ACTA ORTHOPAEDICA SCANDINAVICA
SUPPLEMENTUM NO. 163

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The halo-pelvic apparatus

A clinical, bio-engineering and anatomical study

by
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MUNKSGAARD
Copenhagen 1975

To my father and mother,
John and Mollie O'Brien,
Sydney, Australia.

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ACKNOWLEDGEMENTS

Over the years I have had the great privilege of working with skilled and experienced surgeons who have guided my footsteps in the science of orthopaedics.

I would particularly like to mention Professor A.R. Hodgson, whose guidance, enthusiasm and vision have revealed a whole new dimension in the management of severe spinal disorders. His ideas and ideals are embodied in The Duchess of Kent Children's Orthopaedic Hospital and Convalescent Home, Hong Kong.

None of this work would have been possible without the loyal cooperation and expert nursing care of the Matron, Sister Barbara, and the staff there.

My apprenticeship in spinal surgery was patiently directed by Professor Arthur Yau, whose particular skill with severe neglected kyphosis has made possible excellent results.

Dr. Louis Hsu has been a loyal support for seven years and together we have shared the satisfactions and the trials of our work. Sister Gabriel, Sister Aquinas and Dr. Donald Yue have provided the medical care these patients needed with good humoured understanding of our surgical bias.

In the engineering work, Dr. J. Clark and Mr. L. Kesterton of the Department of Mechanical Engineering, Hong Kong University, have spent many hours on the problems of design of the apparatus and in the development of the force measuring system.

On my sabbatical leave in the Departments of Orthopaedic Surgery I and Medical Electronics in Göteborg, Sweden, I greatly appreciated the help and insight I was given into the fields of medical electronics and biomechanics. In particular I would like to thank Professor Henry Wallman of the Laboratory of Medical Electronics and Dr. Lars Sonnerup of the Department of Mechanical Engineering, Chalmers University of Technology. Dr. Kerstin Boström was most helpful in the autopsy studies connected with Part IV of the thesis.

Dr. Gösta Elfström guided me ably in the new field of electrical engineering and we worked on a project on "Halo-pelvic traction" together with Professor Alf Nachemson who generously sponsored my sabbatical leave in Göteborg and also helped and encouraged the presentation of this thesis.

The growth and development of the halo-pelvic apparatus in Hong Kong has been the result of the team work of many people who have given much of their time and energies over the years. My sincere thanks to them all.

The clinical and experimental studies were financially supported by grants from:
University of Hong Kong;
University of Göteborg, Sweden;
The Swedish Board for Technical Development, No. 73-3766;
Greta och Einar Askers Stiftelse, Göteborg, Sweden;
Kronprinsessan Lovisas Förening för barnasjukvård, Stockholm, Sweden;
AB Stille-Werner, Stockholm, Sweden;
Down Bros. and Mayer & Phelps Ltd., London, England;
Ethicon Foundation, The Royal College of Surgeons, Edinburgh, Scotland.

PREFACE

The rapid development of the halo-pelvic technique was made possible in Hong Kong by the large number of children with gross spinal disorders for whom some successful method of treatment had to be found.

Our experiences with these children over the last five years form the principal part of this study. In order to be comprehensive, a basic introduction to the apparatus and to the safest procedure for application is outlined in Part I.

In Part II, the clinical material, methods of treatment and results are the evidence of our work, and a measure of its success. The complications encountered are described in Chapter II of this section. For the sake of example and clarity they are dealt with in some detail.

Part III describes a combined project, when intravital wireless telemetry was used to measure the forces being transmitted through the spine, and provided confirmation of several of the virtues of the apparatus which beforehand we had only been able to assume.

The anatomical studies in Part IV establish the fundamental safety of the preferred landmarks for applying the halo and the hoop to the patient along with some basic studies of the growth and mechanical strength of the bony ilium.

As this paper specifically studies the halo-pelvic apparatus, details such as surgical approaches to the spine, respiratory function studies and complications related to surgery have been mentioned only briefly so as not to blur the relevancy of the text.

PART I

THE HALO-PELVIC APPARATUS

THE HISTORY OF THE DEVELOPMENT OF HALO-PELVIC TRACTION

The concept of halo-pelvic traction is attributed to Dr. William Green of Boston, U.S.A. (24); thus it is a little surprising that its clinical development has been so recent. In the fifties the skull halo had been developed and perfected by Perry and Nickel (50) who then proceeded to develop a form of pelvic fixation.

In 1958 in Hong Kong, Hodgson and Yau used a form of halo-pelvic traction for a patient with tuberculous kyphosis. Six threaded pins were inserted into the anterior and posterior superior spines of the ilium and the region of the tubercle of each crest, thus employing the skull halo principle.

The first attempts at pelvic fixation by Perry and coworkers, at Rancho Los Amigos, California, involved the use of the skull halo technique directly on the pelvis (51). This produced too much skin tenting around the pins, resulting in skin necrosis and the need for early removal of the apparatus. Secondly, they tried using coarsely threaded pins angled directly down the long axis of each of the four superior spines, but, in this instance, the cancellous bone held less than three weeks. Part of the problem was that severely paralysed patients had very thin iliac crests which were unable to hold the pins.

Garrett (51) used the "button wire technique", placing the buttons on the inside of the pelvis and bringing the wires out on to the pelvic hoop. This worked very well for approximately ten weeks, until irritation began and the fixation had to be removed. Nelson (42), whilst working at Rancho Los Amigos, developed a three pin unit which could be attached directly to the iliac crests. The patients tolerated this quite well, although its fixation to the pelvis required considerable surgery, and there was some drainage in each case.

Several other workers had been involved at this stage in the development of pelvic hoop fixation, including Levine (31). The difficulty, throughout, was the problem of obtaining firm fixation on the pelvis. It was DeWald and Ray who solved this by using threaded pelvic pins which transfixed the iliac crests. They described their experience with their first four patients in 1970 (10).

Our clincal experience began in January 1969; the apparatus and the method of fitting it to the patient have been modified and altered in various ways, for reasons of safety, but the basic technique has remained the same.

THE APPARATUS

The halo-pelvic apparatus consists of five basic parts (Figs. 2, 3 and 4).

a) The skull halo.
b) The pelvic hoop and pins, and their attachments.
c) Four extension bars connecting the hoop to the halo.
d) The force measuring system; a spring at the base of each of the four extension bars.
e) The back winder (Fig. 4).

a) Originally, a 'Rancho' type halo was used; the design was simplified to facilitate manufacture and to reduce the weight of the halo. This meant elimination of the posterior upward flare (as fusion proximally to the skull has not been necessary in our patients), and of the bushings for locking the halo pins in place. Instead, the pins were locked in position by a nut on the threaded pin, external to the skull halo. Multiple threaded holes were added around the perimeter, allowing a wide selection of pin sites.

b) The pelvic hoop and pins initially resembled those described by DeWald and Ray (10) with four 'female' attachments clamped to a hoop of rectangular cross section, which accommodated the extension bars (Fig. 1). The pelvic pins were held in position on the hoop by four clamps.

c) The extension bars were fixed proximally by socket head cap screws to the skull halo. The bars were threaded over their distal ten to fifteen centimetres, and effective lengthening of the distance

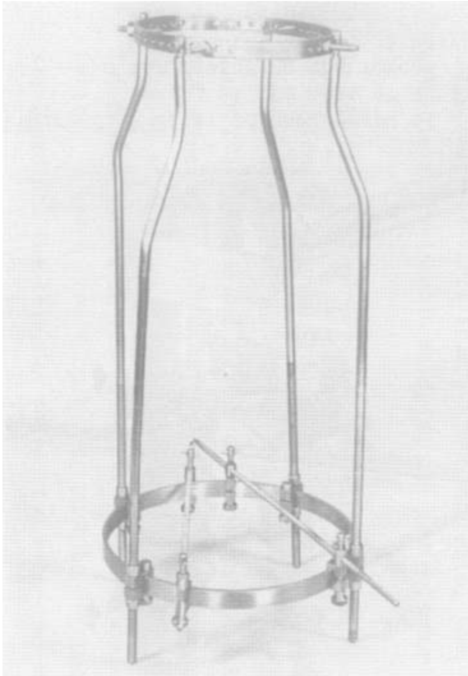

Figure 1. The Mark I halo-pelvic apparatus.

Figure 2. The Mark II halo-pelvic apparatus. Note the multiple holes around circumference of the skull halo for alternative sites for placing the skull pins.

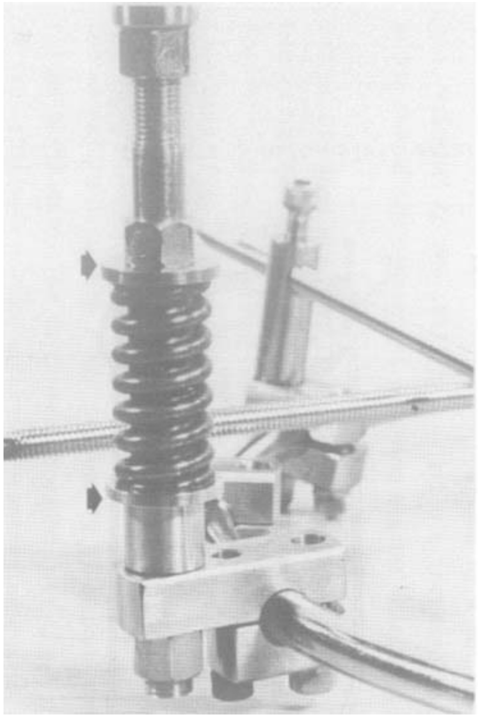

Figure 3. A detailed photograph of a compression spring at the base of an extension bar for measuring the forces. The distance between the arrows is measured with a vernier caliper.

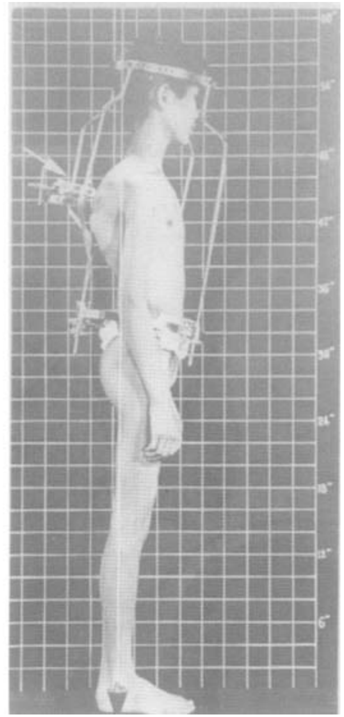

Figure 4. Lateral photograph of case 49, a twelve-year old patient with severe paralytic scoliosis. A back winder is attached to the two posterior extension bars (arrow).

between the halo and hoop was achieved by winding the nut above the 'female' attachment down the thread on the extension bar (one millimetre thread).

Two difficulties arose with this Mark I design (Fig. 1). Firstly, the extension bars protruding distally beyond the pelvic hoop made sitting difficult for the patient, as the two anterior extension bars abutted against the thighs. Secondly, patients with pelvic obliquity presented particular difficulty with the fitting of the extension bars because of the rectangular cross sectional shape of the pelvic hoop.

Modifications to the original design have been made to obviate the problem of the extension bars protruding beyond the pelvic hoop (Fig. 2)(5). A threaded sleeve is now used instead of the original extension bar, which means that none of the extension bars extend beyond the hoop. The pelvic hoop has been designed so that it is now round in cross section, making adjustment of the extension bars an easy matter, even when pelvic obliquity is extreme (Fig. 3).

d) In October 1970, a force measuring system was designed to record the forces being applied to the spine (5). The four springs sit in sleeves at the base of the extension bars, and they are gradually compressed as the distraction progresses (Fig. 3). Each spring has a stiffness of approximately 300 pounds per inch (5.4 kp/mm). The amount of spring deformation measured can be converted into a measurement of force from a standard table, thus providing a valuable guide line in managing the patients during distraction.

e) An adjustable steel pressure pad which clamps to the posterior extension bars can be gradually applied against a kyphos or rib hump, providing an additional local, corrective force. Initial correction of a severe spinal curve is obtained by lengthening the spine, but, in the latter stages of correction, a direct force applied at the apex of the deformity is desirable (Fig. 13 b). Two points should be remembered if the back winder is used. Firstly, a thick foam rubber disc must be interposed between the steel pad and the skin, as there is a high risk of pressure necrosis, particularly when an anterior oblique and a posterior vertical skin incision have been used in approaching the spine. With this combination of incisions a large area of skin is rendered anaesthetic, and there is a high risk of developing ischaemic skin lesions by using the back winder. Secondly, it must be removed from the posterior extension bars when force measurements are being taken.

