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ORIGINAL ARTICLE

Surface anatomical landmarks for the location of posterior sacral foramina in sacral nerve stimulation

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Abstract
Background Sacral nerve stimulation is a common treatment for various pelvic floor disorders. It consists of the percutaneous introduction of electrodes through the posterior sacral foramina for therapeutic stimulation of the target sacral spinal nerve. The aim of our study was to determine the surface anatomical landmarks of the sacrum to facilitate identification of the posterior sacral foramina.
Methods This study was conducted on 20 human cadavers. The cadavers were placed in a prone position, and all the soft tissues of the sacral region were removed to allow exposure of the osseous structures. Different measurements were taken in relation to the posterior sacral foramina, the posterior superior iliac spine (PSIS) and the median sacral crest (MSC). A median coefficient of variation (CV) was determined.
Results The diameter of the second sacral foramen showed the greatest variability. The distances between each individual foramen and the MSC had an acceptable variability (CV $< 20\%$). In contrast, the distance between foramina had a high variability. The distance between PSIS and the second posterior sacral foramen was also found to have an acceptable variability (CV $< 20\%$). However, the angle formed by an horizontal line between PSIS and a line between PSIS and S2 foramina had high variability.
Conclusions We found that the distance between sacral foramina and MSC is relatively constant while the distance between foramina and the relations between foramina and PSIS is highly variable. Detailed knowledge of the anatomy may facilitate electrode placement and is complementary to the regular use of fluoroscopy.

Keywords Sacrum · Posterior sacral foramina · Sacral nerve stimulation · Surface anatomy

Introduction

Sacral nerve stimulation (SNS) is a common treatment for various pelvic floor disorders, such as urinary and fecal incontinence and constipation [1–5].

This technique consists of the introduction of electrodes by a percutaneous approach through the posterior sacral foramina for placement in the proximity of the target sacral spinal nerve for therapeutic low-frequency stimulation [1–5].

One of the most important steps of this technique is the correct topographic identification of the posterior sacral foramina on the body surface of the sacrum [6, 7].

SNS most commonly involves placing tined leads through the S3 sacral nerve foramina [7, 8]. Identification of specific posterior sacral foramina is currently carried out using various bony landmarks such as the sciatic notch,

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midline sacral spinous processes, iliac crest, sacral hiatus, the tip of the coccyx, ischial spine and posterior superior iliac spine (PSIS) [6, 7]. The correct placement of the leads is confirmed using fluoroscopy [8].

However, some of the anatomical structures commonly used as landmarks are not easy to identify in the surface anatomy of the lower back [9]. Because of this, it is sometimes difficult to perform SNS, mainly in those patients with anatomical variations of the sacrum and sacral spinal nerves [6]. Very few studies have addressed the anatomical reference points for this technique. In addition, the validity of landmarks has almost not been assessed in those articles [6, 8, 10–13].

The aim of our study was to determine the surface anatomical landmarks for the localization of the posterior sacral foramina.

Materials and methods

This study was conducted on 6 intact human cadavers (5 males and 1 female) donated to the Department of Anatomy, NOVA Medical School, NOVA University of Lisbon, and 14 pelvises transected at the level of the fourth lumbar vertebra and lateral to the sacroiliac joint (8 males and 6 females) donated to the Department of Anatomy, Faculty of Medicine, Autonomous University of Barcelona. In all transected pelvises, all the relevant anatomical reference points used in the study were maintained.

The study was approved by the ethics committee of each institution. The intact cadavers were stored at 4 °C, and the pelvises were stored at −18 °C. All were then brought to room temperature for 24–36 h before dissection.

