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ORIGINAL ARTICLE

Morphological changes in scoliosis during growth. Study in the human spine☆

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Abstract
Objectives: To analyse the pathological substrate of human scoliotic spine during growth.
Material and methods: We studied two spines obtained at the autopsy of two patients suffering from untreated scoliosis: Sample A (a girl of 13 years and 2 months) and sample B (a boy of 14 years and one month). On the conventional radiological study the curves were measured using the method of Cobb, and the vertebral rotation with the Pedriolle method. A CT scan and analysis of the posterior asymmetry were also performed. The bone structure, growth plate, subchondral bone were evaluated in the histological study, as well as the presence and distribution of fibrous tissue.
Results: Levels from C7 to L5 were studied in sample A, and levels from T2 to L4 in sample B. There was no evidence of vertebral deformity in the frontal, sagittal or axial planes, except for T5 in sample A, where wedging into the concavity in the frontal plane was observed. The deformity originated in the intervertebral discs. Endochondral ossification of the epiphyseal cartilage showed increased activity on the side of the convexity of the curve. Neurocentral cartilage was present at thoracic and cervical levels, having disappeared at lumbar level. No asymmetry was observed in the neurocentral cartilage.
Conclusions: The deformity begins in the intervertebral discs, producing distortions in the epiphyseal cartilage. Those changes may influence the end of growth and therefore the deformity of the scoliotic vertebrae, basically resulting in wedging and rotation of the vertebrae.

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PALABRAS CLAVE
Escoliosis;
Crecimiento;
Raquis

Alteraciones morfológicas en la escoliosis. Estudio en raquis humanos en crecimiento

Resumen

Objetivos: Analizar el sustrato anatomopatológico del raquis escoliótico humano durante el crecimiento.

Material y métodos: Estudiamos el raquis, obtenidos en la necropsia, de 2 pacientes afectados de escoliosis. Muestra A (niña de 13 años y 2 meses) y muestra B (niño de 14 años y un mes). Se estudiaron las piezas anatómicas obtenidas en la necropsia. Se realizó un estudio radiológico convencional; se valoró la intensidad de las curvas con los grados de Cobb y la rotación vertebral con el método de Pedriolle, cortes de tomografía computarizada (TC) y análisis de la asimetría posterior (giba). Además, en el estudio histológico se valoró la estructura ósea, los cartílagos de crecimiento, el hueso subcondral, la presencia y la distribución del tejido fibroso.

Resultados: Se estudiaron los niveles de C7 a L5 de la muestra A y de T2 a L4 de la muestra B. No se evidenció deformidad de los cuerpos vertebrales en el plano frontal, sagital ni axial, salvo en T5 de la muestra A, con acuñamiento en el plano frontal hacia la convexidad. La deformidad se originaba en los discos intervertebrales. La osificación encondral de los cartílagos epifisarios presentaba una mayor actividad en el lado de la convexidad de la curva. El cartílago neurocentral estaba presente a nivel torácico y cervical, habiendo desaparecido a nivel lumbar. No observamos asimetría en los cartílagos neurocentrales.

Conclusiones: La deformidad se inicia en los discos intervertebrales produciéndose alteraciones en los cartílagos epifisarios que pueden condicionar, al final del crecimiento, la deformidad de las vértebras escolióticas, básicamente acuñamiento y rotación.

Introduction

The most important questions about the aetiopathogenesis of idiopathic scoliosis still remain unanswered.[1] Many authors have developed different theories to explain the cause of idiopathic scoliosis.[2] However, the studies that focus on the underlying anatomic pathology of this disease during growth are few.

Nicoladoni,[3] early in the previous century, described the changes observed in the spine of 2 children with scoliosis, observing asymmetry in neurocentral cartilage ossification, with greater osteogenic activity in the convex side. James[4] studied a spinal sample from an 11-year-old patient with congenital scoliosis, noting vertebra rotation. No reference was made to the state of the growth cartilage in that work. In 2002, Parent et al.[5] studied the vertebrae in scoliotic spines using morphometric analysis; there was a description of the structural changes in the pedicles and in the zygapophyseal joints (or facet joints) in the vertebrae of the patients with scoliosis, but without any reference to growth cartilage either.

