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THE INTRODUCTION OF FORCE MEASUREMENTS GUIDING INSTRUMENTAL CORRECTION OF SCOLIOSIS

By

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A review of the extensive literature on the etiology of scoliosis reveals a singular lack of facts on which to develop sound hypotheses concerning treatment (*Waugh* 1966). Many authors have advanced theories, some of which have been partially substantiated by animal experimentation; these have been used to formulate new and presumably improved methods of treatment. That these procedures have not stood the test of time has been proved by the still newer methods that have replaced them. Such has been the rule, but a few exceptions do exist.

The Hibbs spine fusion, the Risser turn-buckle jacket, the Milwaukee Brace of Blount and Schmidt are well known, but very few others have found a place in the present-day treatment of scoliosis. However, the realization of the obvious inefficiency of correction techniques which depend upon transmitting pressure through the entire hemithorax to the vertebral column, or in applying traction to the skull and mandible has driven many surgeons to adopt a more direct approach to the problem of correction. The excision of hemivertebrae for congenital scoliosis has been performed for the past 35 years, but it is only recently that opening and closing wedge osteotomies have been performed at the apex of idiopathic scoliosis curves to correct severe deformity. In 1955, *Allan* reported a series of scoliosis patients in whom he had inserted a metal jack on the concave side of the curve. Since that time, several instrumentation techniques have evolved culminating in the 1962 report by *Harrington* of his experience with the use of a compression and distraction device of his own design. Harrington has since stated that the correction by this technique was unmatched by any other system. There are, however, many surgeons who would question the desirability of striving for a straight spine, on the grounds that such attempts might endanger the vital contents of the trunk. The occurrence of the occasional castastrophy makes a cautious approach mandatory. However, within these limits, it is believed that progress can be made and new attempts should be encouraged to extend our knowledge and improve existing forms of treatment.

At the present time, little is known about the etiology of idiopathic scoliosis, the most common variety of lateral deviation of the spine. Encouraging work is being done by *Ponseti* on possible mucopolysaccharide abnormalities in the disease, and by *James* on the inheritance. But until such time as the pathogenesis is established and can be controlled, treatment must continue to depend on mechanical correction and maintenance.

Mild and moderate degrees of flexible spinal curvature can be treated successfully by plaster jacket correction and spinal arthrodesis. However, in severe degrees of deformity with minimal flexibility, such techniques may produce only 20 per cent to 30 per cent correction with the great likelihood that even this may be lost. It is in the severe cases that spinal instrumentation would appear most useful. The limiting factor, however, has frequently been the strength of the attachment, particularly to the thoracic area. Many surgeons performing spinal instrumentation, have had the unpleasant experience of having their carefully placed hooks cut through the interarticularis. Such are the present problems with instrumentation, that some authors, in reviewing their patients, have not found the results to be an improvement over those obtained with conventional forms of treatment.

With these problems in mind, it was thought to be essential to investigate the strength of conventional mehods of attachment to the spine and explore other systems that might be less liable to failure.

A technique, which used a mould of the posterior elements of self-curing methyl methacrylate, was developed which proved to be two to three times stronger than any existing technique of attachment, as tested statistically on autopsy specimens. However, toxic properties of this plastic exist due to the free monomer, which is present in about 12 per cent concentration with autopolymerization. Although each attachment required only 5 ml of monomer, it was concluded that the implantation of acrylic in a child was not justifiable. It is believed, however, that the wealth of plastic materials which are being discovered, will see the future development of a less toxic substance which would permit the safe use of such a technique.

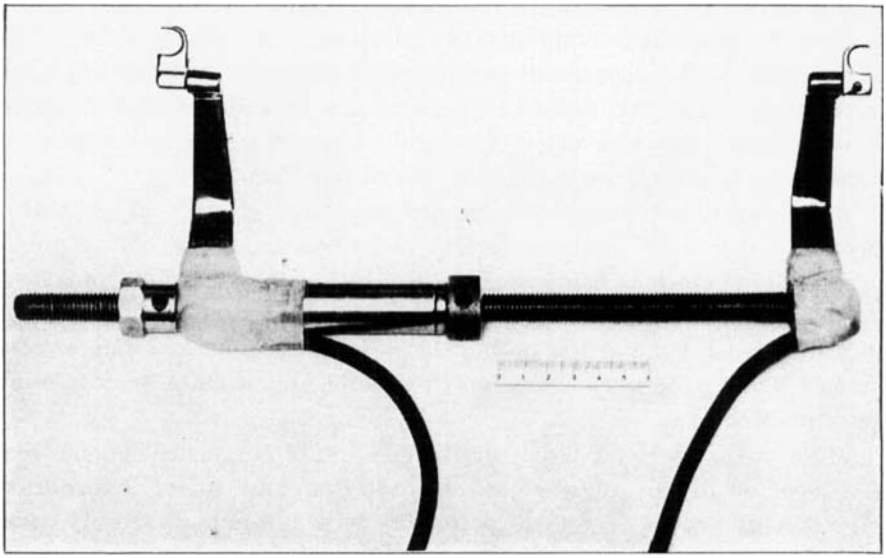


Figure 1. Distraction outrigger with gauges applied.

