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Quantitative measurements of the spinal cord and canal by MR imaging and myelography

L. Ros[1*], J. Mota[1], A. Guedea[1], D. Bidgood[2]

[1] Departamento de Radiología, Hospital Miguel Servet, E-50009 Zaragora, Spain
[2] Department of Radiology, University of Florida College of Medicine and GainesvilleAdministration Medical Center, Gainesville, Florida, USA

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Abstract. There is a large individual variation in human spinal cord and canal size, even in patients of different series studied by the same modality, and no authorized standard method has been established. A comparative study of sagittal diameters of the cervical spinal cord and canal using myelography and MRI is presented. The purposes of this paper are (a) to establish the correction factor (CF) needed for quantitative comparison of the two imaging modalities, and (b) to determine the different factors that may modify the measurement of these diameters. We studied 45 patients with clinical findings compatible with cervical spondilotic myelopathy. In our experience, the CF for accurate correlation of MRI and myelography measurements is 1.32 and depends almost entirely on the radiographic geometry of the myelographic procedure. In addition, there is a variability in the group of MRI results due to imprecision of the pressure-pad measuring/input device of the instrument itself and the sequence performed.

Key words: Spinal cord – Spinal canal – MRI – Myelography

Introduction

The sagittal diameter of the spinal cord and canal and its relationship to degenerative conditions, such as cervical spondylotic myelopathy, symptomatic lumbar spondylosis, and rheumatoid arthritis, have been investigated and shown to be of clinical importance. A congenitally narrow spinal canal may be a predisposing factor for neurological involvement in patients who have a traumatic injury of the cervical spine and no evidence of fracture or a dislocation. Athletes who had a history of transient quadriplegia were shown to have a narrower sagittal diameter of the canal than a group of control patients [1].

Morphometric studies of the human spinal cord and canal have been performed using myelography, CT myelography, and MRI; however, the results obtained in these reports appear to be at variance between the different diagnostic modalities, even in patients of different series studied by the same modality [2].

The simple conventional method, lateral film of cervical spine, determines the distance from the cephalocaudal midpoint (middle of the posterior surface) of the vertebral body to the nearest point of the corresponding spinal laminar line. A ratio method of diagnosing spinal stenosis, independent of magnification factors, has been used [1, 3]. Concerning myelography, there is also an inevitable magnification factor with relation to the focus–film distance.

Spinal stenosis of the lumbar spine is best determined with CT myelography; however, in the cervical spine, lordosis may create a false appearance of spinal stenosis [1, 4].

In our experiment, CT myelographic measurements were not used, although previous reports have been done in cervical spine [5]. The CT myelographic films were not reviewed because no sagittal equivalent view was available.

By MRI, pulse sequence, truncation artifacts, and window level also may influence the measurement. Sherman et al. recommended for evaluating the size of the spinal cord anteroposterior and transverse measurement obtained from axial perpendicular sections to the axis of the spinal cord to avoid obtaining a falsely elongated images [5]. How the sagittal diameter decreases in virtually a linear fashion from C1 to T3 is shown in this study. In addition, it is important to recognize that any individual patient may have cord enlargement or atrophy that can fall within the normal range of measurements presented by the authors.

In this paper we compare sagittal diameters of the spinal cord and canal using myelography and MRI in or-

Correspondence to: L. Ros

[*] *Present address:* Coso 89–91, 3 °D, E-50001 Zaragoza, Spain

der to calculate the correction factor (CF) needed for quantitative comparison of these two modalities. In addition, we study the different factors that can modify the measurements.

Patients and methods

All 45 patients (25 males and 20 females) had clinical suspicion of cervical spondilotic myelopathy (cervical and radicular pain, paresthesias and upper extremity neurological symptoms). Patients ranged in age from 34 to 75 years (average 59 years).

Myelography was performed by radiology residents under the supervision of attending staff radiologists. For cervical myelography, 10–12 cc of Omnipaque 240 (Winthrop Laboratories, Division of Sterling Drug, Inc., New York, N.Y.) were introduced typically at the L2–L3 level and moved by gravity into the cervical region using a tilt table. Overhead films, fluoroscopic spot films, and cross-table lateral films were utilized. Object–film distance and focal-spot–film distances were determined using a metal tape measure incorporated into the collimator system housing. The measurements of spinal cord and canal were made in the sagittal projection at an abnormally narrow level of pathological area and at an area without pathology (midpoint of the posterior border of the vertebral body concerned, and at right angles to the long axis of the cord for the canal, and between two parallel points for the spinal cord).

