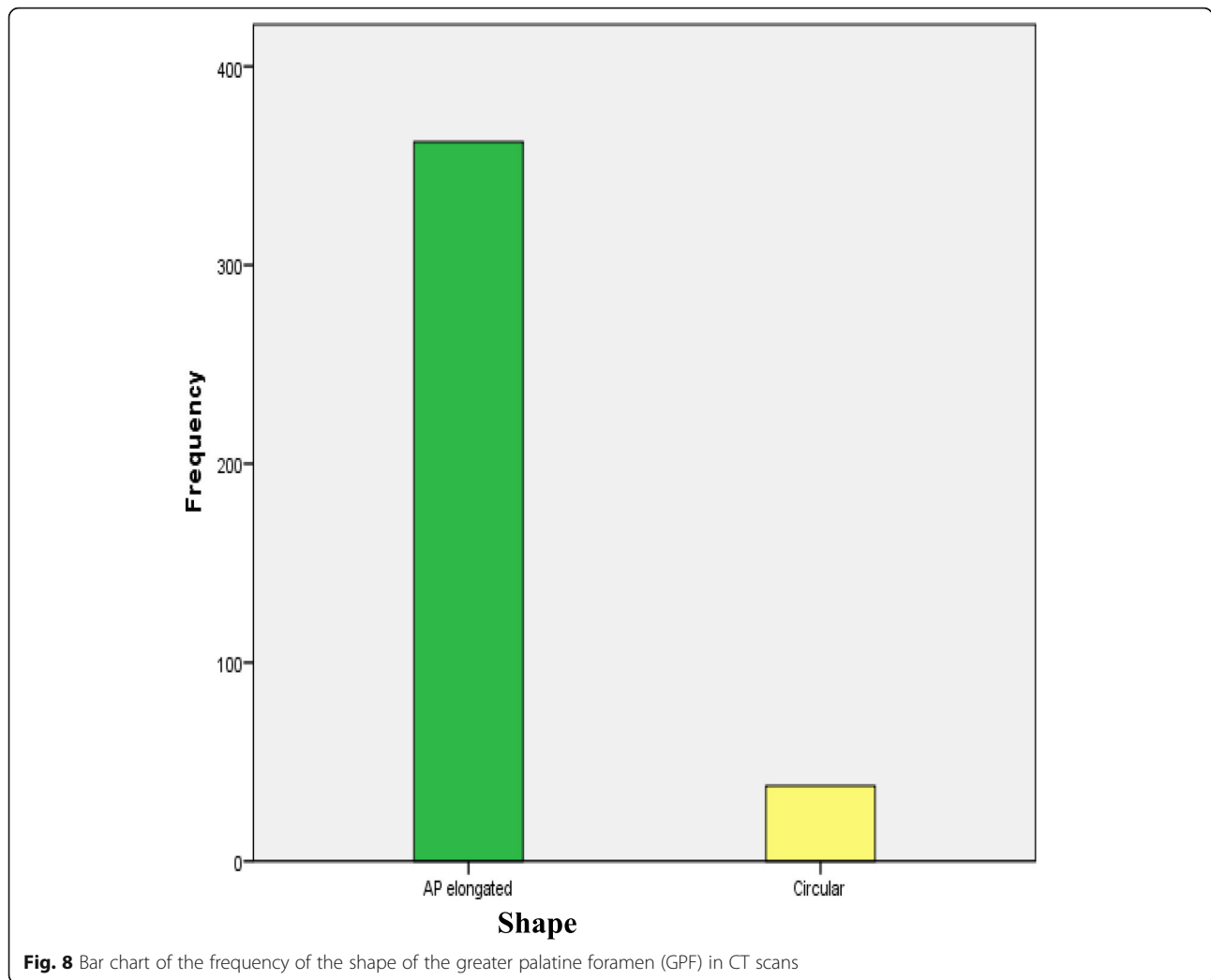
The mean distance from the center of GPF to the center of opposite GPF was 31.22 ± 2.30 mm in males (Fig. 14) and 29.54 ± 2.12 mm in females. *P* value less than 0.01 indicates statistically highly significant using independent *t* test (Table 11).