FITTING OF THE HALO-PELVIC APPARATUS

In the early months of experience with the halo-pelvic apparatus it was apparent that a drilling jig was essential for accurate insertion of the pelvic pins, in order to avoid the severe complications surrounding an inaccurate placement. A drilling jig for arthrodesis of the hip (3) was easily modified for this purpose (Fig. 5).

Major difficulties with several patients were encountered when the extension bars were applied at the same time as the skull halo, pelvic pins and hoop. As a result, the fitting of the apparatus now entails two stages: firstly, the skull halo, pelvic pins and hoop are fitted under general anaesthesia; secondly, several days later, the extension bars are applied to the pelvic hoop and skull halo with the patient awake and cooperating.

General anaesthesia is required, although the skull halo itself can be fitted under local anaesthesia. The patient's tolerance of this first anaesthesia is a fair indication of his ability to withstand subsequent anaesthesia for spinal operations. Endo-tracheal anaesthesia is desirable because of the repeated alterations in position of the patient on the operating table.

Perry has stressed that the skull halo must be placed below the greatest transverse diameter of the skull (52). The assistant may hold the patient's neck with the head extending beyond the end of the operating table, but, if the halo is to be used with any regularity, it is best to have a small thin metal extension to the table on which the patient's occiput can rest (44). The anterior pins are placed in the shallow fossae above the outer aspects of the eyebrows.

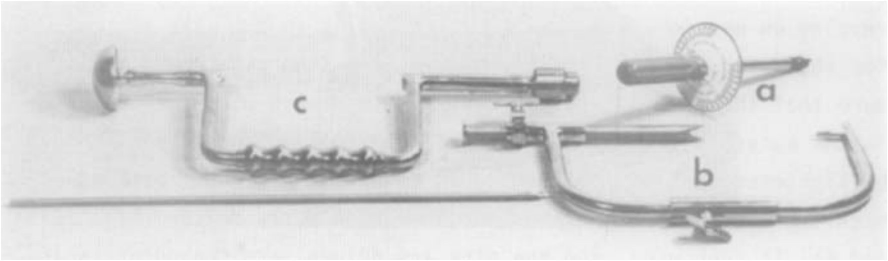

Figure 5. A photograph of the basic instruments required.

a) The torque screw driver.

b) The drilling jig.

c) The carpenter's brace.

The outer table of the skull is quite thick, and with the shouldering of the pins a secure purchase is obtained without excessive and dangerous penetration.

The posterior points selected are above and approximately two centimetres behind the ear. Several of the skull halos slipped off after distraction had commenced, and therefore it was felt that the use of supplementary skull pins would be advisable, particularly for the heavier and the long term patients. If six pins are to be used, the extra two pins are placed approximately two centimetres behind the posterior ones (see Part IV).

The sterile skull halo is placed in position on the patient's scalp resting on his forehead, and the ideal holes in the halo are chosen for inserting the skull pins. The pins are then tightened, making sure that the skull is in the centre of the halo when the pins are in the outer table of the skull; diametrically opposite pins should be tightened at the same time to ensure this. After the pins have been tightened by finger pressure, a torque screw driver (Figs. 5 and 6a) is then used, and the pins are driven into the outer table with a torque force of 5.5 pound inches (0.06 kpm). This procedure is completed by applying the outer locking nuts carefully to the outer extension of the skull pins, so that, when the nuts are tightened, the skull pin is not advanced any further. This can be done by locking the pins with the screw driver.

The patient's position is now changed: he is moved down onto the middle of the table, and placed in the lateral position where the upward facing hemi-pelvis is prepared and draped (Fig. 6b). This position is chosen for several reasons. Firstly, it is easy to see the appropriate landmarks. Secondly, the drilling jig is easily applied to the iliac crest with the patient in the lateral position. A false sense of security should not exist at this stage, as the viscera do not fall away from the upper iliac crest. There is a negative intraperitoneal pressure which prevents any gross movement of the peritoneal contents within the peritoneal cavity.

The points for applying the drilling jig are now selected. The anterior point for introducing the pin is on the iliac crest,

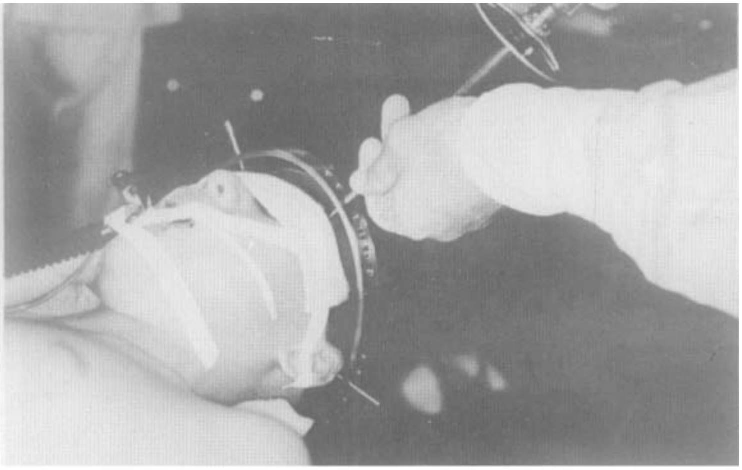

Figure 6 a. Fitting of the skull halo.

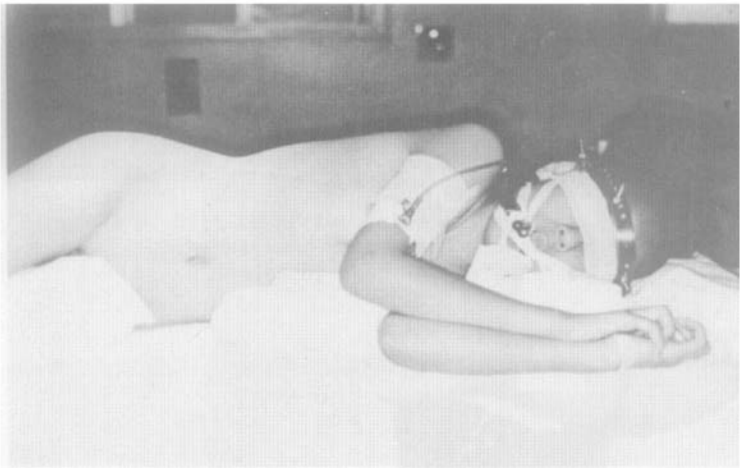

Figure 6 b. The patient placed in the lateral position for insertion of the pelvic pins.

Figure 6 (a), (b), (c), (d) and (e).
A series of photographs to demonstrate the method of fitting of the halo-pelvic apparatus.

Figure 6 c. The drilling jig in position and the pelvic pin inserted with a carpenter's brace.

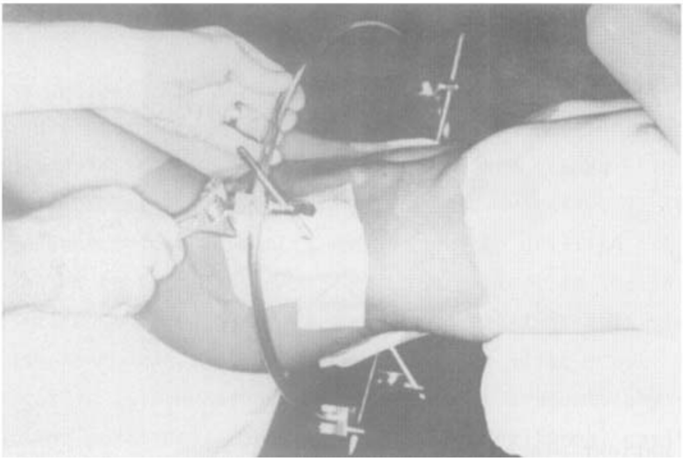

Figure 6 d. The pelvic hoop being placed on the pelvic pins at the end of the operating table.

Figure 6 e. Fitting of the extension bars with
the patient awake and with the halo
suspended by a spring balance.

opposite the gluteal tubercle, "the tubercle of the crest", which may be as much as five centimetres upwards and posterior from the anterior superior iliac spine (Part IV, Fig. 42). It is readily palpated as the subcutaneous iliac crest is widest at this point. With this particular part of the crest grasped between the thumb and index finger a transverse incision is made down to the bone, or cartilage cap, of the crest; the length and depth of the incision depends on the amount of subcutaneous fat present.

The selected point of emergence is the posterior superior iliac spine, which is subcutaneous and easily identified by the overlying skin dimple, and a stab incision is made just medial to it.

The drilling jig is now applied, connecting these two landmarks. It is important to have the points on the jig quite sharp so that they will penetrate the bony landmarks; the telescopic section of the jig ensures that one can use a good deal of hand pressure to push the points securely into bone, then the telescopic portion of the jig is tightened. Ideally an assistant steadies the U-part of the jig whilst the pin is being inserted.

For insertion of the pin, a carpenter's brace is used (Fig. 6c). Power driven machinery for this purpose would be dangerous for, if any part of the pin is within the iliac fossa, it is likely to wrap the peritoneum around itself. Apart from this, it is likely that with high speed drilling, a good deal of bone necrosis occurs (33) and this will merely increase the amount of discharge and probable infection around the pelvic pins.

Preliminary tapping of the sharp drilling point of the pelvic pin through the cortex, or the cartilage cap of the crest of the ilium, is advisable, and the first few turns of the pin through the bone may be made with a Steinman pin holder. Thereafter the carpenter's brace is attached to the end of the pin and, with slow rotation, the pin is advanced through the crest.

Its emergence will be heard and felt by the pin rubbing against the sharp posterior part of the drilling jig. At this point, the jig is detached from the crest, the brace is reattached, and the pin's route continued until an equal length of pin is protruding anteriorly and posteriorly.

It is important that the pin is felt to engage in the anterior part of the crest as it is very easy, particularly in thinner patients, for the pin to slide down the outer or the inner tables of the crest. Should this happen, the seating of the jig must be checked and a further incision attempted. The pin, in the middle of its course through the crest, might be slightly within the pelvis (and it may be palpated here with the patient under anaesthesia).

One must beware of the peritoneum becoming wrapped around the pin at this time; this will be apparent as the anterior abdominal wall becomes 'sucked' into the iliac fossa. It is essential, should this happen, that the insertion be stopped and a second point chosen on the iliac crest for applying the pin.

There will be no difficulties encountered at this stage with patients who have a normally developed pelvis. However, in the much younger patients, and those with wasting of the pelvis associated with long standing paralysis and pelvic obliquity, the insertion of the pins may present problems. If any difficulties are met or any anxiety felt about the precise placement of the pin, it is advisable to make a small incision just above the middle of the iliac crest and to place an exploratory finger within the iliac fossa, so that the direction of the pin, should it be intrapelvic, may be felt with accuracy, and the viscera pushed aside.

It is important to note that the point of pin entry is not at the anterior spine but at some distance from it, and it is best, before applying the halo-pelvic apparatus to any patient, for the surgeon to examine a bony pelvis and check the relative positions of the landmarks recommended. When a line is drawn connecting the anterior with the posterior superior spines, a pin crossing this gap will be almost totally within the iliac fossa with a great danger of bowel perforation.