The anatomical specimens were placed in prone position. The median sacral crest (MSC) and the PSIS were identified by palpation and marked. Then, all soft tissue of the sacral region was gently removed to allow exposure of the osseous structures. Subsequently, we measured the horizontal diameter of the S2, S3 and S4 posterior sacral foramina on each side, the distance from the medial and lateral edge of the S2 and S3 posterior sacral foramina to the MSC on each side, the distance between the medial and lateral edge of the left and right S4 posterior sacral foramina, the distance between the S2 and S3 and S3 and S4 posterior sacral foramina, bilaterally, the distance from PSIS to the S2 posterior sacral foramen bilaterally and the angle formed by an imaginary line running horizontally at the PSIS and a line joining the PSIS and the S2 posterior sacral foramina, bilaterally. The measurements were taken as shown in Fig. 1.

We also measured the distance between the S2, S3 and S4 posterior and anterior foramina on each side, in order to obtain the median depth of the S2, S3 and S4 sacral foramina.

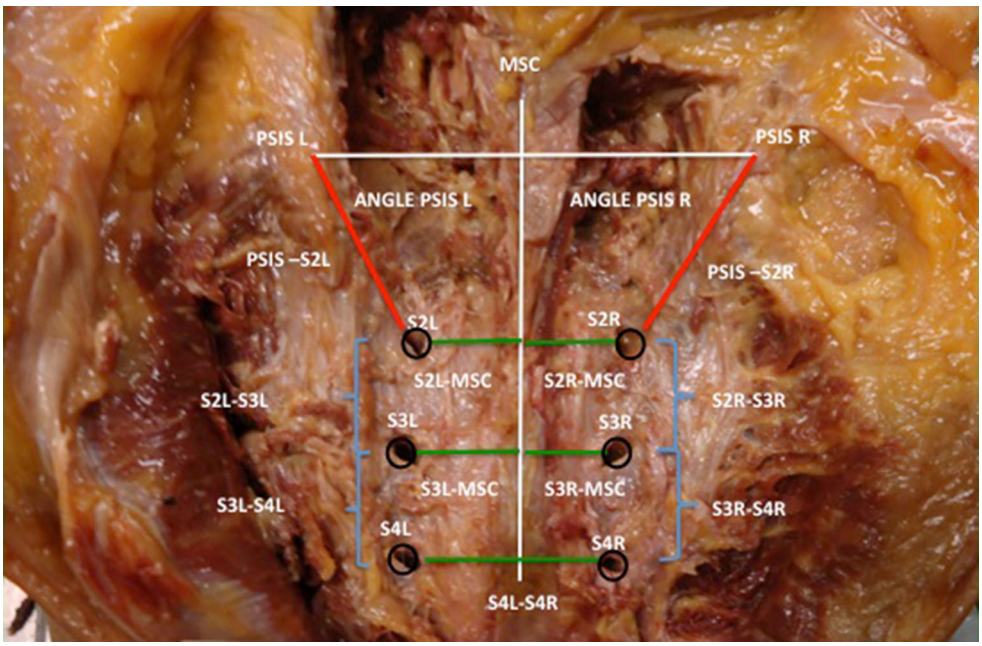

Fig. 1 Measurements between anatomical landmarks taken as part of the present study: *Green line*—distance between sacral foramina and median sacral crest (MSC). *Blue line*—distance between sacral foramina on each side. *Red line*—distance from each posterior superior iliac spine (PSIS) and second sacral foramina

Table 1 Diameter of S2, S3 and S4 posterior sacral foramina

	Right side			Left side			Combined measurements		
	S2	S3	S4	S2	S3	S4	S2	S3	S4
Median	6.0	5.0	4.0	6.0	5.0	4.0	6.0	5.0	4.0
Minimum	3.0	4.0	2.0	3.0	4.0	3.0	3.0	4.0	2.0
Maximum	7.0	6.0	5.0	7.0	6.0	5.0	7.0	6.0	5.0
Interquartile range	2.8	1.0	1.0	2.0	1.0	1.0	2.0	1.0	1.0
Median CV (%)[a]	23.6	15.2	22.9	18.7	15.9	14.4	21.0	15.4	19.0

All measurements in mm

[a] Low variability CV < 10%, acceptable variability CV < 20%

All the measurements were taken twice. The angles were measured using a standard goniometer.