As the limiting factor to the strength of any attachment is the area of contact, a stainless steel hook was designed that closely approximated to the anatomy of the thoracic interarticularis and inferior facet. Although it had only 9 per cent greater surface area than the largest commercially available hook (Zimmer No. 1253), the tested strength was 20 per cent greater. It was presumed that a reduction in stress concentration due to the contour caused the difference in levels of failure.

When testing of existing forms of attachment on autopsy material, it was found that the commercially available *Gruca* hook failed at 55 kp ± 10. This failure occurred before the pedicle, to which it would be attached in an anterior alloplasty procedure. Because of the increase in angle, or spread with the failure of these hooks, it was believed that this could endanger the spinal cord. Such failure might be corrected by a stronger design, if it were desired to exert forces in excess of 45 kp; failure would then be limited by the bony attachment and not the device itself.

The application to patients of information obtained from testing specimens extravitally, can only be made with considerable reservation. No accurate measurement has previously been carried out of the actual force necessary to correct a scoliotic spine, nor is any informa-

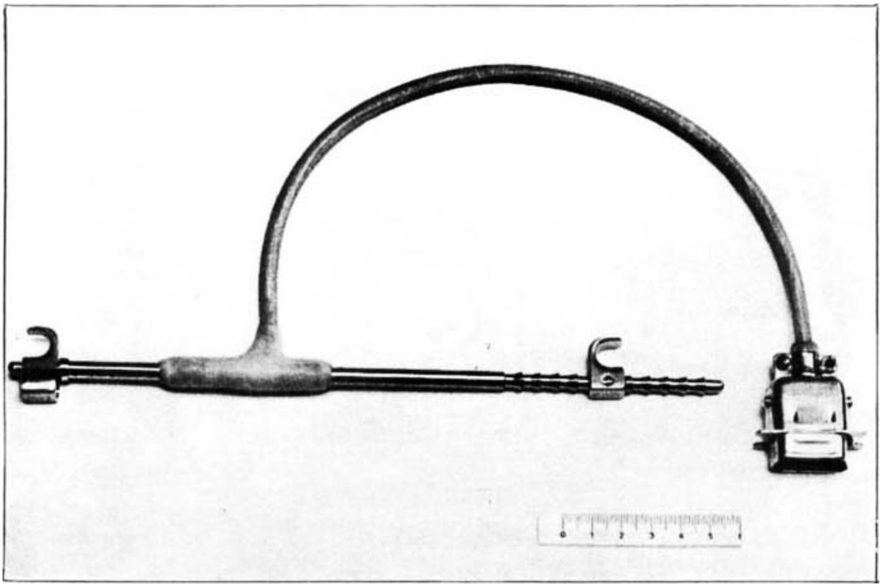


Figure 2. Zimmer No. 1250 Distraction Rod with strain gauges isolated by Silastic 382.

tion available on the rôle of various elements, in either causing deformity or resisting correction. To accomplish such measurements, electrical strain gauges were employed on an outrigger device and Zimmer No. 1250 rods, to act as force transducers (Figures 1–4).

Three patients were selected for intravital measurements who required correction and fusion by the usual surgical criteria. The first two patients had moderately severe flexible curves, the third a resistant inflexible curve of severe degree. Measurements taken during spinal instrumentation procedure indicated that the flexible curves were readily corrected (60 per cent and 75 per cent) by forces of 20–30 kp whereas the inflexible curve was corrected only 25 per cent by forces of this magnitude. A force of 38 kp was sufficient to cause failure of the thoracic attachment, necessitating reposition of the hook at a higher level (Figures 5–8).

The posterior structures were released to determine which, if any of these, resisted correction. In general, there was little change recorded by releasing the paraspinous musculature, concave and convex, and the interspinous ligaments. Section of the apical intertransverse and costotransverse ligaments produced a drop in force in one patient of 4 kp, but in another, the results were inconclusive.