When the first pin has been placed in position, the skin wounds are sutured loosely around it, small dry dressings are applied to these wounds, and the patient's position changed to the opposite lateral position on the table, which ideally is broken across its middle, thus allowing for the protrusion of this first pin.

The patient may therefore need to be steadied by the assistant whilst the second pin is being inserted in an identical manner to the first.

In those patients with pelvic obliquity, the pelvis on the higher side often has better muscles attached to it, and for this reason it is better developed; but its abnormal position increases the risk of perforation of the bowel.

The patient's position is again changed to the supine position, the lower half of his body being supported by the assistant whilst the pelvic hoop is run over the lower limbs and, with the appropriate fittings, locked to the pelvic pins (Fig. 6d). Whether the pelvic hoop be placed above or below the pins depends largely on how distally the spinal surgery will extend. If fusion, be it anterior or posterior, is to include the lower lumbar spine, then it is advisable to place the pelvic hoop below the pelvic pins. It is important for the locking attachments to be firmly tightened so that there is no movement of the pins, as this might produce pain and promote infection.

POST-OPERATIVE MANAGEMENT

During post-operative management the patient is best nursed on a split mattress so that the posterior part of the pelvic hoop is accommodated within the split, and does not cause excessive pressure of the pelvic pins against the iliac crest.

The skull halo pins may cause some headache which should be easily managed with salicylates. Any excessive pain associated with the skull halo pins implies looseness of the fixation.

Likewise, excessive pain associated with the pelvic pins may indicate their inaccurate insertion or looseness which will produce pain in the iliac crests. Excessive and continuing pain may denote bleeding or an injury to the intestines; this will be discussed under complications. For these reasons, it is wise to maintain the patient on close observation for 24 hours after fitting of the halo and the pelvic hoop.

FITTING OF THE EXTENSION BARS

The fitting of the extension bars can take place when the patient has fully recovered from the general anaesthesia and the surgical procedure. The patient is seated comfortably on a stool beneath a strong spring balance which is suspended from the ceiling (Fig. 6e). The balance has attached to it a series of thin ropes and hooks which are hooked into four free holes of the skull halo. A pulley system permits the patient to be drawn up, and this force is registered on the spring balance. The patient should be suspended by the maximum amount of force which is tolerable, comfortable and not producing neck pain. This is often 25 per cent of the patient's body weight, but will obviously depend on many factors, particularly the thickness and strength of the patient's neck.

With the patient in this semi-suspended position the four extension bars are affixed to the skull halo by the socket head cap screws, and to the pelvic hoop by the special clamp attachments. If force measuring springs are used, they must be checked for stiffness before being placed in position. All the fittings are tightened and the pulley with the spring balance can then be released.

Distraction can commence several days after the fitting of the bars, provided that preliminary osteotomies are not required.

DAY TO DAY MANAGEMENT OF THE PATIENT

The skull halo pins require little attention but they should be inspected each day and any discharge should be removed and cultured. All skull pins are checked one week after fitting and tightened up again with the torque screw driver to 5.5 pound inches (0.06 kpm). If a patient experiences pain, it is due to looseness and the skull pin should be tightened; should it be associated with excessive discharge, then that pin should be changed. The multiple holes in the skull halo permit these changes of pin without any difficulty.

The pelvic pin sites likewise are examined daily and kept covered with small dry dressings; any discharge should be cultured and the appropriate antibiotic used.

As regards keeping the patients in bed, it has been customary to confine them to bed only when they are recovering from surgery or are suffering from excessive pain and/or discharge from their pelvic pin sites.

The most important single factor in avoiding infection associated with the skull and pelvic pins is that they must have rigid fixation in bone. Whilst they are firmly fixed in bone, there is only a very slight likelihood of infection. Once looseness develops, infection becomes almost an automatic sequela.

PITFALLS AND GUIDELINES IN USING THE HALO-PELVIC APPARATUS

Selection of the patient

Halo-pelvic traction should be reserved for those patients whose spinal deformities cannot be well corrected by other methods of treatment currently available. In Hong Kong, the main indications for the use of the technique have been tuberculous kyphosis (40%) and paralytic scoliosis (30%). After more than five years experience with halo-pelvic traction, the indications have altered a little but precise indications cannot yet be categorically stated. For those patients with severe scoliosis and severe respiratory insufficiency and those with kyphotic deformities, the halo-pelvic apparatus has, in our hands, remained the mainstay of management.

Faulty preparation of the patient

Any patient whose deformity is severe enough to require treatment with the halo-pelvic apparatus should have:

a) myelography before surgery and

b) adequate preliminary respiratory function tests.

a) Myelography is essential to exclude any intraspinal lesion not detectable with normal routine radiography, or to define the extent of an internal kyphosis with cord compression. If there is a lesion present in the spinal canal, such as diastematomyelia or an intrathecal lipoma, then a strong corrective force applied to the spine is very likely to produce a paraplegia.

b) Respiratory function tests are essential and are used routinely. They should always be mandatory in the operative treatment of scoliosis especially in severe paralytic curves. There is the possibility of a traction injury to the vagus nerve, which will produce loss of the cough impulse and sputum retention. The sequelae of such a complication would be difficult to assess if base line respiratory studies had not been done.

Incorrect fitting of the apparatus

The patient should be relatively comfortable after the fitting of the halo and the hoop, and if there is any undue pain it suggests that there is something wrong. If the skull halo has been firmly fixed, then there should be no more than discomfort associated with the skull pins, if they have been placed in the proper positions. One cause of intense pain has been placing one of the anterior pins too medially, near or through a supraorbital nerve.

Familiarity with the proper siting for placement of the skull pins is important. One must bear in mind the anatomy of the cutaneous nerves of the scalp in the region of the eyebrows and the ears, as their irritation with a skull pin produces intense pain.

Patients with meningomyelocele may have had a Spitz-Holter valve in position, usually above and behind one ear. If the halo is to be used, the pins on the same side as the valve must be placed at some distance from it and its catheter, so as to avoid problems.

The pelvic pins, if firmly embedded in the iliac crests and locked tightly to the pelvic hoop, should not cause anything more than discomfort. If there is pain about the site of entry, or exit, of one of the pelvic pins, then a check should be made to see that skin is not excessively tented about a pin. This can present problems, as an area of necrotic skin will develop, with sloughing and inevitable infection.

In the first 24-hour-period after the fitting of the halo and the pelvic hoop the patient should be kept under routine observation, and if there are any difficulties, such as rising pulse, increasing temperature, or abdominal pain, then a general surgeon should be consulted, particularly if there is any possibility of one of the pins being intrapelvic.

The importance of accurate placement of the pelvic pins cannot be over-emphasised. To the author's knowledge there have been four instances of damage to the peritoneum or the intestines with incorrect insertion of the pelvic pins. Our experience with laceration of the peritoneum is referred to later (Part II, Chapter II). Three instances occurring in other clinics included: a) injury to the outer layer of sigmoid colon, detected post mortem in a patient who died from other causes after surgery; b) perforation of the sigmoid colon; and c) one patient who sustained perforation of both the sigmoid colon and the caecum with the two pins.

This particular sequence has been developed because of its safety for the patient. Points to be re-emphasised are:

1) A drilling jig must be used for safe, accurate insertion of the pelvic pins.

2) A power drill is contraindicated for this procedure. It is dangerous and likely to produce a potentially fatal bowel injury. A carpenter's brace is recommended as it is simple, safe, and if used slowly, is least likely to cause bone necrosis.

3) The lateral position of the patient is selected because it is the easiest position in which to apply the drilling jig, to see all the bony landmarks at one time, and for the surgeon to position himself when doing the instrumentation.

4) The extension bars are not put on the patient while he is under anaesthesia. It is preferable and advisable to apply them several days later.

Complications likely to occur during distraction of the patient

The most common faults are acute distraction of the cervical spine, and cranial nerve injuries. To avoid these problems there are four basic guide lines which must be used during distraction. They are:

A) Regular clinical observation.
B) Daily neurological assessment.
C) Regular lateral radiographs of the cervical spine.
D) The use of force measurements.

A. Regular clinical observation

Any complaint which the patient makes during distraction must be dealt with immediately. In this respect the nursing and paramedical staff must be given encouragement and responsibility in the management of these patients. It is wise to include them in the general teaching programme, so that they are familiar with the apparatus and its use and know how to release the tension in the extension bars should the patient complain of pain or disability. The most common complaint during distraction is of neck pain, and one must not continue distraction until this has settled. If neck pain persists, then the extension bars should be shortened by several turns until the patient is comfortable again.

Nursing care includes daily inspection of the skull halo and the pelvic pin sites, and any change in their state, discharge, pain or looseness, must be reported to the surgeon in charge.

B. Neurological assessment

A daily neurological assessment of each patient must be made during active distraction. For this purpose a basic chart (Table 1) has been developed which permits a rapid check of the nerves at risk.

If a nerve injury occurs or if the patient notices some weakness, the extension bars must be shortened immediately, as the time for recovery of the nerve injury, which is usually a neurapraxia, will depend on how long the nerve has been over-stretched. The quicker the tension is released the faster will be the return of nerve function.

TABLE 1

BASIC NEUROLOGICAL EXAMINATION FOR PATIENTS UNDERGOING DISTRACTION

A. Spinal cord

Questions

1) Any weakness in the legs?
2) Any numbness in the legs?
3) Any loss of bladder function?

Tests

1) Up or down going toes?
2) Any clonus of ankles or knees?

B. Cranial nerves (Tests for VI, IX, X, XII)

Questions

1) Any double vision?
2) Any difficulty swallowing?
3) Difficulty coughing?
4) Any change in voice?
5) Any tongue weakness?

Tests

1) Eye movements (VI)
2) Palate reflex (IX)
3) Explosive cough (X)
4) Quality of speech, nasal? (IX or X)
5) Extend tongue, is it midline? (XII)

C. Upper limbs

Questions

1) Difficulty in moving hand, arm, or shoulder joint?
2) Any numbness or weakness of the hand?

Tests

1) Abduct the shoulder (C5, 6)
2) Flex the forearm (C5, 6)
3) Test grip of hand
4) Test sensation of finger tips (C6-T1)

C. Lateral radiographs of the cervical spine

The upper cervical spine, because of its relative frailty, is the most susceptible region of the spine to over-distraction. For this reason regular lateral radiographs of the cervical spine are mandatory. They should be taken with the patient at a fixed distance from the x-ray plate, so that measurements of films will be comparable.

D. The use of force measurements

The use of a force measuring system is most important. It provides an indication of the amount and rate at which the stress on the spine is being built up. From studies of the pathological changes in the cervical spine with distraction, it is apparent that when forces measuring over 60 per cent of the body weight are applied, the complication rate becomes significantly higher (Part II, Chapter II). By having force measurements available, these complications can be minimised. Some patients have flexible curves, such as those with long paralytic C-curves, while others, like patients with tuberculous kyphosis, have more rigid deformities. The rigidity of the curves differs enormously from patient to patient and depends mainly on their etiology. The force measurements provide the information necessary to avoid building up dangerously high forces too rapidly and this is most important in the rigid deformities.

Removing the halo-pelvic apparatus

The actual removal of the apparatus is relatively simple; deciding when to remove it may occasionally present problems.

The precise procedure will depend on the deformity and the method which has been used to correct and fuse it. It will also depend to a large extent on the internal fixation used and its stability. The most common deformity will be a scoliosis and the most common instrument the Harrington rod; it must be remembered that after several weeks in the halo-pelvic apparatus, there is quite significant osteoporosis and the Harrington hooks are more likely to cut through the softened bone if the spine is suddenly released. It is for this reason that often the extension bars are shortened by 1 or 2 millimetres each day so as to gradually load the rod and place some stress through the fusion mass. If there is any slipping of the implants at this stage, it will be noticed by the patient and check radiographs should be done forthwith.

When the patient has been in the apparatus for some months, large holes will have developed in the crests where the pelvic pins have sawn away the bone with which they are in contact. When the extension bars are slackened a little, these are likely to become even more mobile and therefore painful. This will often force the surgeon to remove the apparatus a little sooner than he may have anticipated.

