STABILITY OF THE LUMBAR SPINE AND METHOD OF INSTRUMENTATION

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We have carried out a biomechanical study to investigate the effect on flexion, extension, and rotation of seven systems of fixation on five cadaveric lumbar spines. Pedicle fixation proved the most effective method to restrict these movements. Facet screw fixation was also successful. Harrington distraction rods, the Hartshill rectangle and the Luque technique, although restricting slight flexion and extension, exerted little control over rotation.
We conclude that pedicular fixation and facet joint fixation provide the greatest overall stability and might, therefore, be the best systems to consider for multilevel fusions in the lumbosacral region.

Keywords : lumbar spine ; stability instrumentation.
Mots-clés : colonne lombaire ; stability ; instrumentation.

Fusion of multiple levels of the lumbar spine is an established method of treatment for a variety of conditions. These include those causing chronic back pain secondary to degenerative disease, previous surgery or trauma, and neoplastic conditions. While there is always the risk of a pseudarthrosis after an attempt to fuse one level of the spine, the frequency of this complication increases with the number of levels involved : Kornblatt *et al.* (4) have reported a rate of between 25% and 33% for three-level procedures. Extending the level of fusion to the sacrum or to the ilium (pelvis) adds to the difficulties of achieving multilevel fusions in the lumbosacral region.

To enhance fusion, especially in multilevel procedures, it has become common practice to add internal fixation. Most devices are applied to the posterior elements of the spine and are not infrequently combined with a posterolateral fusion. The techniques include fixation of the facet joints (1) or the use of Harrington distraction rods. Sublaminar wires may also be used, attached either to vertical rods (Luque technique) or to a rectangular modification of this (Hartshill rectangle (2)). At present the use of transpedicular screws combined either with rods or plates is very popular.

In practice not every type of internal fixation can be used in every situation, and as one might expect there are advantages and disadvantages to each method. Nonetheless, ultimately, the sole common purpose of adding instrumentation to any multilevel fusion operation is to confer increased stability or stiffness to the spine to increase the chance of achieving a solid fusion.

While all manufacturers claim either directly or by inference that their device achieves effective stability, there is little comparative evidence. An experiment was therefore set up to quantify the stability achieved under physiological loads when different fixation devices were used to instrument the same spine between L3 and the sacrum. Altogether seven devices were used on each of five spines with four different techniques of fixation.

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MATERIAL AND METHODS

Spines

Five fresh cadaveric lumbosacral spines with the pelvis attached were obtained from victims of traffic accidents. The subjects were selected on the basis of young age (mean 40 years, range 35-54) to provide consistency for the comparative study and because, having greater mobility than a degenerate spine, they would therefore provide the best indication of the possible effectiveness of fixation devices. All spines were free of malignant or systemic disease. They were retrieved complete and frozen at – 20° C. After thawing, each spine was prepared by removal of all attached muscles. The ligaments were preserved, including the supra- and interspinous ligaments and the joint capsules. Each spine was transected through the L2/3 disc and the lower part (pelvis) was embedded in plaster of Paris within a metal box. A specially designed endcap (3) with a six-inch lever arm attached to it was mounted on the upper part of the spine (L3), allowing motion between L3/4, L4/5, and L5/S1. The endcap had a metal peg attached to it which fitted into the spinal canal at the L3 level. This ensured exact placement of the endcap. Each specimen in its metal box was then mounted in and secured to a specially designed frame (fig. 1). All tests on one spine were done in one day at room temperature with the specimen kept moist to prevent dessication of the tissues increasing the stiffness of the specimen under examination.