**Discussion**

The hard palate is an essential region of the skull; its gross anatomy and morphological variation have been of interest in several studies. Different clinical problems may require surgical approach to the bony palate such as dentofacial orthopedics, implant-assisted dental

**Table 7** Frequency and percent of the shape of the GPF based on side

| Shape of GPF | Side   |        | Total  | p value  |
|--------------|--------|--------|--------|----------|
|              | Right  | Left   |        |          |
| AP elongated | 180    | 182    | 362    | 0.1 (NS) |
|              | 90.0%  | 91.0%  | 90.5%  |          |
| Circular     | 20     | 18     | 38     | 9.5%     |
|              | 10.0%  | 9.0%   | 9.5%   |          |
| Total        | 200    | 200    | 400    | 100.0%   |
|              | 100.0% | 100.0% | 100.0% |          |



reconstruction of oncology patients, maxillary orthodontic protraction, and obvious oral pathology [1].

Greater palatine canal approach to maxillary nerve block demands a perfect three-dimensional orientation of position, direction, and extent of the canal. The

preliminary step is identification of GPF. Utilizing multiple anatomical landmarks to identify the GPF increases the accuracy and minimizes the complications of injecting anesthetic drug [7]. In numerous previous studies using dry adult skulls, there is more emphasis on all the measurements of present study. However, our study, being radiological evaluation, the location of GPF is more accurate than the dry bone studies.

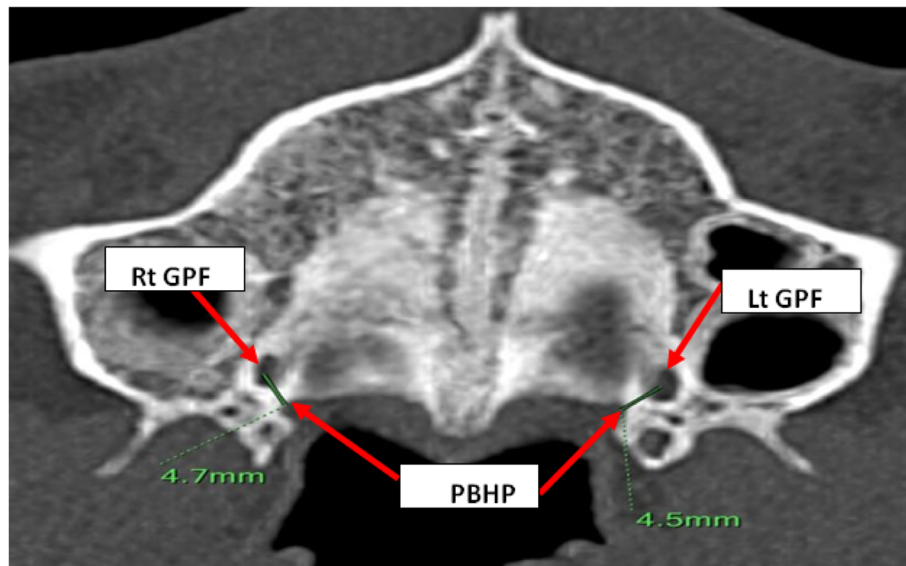
**Table 8** Frequency and percent of the shape of the GPF based on gender

| Gender | Shape of GPF |          | Total  | p value |
|--------|--------------|----------|--------|---------|
|        | AP elongated | Circular |        |         |
| Male   | 188          | 12       | 200    | 0.02    |
|        | 94.0%        | 6.0%     | 100.0% |         |
| Female | 174          | 26       | 200    | 5       |
|        | 87.0%        | 13.0%    | 100.0% |         |
| Total  | 362          | 38       | 400    | 100.0%  |
|        | 90.5%        | 9.5%     | 100.0% |         |

In all examined CT scans, the presence of GPF on both sides was a constant finding. This is consistent with the majority of the surveyed studies [4, 8, 9]. However, discrepancy in the number of GPF has previously been reported by Cagimni et al. [5]. They reported a single GPF in 81%, double GPF in 16%, and triple GPF in 2% of the examined skulls. Multiple GPF transmit greater palatine neurovascular bundle, similar to the single GPF. The presence of multiple GPF is anticipated when the pain is not effectively blocked during anesthesia [5].