Despite these studies, there is very little current information on the factors determining the deformities generated in scoliosis during growth; these changes occur when the vertebral body growth plates are still cartilaginous, capable of producing bone, of becoming deformed or being corrected. Our work makes no attempt to define the cause of scoliosis; we only want to help to understand the anatomopathological basis underlying spinal deformities in scoliosis.

Material and methods

We carried out a descriptive analysis of the spine of 2 patients with scoliosis in the context of congenital spastic tetraparesis, who died from respiratory problems. Both patients were in their growth period when they died. One spine came from a girl aged 13 years and 2 months (Sample A), while the other was from a boy 14 years and 1 month old (Sample B). The patients died without having been treated for the spinal deformity.

The anatomical samples obtained at autopsy after freeing the soft tissue were studied. The samples were also studied using conventional radiology, computerised tomography and histological processes.

Macroscopic study

Before the skeletal processing of the sample, the macroscopic curves in the entire spine were determined in the anteroposterior (AP) and lateral (L) planes. The individual vertebrae were then processed for their macroscopic observation and histological study. We evaluated the degree of skeletal maturation through the morphology, growth cartilage presence/absence, morphotype of the vertebrae and the participation of each one in the deformity. The vertebrae were randomly chosen in the coronal or axial planes for studying the different structures.

Radiological study

In the standard radiological study, the intensity of the deformity was assessed in Cobb degrees for the spinal curves. We studied the intensity of the vertebral rotation vertebral with the method of Perdriolle and Vidal[6] and through CT scan images. We analysed the posterior asymmetry of the gibbous with the help of CT, measuring its intensity at the transverse apophyses.

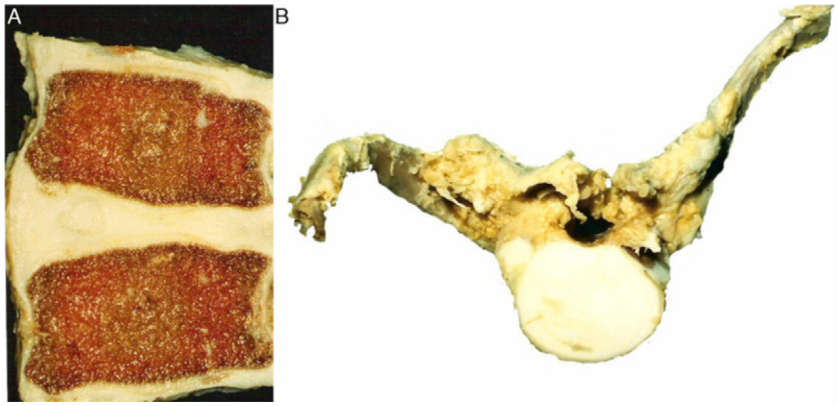

Figure 1 (A) Macroscopic aspect, coronal plane, of the vertebral bodies T12-L1 and the intervertebral disc between them. The deformity in the group can be seen; the height is greater on the side corresponding to the convexity of the curve. The disc is wedged, with a reduction in height on the side of the concavity associated with a displacement of the nucleus pulposus towards the convexity. Remains of neurocentral cartilage can also be seen. (B) Axial view of vertebra T8. Asymmetry between the ribs, in absence of vertebral body alterations, can be seen.

Histological study

We dissected the various vertebrae chosen in the coronal and axial sense, according to the deformity observed in the macroscopic study. The specimens obtained were fixed in 4% phosphate buffered formaldehyde for 24 h. After fixation, they were decalcified in a 10% Tris buffer solution containing polyvinylpyrrolidone (PVP) and EDTA, 0.1 M and pH 6.95 at 4 °C for 3 months. The specimens were dehydrated using ascending grade of alcohol. We then introduced them in xylene and included them in paraffin at 60 °C. Next, 4-μm thick cuts were prepared with a standard microtome (Microm®) and stained with Masson trichrome (MT) and haematoxylin–eosin (HE).

Bone structure, growth cartilage, the subchondral bone, fibrous tissue presence and its distribution were assessed.

Results

Sample A

The human spinal cord of a patient who was 13 years and 2 months old was studied from levels C7 to L5.

Macroscopic study

Overall, no wedging was found. In the T5 vertebral body, we saw wedging towards the concavity (Fig. 1).