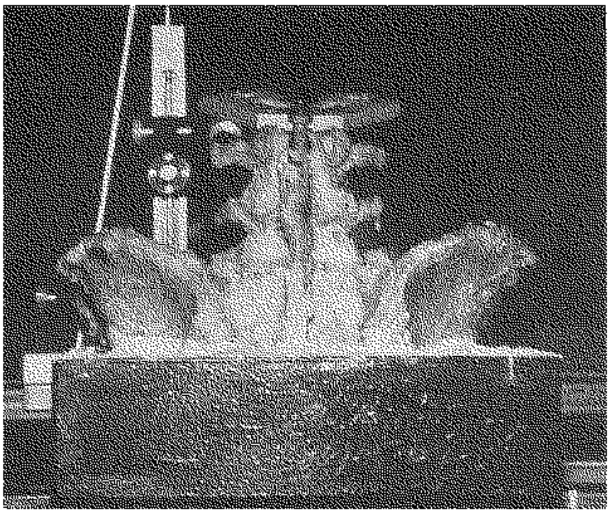

Fig. 1. — Specimen mounted in plaster of Paris in metal box. Endcap sited on L3. Travelling microscope fixed to frame is facing anterior aspect of specimen.

Instrumentation

All devices to be tested were inserted as for operations by experienced spinal surgeons.

The devices tested, listed in order of their insertion, were :

1. *Facet screws.* These were inserted at all three levels (L3to S1) using the technique reported by Boucher (1). Six 4.5 AO cortical screws (each 45 mm long) were used.
2. *Harrington system* (Zimmer UK, Swindon, UK). Two distraction rods and four laminar hooks were used. The hooks were attached to the laminae of L3 and S1, and the system distracted to the tension used in practice.
3. *Hartshill rectangle system* (Surgicraft, Redditch, UK). This smooth, roofed, metal rectangle was secured with sublaminar 16-gauge wires to L3, L4, and L5. Fixation to the sacrum was effected by wires passed through holes in the posterior elements of the sacrum, following recommended practice.
4. *Luque rods system* (Zimmer UK, Swindon, UK). Two 1/4-in. L-shaped rods were fixed with sublaminar 16-gauge wires to L3, L4, and L5, with distal fixation into the posterior iliac wings at the level of the L5/S1 facet joints.
5. *Steffee plate system* (AcroMed UK). This system consists of plates and pedicular screws. Six 6.25, 40-mm screws were used for the lumbar vertebrae, and two 7.00, 35-mm screws for the sacrum.
6. *Mehdian system.* This system is under development by Zimmer and consists of two, smooth 1/4-in. rods and pedicular screws. Six 6.00, 45-mm screws were placed in the lumbar pedicles and two 7.00 35-mm screws in the sacral, S1 pedicles.
7. *Cotrel-Dubousset system* (Sofamor, France). This uses diamond-textured rods and pedicular screws. Six 6.00, 45-mm screws were used for the lumbar vertebrae, and two 7.00, 35-mm screws for the sacrum.

With the exception of the three pedicular devices, the systems were applied to each of the five spines in a specific sequence, starting with the one causing the least interference with the specimen under evaluation. Since the three devices with pedicular screws necessarily used the same sites for fixation (the pedicles), the order of their insertion was rotated for each new spine under study.

All pedicular screws were inserted by probing the pedicles, and the exact placement was confirmed by direct visualization of the pedicle. The rods and plates were contoured to the lumbar lordosis.

Stiffness measurements

Loads were applied to L3 producing moments of 5, 10, and 15 Newton-meters (Nm) first in flexion, then in extension, and then in axial rotation. The moments were generated by application of a force via a cable to the end of the lever arm attached to the endcap (fig. 2). The angular motion produced between L3 and the sacrum was calculated from measurements recorded with a travelling microscope. These measurements were made in the vertical axis for flexion and extension moments and in the horizontal axis for axial rotation moments. Each spine was first tested intact without instrumentation and then again after application of each of the seven fixation devices.