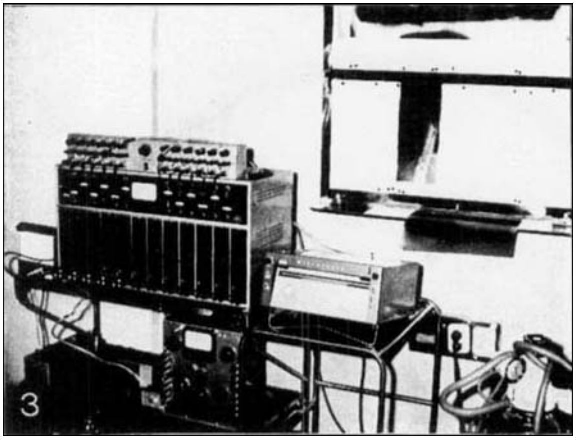


Figure 3. Electronic equipment for measuring strain (Peekel bridge, type 112DA and ABEM Ultralette 5650).

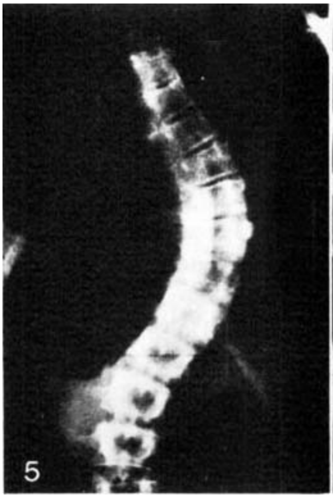
Figure 4. Calibration of distraction outrigger in materials testing machine.

Complete paralysis by the injection of 50 ml of celocurin caused a 40 per cent fall in force when compared with that present during deep surgical anesthesia. Coincident with the return of spontaneous respiration, the axial force returned to the original level.

Final correction was accomplished by insertion of the calibrated distraction rod, to which isolated strain gauges were attached, leads being brought out through the skin incision. With complete recovery from anesthesia, there was no significant change in the recorded axial force on the rod. Coughing, and particularly vomiting, were associated with brief momentary forces up to 68 kp. Voluntary sitting and standing on the day following surgery produced wide fluctuation in axial force, but the highest figures obtained were only 20 kp.

On reexamining the spinal instrumentation procedure of Harrington on the basis of the information obtained from these extravital and intravital measurements, the weak point of attachment of the distraction rod to the thoracic spine was confirmed. The compression system for the concave side of the curve was found to contribute insignificantly to reduction of the magnitude of the forces on the concave distraction rod. This would raise the question of the desirability of the additional surgery necessary to introduce the compression system.

Investigation of the deterioration curve of the axial force revealed a hyperbolic decline. For this reason, distraction should be attained in slow increments, giving the tissues time to adjust. When utilizing the



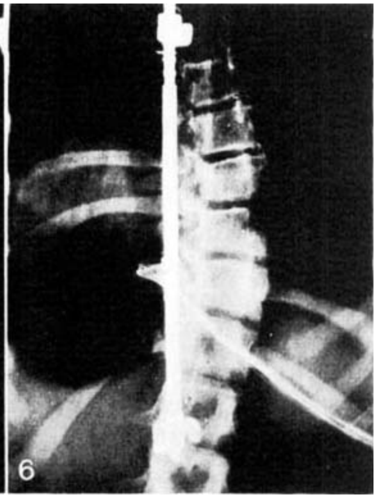


Figure 5. Erect roentgenogram of Patient 1.

Figure 6. Roentgenogram of distraction rod in situ (Patient 1).

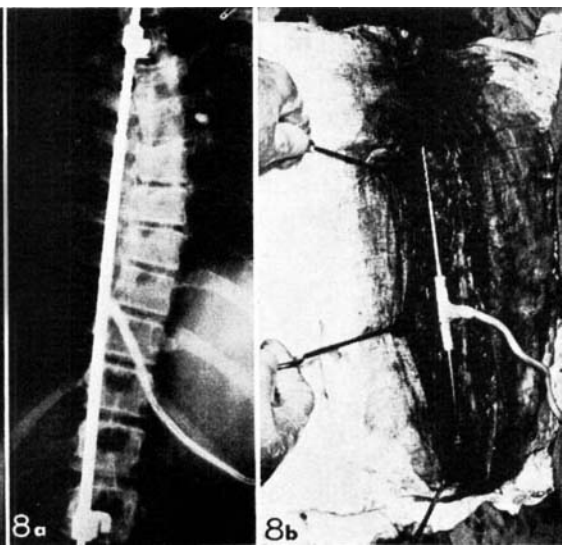


Figure 7. Erect roentgenogram of Patient 2.

Figure 8 a, b. Distraction rod in situ prior to closure (Patient 2).

present commercially available methods of attachment for the Harrington technique, the distraction force should not exceed 30 kp, if a good margin of safety is anticipated.