The actual removal of the apparatus is quite straightforward. Under general anaesthesia, the extension bars are removed. Next the skull pins are removed from the skull and the halo, being particularly careful to cover the eyes which are at risk. Now the pelvic pins are removed using a carpenter's brace. They can be removed either from the front or back; the length of pin which has been protruding is prepared with iodine solution before extracting it from the iliac crest.

The opened wounds are covered with small dry dressings and these invariably heal within a week.

Should there be some concern about the internal fixation or maintaining the correction that has been achieved with the halo-pelvic apparatus, it is possible to apply almost an entire body jacket with the patient still in the halo-pelvic apparatus. Proximally, the cast can be moulded up to the manubrium sterni and posteriorly to the base of the neck; this may be extended proximally to include the neck when the apparatus has been removed. Distally it can be extended down around the pelvic pins to embrace the pelvis so that the pins can be removed and the pelvic portion of the plaster then completed.

Windows of an appropriate size may then be removed from the pelvic portion of the body jacket to dress the skin wounds which heal rapidly. Attention should be given to the pressure on anaesthetic skin over the back if an oblique thoracotomy incision has been combined with a midline posterior vertical incision. In such cases, it is routine to remove that area of plaster which impinges against skin devoid of protective sensation. Failing to do this results in a high incidence of pressure sores.

Inaccurate timing in the removal of the halo-pelvic apparatus

One error is to remove the halo-pelvic apparatus too early, which may result in a significant loss of some of the correction obtained. When internal fixation is possible (usually the Harrington rod), it should be used at the time of posterior fusion, and the traction in the halo-pelvic apparatus should be maintained for a further four to six weeks. The rod can then be gradually loaded by a slight daily shortening of the extension bars, as rapid release is likely to produce compression fractures of the osteoporotic, posterior elements by the hooks.

This phenomenon is of relatively minor importance compared to the great advantages of the apparatus for patients with spinal deformities and respiratory crippling. In such cases, consideration should be given to internal fixation when appropriate, and to the removal of the apparatus when a body jacket could be considered as a reasonable alternative.

SUMMARY

The history of the development of the halo-pelvic apparatus has been described as has the apparatus together with various modifications and improvements which have been made over the years.

A detailed account of the fitting of the halo-pelvic apparatus is presented with particular emphasis on several safety factors which include:

1) The use of a drilling jig and the anatomical landmarks chosen in the iliac crests.

2) Placing the patient in a lateral position on the operating table during insertion of the pelvic pins.

3) Fitting the extension bars at a later stage with the patient awake and co-operating.

Pitfalls and guidelines in using the halo-pelvic apparatus are described with emphasis on the correct selection of the patient and with particular attention directed towards avoiding complications during the use of the halo-pelvic apparatus.

PART II

CLINICAL INFORMATION - TREATMENT, RESULTS AND COMPLICATIONS

CHAPTER I: CLINICAL MATERIAL, METHODS OF TREATMENT AND RESULTS

INTRODUCTION

104 consecutive unselected patients with severe spinal deformities have been treated with the halo-pelvic apparatus at the Duchess of Kent Children's Orthopaedic Hospital and Convalescent Home, Sandy Bay, Hong Kong, over a 3.5 year period from January 1969 to August 1972.

<u>Age and sex</u>

The average age of the patients was 15 years (range 3 to 26 years). 47 patients (45 per cent) were males. Their average age was 14.7 years (range 3 to 23 years). 57 patients (55 per cent) were females. Their average age at the beginning of treatment was 15.2 years (range 5 to 26 years).

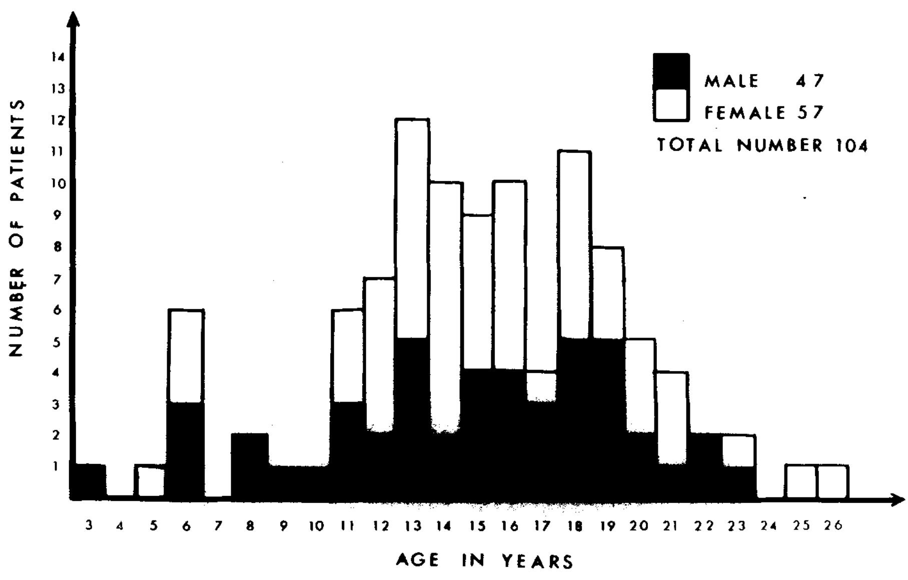

Figure 7. Barograph to show the age and sex of 104 patients.

Etiology of deformity

The etiology of the patients' deformities was:

1. Tuberculous kyphosis: There were 42 patients with tuberculous kyphotic deformities (40 per cent) of which 25 were males and 17 were females. Their average age at the commencement of treatment was 16.1 years (range 3 to 26 years).

2. Paralytic scoliosis: 31 patients had severe paralytic scoliosis (30 per cent). 15 were males, 16 were females and the average age was 14.1 years (range 6 to 25 years).

3. Idiopathic scoliosis: 15 patients (14 per cent) had severe idiopathic scoliosis. There were 14 females and 1 male patient, and their average age was 15.6 years (range 6 to 21 years).

4. Congenital kyphoscoliosis: 10 patients with congenital kyphoscoliosis (10 per cent), included 4 males and 6 females. Their average age at the beginning of treatment was 12.8 years (range 6 to 19 years).

5. Neurofibromatosis kyphoscoliosis: 6 patients had deformities due to neurofibromatosis (6 per cent), 2 males and 4 females, and their average age was 13.8 years (range 10 to 19 years).

6. Salvage group: A separate study was made of the 8 scoliosis patients (paralytic - 4 patients, idiopathic - 4 patients) with previous posterior spinal fusions requiring osteotomies before correction and revision of the fusion.

There were four deaths during treatment (cases 40, 41, 42, 96). Three were patients with severe tuberculous kyphosis and one had a severe congenital scoliosis. Each of these patients died shortly after major spinal surgery and they will be referred to later. All four patients had gross, fixed, spinal deformities associated with severe respiratory insufficiency.

The average time a patient spent in the halo-pelvic apparatus was 7.5 months (range 1 to 16 months)(Fig. 8). The most common period of time in the apparatus was 9 months (12 patients). This long average time is an indication of both the severity and the rigidity of the deformities as well as the associated respiratory insufficiency from which these patients suffer.

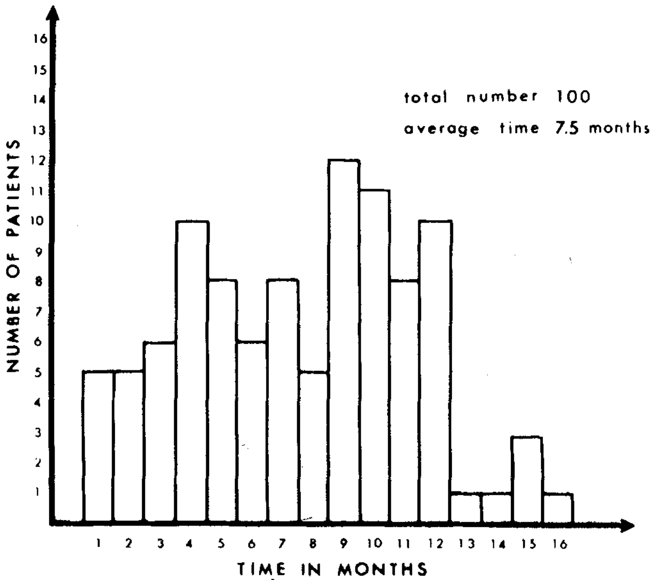

Figure 8. Barograph to demonstrate the length of time patients spent in the halo-pelvic apparatus.

HALO-PELVIC APPARATUS AS EXTERNAL FIXATION OR AS A CORRECTING INSTRUMENT

Whilst most patients had halo-pelvic distraction to correct major spinal deformities, in some (cases 28, 73, 89, 90, 103) the apparatus was used mainly as a means of external spine fixation so as to provide stability in situations where the spine was particularly unstable. There were also several patients where maximum distraction was not attempted because of the potential risk to the spinal cord; however, stability was provided by the apparatus and slight, careful distraction was allowed.

1. TUBERCULOUS KYPHOSIS

Introduction

There were 42 patients with tuberculous kyphosis; three of these patients died during treatment. In one of the remaining 39 patients the apparatus was used as external spine fixation rather than as a correcting instrument. There were 25 males (average age 16.0 years) and 17 females (average age 16.3 years) (Fig. 9). Their average time in the halo-pelvic apparatus was 8.4 months with a range of 1 to 16 months (Fig. 10). The average length of follow-up for this group of patients was 2.9 years.

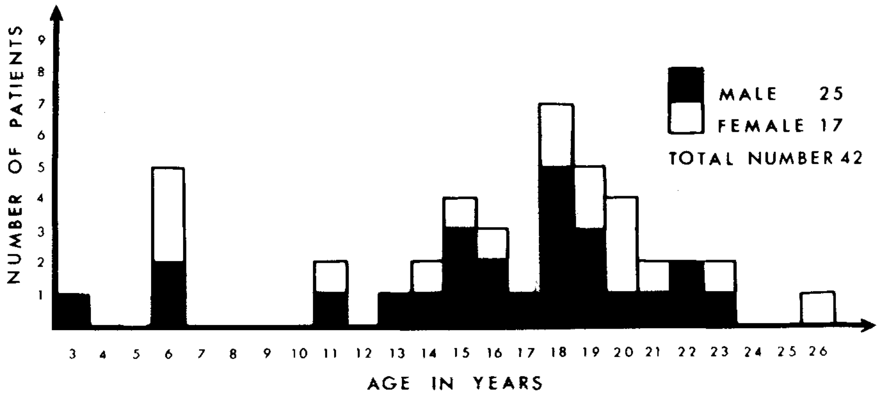

Figure 9. Tuberculous kyphosis. Barograph showing the age and sex of patients.

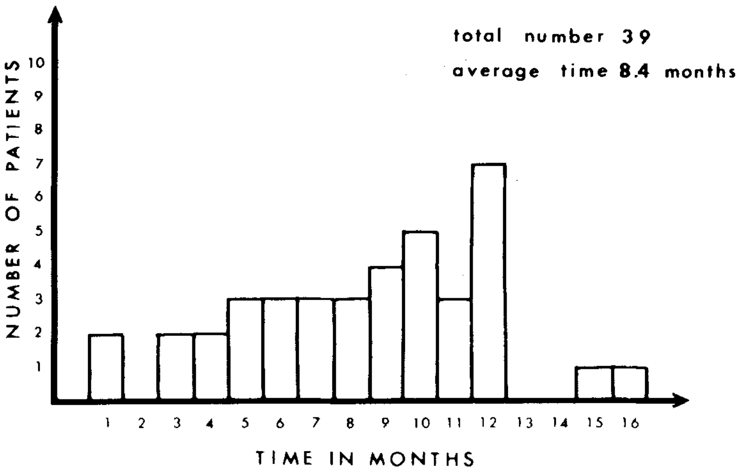

Figure 10. Tuberculous kyphosis. Barograph showing the length of time spent in the halo-pelvic apparatus.