The MRI examinations were conducted on a Siemens 1.5-T Magnetom GBS-2 system using a Siemens (Siemens Medical System, Iselin, N.J.) anatomical Helmholz neck coil. Pulse gating was used for all studies. The field of view was 30 cm. Sagittal T1-weighted sections (TR 500 ms, TE 15 ms, 4-mm slice thickness, 256×256 2 NEX, typically 11 sections) and dual-echo T2-weighted sections (TR 2600–3100 ms, TE 45/90 ms, 4-mm slice thickness, 256×256, 1 NEX, typically 13 sections) were used. Para-axial T1-weighted sequences (TR 450 ms, TE 19 ms, 196×256, 3-mm slice thickness, 2 NEX) and gradient-echo FISP (Siemens Medical Systems, Iselin, N.J.) para-axial sequences (TR 200 ms, TE 13 ms, slice thickness 4 mm, 256×256, 1 NEX) were directed to the pertinent areas of clinical interest.

The measurements were performed at two levels (pathological and nonpathological levels) on three sets of images: T1, proton density (PD), and T2. Measurements were made with the pen pressure/pad input device of the Siemens GSB II MRI Scanner, positioning the cursor on the edges of the object of measure (spinal cord or canal; Fig. 1). We are aware that the cursor jitters and is unstable in positioning. (The pressure pad produces some intermittency that was judged by a Siemens representative to be within the usual range for this instrument.)

Having noted the variability of measurements, we undertook a secondary study to evaluate the precision of the measuring device itsef. A series of ten phantom objects were presented as unknowns to four trained MRI operators for measurement, obtained after the standard deviations of 40 measurements (of ten different objects by four people; Fig. 2).

Phantom specifications

One reference phantom was constructed for examination by MRI and plain films (simulated myelography). Phantom was a polyvinyl chloride (PVC) cylinder (21.4-mm outer diameter and 16.4-mm inner diameter) containing air, suspended in a 14.15-cm-diameter water-filled plastic bottle (Fig. 3).

A series of 12 cervical myelograms were performed to establish the range of film–focal distance (FFD) and object–focal distance (OFD) for this procedure.

Results

Myelographic measurements

Correction factor for myelography determined from the phantom measurements

At an FFD of 45 cm and an OFD of 35 cm, the uncorrected direct measurement of phantom inside diameter from plain films was 21 mm, measured two times. This value times a CF for magnification (OFD/FFD or 35 cm/45 cm = 0.78 for this experiment) is 16.3 mm, which is within 1% of the actual size of 16.4 mm, measured with a micrometer. The simulated myelographic plain films magnified the test object by a factor of approximately 1.28 under the condition of this experiment.

MRI measurements

Correction factor for MRI

The uncorrected direct measurement of the outside diameter of the phantom by MRI was 21, 20, and 21 mm on three determinations, averaging 20.7 mm (Table 1). A CF of approximately 1.03 is required to scale this measurement to the actual dimension of the test object. This CF is obtained dividing the outer diameter of the phantom (21.4) by the average diameter on the 3 determinations. (20.7). The MRI system slightly minified the object by a factor of approximately 0.97 in this experiment. The CF was established on T1-weighted sequence because no differences were expected on PD- and T2-weighted images. One experienced technologist performed all measurements using a pen–pad interface.

By dividing the myelography CF by the MRI CF, a myelogram–MRI correction factor is obtained. With this compound CF, one can precisely compare the results of the two examinations in order to evaluate the precision of T1, PD (45 ms), or T2 (90 ms). The measurements are summarized in Table 1. In this data, we observe that in MR measurements, the highest values are measured on T1-weighted images and the next highest are on PD (45 ms). The greatest differences corre-