Radiological study

The girl had an idiopathic curve pattern, with a scoliosis in the coronal plane having a thoracic curve from C7 to T9 of 51° Cobb angle, convex to the right, and a lumbar curve T9 to L5 of 44° Cobb angle, convex to the left. Of the 51° of dorsal curve, 70.6% (36°) originated in the intervertebral discs; at lumbar curve level, 84% of the degrees also corresponded to the intervertebral discs (37°) (Fig. 2).

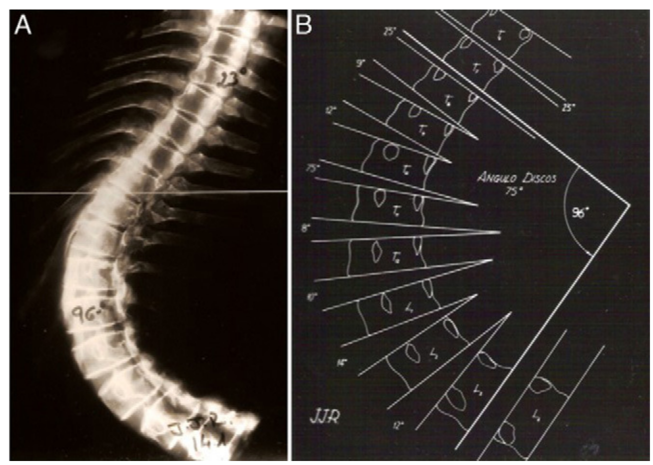

Figure 2 (A) Anteroposterior (AP) X-ray of the Sample A spinal column, after freeing the soft tissues. The severity of the thoracolumbar scoliotic curve can be observed. (B) Image corresponding to the tracing of the X-ray, where the curve intensity was measured in Cobb degrees: 75° of the 96° originated at the disc level.

In the sagittal plane, after liberating the soft tissues, we saw a 40° dorsal kyphosis and a 58° lumbar lordosis.

The results of the degrees of vertebral body rotation, as well as the magnitude of the posterior asymmetry (measured using the Perdriolle method on CT), are summarised in Table 1.

Histological study

In the transversal histological specimens at the C7 vertebral body, we found neurocentral cartilage. As we headed distally in the thoracic spine, we could see a decrease in size (length and width) of the neurocentral cartilage in the vertebral bodies. We found only isolated islets at the T12 level, while no activity was seen in the lumbar region. We found

Table 1 Sample A: degrees of rotation of the vertebral body growth plates and posterior asymmetry.

Vertebra	CT rotation		Perdriolle rotation		Gibbous protrusion (mm)
	Degree	Direction	Degree	Direction	
T2	8	Concavity	5	Convexity	5.5
T3	7	Concavity	5	Convexity	5.5
T4	9	Concavity	10	Convexity	6
T5	10	Concavity	15	Convexity	9
T6	15	Concavity	8	Convexity	14
T7	22	Convexity	5	Convexity	16.5
T8	29	Convexity	15	Convexity	18
T9	34	Convexity	30	Convexity	20
T10	34	Convexity	32	Convexity	22
T11	40	Convexity	35	Convexity	26
T12	44	Convexity	37	Convexity	26
L1	42	Convexity	35	Convexity	34
L2	33	Convexity	32	Convexity	28
L3	26	Convexity	20	Convexity	19
L4	22	Convexity	5	Convexity	13

symmetry and lack of rotation deformity in the vertebral bodies (Fig. 3).

Sample B

The human spinal column of a patient who was 14 years and 1 month old was studied from levels T2 to L4.

Macroscopic study

No asymmetry was observed in the vertebral bodies; no wedging was found in the frontal plane, nor vertebral body deformity, only vertebral rotation in the axial plane (Fig. 4A). There was a deformity in the frontal plane in the intervertebral discs, showing disc wedging with displacement of the nucleus pulposus towards the convexity associated with destructuring of the annulus fibrosus. This confers a cuneiform morphology to the intervertebral disc. Neurocentral cartilage was found in all the thoracic levels, having disappeared almost completely at the lumbar level.

Figure 3 Coronal histological specimen of intervertebral disc T12-L1 and a portion of the adjacent vertebral bodies. Wedged intervertebral disc, with the nucleus pulposus displaced towards the convexity. Break in the growth plate concavity. Adjacent to the nucleus pulposus, a growth plate ossification centre can be seen (Masson Trichrome, ×4).