In the present study, the GPF was most frequently located opposite M3 (41%). Other less frequent locations

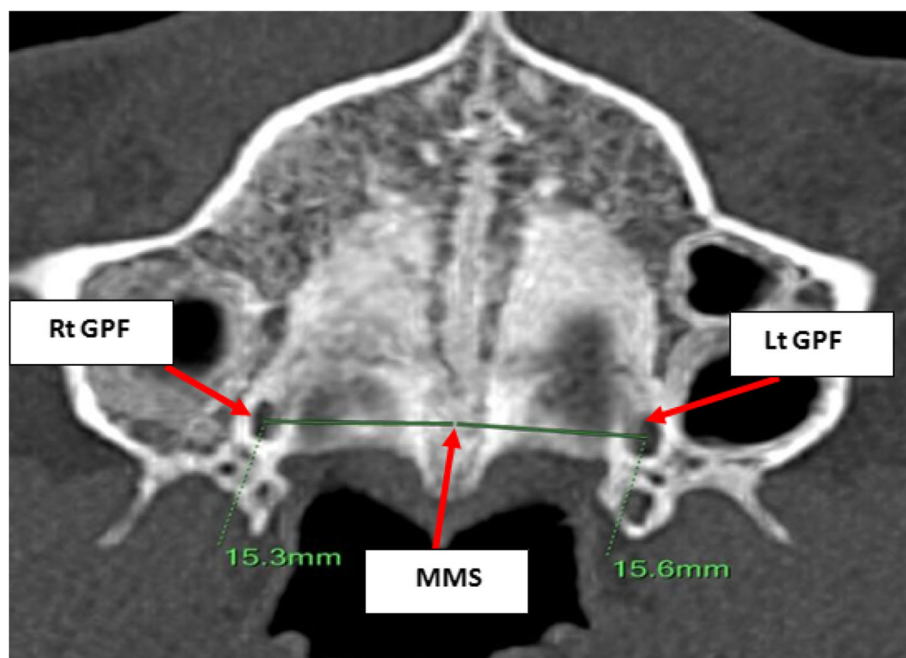




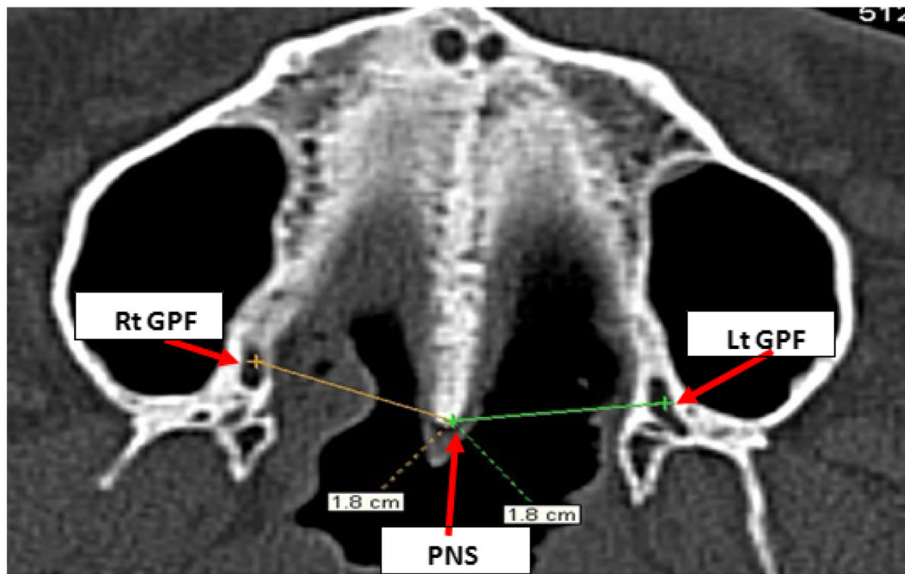
**Fig. 9** A CT scan at the region of hard palate illustrating the shortest distance from the center of GPF to posterior border of hard palate (PBHP)

were behind M3 (25.8%), between M2 and M3 (23.2%), and opposite M2 (10%). The same most frequent location (opposite M3) was reported by Shalaby et al. [9] in their study on Egyptian skulls (84%). Our results also match with Varalakshmi et al. [6] and Beetge et al. [10] who stated that GPFs were close to the third maxillary molar in 69.8% and 66.65% of their cases, respectively.