Statistical analysis

The Lilliefors corrected Kolmogorov–Smirnov test was used to determine the normal distribution of the data. Since most of the variables showed nonnormal distribution, data were presented as median and interquartile range. Variability between subjects was expressed as the median CV. The median CV was the result of expressing the root mean squares of deviation from the median as a percentage of the median.

A CV <10% was considered good and <20% was acceptable. To compare differences between sides, we performed the nonparametric Wilcoxon and Friedman tests. The Mann–Whitney test was used to examine differences between gender. The significance level was set at $p \leq 0.050$.

Results

The median size of the sacral foramina was as follows: 6.0, 5.0 and 4.0 mm for the S2, S3 and S4 posterior sacral foramina, respectively (Table 1). No significant differences were found between sides ($p > 0.050$). No significant differences were found between male and female cadavers, except for the median of size of the left S3 foramen (female 5.0 mm vs. male 4.0 mm, $p = 0.037$).

The median distance between the medial edge of the S2 foramen and the MSC was 21.0 mm, and between the medial edge of the S3 foramen and the MSC it was 19.5 mm. The median distance between the lateral edge of the S2 foramen and the MSC was 26.4 mm, and between the lateral edge of the S3 foramen and the MSC it was 25.1 mm. No differences were found between male and female cadavers (Table 2).

The median distance between the medial edge of the left S4 foramen and the medial edge of the right S4 foramen was 39.0 mm (Table 2). The median distance between the lateral edge of the left S4 foramen and the lateral edge of the right S4 foramen was 46.0 mm. No differences were found between male and female cadavers.

The median distance between the S2 and the S3 foramina was 20 mm on the right side and 18 mm on the left side. The median distance between the S3 and the S4 foramina was 17 mm on the right and left side (Table 2). No differences were found between male and female cadavers.

The median distance from the PSIS to the S2 foramen was 26 mm on the left and right side. The median of the angle formed by a line passing horizontally from the PSIS and a line between the PSIS and the S2 foramen was 39° on the right side and 51° on the left side (Table 3). No significant differences were found between male and female cadavers, except for the median of the angle formed by a line passing horizontally from the PSIS and a line between the PSIS and the S2 foramen on the right side (female 32.5° vs. male 50°, $p = 0.010$).

The median distance between the posterior and anterior S2 foramina (depth of sacral foramina) was 18.5 mm on the right and on the left side. The median distance between the S3 posterior and anterior foramina was 12.35 mm on the right side and 13.35 mm on the left side. The median distance between the S4 posterior and anterior foramina was 8.65 mm on the right side and 9.15 mm on the left side (Table 4). No significant differences were found between male and female cadavers, except for the median distance between the S2 posterior and anterior foramina on the left side (female 16.95 mm vs. male 19.95 mm, $p = 0.010$).

Coefficient of variation

Regarding the diameter of the posterior sacral foramina, all the results had an acceptable variability, except the diameter of the S2 posterior foramina (CV = 21.0%) (Table 1).

The distance between the posterior sacral foramina and between each posterior sacral foramen and the MSC also had acceptable variability (CV between 8.9 and 19.1%), while high variability was noted in the distance between S3

Table 2 Measurements from the medial and lateral side of each posterior sacral foramen horizontally to the median sacral crest (MSC)

	Right				Left				Distance between medial sides of S4	Distance between lateral sides of S4	S2–S3 right	S3–S4 right	S2–S3 left	S3–S4 left
	S2 Medial–MSC	S2 Lateral–MSC	S3 Medial–MSC	S3 Lateral–MSC	S2 Medial–MSC	S2 Lateral–MSC	S3 Medial–MSC	S3 Lateral–MSC						
Median	20.0	26.0	19.0	24.0	22.0	27.5	20.5	25.5	39.0	46.0	20.0	17.0	18.0	17.0
Minimum	17.0	23.0	16.0	21.0	18.7	23.0	15.0	19.0	32.0	40.0	10.0	6.0	1.0	7.0
Maximum	25.0	32.0	26.0	31.0	27.0	34.0	27.0	32.0	52.0	58.0	24.0	23.0	23.0	24.0
Interquartile range	3.0	2.0	2.8	3.0	5.0	5.0	6.5	6.0	7.0	6.0	4.0	8.0	7.0	6.0
Median CV (%)[a]	10.5	8.9	13.7	11.1	13.3	10.8	18.3	14.4	12.3	9.3	19.1	30.1	34.2	27.7