Radiological study

The patient presented a pattern of paralytic curve. In the frontal plane, we observed a scoliotic curve, from T2 to T7, with a Cobb angle of 23° with right convexity, and from T7 to L4, with a Cobb angle of 96° with left convexity. Of the degrees of this deformity, 78% originated in the intervertebral discs (75°), while only 22% of the deformity derived from the vertebral bodies (21°) (Fig. 4B and C).

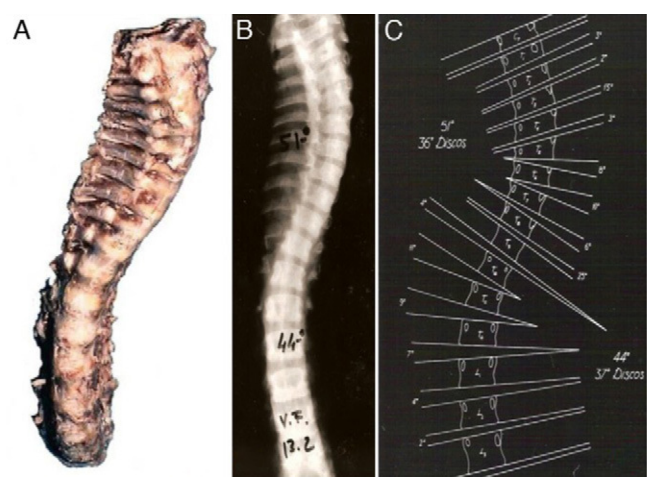

Figure 4 (A) Frontal view of Sample B spine, after soft tissue liberation. The double curve (idiopathic scoliosis pattern) and the vertebral body rotation can be seen. (B) Anteroposterior (AP) X-ray of Sample B spinal column, after soft tissue liberation. The typical scoliotic curve pattern (double curve) can be seen. (C) X-ray tracing image, where curve intensity was measured using Cobb degrees.

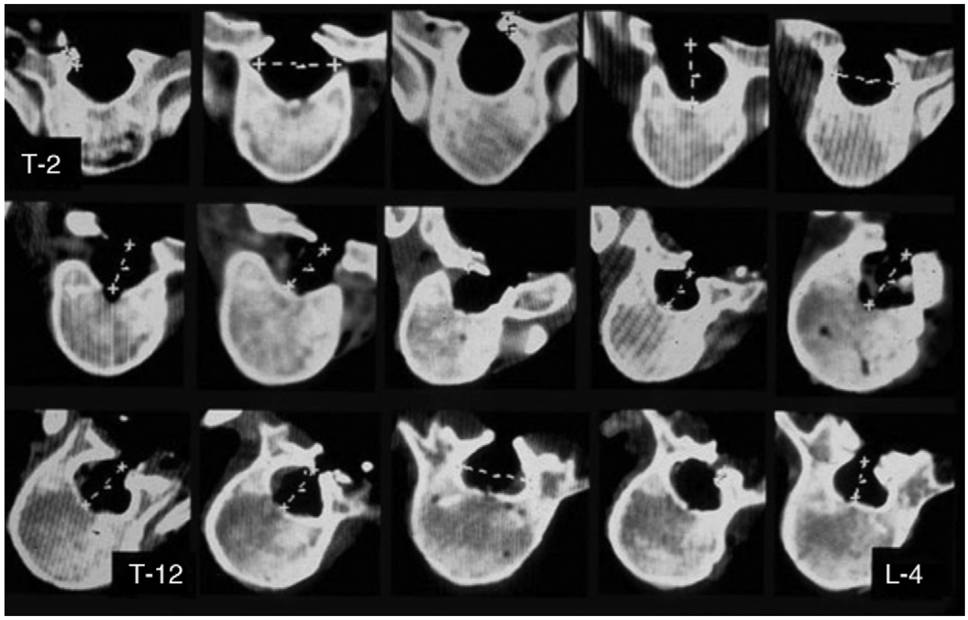

Figure 5 Sample B: CT scan image from T2 to L4, showing that the vertebral bodies lack bone deformity but are in rotation.

In the sagittal plane, after freeing the soft tissues, there was a reduction in the dorsal kyphosis with mild lumbar lordosis. The vertebral bodies, positioned in rotation, lacked bone deformities, as can be seen in the CT scan images (Fig. 5).