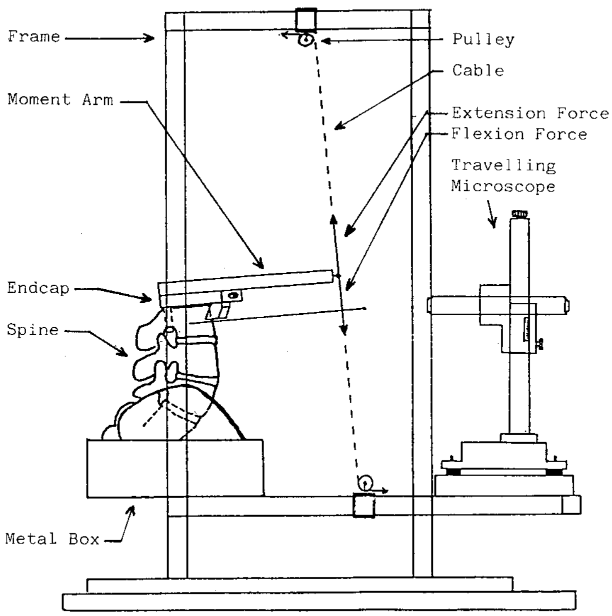

Fig. 2. — Diagram of pulley systems to generate flexion, extension, and rotation moments.

RESULTS

The pattern of the results was the same for each spine. Thus increasing moments produced increasing displacements both in the intact (noninstrumented) spine and in the instrumented spine. This occurred regardless of the type of device used. The displacement occurring with each moment was nonetheless reduced in every case by instrumentation. There was no mechanical failure of any type of instrumentation during these studies.

The mean measurements for flexion, extension, and rotation moments of 5, 10, and 15 Nm are shown in Figs. 3a, b, c.

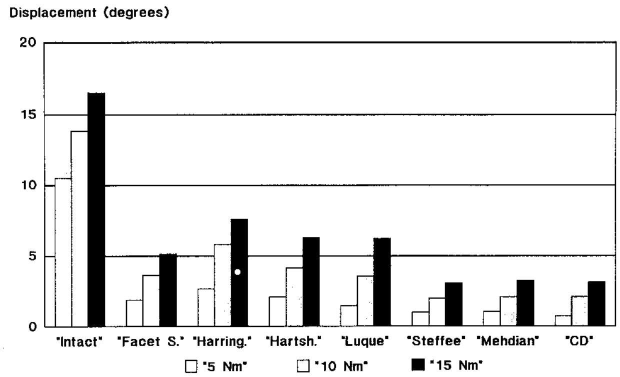

Fig. 3a

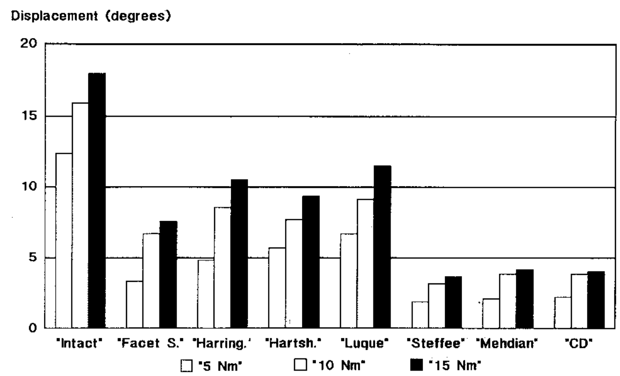

Fig. 3b

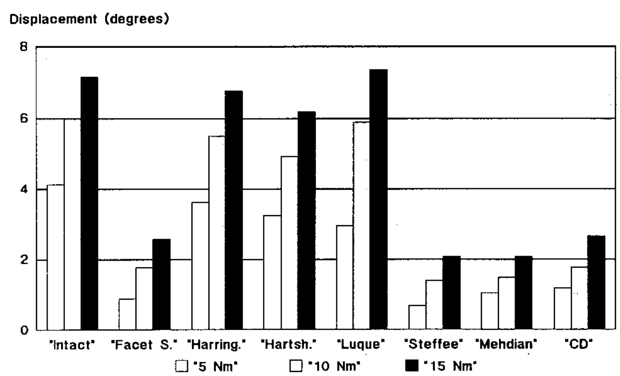

Fig. 3c

Fig. 3. — Histograms of mean (n = 5) flexion (a), extension (b), and rotation (c) moment displacement in intact spines and after application of seven fixation devices. Horizontal axis shows the moments (Nm).