Measurements between the medial sides of S4 and between the lateral sides S4 posterior sacral foramina. Measurements between the inferior side of the S2 and the superior side of the S3 posterior sacral foramen and between the inferior side of the S3 and the superior side of the S4 posterior sacral foramen on each side

All measurements in mm

[a] Low variability CV < 10%, acceptable variability CV < 20%

and S4 on both sides (CV = 30.1% on the right and CV = 27.7% on the left) (Table 2) and in the distance between S2 and S3 on the left (CV = 30.2%).

The distance between the PSIS and the S2 foramina has an acceptable variability (CV = 11.4% to PSIS—on the right; CV = 15.2% to PSIS—on the left). However, a high variability was found when looking at the angle formed by a line passing horizontally from the PSIS and a line between the PSIS and the S2 posterior foramina (CV = 38% on the right and CV = 24.1% on the left) (Table 3).

The median depth of each sacral foramen had acceptable variability (CV between 11.1 and 18.2%) except for the depth of the S3 right foramina (CV = 21.3%) (Table 4).

Discussion

SNS lead placement is a technique in which the most important step is the correct identification of the position of the posterior sacral foramina [1–5]. Identification of a particular posterior sacral foramen can be carried out using various bony landmarks such as the sciatic notch, the midline sacral spinous processes, the iliac crest, the sacral hiatus and the tip of the coccyx [6].

Taking into account the surface anatomy of the lower back, we decided to use the MSC and the PSIS as surface landmarks for the localization of the posterior sacral foramina, since they are easily palpable and identifiable anatomical landmarks in the sacral region [9].

In Fig. 2 we show how it is feasible to determine the surface localization of the different posterior sacral foramina, using the MSC and PSIS as reference points.

While there is a well-known association between the PSIS and the S2 segment level, a relationship between the PSIS and the S2 posterior sacral foramina has not been well documented. There are only two studies that look at bony landmarks in the sacral region related to the PSIS and the S2 posterior sacral foramina [9, 10]. Our results were quite similar to those obtained by McGrath [10], particularly regarding the angle formed by a line that runs horizontally at PSIS and a line joining the PSIS and the S2 posterior sacral foramen (angle PSIS–right S2 foramen = 39.0 in both studies; angle PSIS–left S2 foramen = 51.0 in our study vs. 56.8 in McGrath) and the distance from PSIS to the S2 posterior foramen (PSIS–right S2 foramen = 26 mm in the present study vs. 32.2 mm in McGrath; PSIS–left S2 foramen = 26 mm in the present study vs. 28.1 mm in McGrath).

The measurements of the angle and the distance between the PSIS and the S2 posterior sacral foramen were less reliable than the other measurements probably because

Table 3 Distance and angle between posterior superior iliac spine and second sacral foramina

	PSIS–S2 right	PSIS–S2 left	Angle PSIS–S2 right	Angle PSIS–S2 left
Median	26.0	26.0	39.0	51.0
Minimum	20.0	20.0	22.0	23.0
Maximum	31.0	30.0	74.0	70.0
Interquartile range	3.0	4.5	19.8	8.0
Median CV (%)[a]	11.4	15.2	38.0	24.1
p		0.623		0.888

Measurements in mm and degrees

p values compare differences between sides

PSIS posterior superior iliac spine

[a] Low variability CV < 10%, acceptable variability CV < 20%

Table 4 Measurements of foramina depth of S2, S3 and S4 sacral foramina of each side

