VARIATION OF THE LUMBOSACRAL MYOTOMES WITH BONY SEGMENTAL ANOMALIES

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Clinical localisation of a disc prolapse requires dependable knowledge of the muscles supplied by the lumbosacral nerve roots. Localisation is most difficult in the 10 per cent of patients who have lumbosacral bony segmental anomalies. The lumbosacral plexus has been dissected in 11 cadavers with such anomalies and electrical stimulation studies carried out in 15 patients similarly afflicted. It is suggested that whatever the anomaly the "last fully mobile level" should be identified as the lowest level with a fully formed disc space, bilateral facet joints and two free transverse processes which do not articulate with the sacrum or pelvis. In three out of four patients with bony segmental anomalies the fifth lumbar root emerges at the last fully mobile level.

Prolapse of a lumbar intervertebral disc occurs mainly at the L5/S1 or L4/5 level, usually with involvement of the S1 and L5 roots respectively. Diagnosis of the lesion is based on clinical findings of root pain and paraesthesiae, with signs of root irritation and compression. The anatomical localisation of the prolapse is determined by evaluation of the motor, sensory and reflex impairment, and by interpretation of contrast radiography, particularly myelography. Oil myelography will correctly predict the surgical findings in 75 to 80 per cent (Hudgins 1970), while water-soluble myelography improves the accuracy to 90 to 95 per cent (Hirsch and Nachemson 1963). However, neither reliably distinguishes a disc prolapse from fibrosis and lateral pressure on the nerve root may be present in spite of a normal appearance of the contrast medium (Schlesinger 1957; Macnab 1971) while falsely positive findings are not uncommon, even in asymptomatic patients (Hitselberger and Witten 1968). A reliable knowledge of the anatomical pattern of muscles supplied by the L5 and S1 roots is a valuable aid to clinical diagnosis. Particular difficulty may arise in localisation of the lesion in patients with bony segmental anomalies, such as variable numbers of vertebrae or a transitional vertebra, which are present in about 10 per cent of patients. In the presence of such abnormalities the last fully mobile level should be identified as the lowest level with a fully formed disc space, bilateral facet joints and two free transverse processes which do not articulate with the ala of the sacrum or the pelvis. This level is L5/S1 in a patient with normal anatomy. Any intervertebral space beneath the last fully mobile level should be referred to as a partly formed level and may take the form of varying degrees of incomplete

segmentation either of the disc space or of the posterior elements (Fig. 1). Higher levels can be identified as the second or third last fully mobile levels.

This paper describes a study of the site of the L5 and S1 nerve roots in 11 cadavers with lumbosacral anomalies and evaluates the effect of electrical stimulation of the L5 and S1 nerve roots in five patients with normal lumbosacral spines and 15 with segmental anomalies.

MATERIAL AND METHODS

Anatomical dissections. Eleven cadavers with lumbosacral anomalies were studied. The nature of the segmental anomaly was demonstrated by radiography and the lumbar and sacral plexuses were dissected out.

Stimulation studies. Patients undergoing chemonucleolysis for lumbar disc prolapse provided an ideal opportunity for study as the needles passed within a few millimetres of the nerve roots in otherwise healthy, unselected adults (McCulloch 1977). The five patients with normal bony anatomy all had disc prolapses on the left side with no clinical evidence of neurological involvement on the right.

After infiltration of the subcutaneous tissues with local anaesthetic, 3.5 inch 14 gauge needles were inserted through the right lateral approach (McCulloch and Waddell 1978) close to the emerging nerves at the L4/5 (L4 nerve root) and L5/S1 foramina (L5 nerve root). Through each needle in turn was passed a blunt-tipped electrode insulated except for a five millimetre bare tip (OWL RF lesion electrode, OWL Instruments Limited, Downsview, Ontario, Canada M3J 2H2). With the aid of a biplane image intensifier the tip of the electrode was positioned immediately inferolateral to the pedicle. Contact with the nerve was confirmed by the patient experiencing radiating root pain momentarily. In three patients the findings were confirmed after reinserting the electrode in the same position. In two other patients the electrode was replaced by a fine needle and the relationship to the nerve confirmed by injection of the root sleeve with radio-opaque dye. Using an OWL RF generator/stimulator, Model RFS-1, a three millisecond negative phase rectangular electrical pulse was passed through the electrode at intervals of one second. In one patient the study was repeated with a more conventional 0.1 millisecond stimulus giving identical results at a slightly higher voltage.