Flexion Moment Displacement (fig. 3a)

Increasing moments caused a rise in displacement values both in the intact noninstrumented spines and in the instrumented spines. All fixation devices reduced the displacement by more than 50%. This reduction was least with the Harrington distraction rods and greatest (more than 90%) with the pedicular systems. The three pedicular devices did not differ.

Extension Moment Displacement (fig. 3b)

Increasing moments caused an increased displacement both in the intact noninstrumented spines and in the instrumented spines. These displacements were slightly greater in extension than those achieved in flexion for both for the intact and the instrumented spines.

The greatest reduction in displacement was again provided by the three pedicular systems followed by the facet screw construct. The least reduction in displacement was seen with the Harrington rods and sublaminar systems (less than 50% reduction with a 15-Nm extension moment).

Rotation Moment Displacement (fig. 3c)

Increasing moments again caused increasing displacement both in the intact and in the instrumented spines. The displacement in the intact spines for each moment in rotation was, however, less than 50% of that which occurred in flexion and in extension.

The pedicular systems and the facet screws reduced the displacement significantly. The Harrington distraction rods and the sublaminar systems had little effect on displacement.

DISCUSSION

Few other biomechanical studies on the lumbosacral spine have considered the possible effects of the pelvis as a stabilizing force. In this research the wings of the pelvis were preserved intact with the sacrum and lumbar spine to reproduce better the in-vivo situation. Furthermore fixation to the pelvis (ilium) is one of the techniques used in lumbosacral fixation, and keeping the wings also permitted this type of fixation to be tested. The devices we investigated were selected because they involved different techniques of fixation, because they were commonly used, and because they were familiar to and used by the authors of this report.

Any comparative study should compare like with like. For this reason all seven devices were applied in turn to each spine. The order of application of these devices (four techniques of fixation) ensured the least interference with the specimen. In practice this meant that there was little more dissection than would be required to seat that particular device. The possible exception was the resection of a limited amount of ligamentum flavum at all levels for the passage of sublaminar wires for the Hartshill and Luque systems before testing of the pedicular systems. Although resection of the ligamentum flavum is not a prerequisite for insertion of pedicular screws, nonetheless in practice it is not an infrequent association. Since, however, this method of fixation was shown to provide the greatest stiffness to the spine, the prior excision of ligamentum flavum clearly did not change the comparative result.

There was a striking consistency in the results obtained relating not only to the noninstrumented but also to the instrumented spines.

The results from the noninstrumented spines show clearly that increasing moments produce greater displacements. Furthermore they show that similar values of displacements occur in flexion and extension with the same moment but are consistently greater in extension than in flexion. By contrast, displacements occurring with rotation moments are less than 50% of those seen in flexion and extension. If stiffness of the spine is, as we believe, a prerequisite to achieve multilevel fusions of the spine, then not only is it important to reduce the magnitude of the moment but it may also be important to consider multidirectional control.

It is not known in practice to what extent and in what direction displacements have to be limited in the living spine to achieve fusion. Without that knowledge one must presume that it is likely to be most helpful to keep the displacements in all the main movements of the lumbar spine —

namely, flexion, extension, and rotation — to a minimum.

The results obtained for the different fixation devices showed, as with the noninstrumented spine, that limiting the moment reduced the displacement. The extent of this reduction varied with the fixation device used. Furthermore, any one device did not necessarily limit movements in the different directions to the same extent.

The three pedicular systems provided the most rigid fixation. They significantly reduced motion in flexion, extension, and rotation, under different loads. With regard to application we noted that the CD rods were easy to contour, whereas with the Mehdian system and especially with the Steffee systems the alignment of the screws was important.

