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ORIGINAL ARTICLE

Sacral malformations: use of imaging to optimise sacral nerve stimulation

A. Povo[1,2,3] · M. Arantes[1,4] · K. E. Matzel[5] · J. Barbosa[6] · M. A. Ferreira[1]

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Abstract
Introduction The success of sacral nerve stimulation, a common treatment for pelvic floor disorders, depends on correct placement of the electrodes through the sacral foramina. When the bony anatomy and topography of the sacrum and sacral spinal nerves are intact, this is easily achieved; where sacral anomalies exist, it can be challenging. A better understanding of common sacral malformations can improve the success of sacral nerve stimulation (SNS) electrode placement.
Material and methods We reviewed 998 consecutive MRI scans performed to investigate low back pain in patients who had undergone CT and/or X-ray.
Results Congenital sacral malformations were found in 24.1 %, the most common being sacral meningeal cysts (16 %) and spina bifida occulta (9.9 %). Others were lumbosacral transitional vertebrae (2.5 %), anterior occult meningocele (0.5 %), partial sacral agenesis (0.2 %) and vertebral dysplasia of S1 (0.2 %).
Conclusion This radiologic review uncovered a high incidence of sacral malformations, and most were asymptomatic. All surgeons who perform SNS should have a basic understanding of sacral malformations, their incidence and effect on foraminal anatomy. Imaging will aid procedural planning.

Keywords Sacral malformations · Sacral nerve stimulation · Sacrum · Sacral plexus · Imaging anatomy

✉ A. Povo
anapovo@sapo.pt

[1] Department of Anatomy, Faculty of Medicine, University of Porto, Porto, Portugal

[2] Centro Integrado de Cirurgia Ambulatório Centro Hospitalar do Porto, Porto, Portugal

[3] Department of Anatomy (Faculdade de Medicina Universidade do Porto), Alameda Professor Hernâni Monteiro, 4200-319 Porto, Portugal

[4] Instituto Português de Oncologia, Porto, Portugal

[5] Department of Surgery, University of Erlangen, Erlangen, Germany

[6] Center for Medical Education, Faculty of Medicine, University of Porto, Porto, Portugal

Introduction

Correct electrode placement in sacral nerve stimulation (SNS) is imperative for the technique's success and depends on intact anatomy and topography of the sacrum and sacral nerves [1–5].

Sacral anatomy can be highly variable. Indeed, several reports document morphologic anomalies and a high incidence of sacral malformations ranging from 10 to 58 % [6–19]. Many of these are clinically imperceptible. In patients in whom they are unknown or undetected, SNS can be difficult or impossible [1, 3, 4].

Sacral malformations can involve bone (the sacrum), the spinal cord and/or sacral spinal nerves. Their relevant implications will vary. The clinical spectrum can range from the asymptomatic to patients with lumbar pain or those with minimal to severe neurologic symptoms [6, 9–19].

The objective of this study was to evaluate the frequency and types of sacral malformations and their implications for the success of SNS.

Materials and methods

We reviewed 998 consecutive MRI scans in the Images Database of the Pedro Hispano Hospital (Matosinhos, Portugal)

performed for the investigation of low back pain in patients who had undergone CT and/or X-ray. Patients with radiologic evidence of previous lumbosacral surgery were excluded.

The images were reviewed by two investigators, an assistant professor of anatomy (imaging anatomy)/general surgeon with expertise in SNS and a neuroradiologist. Each reviewed the MRI and CT and/or X-ray independently, and all deviations from normal anatomy were recorded. All the scans thus labelled abnormal were thereafter reviewed by both investigators a second time to evaluate interobserver agreement.