Also, this stands in agreement with Tomaszewska et al. [11] who found GPF most frequently located opposite M3 (74.7%), both in Europe and worldwide. On the other hand, Wang et al. [12] who conducted their study on Chinese recorded that the most frequent location of GPF was between M2 and M3, while Klosek and Rungruang [13], in Thais, considered the most frequent



**Fig. 10** A CT scan at the region of hard palate illustrating the shortest perpendicular distance from the center of greater palatine foramen (GPF) to midline maxillary suture (MMS)

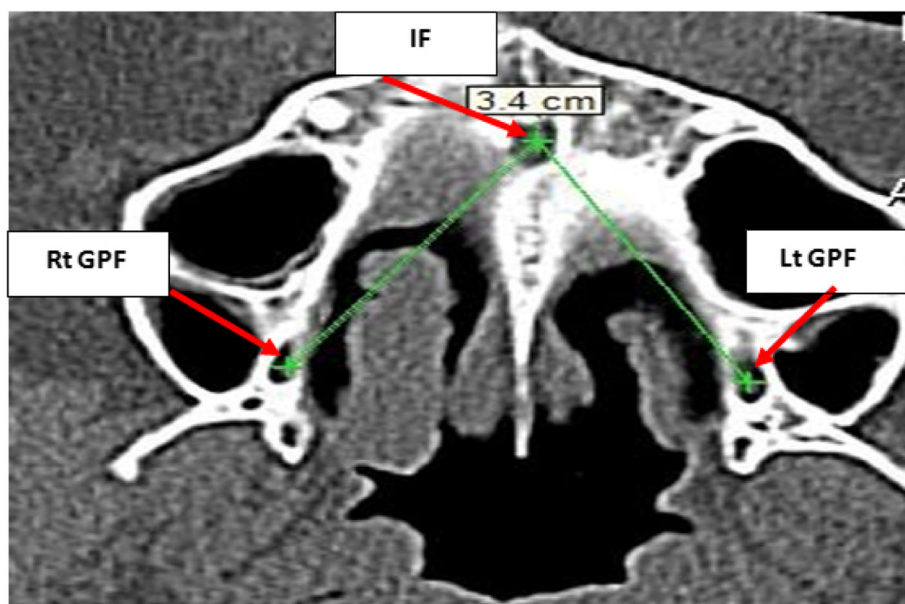


**Fig. 11** A CT scan at the region of hard palate illustrating the distance from the center of greater palatine foramen (GPF) to posterior nasal spine (PNS)

location to be opposite M2. Despite numerous studies, there is still no agreement to whether the position of GPF is prone to ethnic variability. The cause of GPF position diversity may be due to the difference in the quality of procedures performed, as well as the way the GPF was related to maxillary molars [10, 11].

Despite differences in the methods of assessment of GPF, the dimensions did not significantly differ among studies. In our study, the mean AP diameter of GPF was

$3.94 \pm 1.13$  mm on the right side and  $4.22 \pm 1.21$  mm on the left, while the mean LM diameter was  $2.17 \pm 0.59$  mm on the right side and  $2.28 \pm 0.74$  mm on the left. The GPF was described as AP elongated in 90.5% and circular in 9.5%. These results are almost close to most prior studies [4, 11]. In the study of Beetge et al. [10], the mean GPF dimensions were an A-P of 5.22 mm and an L-M of 2.81 mm. Shalaby et al. [9] measured the mean AP as  $4.86 \pm 0.9$  mm on the right side and  $4.78 \pm$



**Fig. 12** A CT scan at the region of hard palate illustrating the distance from the center of greater palatine foramen (GPF) to incisive fossa (IF)