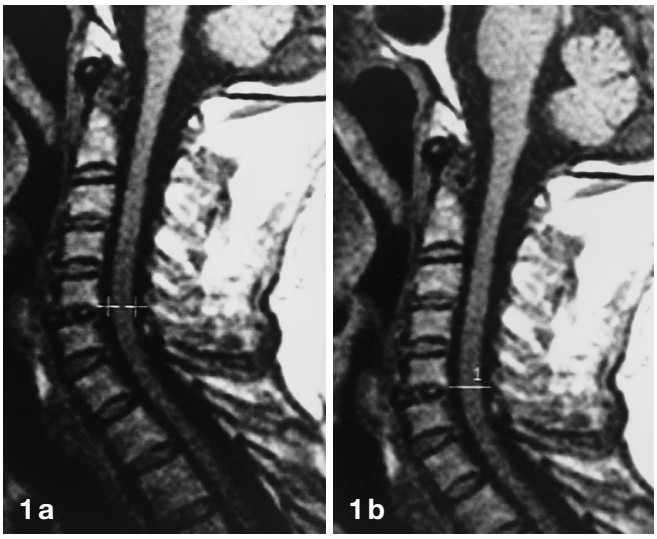

Fig. 1. Cervical **a** spinal cord and **b** canal measured by MRI (T1-weighted) at pathological level

Fig. 2. **a** Phantom to evaluate the precision of the measuring device. **b** MR imaging of the phantom

Fig. 3. **a** Phantom constructed to establish the range of film–focal distance and object–focal distance for myelography, and MRI assessment. **b** MRI of the phantom

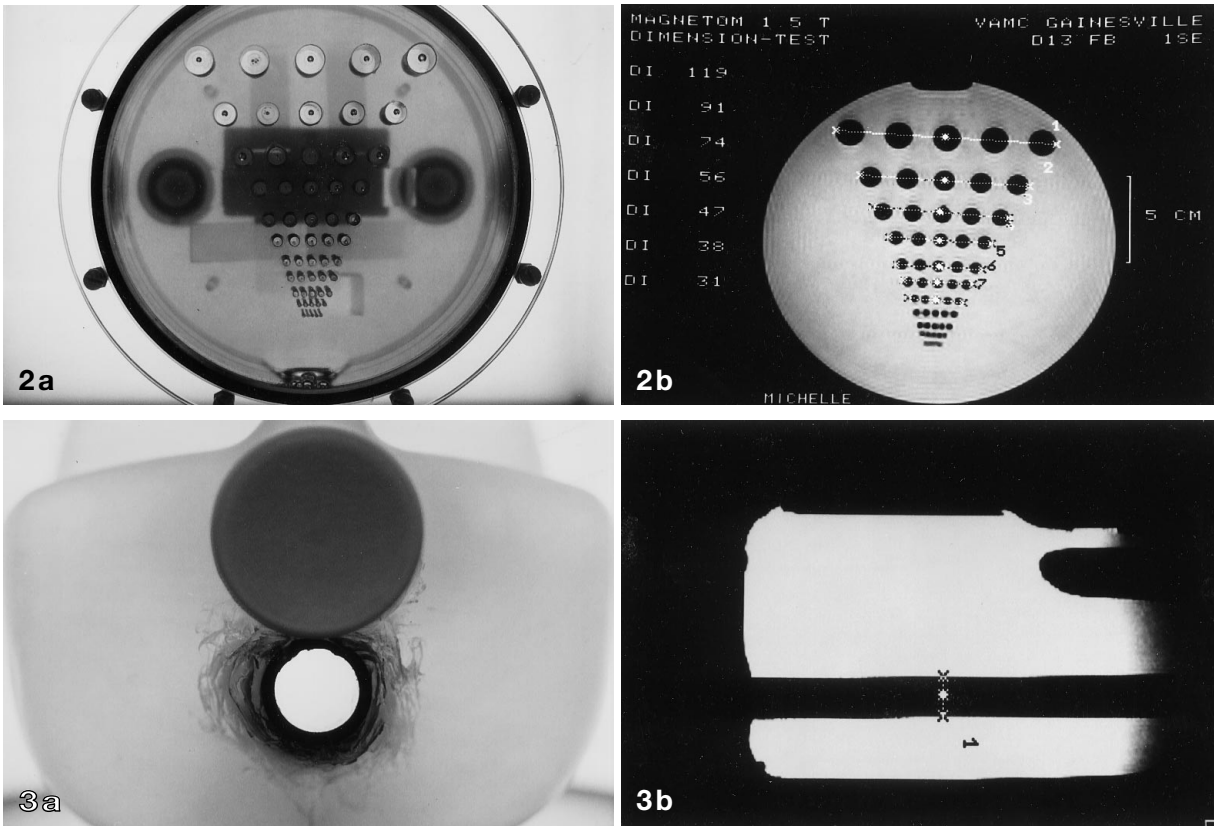

Table 1. Measurements of spinal cord and canal by MRI and myelography: quantitative correlation. *N* no. of patients