Extent and degree of deformity

The average number of vertebrae destroyed by the tuberculous process was 6 (range 3 to 9 vertebrae) (Fig. 11).

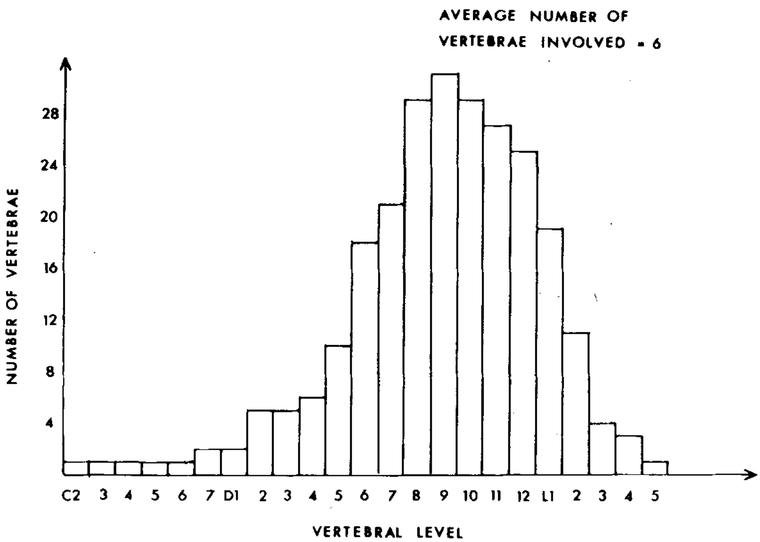

Figure 11. Barograph demonstrating the level and number of vertebrae destroyed by tuberculous disease process. The average number of vertebrae involved per patient was 6.

The vertebral body most commonly destroyed was the 9th thoracic vertebra. The average angle of kyphosis measured 117 degrees (range 59 to 147 degrees).

Previous surgery

There were 11 patients who had had previous surgery for their tuberculous disease. This surgery included fusions in all but two cases where debridements alone were done.

Cord compression

16 patients had clinical evidence of cord compression before surgery. All had significant narrowing of the spinal canal, best demonstrated

by myelography (Fig. 12).

The degree of cord compression varied clinically from slight spasticity in the lower limbs in most patients, to the more extreme variety, with marked spasticity, severe clonus of knee and ankle and walking being difficult, if not impossible. This latter group represents the usual manifestations of penetration of the cord by the tuberculous disease process (28).

METHOD OF TREATMENT

The general plan of treatment in these patients was to decompress the spinal cord by removing the internal kyphos and, following gradual correction over some weeks with halo-pelvic distraction, to perform anterior and posterior fusions (64).

Chemotherapy

The routine treatment included the standard anti-tuberculous drugs, even for those patients with apparently healed spine disease. The drugs were continued for up to 18 months. Reactivation of infection in several earlier patients after surgery has now made the inclusion of the appropriate drug therapy routine.

Planning the operations

The sequence of operations, while conforming to a basic pattern, was varied according to the needs of each individual patient. This entailed mobilisation of the deformity and simultaneous cord decompression by removing the internal kyphos, gradual correction and then fusions. This planning depended on the site and extent of the kyphos and the respiratory reserve of the patient.

Four separate combinations of mobilising osteotomies and fusions were employed.

A. One stage osteotomy - "Three-quarter circumferential" osteotomy

This entailed:

1. Removal of the internal kyphos and half the (usually) spontaneously fused posterior elements at the same sitting.

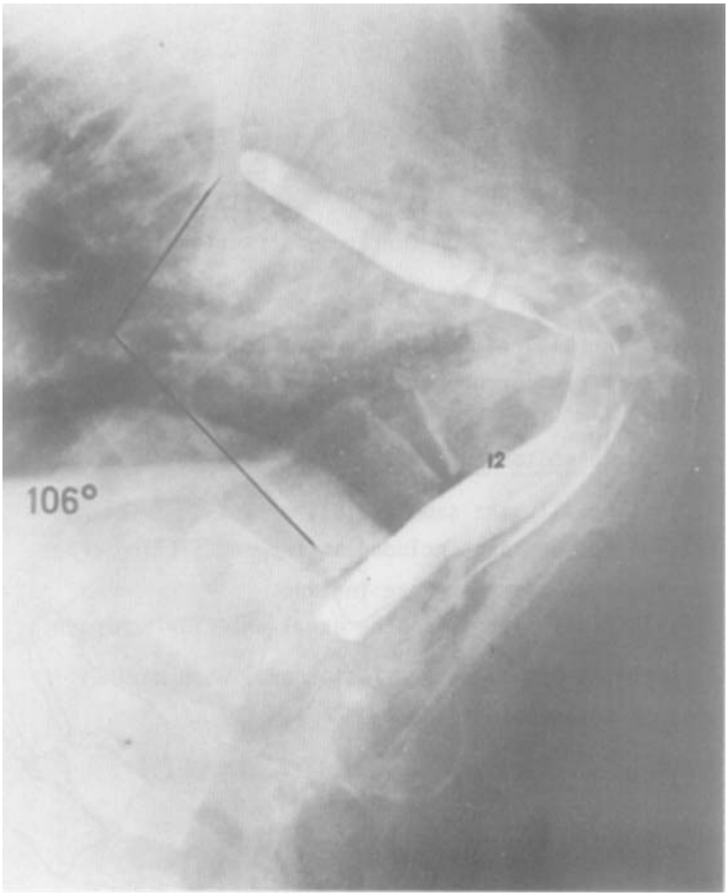

Figure 12. Case 1. A lateral myelogram in tuberculous kyphosis to demonstrate the acute angulation of the spinal canal and its narrowing at the level of the internal kyphos. This knuckle of bone must be removed <u>before</u> safe distraction can be undertaken.

2. Following maximal distraction, posterior fusion.

3. Anterior fusion.

B. Two stage osteotomies

This included:

1. Removal of the internal kyphos followed by distraction.

2. Posterior osteotomy, after which further distraction.

3. Posterior fusion.

4. Anterior fusion. The biggest single drawback to this sequence is that it involves four major operations.

C. Combined posterior osteotomies and fusion

This sequence is essentially the same as (B), except that the posterior osteotomies and fusions are included at the one sitting (Figs. 13 a, b, c). The three stages therefore include:

1. Removal of the internal kyphos via the usual anterior approach.

2. Posterior osteotomies and extensive fusion and, when maximal distraction has been achieved,

3. anterior fusion (Fig. 13 c).

D. Extrapleural costotransversectomy approach

The internal kyphos may be removed from in front of the spinal cord by an extrapleural costotransversectomy approach (5 cases). This must be considered for those patients with severe respiratory insufficiency and kyphoses which are either very deep or else situated in the cervico dorsal spine. Because of severe respiratory impairment, two of these patients required elective pre-operative tracheostomy.

A complete circumferential osteotomy in one operation is not advisable because, apart from danger to the cord and its blood supply, the subsequent distraction will merely pull the limbs of the kyphos apart without necessarily improving the angle of the deformity. A thin bridge of bone must initially connect the limbs of the kyphos so that distraction will hinge the kyphos open.

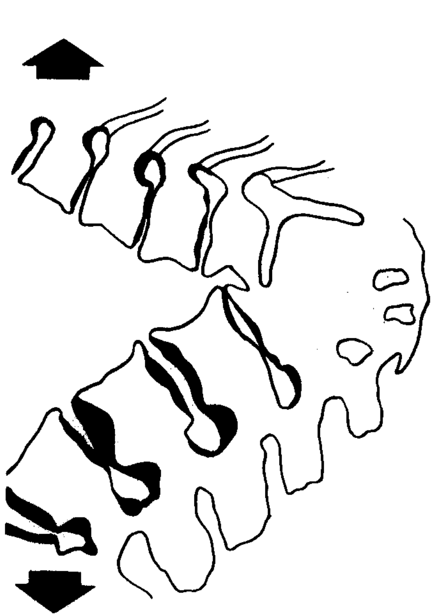

Figure 13 a. Pre-operative tracing. Correction requires forces applied in the direction shown by arrows.

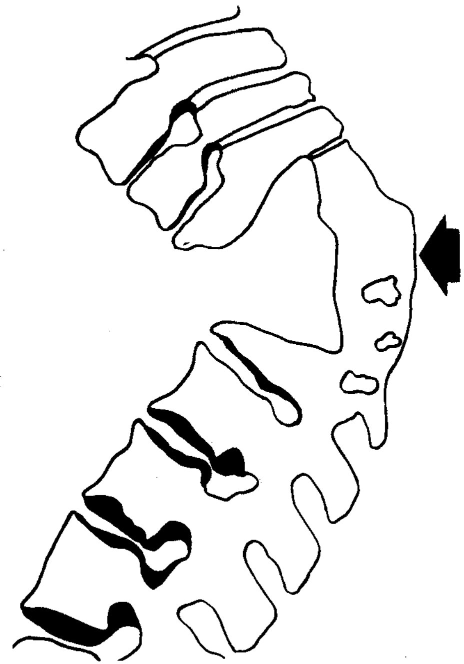

Figure 13 b. Tracing towards completion of distraction. Corrective force is now applied over the external kyphos (arrow).

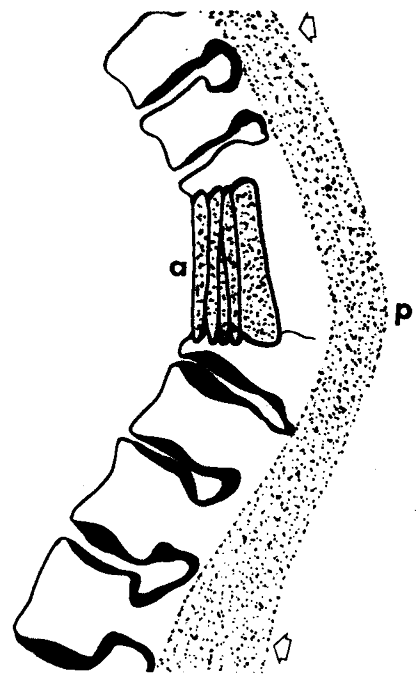

Figure 13 c. Tracing after anterior (a) and posterior (p) fusions. Note extent of posterior fusions (arrows) and bulk of anterior bone graft.

Figure 13. Case 23 - Tuberculous kyphosis. Tracings of lateral radiographs before, during and after surgery. Technique used was method of treatment (c); see text.

No osteotomies were performed in five patients (cases 14, 22, 25, 30, 32), as they had relatively mobile and less marked deformities associated with active disease in the spine (their average age was 7 years). Following very carefully supervised distraction they subsequently had anterior and posterior fusions.

A one-staged osteotomy was used in 12 patients and a two-stage osteotomy in 20 patients. 6 of these 20 patients had combined posterior osteotomies and fusions. Two patients required revision of the osteotomies in order to mobilise the deformities sufficiently for distraction to be effective.

Two patients had an anterior spinal fusion alone (cases 3, 6); the remaining patients had anterior and posterior fusions. In several cases the latter was done when loss of correction had already occurred. In order to maintain the correction achieved, a double fusion is mandatory, especially in those patients with severe deformities.

Post-operative management

Following the last operation, the patients were maintained in the halo-pelvic apparatus until the grafts had consolidated. Initially this period of time was usually up to 6 months, but it has been reduced more recently because of the higher incidence of cervical spine complications associated with prolonged immobilisation. Following removal of the halo-pelvic apparatus under general anaesthesia the patients remained in bed for one week, until the pin site wounds had healed and a full length body cast was applied to provide a total period of immobilisation of twelve months.

RESULTS - TUBERCULOUS KYPHOSIS (Table 2)

Of the 42 patients, 3 died as a result of surgery, 2 had the apparatus removed early and in one case, it was used as a holding device. The remaining 36 patients were followed for an average of 2.9 years (range 1.25 to 4.5 years).