The MRI scans were acquired on a GE Signa Horizon 1.5-T system with a lumbar spine coil and a standard protocol for lumbosacral spine MRI. Both T1-weighted spin-echo images (repetition time (TR)/echo time (TE), 400/24) and T2-weighted fast spin-echo images (TR/TE, 4000/120) were obtained through the lumbosacral spine in the sagittal and axial planes. The field of view was 340×340 mm for sagittal scans and 200×200 mm for axial scans, with a matrix of 256×256, slice thickness of 4 mm and a 0.4-mm gap for both axial and sagittal imaging.

The CT scans were acquired with a GE LightSpeed 4 Slice CT Scanner. Patients were examined in the supine position with both arms extended overhead. A lateral 26-cm scout view was obtained at 140 kVp and 100 mA, followed by a standard-dose CT acquisition in the craniocaudal direction from the pedicles of the first lumbar vertebra to the laminae of the last sacral vertebra. Anterior and lateral X-rays of lumbosacral vertebrae were also obtained.

Statistical analysis was done with the software Statistical Package for the Social Sciences® version 18.0. Variables were summarised by frequency and proportion. The chi-squared test was used to identify the association between demographic variables and sacral malformations. The significance level was set at 0.05.

The authors declare that for this project, there were no experiments on humans or animals.

Results

Of the 998 patients whose images were reviewed, 41.8 % were men and 58.2 % were women. The median age was 53.92 years (range 18–88 years). The incidence of sacral malformations was 24.1 %.

Although they were more common in women (26.5 vs 20.9 % in men), the difference was not statistically significant (p=0.117). This remained true for age distribution also. For two types of sacral malformation, however, the gender difference was significant; spina bifida occulta was found in 12.5 % of men versus 8.1 % of women (p=0.05), and meningeal cyst was found in 12.2 % of men versus 18.8 % of women (p=0.033) (Table 1).

The most frequent sacral malformation was meningeal cyst type II, present in 16 % of the MRIs (Tables 1 and 2 and Fig. 1 (1a, 1b)). These showed that different patterns of distribution along the sacral roots and in 7.7 % of the cases were multiple (Table 3).

The second most common sacral malformation found was spina bifida occulta (SBO) (9.9 %) (Tables 1 and 2 and Fig. 1 (3)), which is historically seen more in the young. In our study, we also found a higher frequency in the younger age group (Table 1), but, as stated above, this was not statistically significant (p=0.116).

In descending order of frequency, the other sacral malformations were lumbosacral transitional vertebra (LSTV) in 2.5 % (Tables 1 and 2 and Fig. 1 (5a, 5b)), anterior occult meningocele in 0.50 % (Tables 1 and 2 and Fig. 1 (2a, 2b)), partial sacral agenesis in 0.2 % and vertebral dysplasia of S1 in 0.2 % (Tables 1 and 2 and Fig. 1 (4)).

In 21 of the 998 patients (2.1 %), two sacral malformations were found; 11 had SBO and meningeal cyst, 5 SBO and lumbarisation, 3 lumbarisation and meningeal cyst, 1 sacralisation and meningeal cyst and 1 anterior occult meningocele and meningeal cyst.

Table 1 Frequency and distribution of each sacral malformation with regard to sex and age

	Sacralisation		Lumbarisation		Spina bifida occulta		Meningeal cyst		Anterior occult meningocele		Partial sacral agenesis		Vertebral dysplasia of S1	
	%	*p* value	%	*p* value	%	*p* value	%	*p* value	%	*p* value	%	*p* value	%	*p* value
Sex														
Male	0.2	0.41	1.7	0.53	12.5	0.05	41.812.2	0.033	0.2	0.644	0	0.999	0	0.513
Female	0.7		2.2		8.1		18.8		0.5		0.2		0.3	
Age														
<=43	0.4	0.94	2.8	0.6	13.8	0.116	12.7	0.113	1.2	0.069	0.4	0.485	0	0.25
44–54	0.8		1.2		8.2		16.1		0		0		0	
55–65	0.4		2.3		10.5		15.0		0		0		0.8	
>65	0.4		1.7		6.8		20,7		0.4		0		0	
Frequency	0.50 %		2 %		9.90 %		16 %		0.50 %		0.20 %		0.20 %	