		T1	PD (45)	T2 (90)	MYELO	MYE/T1
Normal cord	*N*	45	41	43	45	41
	Diameter (mm)	8.6	8.5	8.2	10.7	1.2
Normal canal	*N*	45	43	44	45	42
	Diameter (mm)	12.4	12.4	12.3	17.1	1.4
Abnormal cord	*N*	45	41	44	45	37
	Diameter (mm)	6.9	6.7	6.5	8.4	1.2
Abnormal canal	*N*	45	43	43	44	39
	Diameter (mm)	9.2	8.2	8.2	13.0	1.4

spond with the measurements of abnormal canal region. T1 magnifies to higher degree than PD (45 ms) or T2 (90 ms).

Comparing MR measurements with myelographic measurements, the greatest differences occur in the values of vertebral canal (either normal or abnormal). Myelography delineates the margins of diameter canal less distinctly than MRI. However, the ratio between MR measurements and myelographic measurements for the vertebral canal is the same for normal and pathological canal. The error is judged to be in the myelographic measurement. The ratio between MR and myelographic measurements for spinal cord are the same for normal and pathological ones.

Under the experimental conditions, using a standard phantom for both MRI and simulated myelographic films, the CF is approximately 1.32 (which depends primarily on the FFD and OFD).

Observation of 12 cervical myelograms performed according to standard departmental protocol yielded data on typical OFD and FFD for this procedure in our department. The ranges were 39–45 cm for FFD and 31.5–37.5 for OFD. The average values were 45 cm (FFD) and 34 cm (OFD). Note that the CF obtained (above) could vary widely from case to case depending on the actual geometry.

Five hundred forty measurements of normal and pathological regions of spinal canals and cords by MRI and 90 measurements of the same objects by myelography revealed some interesting findings. The canal diameter is rendered larger by T1-weighted than by T2-weighted sequences. Variability is greater in pathological regions. Myelographic measurements are more difficult technically and frequently are impossible in areas easily evaluated by MRI. The data table (in Microsoft Excel format) is available upon request.

Discussion

Measurement of the normal spinal cord and canal have been performed in cadaveric specimens and in vivo using different modalities [1–16]. Comparison of different data in the literature reveals disparate measurement variation.

The simple conventional technique, lateral film of cervical spine, using a ratio method has been a reliable method for determining cervical spinal stenosis [1]. Subsequent studies were performed using myelography, CT myelography, and MRI.

Myelography offers information about the width of the canal as well as the thickness of the spinal cord; however, myelography is less useful in detecting minor intramedullary changes and is invasive. The anteroposterior myelographic diameters obtained in our experience were in accordance with those seen in other reports [6]. The largest diameter in this study, comparing CT, myelography, and MRI were provided by myelography as well, mainly due to the focus films and focus object distances introducing an inevitable magnification factor. In our experiment we focused only on the sagittal diameter, but axial diameter has been used by other authors [5].

Magnetic resonance imaging provides more detail than other modalities. T2 imaging is frequently used but has some limitations, e.g., artifacts secondary to magnetic field or tissue inhomogeneity, decreased sensitivity to disc desiccation, exaggeration of stenosis [7], or limitations with relation to the influence of cerebral spinal fluid pulsation [6]. In addition, MRI measurements have considerable variability despite being performed by a single technologist using a standard protocol. However, experiences on cadavers have shown an accurate correlation between the measurements of the cervical spinal cord by MRI and callipers [5, 8].