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Fig. 1

The voltage was gradually increased from one to five volts until a motor response was obtained. Impedance studies suggested that with the low voltage used the fall-off in current strength within one centimetre minimised the risk of spread to other nerves (Organ, Tasker and Moody 1968). With increasing voltage, pain became more severe with the development of a larger and more widespread motor response. After rapid initial recruitment of different muscles (with between 2.0 and 2.5 volts) there was a gradual increase in the power of contraction (up to MRC Power 5) of a discrete group of muscles, which appeared to consist of the main myotome innervated by the nerve, until the limit of pain tolerance was reached at about five volts.

Root stimulation studies were carried out in 15 patients with prolapsed lumbar intervertebral discs whose radiographs showed a bony segmental anomaly (Table I). Stimulation was again carried out on the right side. No patient had any clinically detectable motor weakness affecting the muscles of the right leg. The pattern of motor response to stimulation was recorded clinically from at least two adjacent nerve roots. The root levels were then identified from the myotomes according to the pattern established above.

RESULTS

Anatomical dissections

The findings are shown in diagrammatic form in Figure 2. In all cases the two sides were identical.

In the normal spine the L5 nerve root forms the most cephalad main component of the sacral plexus, and emerges through the foramen at the last fully mobile level. In eight out of 11 dissections of segmental anomalies the most cephalad root of the sacral plexus (L5) emerged at the last fully mobile level (Fig. 2). In two it emerged at the second last fully mobile level and in one at the partly mobile level. Thus the most common neurological arrangement in association with a bony segmental anomaly was still the emergence of L5 at the last fully mobile level.

Stimulation studies

Normal bony anatomy. The motor response to stimulation of the L4 and L5 nerve roots in five adults with normal bony anatomy is shown in Table II.

Throughout the stimulation studies, and in larger series of patients undergoing both chemonucleolysis and percutaneous radio-frequency rhizolysis, the patterns of radiation of pain and paraesthesiae were variable and inconsistent. There was usually a clear distinction between root pain and referred pain (Kellgren 1938). Stimulation of the supraspinous and interspinous ligaments, the intertransverse ligaments and muscles, the facet joints, the extradural tissues, the posterior longitudinal ligament, the annulus and the nucleus pulposus could produce pain referred to the buttock and the posterior or lateral thigh but rarely below the upper calf. This pain was dull and poorly localised and was

rarely described as paraesthesia. Stimulation of the nerve root gave a sharper, well-localised pain, commonly with an element of paraesthesia, and with L5 or S1 nearly always radiated to or below the ankle. It was often difficult to distinguish between the pain patterns of

Table I. Patients with bony segmental anomalies

Patient	Sex	Age	Number of lumbar vertebrae	Lumbosacral segmental anomaly (see Fig. 1)
1	M	52	4	E
2	M	36	5	F
3	F	48	4	B
4	M	36	5	D
5	F	39	4	G
6	M	23	5	Short 12th ribs. A
7	F	77	6	6 lumbar vertebrae, high sacrum. A
8	M	42	4	4 lumbar vertebrae. H Very short 12th ribs
9	M	31	6	6 lumbar vertebrae. A
10	M	22	5	B
11	F	33	6	11 ribs. A
12	M	43	6	6 lumbar vertebrae. C (minimal)
13	F	52	6	6 lumbar vertebrae. A
14	M	25	5	Very short unilateral L1 rib. D
15	M	40	5	Very low set sacrum. C (minimal)

Fig. 2

Dissections of the lumbosacral plexus in 11 cadavers with bony lumbosacral segmental anomalies.