**Table 9** Measurements taken from the GPF based on side

| Measurement   | Side  | N   | Distance (mm) | p value   |
|---------------|-------|-----|---------------|-----------|
| GPF-PBHP (mm) | Right | 200 | 3.90 ± 1.21   | 0.80 (NS) |
|               | Left  | 200 | 3.93 ± 1.13   |           |
| GPF-MMS (mm)  | Right | 200 | 14.95 ± 1.30  | 0.75 (NS) |
|               | Left  | 200 | 14.99 ± 1.24  |           |
| GPF-PNS (mm)  | Right | 200 | 16.55 ± 1.61  | 0.66 (NS) |
|               | Left  | 200 | 16.48 ± 1.60  |           |
| GPF-IF (mm)   | Right | 200 | 38.06 ± 3.10  | 0.74 (NS) |
|               | Left  | 200 | 37.96 ± 3.17  |           |

1.01 mm on the left. The mean LM diameter was  $3.02 \pm 0.7$  mm on the right side and  $3.01 \pm 0.9$  mm on the left side. This minimal discrepancy could be attributed to the fact that measurements in the present study were obtained radiologically unlike Shalaby et al. [9] who performed it manually on dry skulls.

The present study is similar to the majority of studies [11, 13, 14] in which the GPF was mostly described as anteroposteriorly elongated rather than oval in shape.

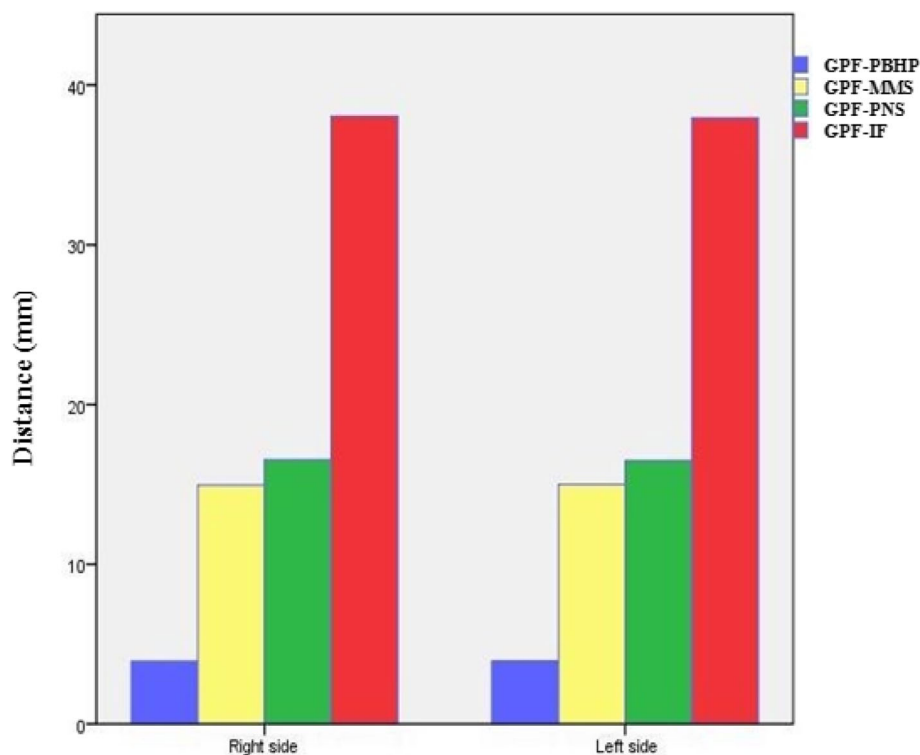
In this work, it was attempted to locate the GPF in relation to specific surrounding anatomical landmark such as posterior border of hard palate (PBHP), midline maxillary suture (MMS), posterior nasal spine (PNS), and incisive fossa (IF).