Many different factors may modify the measurement of the spinal cord and canal by MRI and myelography. In our study, this variability is due primarily to three different factors:

1. Imprecision of the pressure-pad measuring/input device of the instrument itself. We have already commented that the cursor is positioned at the edges of the object being measured; however, the cursor (of this instrument) jitters and is unstable in positioning. The tolerances of distance-measurement peripheral devices should be determined as part of the routine quality-control assessment of MRI equipment.
2. The correction factor for accurate correlation of MRI and myelographic measurements depends almost entirely on the radiographic geometry of the myelographic procedure. In our department, the average CF is approximately 1.32.
3. Note the variability in relation to the properties of the diagnostic modality used. T1-weighted sequences offer less contrast than T2-weighted images, so in T1, the disk and fibrous tissue are similar to bone and fluid, a fact that explains the apparent magnification of spinal canal diameter on T1-weighted images.

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Book review

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Weir, J., Abrahams, P. H.: Imaging atlas of human anatomy, 2nd ed. St. Louis: Mosby 1997. 206 pp., (ISBN 0-7234-2283-4), $ 36.95.

Imaging methods to display human anatomy have been greatly improved in the last two decades by more specialized technology, now able to produce images of hidden areas such as the brain, muscles, ligaments and ganglia. This 206-page book perfectly illustrates how new imaging modalities may change the teaching of anatomy.

After a short introduction to the four most sophisticated imaging techniques of angiography, computed tomography (CT), magnetic resonance imaging (MRI) and ultrasound (US), the book presents anatomy in seven chapters.

Chapter 1 deals with head, neck and brain. It is a miscellaneous chapter, including anatomical structures of very different areas and functions such as brain, larynx and salivary glands. All imaging methods contribute to illustrating the anatomical details, with a large contribution from CT and MRI, although a few old images of the ear and the larynx are shown by multidirectional and unidirectional tomography respectively.

The vertebral column and the spinal cord are included in Chapter 2. The complex anatomical details of vertebrae are shown not only by panoramic views, but also by isolated specimens of single vertebrae. Excellent myelo-CT images show the anatomy of the spinal cord and canal, thus paralleling the more usual MR sequences.

Chapters 3 and 7 are devoted to the upper and lower limbs. Conventional radiography is used to illustrate the anatomy of the bones, while angiography extensively shows arterial and venous vascularity of these areas. MRI gives the most impressive pictures of limb segments, as it allows muscles, ligaments and tendons to be added to the anatomy of bones and vessels. For that reason, conventional contrast arthrography has no place in the book.

Chapter 4, on the thorax, has its most extensive and interesting part represented by the mediastinum. Axial CT images and three-plane MR images permit a full understanding of this complex anatomy, captioned by plenty of references.

Abdomen is another miscellaneous chapter, as it includes all anatomical parts located between the diaphragm and pelvis. In this large area all imaging modalities play a role, from barium meal and enema, to intraoperative cholangiography, ERPC and lymphography. Once again, CT and MRI are able to provide the best understanding of relationship between different organs, due to the large field of view of their sections.

Chapter 6 is completely devoted to the pelvis. This area is substantially divided into the male and female pelvis. While the male pelvis is illustrated either by CT or MRI, the female pelvis has its anatomical pattern represented only by MR images. Axial, coronal and sagittal planes acquired through the MR technique give a wonderful representation of the anatomy of this complex area. In fact the representation of female pelvis by MRI is so good that other imaging methods become obsolete. Furthermore, the US anatomy of the fetus is illustrated by 12 excellent pictures.

An exhaustive index of anatomical terminology is a helpful conclusion to the book. Coming in a long line of atlases of anatomy illustrated by radiological images, this *Imaging Atlas of Human Anatomy* is not original. Nevertheless, it has the particular feature of showing anatomical structures by means of all the imaging modalities now available, chosen according to their ability to best describe the details of a structure. The images are excellent, except for a few cases where the pictures are too small, as in the skull base and temporal bone, or of poor reproduction, as in the bronchial tree. Sub-specialists such as neuroradiologists or pediatric radiologists might not find all the anatomical details they need. On the other hand, the aim of this book is to give an up-to-date overview of radiological anatomy to everyone involved in patient care (not only radiologists, but also clinicians). Furthermore, this second edition has considerably improved the number of MR and US images and almost 50 % of all images have been updated, with an increased number of views and the addition of some MR angiographies.

As the book is quite cheap, considering the number of illustrations, the relation of content to price highly recommends it to personal and departmental libraries. A. Chiesa, Brescia