Table II. Nerve stimulation studies in conscious adult patients with normal bony anatomy

Patient	Segmental level	
	L4	L5
1	Quadriceps Hamstrings	Peronei Glutei, tensor fascia lata, lateral hamstrings
2	Quadriceps	Peronei, extensor digitorum longus, gluteus maximus, tensor fascia lata, medial hamstrings
3	Quadriceps	Peronei, extensor digitorum longus, extensor hallucis longus, glutei, medial hamstrings
4	Quadriceps	Peronei, extensor digitorum longus, extensor hallucis longus, tibialis posterior, gluteus medius and minimus, tensor fascia lata, medial hamstrings
5	Quadriceps, tibialis anterior, medial hamstrings, gluteus medius and minimus	Peronei, extensor digitorum longus, tibialis posterior, gluteus maximus, hamstrings

L5 and S1, although in general L5 radiated to the dorsum of the foot and big toe while S1 radiated to the heel or to the lateral border of the foot. It was impossible to differentiate between L5 and S1 above the ankle. There was considerable overlap in the foot and an increase in the strength of the stimulus could produce a different pattern; there was often conflict between the pattern of distribution of pain and paraesthesiae and the motor findings, which were more consistent.

Segmental anomalies. On the basis of our investigations on lumbar disc lesions involving a single nerve root, and discounting the "non-organic" pattern of regional giving-way of many muscle groups (Walters 1961; Waddell *et al.* 1980), we used the following pattern of innervation of myotomes for analysis of the stimulation findings associated with bony segmental anomalies. The

quadriceps femoris muscle is innervated by L4 (or higher). The L5 root supplies tibialis anterior, the peronei, extensor hallucis longus and extensor digitorum longus, but an L5 lesion does not usually give weakness of all these muscles. The gastrocnemius and soleus muscles are supplied by the S1 root. The ankle dorsiflexors may have some supply from L4 and the dorsiflexors of the toe from S1. The root innervation of the glutei and hamstrings is so variable that it is completely unreliable in assessing root lesions. Our findings in this group of patients are shown in Table III. In 11 of the 15 patients the L5 root emerged at the last fully mobile level. In two its position was uncertain (Patients 3 and 14), in one (Patient 13) the L5 root emerged at the second last fully mobile level and in one (Patient 10) at the partly mobile level. In agreement

Table III. Results of root stimulation in patients with segmental anomalies

Patient	Segmental level stimulated	Quadriceps	Tibialis anterior	Tibialis posterior	Peronei	Extensor hallucis longus	Extensor digitorum longus	Extensor digitorum brevis	Gastrocnemius and soleus	Root
1	Last fully mobile Partly mobile		+		+	+	+		+	L5 S1
2	Second last fully mobile Last fully mobile	+	+		+	+	+			L4 L5
3*	Second last fully mobile Last fully mobile	+	+							?L4 ?L5
4	Second last fully mobile Last fully mobile	+	+		+					L4 L5
5	Second last fully mobile Last fully mobile	+	+			+	+			L4 L5
6	Second last fully mobile Last fully mobile	+	+		+		+			L4 L5
7	Third last fully mobile Second last fully mobile Last fully mobile	+	+	+(slight) ?	+		+			L3 L4 L5
8	Second last fully mobile Last fully mobile	+	+	+	+	+		+		L4 L5
9	Second last fully mobile Last fully mobile	+	+	+	+	+	+			L4 L5
10*	Last fully mobile Partly mobile	+	+		+(slight) +		+			L4 L5
11	Second last fully mobile Last fully mobile	+	+		+		+			L4 L5
12	Second last fully mobile Last fully mobile	+	+	+	+(slight) +	+	+			L4 L5
13*	Second last fully mobile Last fully mobile		+	+	+	+	+		+	L5 S1
14*	Last fully mobile Partly mobile			+	+	+	+	+		?L5 ?L5
15	Second last fully mobile Last fully mobile	+		+	+			+		L4 L5

*Not fitting common pattern

with the plexus dissections, these observations suggest that in the presence of a bony segmental anomaly the L5 root emerges at the last fully mobile level.