Table 2 Imaging mode: relevance to each sacral malformation

Malformation	MRI	CT	X-ray
Sacralisation	Visible	Best technique	Visible
Lumbarisation	Visible	Best technique	Visible
SBO	Visible	Best technique	Visible
Meningeal cyst	Best technique	Visible	Not visible
Anterior occult meningocele	Best technique	Visible	Not visible
Partial sacral agenesis	Visible	Best technique	Visible
Vertebral dysplasia of S1	Visible	Best technique	Visible

Discussion

The success of SNS depends largely on the optimal placement of the electrode in proximity to the targeted nerve. In many cases, however, electrode placement fails for unknown reasons [1, 3, 4]. One of the main contraindications for SNS is the presence of sacral malformations, as these can alter the anatomical references in the sacral foramina [1, 3, 4]. The incidence of 24.1 % in our study accords with that reported in the literature (Tables 4 and 5) [6–19].

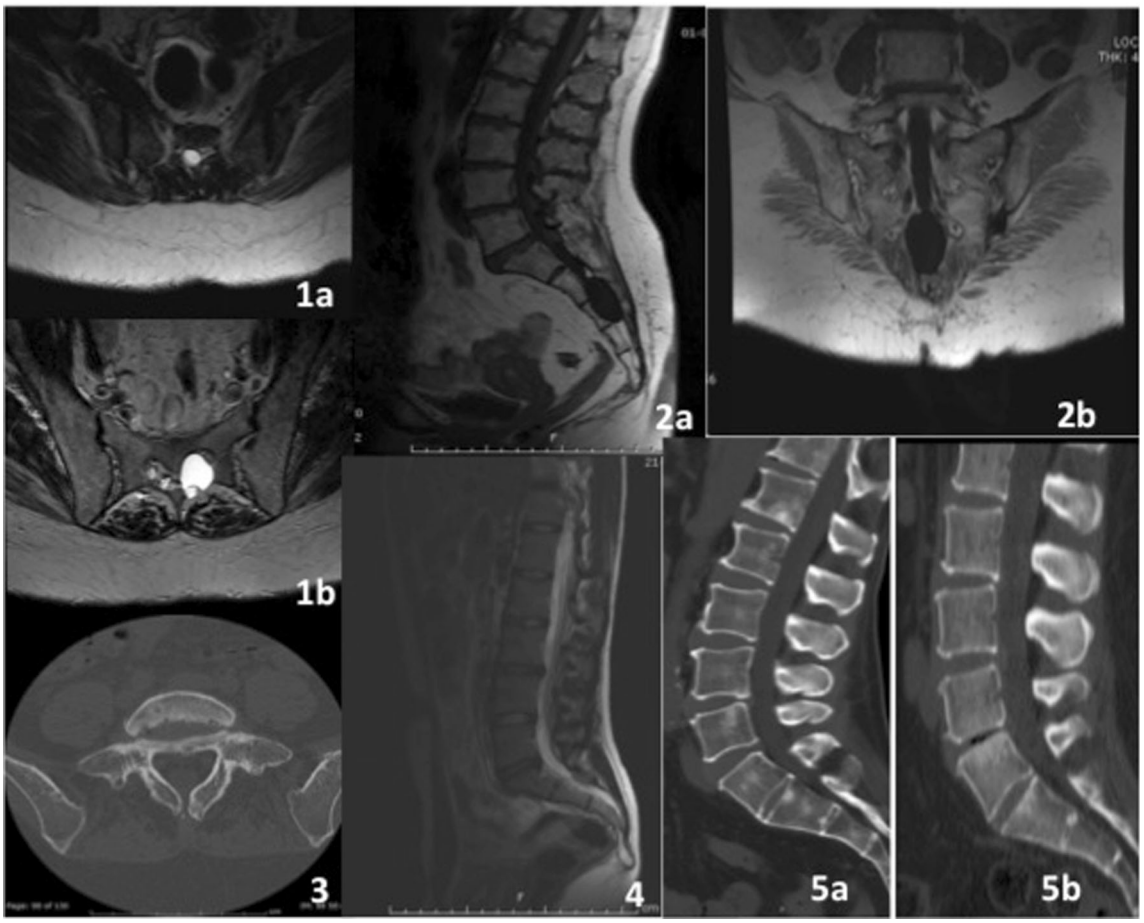

Fig. 1 Representative examples of sacral malformations amongst the reviewed images. *1*, Meningeal cysts: *a*, axial T2WI MRI demonstrates a small extradural cyst in the sacral canal, corresponding to dilatation of nerve root meningeal sleeve; *b*, axial T2WI MRI shows a cyst in the sacral canal, at the level of S2, obliterating the left posterior neural foramina. *2*, Intrasacral meningocele: *a*, sagittal T1WI MRI shows a typical occult sacral meningocele, with smooth remodelling and enlargement of sacral canal; *b*, coronal T1WI MRI depicts an extradural cyst, with superior displacement of nerve roots. No neural elements are present within the cyst. *3*, SBO. Axial bone CT depicts incomplete fusion of the S1 posterior elements. Osseous margins are rounded and well-corticated. *4*, Partial sacral agenesis. Sagittal T2WI MRI shows hypoplastic S4 and S5 vertebrae. *5*, Lumbosacral transitional vertebrae: *a*, lumbarisation of S1. Sagittal CT image demonstrates "squaring" of a lumbarised S1 vertebral body. Additionally, there is a full-sized lumbar-type disc between S1 and S2, compared with the characteristic vestigial disc typically seen at this level. *b*, Sacralisation of L5. Sagittal CT image demonstrates sacralised L5 vertebral body

Table 3 Number and topographic distribution of meningeal cysts