TABLE 2

TUBERCULOUS KYPHOSIS

Case number	Pre-op. degree (average)	Maximum correction Average	As a %	Follow-up Correction (average)	Length of time in years
1 to 10	117°	to 80° (Corr. of 37°)	32%	93° (Loss of 13°)	3.9
11 to 20	114°	to 70° (Corr. of 44°)	39%	77° (Loss of 7°)	3.1
21 to 27	106°	to 73° (Corr. of 33°)	32%	76° (Loss of 3°)	2.5
31 to 39	128°	to 101° (Corr. of 27°)	22%	104° (Loss of 3°)	1.7
Total number of patients 36	117°	to 81° (Corr. of 36°)	31%	88° (Loss of 7°)	2.9

There were no figures to indicate that deformities more proximal in the spine achieved better correction, because the variables were so great: age, activity of disease and previous surgery, etc. From a mechanical point of view, however, it is apparent that the more proximal regions in the spine have greater forces applied in the halo-pelvic apparatus and the clinical impression is that the younger the patient, the more active and the more recent and the more proximal the disease, the greater the correction with the halo-pelvic apparatus.

The average pre-operative angle of kyphosis was 117 degrees and after correction and fusion the average angle was 81 degrees representing a correction of 36 degrees (or 31 per cent). As most deformities were in the thoracic spine, where the normal kyphosis measures from 20 to 40 degrees (54), this correction is in fact better than it would seem from the angular measurements alone. At follow-up of the 36 patients, three years later, there was an average loss of 7 degrees of correction. The final correction was 30 degrees (or 26 per cent).

Various factors were analysed to determine whether they had any significant influence on the final result and the correction achieved. The younger patients who had active disease had a significantly better correction. Those who had a more extensive mobilising excision of the internal kyphosis likewise had a better correction, as would be expected. Surprisingly there was no difference between those patients who had had previous spinal fusions, and those who had no previous surgery.

The patients (1) who had had previous fusions and (2) those without previous surgery were analysed separately. Those with previous fusion (11 patients) had a pre-operative angle of 116 degrees corrected to 78 degrees (a correction of 38 degrees or 33 per cent) with a loss at follow-up of only 3 degrees.

Those who had not had previous surgery (25 patients) had a pre-operative angle of kyphosis of 118 degrees corrected to 84 degrees (a correction of 34 degrees or 29 per cent). At follow-up a final correction of 89 degrees or a loss of 5 degrees was measured. There was thus no marked difference in the end result whether the patient had had previous fusion or not.

The patients were taken in four separate chronological groups (see Table 2), to evaluate whether significant improvement in either the techniques of surgical mobilisation or use of the halo-pelvic apparatus had occurred with increasing experience. The average pre-operative angle of kyphosis was approximately the same and the degrees of correction were similar in the first three groups. However, the smaller correction in the fourth group (cases 31 to 39) reflected the greater deformity in those patients who have been treated latterly.

Loss of correction after surgery

More than 10 degrees of loss occurred in 4 patients. One expects to lose no more than 5 degrees if the basic rules are adhered to and if the bone grafts have been protected for a sufficient period of time. Loss of correction in several of the early patients was due to failure to carry out a routine posterior fusion. The average loss of correction was 7 degrees.

There was one pseudarthrosis in this group, probably caused by a posterior fusion too short to protect the vulnerable anterior grafts (case 18).

The average number of anterior spinal grafts used was 5 (usually rib struts), but in several of the patients with lumbar lesions, blocks of iliac crest were used. The average length of the anterior spinal graft as measured on the first post-operative radiographs was five centimetres.

Minimal loss of correction occurred under the following circumstances:
1) where anterior and posterior fusions were done;
2) an adequate period of immobilisation in the halo-pelvic apparatus;
3) where a sufficient volume of autogenous bone graft was used;
4) when the posterior fusion extended proximally and distally well into the secondary lordotic curves (which were also corrected significantly with distraction);
5) when the sites of the posterior osteotomy were sufficiently covered with bone graft.

The following case report is included to demonstrate the principles involved in correcting tuberculous kyphoses. A fifteen year old male patient (case 20) had a kyphotic deformity of 121 degrees and clinical signs of spinal cord compression (Fig. 14 a). The treatment programme included (1) excision of the entire internal kyphos to decompress the cord and mobilise the deformity, (2) gradual distraction (one to two millimetres per day) followed by (3) posterior osteotomies and a fusion. Finally, rib grafts were placed under compression into the

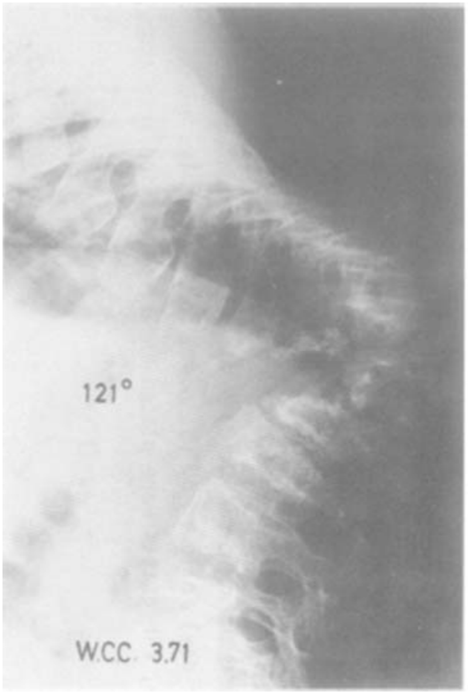

Figure 14 a. Lateral radiograph before correction.

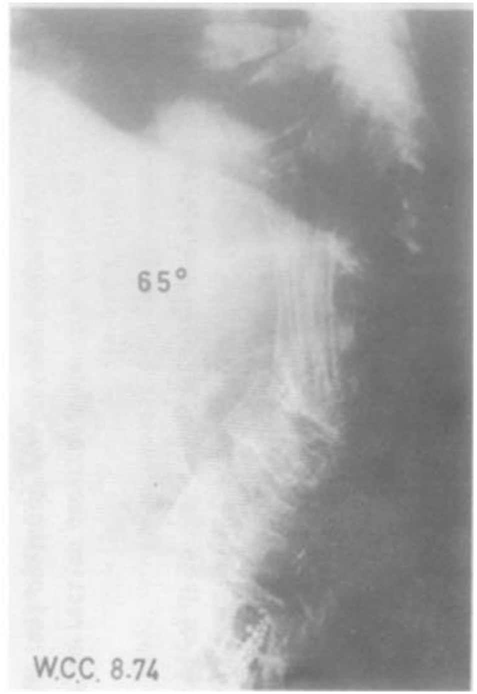

Figure 14 b. Lateral radiograph three years and five months after surgery. No loss of correction has occurred.

Figure 14 (a) and (b). Case 20. Tuberculous kyphosis in a fifteen year old male patient.

anterior interbody gap. At follow-up three years and five months later the correction of 65 degrees had been maintained (Fig. 14 b).

Neurological and cervical spine complications

16 patients had clinical evidence of marked spinal cord compression before surgery, 13 were completely relieved of their spasticity. 3 patients were paraplegic after surgery (cases 31, 34, 36); the pre-operative clinical condition indicated that they had penetration of the spinal cord by the tuberculous disease process (28), and this was confirmed at the time of posterior surgery in two of the patients where tuberculous follicles were detected on the dura mater.

During the course of correction, 2 patients developed increased spasticity; with the combination of close observation and the ability to release the distraction immediately, the tension on the cord was reduced and the spasticity in both patients subsided.

30 patients had cervical spine radiographs available. 14 of these patients (47 per cent) developed cervical spine complications as a result of distraction in the halo-pelvic apparatus. These and the neurological complications mentioned above will be discussed in full detail in the section on complications.

SUMMARY AND CONCLUSIONS

42 patients with tuberculous kyphosis were treated by osteotomies, correction with the halo-pelvic apparatus and fusions.

The average follow-up of these patients was 2.9 years (range 1.25 to 4.5 years). The average initial correction of the kyphos was 36 degrees. 3 patients died following surgery, all of them with severe deformities and respiratory insufficiency.

3 patients with penetration of the cord by the disease process and near complete paraplegia were completely paraplegic after spine surgery.

Late neglected kyphotic deformities have associated cord compression and respiratory insufficiency. They can only be corrected with any safety by multiple staged operations and with gradual distraction before fusions are done. The halo-pelvic apparatus provides the stability necessary for this programme of management and does not interfere with the respiratory impairment from which these patients suffer.

2. PARALYTIC SCOLIOSIS

Introduction

31 patients with paralytic scoliosis commenced treatment in the halo-pelvic apparatus. There were 15 males (average age 13.0 years) and 16 females (average age 15.1 years).

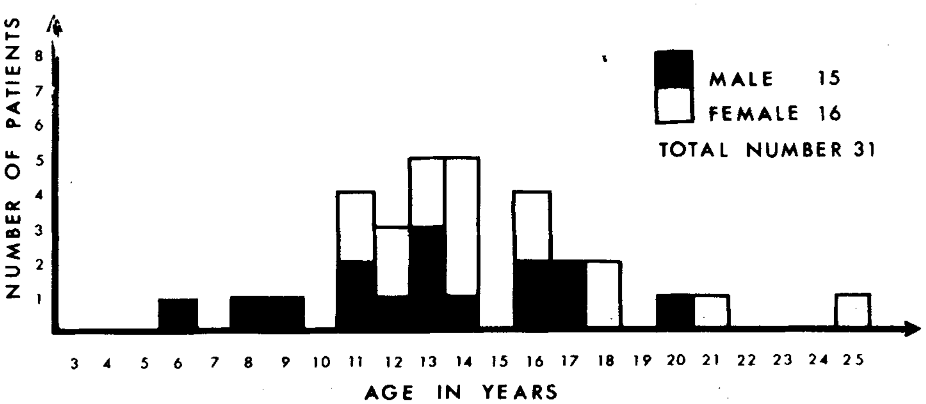

Figure 15. Paralytic scoliosis. Barograph demonstrating the age and sex of patients.

The average age of the patients was 14.1 years (see Fig. 15). Three patients required removal of the apparatus before treatment had been completed (see Complications), four had had previous fusions which required osteotomy before correction; they will be discussed separately ("Salvage group").

The average period of time in the apparatus for the paralytic scoliosis patients was 7.6 months (Fig. 16).

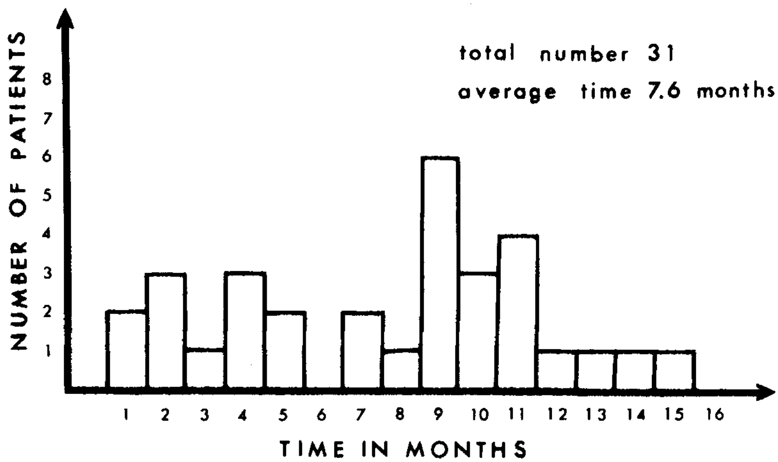

Figure 16. Paralytic scoliosis. Barograph to show the time spent in the halo-pelvic apparatus. The average time was 7.6 months.

Site and extent of deformity

The curve types were as follows: thoracic, 13 patients; thoraco-lumbar, 12 patients; lumbar, 6 patients. The average major curve measured 111 degrees (range 59 to 164 degrees); the average flexibility with suspension was 25 per cent. These measurements were made from radiographs taken with the patient suspended from a head halter, a posture maintained without discomfort for several seconds.