DISCUSSION

There is considerable confusion and disagreement as to what constitutes "normal" neuro-anatomy in the lumbosacral region. There are a limited number of studies on experimental animals and detailed clinical analyses upon which most textbooks are based (Table IV). Sherrington (1892) first reported multiple innervation of most muscles and introduced the concept of the pre-fixed and post-fixed plexus. This concept of a wide range of multiple and variable innervation has since dominated anatomy books. Most clinical studies which

(Brailsford 1929; Barton and Biram 1946), irrespective of whether or not they have backache (Ford and Goodman 1966). The commonest anomaly of segmentation is enlargement of the transverse process which forms a syndesmosis with the ala of the sacrum or with the pelvis. This mildest form occurs with approximately equal frequency either unilaterally or bilaterally. Varying degrees of developmental narrowing of the disc space may be related to such abnormal transverse processes and a narrow lumbosacral disc in isolation is not uncommon. The sacrum may be set unusually high or low relative to the pelvis, but there is no evidence to suggest that this is of any significance with regard to the levels of segmentation or root origins. The size of the last rib is very variable but again of doubtful significance.

Table IV. Summary of experimental evidence for motor distribution of the lumbosacral plexus

	Ferrier and Yeo (1881) 4 monkeys	Sherrington (1892) 27 cats	Sherrington (1892) 73 monkeys	Jefferson (1954) 12 cats	Sharrard (1955) Polio (7 cords + 142 patients)	Sharrard (1964) Myelomeningocele (41 cords + 312 patients)	Guttmann (1976) Human spinal injuries	Thage (1965) 55 human roots
Glutei	L4-5	L5-S1	L5-S2	—	S1-2	L4-S2	L4-S2	(L2) L3-4 (L5)
Hamstrings	L5-S1	L4-S1	L3-S2	L4-S2	L4-S2	L4-S1	L4-S2	(L4) L5 S1 (S2)
Quadriceps	L3-4	L3-4	L2-4	—	L2-4	L2-4	L2-4	—
Tibialis anterior	L5	L4-5	L4-S1	L4-S1	L4-5	L4-5	L4 (L5)	L4-5 (S1)
Tibialis posterior	L5	L5	L4-S1	L5-S2	L5	L4-5	L4-S1	—
Peronei	L4-5	L4-S1	L4-S1	L5-S2	L5-S1	L5-S2	L5-S1	L5-S1
Extensor hallucis longus	L5	} L4-5	L5-S1	} L5-S2	} L5	L5 (S1)	L4-S1	—
Extensor digitorum longus	L5		L4-S1			L5 (S1)	L4-S1	—
Extensor digitorum brevis	—	—	L5-S1	—	—	—	L4-S1	L5-S1
Gastrocnemius and soleus	L5-S1	L4-S1	L5-S2	L5-S2	L5-S3	(L5) S1-2	L5-S2	L5-S1 (S2)

Equivalent human levels are given where L7 in the monkey is approximately equivalent to S1 in humans

support this view are based on massive neurological lesions (Table IV). In contrast, most clinical analysis of discrete single root lesions caused by disc disease (Norlén 1944; Hakelius and Hindmarsh 1972; Weber 1975) support the stimulation findings of Thage (1965) and ourselves (Table II), which suggest that in the clinical assessment of lumbar disc lesions many muscles can be regarded as having a predominantly monosegmental innervation.

Between two and four per cent of individuals have six free lumbar vertebrae between the last ribs and the sacrum and approximately one per cent have four lumbar vertebrae (Bardeen 1904; Bornstein and Peterson 1966). Segmental anomalies are commonest at the lumbosacral junction where a transitional vertebra occurs in between five and 10 per cent of the population

The pattern of the anomaly can be simplified if the last fully mobile level is identified. Both our dissections and our stimulation studies demonstrate that in the presence of bony segmental anomalies the L5 nerve root usually emerges at the last fully mobile level. As in normal embryology, neurological and bony segmentation appear to develop in parallel and the myotomes tend to match the bony anomaly.

Transitional vertebrae and any partly formed level can be of considerable mechanical significance and may influence patterns of degeneration. A partly formed level may be less likely to undergo disc prolapse because it is more stable and better protected from stress. The presence of such an anomaly should not in itself be considered a cause for backache.

Recognition and analysis of any lumbosacral bony

segmental anomaly is essential before operation since incomplete segmentation of the posterior elements may confuse identification of the levels. A partly formed level may either be mistaken for part of the sacrum or counted as the last fully mobile level. In the presence of bony anomalies the level of a disc prolapse should be confirmed by myelography and the level at operation by lateral radiography. However, recognition of the clinical pattern is vital and radiography should not be used as a substitute for clinical judgment.

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