Number	Frequency	Distribution	Frequency
0	84 %	L5-S1	2.9 %
1	8.3 %	S1-S2	38 %
2	5.6 %	S2-S3	53.3 %
>3	2.1 %	S3-S4	5.8 %

The wide range in frequency in the different studies [9, 11, 16–27] (Table 4) can be explained by a variance in study objectives, design, focus and technique. The populations investigated were heterogeneous with regard to age, ethnicity and gender, as were the materials used (e.g. skeletal remains and images generated by different techniques). Our study, which includes a large number of patients, is the only to apply the following multiple imaging techniques simultaneously: MRI, CT and/or X-ray. This combination can detect both sacral skeletal malformations and spinal cord and sacral nerve root malformations.

CT is the technique of choice for the evaluation of bony details, and it is the first-line tool for SBO, LSTV, partial sacral agenesis and vertebral dysplasia of S1. X-ray can raise the suspicion of these lesions, but CT is always necessary to confirm (Table 2). With regard to meningeal cysts, CT can raise suspicion, but MRI must confirm. Indeed, all of the malformations can be detected by MRI (Table 2).

The anatomy of the sacral foramina will be changed by some sacral malformations, SBO, meningeal cyst, anterior occult meningocele and sacral agenesis. These were present in 21.7 % of all MRIs reviewed. In the 0.7 % patients with anterior occult meningocele and sacral agenesis, SNS would be impossible; in the 21 % with SBO and meningeal cyst, MRI would facilitate foraminal choice. Table 5 presents a summary of the implications for SNS of each sacral malformation.

In our study, meningeal cysts were the most common sacral malformation and were more frequent in women—a particularly relevant finding, as more SNS patients are women. Most of these cysts are asymptomatic, and those adjacent to the sacral foramina could be accidentally punctured during electrode introduction (although the literature does not hold a documented report), creating a cerebrospinal fluid fistula with potentially consequent hypotension syndrome [14, 15, 17]. Preoperative MRI will aid in the localisation of these lesions and allow the electrode to be introduced into a foramen with no meningeal cyst.