An average number of 9 vertebrae was involved in the major curve (range from 6 to 14 vertebrae). The barograph (Fig. 17) confirmed that the most common vertebrae involved were thoracic 10 and 11, with a high incidence of lumbar vertebrae in the major curve.

Paralytic pelvic obliquity will be discussed separately, as it is felt that this deformity is major enough to warrant separate consideration.

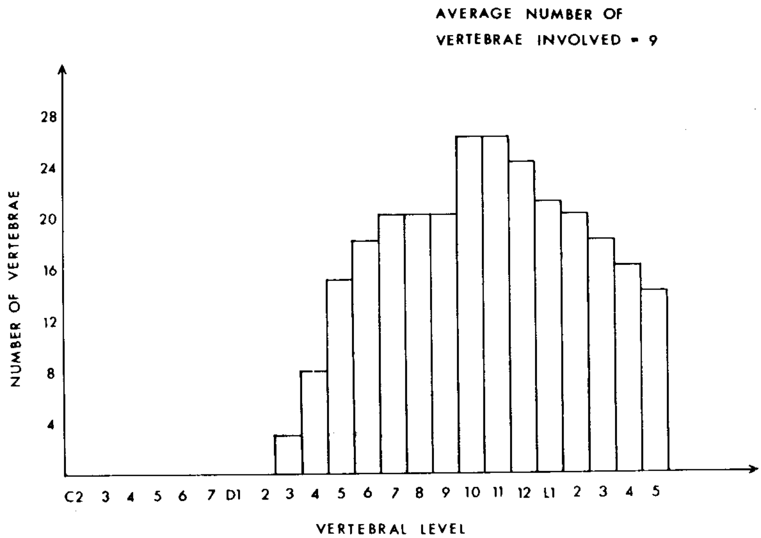

Figure 17. Barograph to demonstrate the vertebrae included in the major curve in paralytic scoliosis.

Respiratory insufficiency

Although the association of paralytic spinal deformities with depleted lung function presents one of the major hazards in this field of work (23), this paper will not deal in any detail with the problem of respiratory insufficiency. The accurate assessment of lung function before, during and after surgery is a vital aspect of the general management of these patients. Supportive respiratory therapy before and during surgery, the need for tracheostomy, assisted respiration after surgery, the practicability of an anterior approach and the advisability of staging long spinal fusions are all questions which require to be evaluated in collaboration with a respiratory physician.

Severe respiratory insufficiency was most commonly seen in patients whose curves were collapsing or situated in the thoracic spine. Whilst post-operative respiratory function tests did not always indicate a great improvement in lung function, the patients were subjectively much better because they required less effort and energy with sitting or walking, once the spine had been centred and stabilised over the pelvis.

Other surgery involved

Of the 31 patients with paralytic scoliosis only 8 did not require associated surgery for their limb deformities. The majority required extensive surgery for correction of hip and knee contractures, the result of long standing poliomyelitis. The general aim of the treatment was to make the patient as independent as possible, and to allow him to sit or walk with the minimum possible effort required.

METHODS OF TREATMENT

The treatment programme (Table 3) included correction with the halo-pelvic apparatus followed by:

A) posterior fusion without a Harrington rod (11 patients);

B) posterior fusion with a Harrington rod (3 patients);

C) Dwyer's operation and the supplementary posterior fusion without a rod (5 patients);

D) Dwyer's operation and posterior fusion with rodding (3 patients);

E) posterior releases without fusion followed by Dwyer's operation (2 patients).

The 7 patients not accounted for in this treatment summary were as follows:

a) three patients had early removal of the halo-pelvic apparatus;

b) four patients who had osteotomy and correction of previous posterior fusion masses will be considered later together with a similar number of idiopathic cases in the so-called "Salvage group".

The patients who had the halo-pelvic apparatus removed prematurely had a combined staged anterior (Dwyer) and posterior correction and fusion (2 patients), except for one (aged six years) who has not yet had surgery.

A preference for supplementary anterior surgery

With 51 per cent (average) correction of a paralytic scoliosis possible with the halo-pelvic apparatus (range 24 to 81 per cent)

TABLE 3

PARALYTIC SCOLIOSIS - RESULTS

Group	Type of treatment	No. of patients	Pre-operative degree	Correction with halo-pelvic apparatus (degrees)	(%)	Correction with Dwyer's instrumentation	Final correction at follow-up (average 3.3 years)(degrees)
A	P.S.F. without Harrington rod	11	115^0	to 57^0	51%	-	73^0 (Loss of 16^0)
B	P.S.F. with Harrington rod	3	100^0	to 45^0	55%	-	51^0 (Loss of 6^0)
C	Dwyer, P.S.F. without Harrington rod	5	113^0	to 54^0	51%	41^0 (64%)	42^0 (Loss of 1^0)
D	Dwyer, P.S.F. with Harrington rod	3	110^0	to 56^0	49%	31^0 (72%)	36^0 (Loss of 5^0)
E	Dwyer with posterior osteotomies (no fusion)	2	112^0	to 66^0	41%	57^0 (49%)	74^0 (Loss of 17^0)

and little further correction possible with the Harrington rod, the addition of the anterior approach seemed appropriate in many cases. Further correction with Dwyer's instrumentation should be considered when the patient's type of scoliosis and his respiratory function deem it advisable. A posterior fusion with rodding was then done to include the entire deformed spine (47). Further correction with Harrington's instrumentation was often neither possible because of osteoporosis nor was it advisable because of an already taut spinal cord.

RESULTS

24 patients with paralytic scoliosis not previously treated had an average pre-operative curve of 111 degrees corrected by the halo-pelvic apparatus to 55 degrees, an average correction of 51 per cent.

The average length of follow-up was 3.3 years and the average loss of correction was 10 degrees.

These patients have been grouped according to the type of surgery which they had undergone (Table 3). Group A (11 patients) had a posterior fusion without rodding. Their average pre-operative curve was 115 degrees which corrected to 57 degrees with distraction, a correction of 51 per cent. Their average loss of 16 degrees at the follow-up is a reflection of the failure to use internal fixation.

Group B (3 patients) had posterior fusions with rodding following maximal correction with the halo-pelvic apparatus. Their curve averaged 100 degrees, and it corrected to 45 degrees with distraction, representing a correction of 55 per cent. Their loss of correction at follow-up was only 6 degrees, and the advantage of internal fixation is apparent when compared with Group A.

Group C (5 patients) had Dwyer's instrumentation following distraction, and subsequently a posterior fusion without rodding. They had an average curve of 113 degrees corrected to 54 degrees with distraction, an average of 51 per cent correction. The Dwyer's operation achieved a total correction of 64 per cent; the loss of correction at follow-up averaged only 1 degree.

Three patients in Group D (Dwyer's, posterior fusion and rod) with an average curve of 110 degrees corrected to 56 degrees with distraction (49 per cent correction). With Dwyer's operation this was increased to 72 per cent correction with an average loss of 5 degrees at follow-up.

Two patients in Group E (posterior osteotomies, distraction and Dwyer's operation) with an initial average curve of 112 degrees had an initial correction of 41 per cent with distraction and a total correction of 49 per cent following Dwyer's instrumentation. They lost correction because supplementary posterior fusions were not done. The average loss of correction of 17 degrees at the time of follow-up demonstrates this point amply.

Functional improvement

Seven patients had not been able to walk before surgery because of gross deformities and paralysis in their lower limbs, associated with severe collapsing scoliosis. A further seven patients could walk with the aid of long braces and elbow crutches, but their walking required such an enormous effort that they preferred a wheelchair existence. Of the seven patients who had no walking potential at all, two were made to walk by stabilisation of the spine and correction of the pelvic obliquity, together with multiple operations on the lower limbs. The other five patients were far too extensively involved ever to walk, but as a result of surgery their sitting balance has improved to the point where they do not need their upper limbs for trunk support. They are therefore free to sit in a suitable chair at a bench and employ themselves gainfully.

Major loss of correction

Seven patients lost more than 10 degrees of correction at the time of follow-up. Failure to use internal fixation was responsible for this loss in correction in five of these patients, the other two had Dwyer's operation without posterior fusions (cases 46, 50).

Exploration for pseudarthrosis

Sixteen patients had routine exploration of their posterior fusion masses at least six months after the fusion had been done. Fifteen of them were judged to be solid. A pseudarthrosis was repaired in one patient and a Harrington rod was then inserted to protect the newly-added bone graft (case 64).

One patient, in whom a Harrington rod was not used, developed a pseudarthrosis eighteen months after immobilisation had been discontinued. She subsequently had the pseudarthrosis repaired, and underwent a supplementary anterior fusion, because of the increasing kyphotic deformity which developed at the level of pseudarthrosis (case 51).

One patient, in whom a Harrington rod had not been used, had radiological evidence of a pseudarthrosis, but she declined further surgery. The result was an increase in her lumbar curve which has now stabilised; the pseudarthrosis healed spontaneously and there has been no increase in the curve beyond the original pre-operative deformity four years after surgery (case 47).

In summary, a pseudarthrosis was found in only one of the sixteen patients with paralytic scoliosis routinely explored, although only three of these patients had Harrington rods supporting the fusion masses; this would appear to be clinical confirmation of the inherent stability of the halo-pelvic apparatus.

PELVIC OBLIQUITY

Eleven patients with paralytic scoliosis had pelvic obliquity (Table 4). The range of obliquity was from thirty to seventy degrees, an average of forty-nine degrees. The "angle of pelvic obliquity" was measured from an antero-posterior radiograph with the patient seated. It is the angle subtended by the line drawn across the top of the first sacral vertebral body with the horizontal.

Results

Pelvic obliquity was corrected from forty-nine degrees (average) to fourteen degrees (average), a correction of 72 per cent. At follow-up (average 3.3 years later), there had been an average loss of 5 degrees. The final correction of pelvic obliquity was therefore sixty-two per cent. Only two of the eleven patients had pelvic obliquity initially fully corrected by the apparatus (Table 4)(see Figs. 36 a to d, page 106). Pelvic obliquity is a common accompaniment of paralytic scoliosis (11 out of 31 patients). It is seen with muscle imbalance above or below the pelvis (or both).

TABLE 4

PELVIC OBLIQUITY

No. of patients	Case No.	Pre-operative degree*	Post-traction degree	Correction maintained at follow-up (average 3.3 years)(degrees)
1	46	60	30	42
2	52	63	10	25
3	54	60	0	0
4	56	50	10	10
5	60	40	14	14
6	62	30	20	20
7	63	30	17	17
8	67	40	28	28
9	69	70	10	30
10	71	60	18	18
11	72	35	0	10
Average		49^{0}	14^{0} (72%) (correction of 35^{0})	19^{0} (62%) (loss of 5^{0})

*See text for definition of "The angle of pelvic obliquity" (page 63).

When there is muscle imbalance above the pelvis, for example, with unilateral paralysis of the lateral trunk flexors, a progressive form of scoliosis with pelvic obliquity will develop which in its fully advanced form will lead ultimately to a dislocated hip (Figs. 18 a and b).

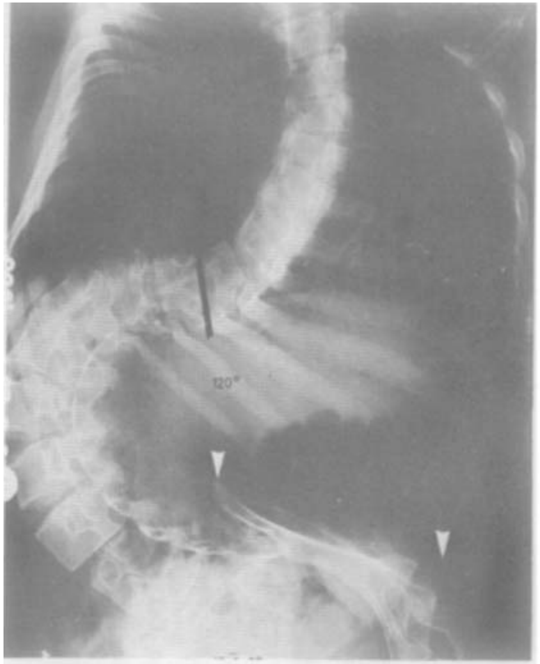

Figure 18 a. Case No. 46. Severe collapsing scoliosis in a seventeen year old male patient. Gross pelvic obliquity and dislocating left hip joint. Note that the left iliac crest is almost horizontal and that the left hip joint is totally uncovered (arrow).