The results of the degrees of rotation of the vertebral bodies, as well as the magnitude of the posterior asymmetry (gibbous), are summarised in Table 2.

Histological study

The neurocentral cartilages had disappeared at the lumbar level, with some persistent remains, interrupted by bridges at the dorsal level (Fig. 6A). We observed epiphyseal growth cartilage with chondral cells at all levels (Fig. 6B). The most active endochondral ossification was found in the side of the curve convexity.

Discussion

There is very little information available on how vertebral deformities are produced in scoliosis. In our opinion, this article is of great interest because of the rarity of the material studied and the information provided, given that both spinal columns belonged to patients that were untreated and were still growing. We believe that this is the first

Table 2 Sample B: degrees of rotation of the vertebral body growth plates and posterior asymmetry.

Vertebra	CT rotation		Perdriolle rotation		Gibbous protrusion (mm)
	Degree	Direction	Degree	Direction	
T2	13	Convexity	10	Convexity	0
T3	14	Convexity	15	Convexity	0
T4	18	Convexity	15	Convexity	4
T5	20	Convexity	20	Convexity	7
T6	10	Convexity	20	Convexity	5
T7	13	Convexity	23	Convexity	–
T8	19	Convexity	25	Convexity	–
T9	2	Convexity	15	Convexity	0
T10	17	Convexity	0	Convexity	8
T11	23	Convexity	5	Convexity	15
T12	23	Convexity	5	Convexity	23
L1	25	Convexity	0	Convexity	28
L2	24	Convexity	0	Convexity	21
L3	23	Convexity	5	Convexity	15
L4	18	Convexity	5	Convexity	15
L5	19	Convexity	0	Convexity	15

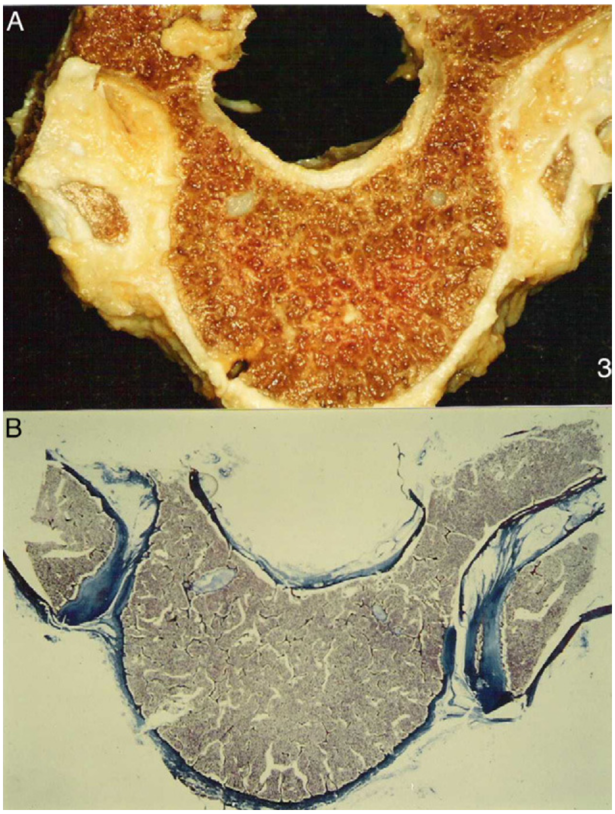

Figure 6 Sample B: axial specimen of the vertebra T3. Histological (A) and microscopic (B) (Masson trichrome, ×4) views, where islets of neurocentral cartilage can be seen.

description of complete spinal columns with scoliosis still in the growth period. Nicoladoni[3] studied the spines of 2 patients, 1 aged 6 years and 5 months and the other 7 years old; however, only 2 vertebral bodies per patient were analysed in both instances.

With respect to the radiological study, we should mention that our patients presented sequelae from childhood cerebral palsy, but from the viewpoint of scoliotic curve pattern, both very different. The first patient (Sample A) presented a double curve, typical in idiopathic scoliosis, while the second patient (Sample B) presented a clearly neuromyopathic pattern. As we have mentioned, most of the degrees of the scoliotic curves originated in the intervertebral discs. We found a lack of bone deformities in the vertebral bodies at these ages. The capacity for ossification the vertebral bodies showed was normal. We did observe the apophyseal rings of the vertebral body at the level of the curve convexity. These findings correlate with those that Nicoladoni[3] described. In our opinion, this disparity in chondral activity may be related to the differences in the pressures to which these structures are submitted.