While it is not possible to use the measurements obtained to either advance or negate any of the existing theories of the etiology of idiopathic scoliosis, one cannot but be impressed by several of the findings in this study. Contrary to expectation, the force necessary to correct moderately severe scoliotic deformity was only in the order of 20–30 kp. This might suggest that the forces causing idiopathic scoliosis deformity are of equally small magnitude. The paraspinous musculature, under anesthesia, did not influence the deformity. However, the intercostal muscles, when paralysed, significantly changed the recorded axial force. This could raise the question of a possible etiological rôle of the intercostals in the development of idiopathic scoliosis. The interspinous ligaments did not appear to influence the deformity, and the intertransverse and costotransverse ligaments did so in only one patient. On this basis, their contribution to the scoliosis deformity is not determinable.

SUMMARY

1. The ultimate strength of lumbar and thoracic laminae has been estimated in autopsy material. Lateral parts are stronger than medial and lumbar spines tolerate more force than thoracic areas. The maximal tolerance was 40 kp in thoracic arches.

2. A device has been constructed recording the applied force during correction of scoliosis. It was used at surgery in two flexible and one resistant curvature.

3. Forces above 30 kp fractured the laminar bone of the patient. 30 kp was sufficient to correct 75 per cent of the flexible spines whereas the inflexible ones were only corrected 25 per cent by the same force.

4. It is suggested that correction should be done gradually, perhaps at intervals of several weeks before the final fusion is made.

5. The inserted Harrington-rods had wire connected built-in strain-gauges and the leads were brought out through the skin incision. Measurements were taken during the following 24 hours, the patient being allowed to sit and stand. The highest figures obtained were less than 20 kp. The leads were then removed.

RESUME

1. On a procédé sur un matériel d'autopsie à l'appréciation de la force ultime de l'arc postérieur des vertèbres lombaires et thoraciques. Les parties latérales sont plus fortes que les parties médianes et la colonne lombaire supporte une plus grande force que la région thoracique. La tolérance maximum est de 40 Kp pour les arcs thoraciques.

2. Un relevé a été établi enregistrant la force utilisée pour corriger la scoliose. Il a été utilisé en chirurgie dans deux courbures flexibles et une résistante.

3. Des forces d'environ 30 Kp entraînent la fracture de l'arc postérieur du malade. 30 Kp suffisent pour corriger 75 pour cent d'une colonne flexible, alors que les colonnes inflexibles ont été corrigées avec seulement 25 pour cent de la même force.

4. Il est suggéré que la correction soit faite graduellement, peut-être avec des intervalles de plusieurs semaines avant d'opérer la fusion finale.

5. Les tiges Harrington insérées sont reliées par fils à des jauges de tension introduites dont les fils sont ramenés à l'extérieur par une incision à travers l'épiderme. Des mensurations ont été effectuées durant les 24 heures suivantes, le malade étant autorisé à s'asseoir et à se lever. Les plus hauts chiffres obtenus ont été inférieurs à 20 Kp. Les fils sont alors retirés.

ZUSAMMENFASSUNG

1. Die äusserste Stärke von lumbalen und thorakalen Laminae wurde an einem Autopsiematerial geschäzt. Die lateralen Anteile sind stärker als die medialen und Lendenwirbelsäulen ertragen eine grössere Gewalt als Brustwirbel. Die grösste Widerstandsfähigkeit war 40 Kp im Gebiete der Brustwirbelsäule.

2. Eine Vorrichtung wurde konstruiert, die die angewendete Kraft während der Korrektur einer Skoliose angiebt. Sie wurde während der chirurgischen Behandlung von zwei beweglichen und einer steifen Kurvatur angewendet.

3. Kräfte von über 30 Kp brachen den laminären Knochen des Patienten. 30 Kp waren ausreichend um 75 Prozent der beweglichen Wirbelsäulen zu korrigieren, während die umbeweglichen nur zu 25 Prozent mittels der gleichen Kraft korrigiert wurden.

4. Man schlagt vor, dass die Korrektur gradweise vorgenommen wer-

den sollte, möglicherweise in Pausen von mehreren Wochen, ehe die endgültige Versteifung ausgeführt wird.

5. Die angebrachten Harrington Stäbe hatten drahtverbundene eingebaute Belastungsmasstäbe und die Leitungen wurden durch den Hautschnitt herausgebracht. Messungen wurden während der folgenden 24 Stunden ausgeführt und der Patient durfte sitzen und stehen. Die höchsten, erhaltenen Zahlen waren unter 20 Kp. Die Leitungen wurden dann entfernt.

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