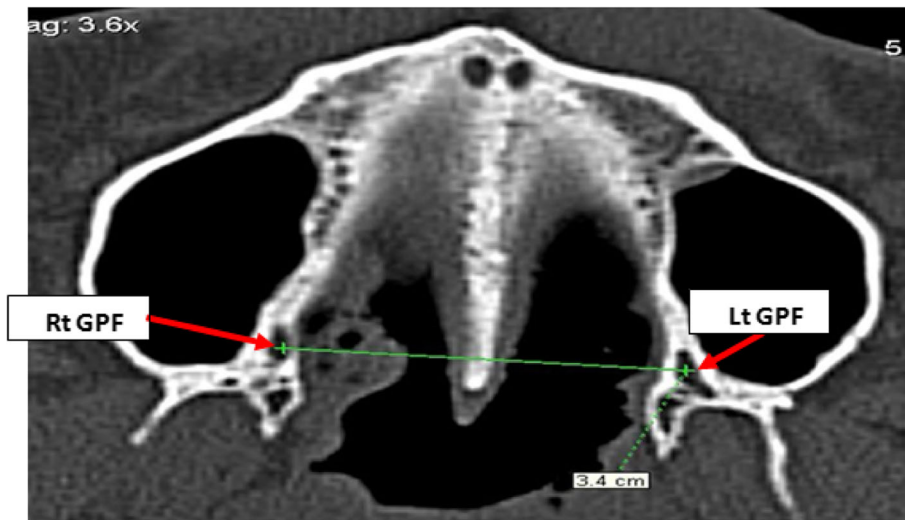
The distance between GPF-PBHP holds its importance in successful localization of GPF and prevention of accidental injury to nearby lesser palatine nerves and soft palate. Moreover, this dimension helps in localization of GPF in these cases where the third maxillary molar failed to erupt or is damaged due to any reason [15].

In the present study, the GPF-PBHP distance was  $3.9 \pm 1.21$  mm on the right side and  $3.93 \pm 1.13$  mm on the left. This is consistent with [16] where GPF-PBHP distance was recorded as  $3.63 \pm 1.91$  mm on the right side and  $3.94 \pm 1.97$  mm on the left. Shalaby et al. [9] in their Egyptian study on dry skulls measured the GPF-PBHP distance as  $4.39 \pm 1.73$  mm on the right side and  $4.53 \pm 1.23$  mm on the left. However, Shalaby et al. [9] took their measurement from the posterior edge of GPF to the point of maximum concavity on PBHP, while in the present study it was taken from the center of GPF to the shortest distance on the posterior border of hard palate.

Linear measurements in the present study showed the mean distance from the center of GPF to MMS as  $14.95 \pm 1.3$  mm on the right side and  $14.99 \pm 1.24$  mm on the left. These values were close to radiological results of [8] in which the GPF-MMS distance was estimated as  $\pm 1.45$  mm.

In the present study, the mean distance from the center of GPF to PNS was  $16.55 \pm 1.61$  mm on the right

**Fig. 13** Bar chart of the distances taken from the center of GPF to surrounding anatomical landmarks based on side



**Fig. 14** A CT scan at the region of hard palate illustrating the distance from the center of greater palatine foramen to the center of opposite greater palatine foramen

side and  $16.48 \pm 1.6$  mm on the left while the distance from the center of GPF to the center of IF was  $38.06 \pm 3.10$  on the right side and  $37.96 \pm 3.17$  on the left. These figures are disparate from the radiological results of Tomaszewska et al. [11], who estimated the GPF-MMS distance as  $34 \pm 3$  mm on the right side and  $34.3 \pm 3.1$  on the left, though the same methodology was applied in both studies.

Surveying different studies, it could be deduced that variation exists in linear measurements in different population; even interpopulation variation could exist. These differences might be related to ethnic factor [17] or quality of procedure performed [11]. Aterkar et al. [18] pointed out that linear measurements from GPF increase in edentulism; therefore, this distance may become variable according to palate width.

In the present study, a statistically significant side difference was found in the dimensions of GPF. Previous radiological studies provided no data regarding this point [8, 11, 19]. Although Shalaby et al. [9] did not recognize a statistically significant difference between

the dimensions of GPF on both sides in their study on dry skulls, radiological data should be considered more accurate in this respect.

In the present study, a statistically highly significant difference in linear measurements from the center of GPF to surrounding anatomical landmarks as well as the dimensions of GPF existed between males and females. This is similar to results of [9, 11, 20]. Male skulls are generally larger than the female ones [20].