We studied the axial plane, observing the clinical repercussions produced by vertebral body rotation. The results obtained with CT scans are practically superimposable to those obtained using the method of Perdriolle and Vidal.[6] Although the spinal column as a whole evidently rotates, we did not see any deformities in any of the vertebral bodies.

Veldhuizen et al.[2] believe that, the loss of mechanical stability during growth originates in the deformity of the vertebral bodies and of the ribs. However, our results suggest that spinal deformity originates in intervertebral discs, conditioned by forces extrinsic to the spinal column.

According to Roberts,[7] the structure and form of the intervertebral ring depend on the type of molecules it presents and how they interrelate; but we could see a disorganisation of the intervertebral disc with destruction of the fibrous ring and deviation of the nucleus pulposus towards the curve convexity. Some authors defend the idea that intervertebral disc alterations in scoliosis could be influenced by ossification of growth cartilage and that the alterations can interfere with the flow of nutrients and metabolites between the growth plate and the epiphyseal plate.[8] This flow modification could explain the reduction in the number of viable cells in the intervertebral disc in scoliosis,[9] which can lead to a change in elastic fibre distribution.[10]

As is known, vertebral body growth occurs through 2 cartilaginous structures. The growth in the frontal plane (height) is produced thanks to the endochondral ossification of the apophyseal rings, cephalic and caudal to the vertebral bodies. In turn, the activity of the neurocentral cartilage generates the growth in the axial plane (width).

In scoliosis, the vertebrae grow disproportionately.[1] In our samples, we saw different ossification in the apophyseal rings, which could be related to the wedging found in the intervertebral disc. The gradient of chondral activity might be due to a pressure asymmetry. We suspect that this difference in growth plate activity could be a consequence, more than a cause, of the deformity. Alterations in the sagittal plane are in theory caused by an asymmetry in the growth of those components.[11] However, we saw none of these alterations in the specimens studied.

Parent et al.[5] described a pattern of deformity in the scoliotic vertebrae in their morphometric analysis using a 3D digital protocol. This pattern is characterised by the presence of wedging in the curve concavity, with reduced pedicle width in the concavity and altered zygapophyseal joints. Such modifications have also been seen using magnetic resonance with multiplanar reconstruction,[12] but both were studies using adult specimens, in which the growth capacity has ended and the bone deformities are established.

From a structural and functional viewpoint, the disc and vertebra should be acknowledged as 2 elements of the same unit.[13] Consequently, although we saw the main effect in the intervertebral disc, the resulting deformity can affect the discos and vertebrae during the growth period.

In contrast to what has been described by other authors, we found neurocentral cartilage activity in individuals aged more than 6–8 years, especially at the high thoracic and cervical levels. The chondral activity asymmetry of the neurocentral cartilage, which Nicoladoni[3] observed, could be related to the residual vertebral rotation in scoliosis.

These alterations in the shape and orientation of the spinal column seem to be driven by factors external to it, still unidentified.[14] The deformity, while growth exists, is produced in the mobile elements.

From the clinical point of view, corrective forces (internal or external) should be applied before growth ends, so that the intervertebral discs, which maintain elasticity, let us correct the deformity as much as possible before bone maturity.

In view of the results obtained, we can conclude that the changes in scoliosis, in spinal columns still in growth, are due to factors external to the spine. There were no structural alterations of the vertebrae that justify such a deformity.

The deformity begins in the intervertebral discs, with secondary alterations in the neurocentral and apophyseal rings that can be explained by the asymmetry of the pressures between the concavity side and that of the convexity.

Level of evidence

Level of evidence V.

Ethical responsibilities

Protection of persons and animals. The authors declare that no experiments have been performed in humans or animals for this research.

Data confidentiality. The authors declare that no patient data appear in this article.

Right to privacy and informed consent. The authors declare that no patient data appear in this article.

Declaration of authorship

José Luis Beguiristain and Julio Duart participated in the conception of the study, its design, data search and data analysis and in writing the article. Rafael Llombart worked on the references, gave ideas on the first drafts and agreed with the final results. Julio Duart is the person responsible for the article.

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Conflict of interests

The authors have no conflict of interests to declare.

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