The Boucher screw fixation of the facet joints provided increased spinal stiffness although in one spine, loosening of the screws occurred at higher loads. Nonetheless this simple, cheap, and minimally invasive method provided a surprisingly good increase in stability. It is possible that the translaminar technique of facet joint fixation reported by Magerl (6) might avoid such screw loosening and provide even greater stability.

The Luque L rods combined with the sublaminar wires provided good stability in flexion under moderate loads, but at higher loads the wires slipped over the rods resulting in increased movement. The Hartshill rectangle performed in a similar way to the Luque rods. Both these systems secured by sublaminar wires failed to limit extension and axial rotation.

The Harrington rods provided poor stability. While the stability in flexion and extension could be improved by providing more distraction this would result in a severe flattening of the lumbar lordosis. Contouring square ended rods and adding sublaminar wires might reduce this complication and increase stability.

While there are many indications for fusion of the lower lumbar spine not every surgeon would choose to supplement a grafting procedure with instrumentation. Nonetheless there would be much less disagreement about the inclusion of instrumentation if the fusion extended over the lower three motion segments of the lumbar spine, as indeed it not infrequently does in surgery for chronic pain. To this end the research we report clearly has applied clinical significance.

From these initial studies, we conclude that the three pedicular systems tested (Steffee, CD, and Mehdian) provide the greatest increase in overall stability in flexion, extension, and axial rotation. The facet screws provided a similar increased stability to the pedicular screws in flexion and rotation, but less in extension. The Harrington, Hartshill and Luque systems provided some increase in flexion and extension stability but did not increase significantly rotation stability. We appreciate that in practice there are other considerations besides biomechanical factors that may govern what device can be used, which include the existing anatomy, the instrumentation available, and the costs. Nonetheless we hope that our results will assist the individual operator in his choice of spinal fixation devices in certain situations.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

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SAMENVATTING

L. VANDEN BERGHE, H. MEHDIAN, A. J. C. LEE, C. R. WEATHERLEY. Stabiliserend effekt van fixatie systemen voor lumbale wervelzuil.

Er werd een biomechanische studie verricht om het stabiliserend effekt te evalueren van 7 inwendige fixatiesystemen voor de lumbosacrale wervelzuil. De fixatiesystemen werden getest in flexie, extensie en rotatie. Pediculaire fixatie was het meest effektieve systeem om al deze bewegingen te beperken. Facetschroeffixatie gaf ook een goede stabiliteit. Harrington distractie staven, hat Hartshill kader en de Luque staven beperkten in zekere mate de flexie en extensie, doch beperkten de rotatie niet significant.
We besluiten dat pediculaire fixatie en facetschroeffixatie de beste stabiliteit geven en daarom waarschijnlijk de beste systemen zijn voor inwendige fixatie bij multisegmentaire fusies in het lumbo-sacraal gebied.

RÉSUMÉ

L. VANDEN BERGHE, H. MEHDIAN, A. J. C. LEE, C. R. WEATHERLEY. Effect stabilisateur des procédés de fixation et la colonne lombaire.

Une étude biomécanique a été réalisée sur 5 colonnes lombosacrées afin d'évaluer l'effet stabilisateur d'ostéosynthèses en rotation, flexion et extension. La fixation pédiculaire est le système le plus efficace pour réduire ces mouvements. La fixation à l'aide de vis transfacettaires procure également une bonne stabilité. Tiges de distraction de Harrington, cadre de Hartshill et cadre de Luque réduisent dans une certaine mesure la flexion et l'extension, mais ne limitent pas de manière significative la rotation.
Nous en concluons que la fixation pédiculaire et la fixation transfacettaire par vis donnent la meilleure stabilité et sont donc les meilleurs procédés d'ostéosynthèse pour les fusions multisegmentaires de la colonne lombo-sacrée.