Although Moreira et al. [21] and Nascimento et al. [22] observed a statistically significant difference between males and females regarding the distance from GPF to IF, no statistically significant difference existed regarding the distance between right and left GPF.

According to Tomaszewska et al. [11], position of GPF in relation to surrounding anatomical landmarks could be used in forensic examination to identify a person's sex. Nascimento et al. [22], though considering this method valid, simple, reproducible, and inexpensive, recommended using it only when more accurate techniques are not applicable. Although the present study adopts this point view as confirmed by the radiological results, but it would not have been accurate to rely on the general features to govern out gender of skulls without available records.

CT scans revealed one lesser palatine foramen on both sides in 75.5%, two foramina in 22%, three foramina in

**Table 10** Measurements taken from the GPF based on gender

| Measurement   | Gender | N   | Distance (mm)    | p value |
|---------------|--------|-----|------------------|---------|
| GPF-PBHP (mm) | Male   | 100 | $4.22 \pm 1.21$  | 0.000   |
|               | Female | 100 | $3.61 \pm 1.04$  |         |
| GPF-MMS (mm)  | Male   | 100 | $15.37 \pm 1.21$ | 0.000   |
|               | Female | 100 | $14.57 \pm 1.21$ |         |
| GPF-PNS (mm)  | Male   | 100 | $17.13 \pm 1.54$ | 0.000   |
|               | Female | 100 | $15.90 \pm 1.42$ |         |
| GPF-IF (mm)   | Male   | 100 | $38.89 \pm 3.28$ | 0.000   |
|               | Female | 100 | $37.13 \pm 2.70$ |         |

**Table 11** Mean  $\pm$  SD distance from the center of GPF to the center of opposite GPF based on gender

| Measurement  | Gender | N   | Distance (mm)    | p value |
|--------------|--------|-----|------------------|---------|
| GPF-GPF (mm) | Male   | 100 | $31.22 \pm 2.30$ | 0.000   |
|              | Female | 100 | $29.54 \pm 2.12$ |         |

2%, and none in 0.5% (two skulls on the left side only). The results presented in the present study are comparable with those by Sushobhana et al. [23].

In the present study, the palatine crest was a constant finding in all CT scans. However, the percent of the presence of palatine crest was highly variable among previous studies. Jaffar and Hamadah [24] reported a 67% on both sides, Piagkou et al. [25] a 57.8% on the right side and 56.3% on the left.

The limitations of our study included the relative small number of patients, and we have not commented on the length of the canal in the present study.

## Conclusion

Proper localization of GPF is important to facilitate therapeutic, local anesthetic, and surgical manipulation in the maxillofacial region. By use of multislice CT, we can assess variation in number, size, shape, and location of greater and lesser palatine foramina in relation to multiple anatomical landmarks. The GPF is most often located opposite the M3 in the majority of the cases, and the maxillary molars are the best landmarks for determination of their location.

## Abbreviations

CT: Computed tomography; LPF: Lesser palatine foramina; GPF: Greater palatine foramen; M: Maxillary molar; AP: Anteroposterior; LM: Lateral-medial; PBHP: Posterior border of hard palate; MMS: Midline maxillary suture; PNS: Posterior nasal spine; IF: Center of incisive fossa

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## Authors' contributions

AS formulated the research goals, designed the study methodology, and supervised/actively participated in the research activity planning/execution. HM conducted/actively participated in the research process, performed the data collection/data analysis, and wrote the initial draft of the manuscript. HG shared in study conception and design and shared in writing and correcting the manuscript and revision. ME actively participated in research activity execution, assisted in data analysis, and largely contributed in reviewing and writing of the manuscript. TR shared in the study conception and design, acquisition of data, analysis and interpretation of data, and drafting of the manuscript. All authors read and approved the final manuscript.

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## Availability of data and materials

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

## Ethics approval and consent to participate

This study was approved by the Research Ethics Committee of the Faculty of Medicine, Cairo University on 3 May 2016. Ethics Committee reference number is not available (was not provided). Written informed consent was obtained from all the study patients before any data or scans were gathered or performed.

## Consent for publication

All patients included in this research gave written informed consent to publish the data contained within this study.

## Competing interests

The authors declare that they have no competing interests.

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