	Right side			Left side		
	S2	S3	S4	S2	S3	S4
Median	18.5	12.35	8.65	18.5	13.35	9.15
Minimum	14.9	10.1	6.8′	15.5	10.0	6.90
Maximum	22.9	19.7	12.1	22.8	19.0	10.7
Interquartile range	2.4	2.7	2.5	2.9	3.4	2.7
Median CV (%)[a]	11.9	21.3	18.2	11.1	17.2	14.9

All measurements in mm

[a] Low variability CV < 10%, acceptable variability CV < 20%

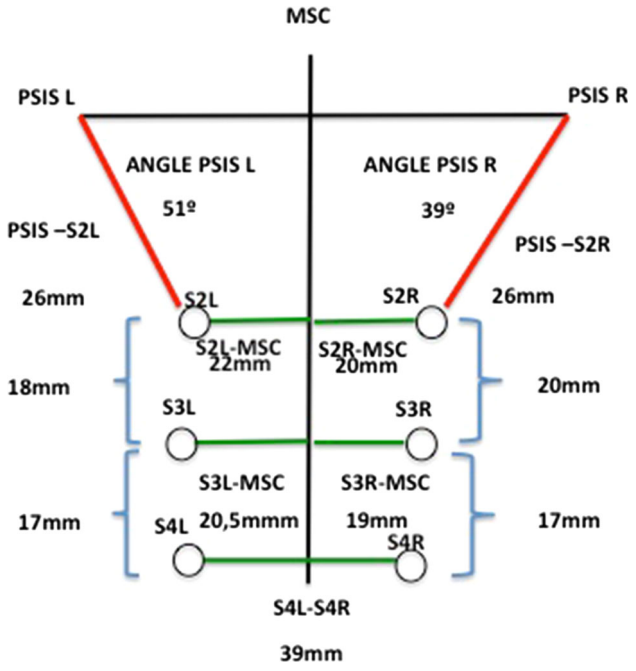

Fig. 2 Results of the present study expressed in median mm and median degrees. *MSC* median sacral crest, *PSIS* posterior superior iliac spine

of the acknowledged difficulty in defining a single PSIS "point" [9].

There are three other studies that show the importance of sacral foramen anatomy in SNS. However, these studies used only a few cadavers (from 5 to 10) and had very different objectives [11–13].

Hasan et al. [6] looked for the surface localization of sacral foramina. The results obtained were similar to ours regarding the measurements of the distances between sacral foramina, although they did not use the same anatomical reference points for the localization of the foramina [6]. They defined localization of the sacral foramina in relation to the overlapping sacral triangles, using the PSIS and the sacral cleft [6].

Hasan et al. and Buchs et al. looked for a better angle of entry into the sacral foramina, but this was not the purpose of our study [6, 11]. Hasan et al. and Liguoro et al. also aimed to establish the nature of the vascular and nervous structures and their relations in the posterior sacral foramina [6, 12].

Compared to the above-mentioned studies we used a larger number of cadavers and more easily identifiable anatomical landmarks, since we decided to use only two anatomical references (MSC and PSIS). As a result, our model is much easier to apply than the models described in other studies (Fig. 2). Our study is the only one that obtains the median depth of the S2, S3 and S4 foramina.

Our results were similar to the results found in the other studies. However, only our study explored the variability of the anatomy in the sacral region. We found high variability in the distance between the S3 and S4 and the angle formed by a horizontal line between PSIS and a line between the PSIS and the S2. In the majority of the measurements no significant difference was found between males and females, although it must be kept in mind that we had more male than female cadavers (14 vs. 7).

Conclusions

Our results demonstrate that using only two easily palpable anatomical reference points, the MSC and PSIS, is possible to determine the surface localization of the different posterior sacral foramina.

Our model can be easily be applied in most patients, complementing the regular use of fluoroscopy for the electrode placement.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This study was conducted on human cadavers donated to the Department of Anatomy Nova Medical School, NOVA University of Lisbon and to the Department of Anatomy, Faculty of Medicine, Autonomous University of Barcelona. This study was approved by the ethics committee of each institution.

Informed cosent Informed consent was obtained from all individual participants included in the study.

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