Preoperative CT could detect SBO, the second most frequent sacral malformation in our study and also asymptomatic in the majority of the cases. Imaging could allow the electrode to be introduced at a level safely below the osseous defect.

The finding of LSTV, despite being the third most frequent (2.7 %), is not a universal contraindication; spina bifida aperta and sacral agenesis are, but they are rare and are clinically symptomatic [3].

Although we found an incidence of sacral malformation similar to that in the literature, our study was a radiologic review of MRI scans in patients with low back pain. One might speculate that the incidence would be less if we looked at healthy volunteers. However, low back pain is one of the most common complaints in the general population and is mostly related to pathologic spinal conditions including intervertebral disc herniation and/or degeneration, facet joint arthrosis and spinal canal or foraminal stenosis. Of sacral malformations, only LSTV and sacral meningeal cysts can be associated with low back pain (Table 5). These two are common, and it thus remains a challenge to relate them specifically to the patients' symptoms. Indeed, the literature shows that, in most patients with LSTV, secondary spinal conditions often coexist and complicate determination of the underlying cause of pain [9, 18]. The majority of meningeal cysts are asymptomatic, usually reported as an incidental finding [14, 15, 17]. In only 1 % of the series reported by Paulsen et al. were the cysts responsible for either local sacral pain or sacral radiculopathy [17]. (The authors did not look for them in the lumbar region.)

More than half of the patients in our radiologic review (57 %) had pathologic findings such as intervertebral disc herniation and/or degeneration, facet joint arthrosis and spinal canal or foraminal stenosis, and all with LSTV and sacral meningeal cysts had co-existing conditions. Thus, ascribing their low back pain specifically to their sacral malformation was not possible.

In conclusion, sacral malformations were found in almost one quarter of our 998 cases and may represent an underreported cause of inadequate (or impossible) electrode placement. We therefore recommend a sacrum X-ray before SNS or the use of fluoroscopy guidance for placement—an easy technique that can identify LSTV, SBO, sacral agenesis and vertebral dysplasia. In all patients with minimal or major symptoms of unknown cause, such as lower back, perianal or sciatic pain or sacral radiculopathy, an MRI before SNS may be helpful to exclude meningeal cysts and meningocele. In all patients in whom appropriate formaminal placement is difficult or impossible, we recommend a CT scan or MRI to exclude sacral malformations.

All surgeons who perform SNS should have an understanding of sacral malformations and their implications for sacral foraminal anatomy. The use of imaging techniques will allow them to plan for efficient and successful placement and to avoid possible complications such as accidental puncture of a meningeal cyst. We believe that, in the future, a three-dimensional anatomic model based on radiologic studies of the sacral malformation will ease the navigation and placement of electrodes in a variety of conditions that are currently considered contraindications for SNS.

Table 4 Incidence of sacral malformations: literature reports

Author	Year	Source of data	Number	Ethnicity	Frequency (%)	Transitional vertebra (%)	Sacralisation (%)	Lumbarisation (%)	Spina bifida (%)	Sacral agenesis (%)	Meningeal cysts (%)	Meningocele (%)
Paulsen et al. [17]	1994	MRI	500	NR	NR	NR	NR	NR	NR	NR	5 %	NR
Li-Ping Wu et al. [16]	2009	Skeletal remains	208	Chinese	58.10 %	16.70 %	12.00 %	4.32 %	28.1 %	NR	NR	NR
Taskaynatan et al. [18]	2005	Radiographic method	881	Turkisk	9.99 %	5.67 %	NR	NR	4.54 %	NR	NR	NR
Fidas et al. [19]	1987	Urinary X-ray films	2707	British	NR	NR	NR	NR	22 %	NR	NR	NR
Avrahami et al.[20]	1994	X-ray and CT scans	1200	Israeli	NR	NR	NR	NR	17 %	NR	NR	NR
Schweitzer et al.[21]	1993	Abdominal X-ray	108	American	NR	NR	NR	NR	17 %	NR	NR	NR
Eubanks et al.[11]	2009	Osteologic specimens	2866	American	NR	NR	NR	NR	12.4 %	NR	NR	NR
Mahato et al.[9]	2010	Dried human sacra	332	Indian	NR	NR	NR	3.90 %	0 %	NR	NR	NR
Boone et al.[22]	1985	Frontal X-rays	653	English	NR	NR	NR	NR	17 %	NR	NR	NR
Ferembach [23]	1963	Skeletal remains	15	Moroccan	NR	NR	NR	NR	27 %	NR	NR	NR
Henneberg and Henneberg [24]	1999	Skeletal remains	124	Italian	NR	NR	NR	NR	11 %	NR	NR	NR
Thoper et al. [25]	1994	Abdominal X-rays	48	British	NR	NR	NR	NR	23 %	NR	NR	NR
Trotter [26]	1947	Skeletal remains	1227	American	NR	NR	NR	NR	1 %	NR	NR	NR
Vannier et al.[27]	1981	X-rays	299	French	NR	NR	NR	NR	8 %	NR	NR	NR

Table 5 Implications for sacral nerve stimulation of various sacral malformations

Sacral malformation	Description	Clinical issues	Frequency	Bone malformation	Spinal cord or root malformation	Neurologic dysfunction	Implications in SNS
Lumbarisation	Transformation of the first sacral vertebral towards a lumbar vertebral configuration	Asymptomatic or possible lumbar pain	5.5 %	Yes	No	No	[a]
Sacralisation	Fusion between the costal elements and the body of the fifth lumbar vertebra with the first sacral segment	Asymptomatic or possible lumbar pain	7.5 %	Yes	No	No	[a]
Spina bifida occulta	Spinous process/lamina fusion failure without underlying neural or dural abnormality	Usually asymptomatic if no cutaneous stigmata or occasionally skin dimple on back	1.2–50 %	Yes	No	No	[b, c]
Sacral agenesis	Constellation of caudal developmental growth abnormalities with associated regional soft tissue anomalies	Neurogenic urinary bladder dysfunction (nearly all patients) From neurologically asymptomatic to sensorimotor paresis (dependent on the kind of sacral agenesis)	0.005–0.01 %	Yes	Yes	Yes	[c]
Anterior meningocele	Sacral meninges hemiated anteriorly into the pelvis through focal erosion of hypogenesis of sacral ± coccygeal vertebral segments	Asymptomatic or manifested by nonspecific symptoms as a result of pressure on the viscera such as constipation, urinary problems, dysmenorrhea or pain in the lower back or pelvis Possible sciatica, diminished rectal/destrusor tone and parathesia in lower sacral dermatomes	About 300 cases in the literature	Yes	Yes	No	[c]
Posterior meningocele	Dorsal herniation of dura, arachnoid and CSF into spinal subcutaneous tissue	Palpable skin-covered mass or incidental discovery during imaging for other indication Back pain	10 % of all patients with spina bifida	Yes	Yes	No	[c]
Spinal meningeal cysts	CSF-filled sacs located in the spinal canal of S1–S4 region can be distinguished from other meningeal cysts by nerve fiber-filled walls	Asymptomatic or lower back pain, sciatica or bowel and bladder dysfunction	5 %	No	Yes	No	[b, c]

[a] Possible with change in anatomical reference

[b] Sacral foraminal anatomy changed, but MRI may make SNS possible

[c] SNS not recommended

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Compliance with ethical standards

Conflict of interest Ana Povo, Mavilde Arantes, Joselina Barbosa and Maria Amélia Ferreira declare no conflicts of interest. Prof. Klaus Matzel is a Medical Advisor to Medtronic®. There has been no significant financial support for this work that could have influenced its outcome.

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