Figure 18 b. Case No. 46. Following gradual distraction, the scoliosis was reduced from 120^{o} to 55^{o} and the pelvic obliquity significantly but not totally corrected (arrow). Further correction of the pelvic obliquity and scoliosis can only be obtained with anterior surgery.

Halo-pelvic distraction is a satisfactory method of reducing the scoliosis-pelvic obliquity complex when it is due to paralytic contracture. For those patients with walking potential the fullest possible correction of obliquity is an essential aspect of their management. A scoliosis fused with thirty degrees of residual spinal curvature will not be particularly significant but thirty degrees of residual pelvic obliquity will be disabling because of the extent to which the higher hip joint has been uncovered. For patients with limited walking potential, covered hip joints are essential.

The reason for this inability to correct pelvic obliquity totally with halo-pelvic distraction (only 2 out of 11 had total correction of the obliquity) is as follows: whilst the soft tissues on the concavity of the scoliosis are shortening, there is increased compression on the concave aspects of the vertebral end plates reducing growth. Less compression on the convex sides of the end plates of the vertebral bodies produces relatively more growth; the end result is that the vertebral bodies become wedge shaped. Halo-pelvic distraction will overcome the soft tissue contracture but will not alter the shape of the vertebral bodies; this can only be refashioned by a direct approach; ideally by Dwyer's anterior instrumentation (Figs. 19 a and b).

With preliminary traction followed by Dwyer's anterior instrumentation, the pelvic obliquity can in many cases be totally corrected. When the scoliosis includes the fifth lumbar body, the anterior instrumentation should extend as far distally. Extensive posterior fusion extending to the sacrum is then required to avoid a recurrence (38).

Should one consider using halo-pelvic distraction in pelvic obliquity, the altered anatomy of the iliac crests must be taken into consideration. There is a definite risk of perforation of the intestines when inserting the pelvic pins in such patients. The thoracic cage may often be intra-pelvic in the extreme types and the safest method, if the halo-pelvic apparatus is to be used, may be firstly to apply halo-femoral traction so that part of the obliquity can be overcome, before inserting the pelvic pins which can then be done with greater safety.

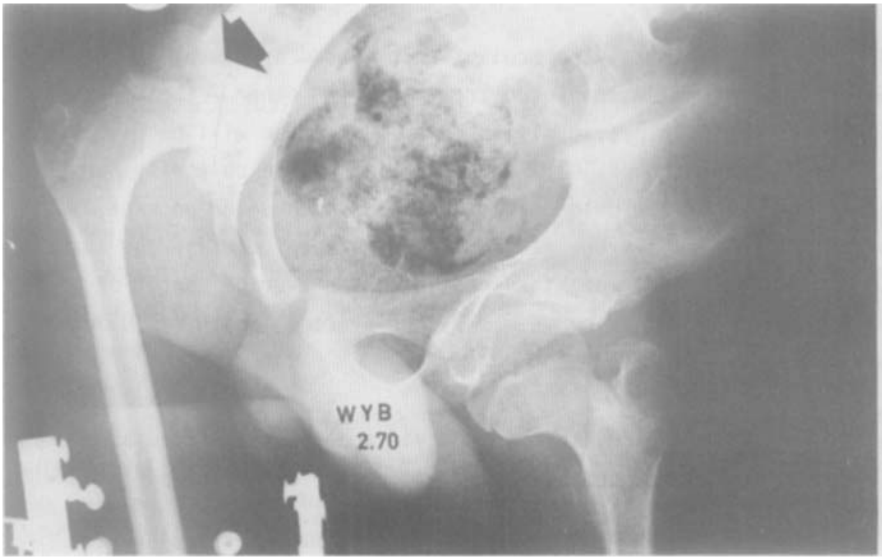

Figure 19 a. Pre-operative standing radiograph. Note the dislocating right hip joint (arrow) associated with the pelvic obliquity.

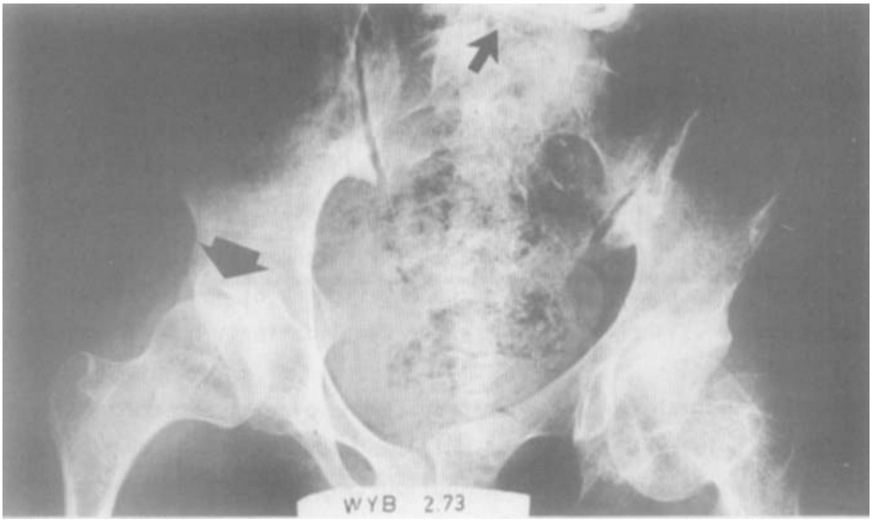

Figure 19 b. Anterior-posterior radiograph three years after corrective surgery (Dwyer's anterior surgery distally to L5 and posterior spine fusion). Note the right hip joint is now reasonably well covered (large arrow). The pelvic obliquity has been well corrected and fusion extends to the sacrum (small arrow).

Figure 19 (a) and (b). Case 56. Fourteen year old male patient with severe lumbar scoliosis and pelvic obliquity.

SUMMARY AND CONCLUSIONS

31 patients with paralytic scoliosis commenced treatment in the halo-pelvic apparatus. 24 completed treatment; the other 7 included:
1) 4 patients with previously fused spines; these will be discussed in the "Salvage group". 2) 3 patients with pelvic obliquity had early removal of the halo-pelvic apparatus because of poor pelvic pin fixation. The average flexibility was 25 per cent in the suspension film (full body weight suspension); the average number of vertebrae in the major curve was 9. The average length of follow-up was 3.3 years.

As a correcting device, the halo-pelvic apparatus achieved an average correction of 51 per cent (range 24 to 81 per cent) for patients with an average paralytic scoliosis of 111 degrees.

The actual methods of fusion were: posterior fusion without rodding, 11 patients; and with rodding, 3 patients. Posterior fusion without rodding and with a supplementary Dwyer's operation, 5 patients; posterior fusion and rodding with Dwyer's operation, 3 patients, and Dwyer's operation with posterior osteotomies, 2 patients.

The average loss of correction was 10 degrees. The loss tended to be less in those patients with internal fixation and those where supplementary anterior surgery (Dwyer instrumentation) was employed.

40 per cent of the patients with paralytic scoliosis whose cervical spine radiographs were reviewed showed evidence of degenerative changes; they will be discussed under Complications.

11 patients in the series treated by the halo-pelvic apparatus had associated pelvic obliquity. In only two was that obliquity totally corrected initially. When pelvic obliquity is present and has not been sufficiently corrected, Dwyer's anterior instrumentation should be considered because of the importance of adequately covering both hip joints, particularly in patients with walking potential.

The available evidence suggests that the halo-pelvic apparatus can be relied on to achieve an initial average correction of 51 per cent in paralytic scoliosis and 71 per cent of associated pelvic obliquity. It has a significant part to play in those patients with poor respiratory reserve.

3. IDIOPATHIC SCOLIOSIS

Introduction

There were 15 patients with idiopathic scoliosis treated by the halo-pelvic apparatus. 4 patients had had previous surgery (cases 75, 82, 86, 87, see appendix B) and they will be discussed separately in the "Salvage group".

There was 1 male and 14 females and their average age at the time of surgery was 15.6 years. The average time spent by these patients in the halo-pelvic apparatus was 6.4 months (range 1 to 12 months)(Fig. 20). Their follow-up ranged from 1.5 years to 3 years (average 2.4 years).

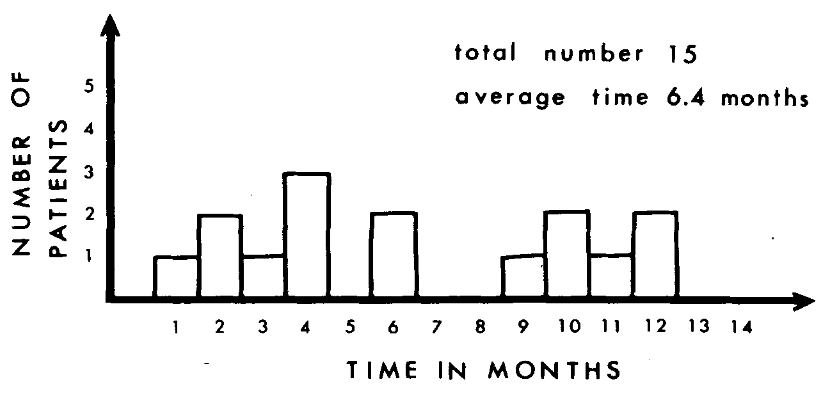

Figure 20. Idiopathic scoliosis. Barograph demonstrating the time spent by the patients in the apparatus. Average time was 6.4 months.

The average curve before surgery, measured from pre-operative standing radiographs, was 82 degrees (range 47 to 97 degrees). Barograph of the vertebrae included within the major curve (Fig. 21) demonstrates that the vertebral levels T10 and T11 were the most frequently involved. An average of seven vertebrae were included in each major curve.

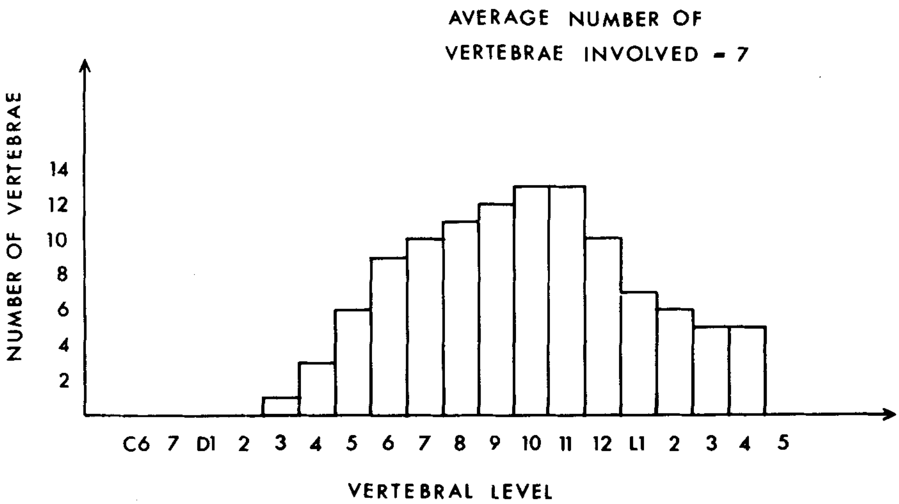

Figure 21. Barograph to demonstrate the vertebrae involved in the major curve in idiopathic scoliosis. The average number of vertebrae involved was 7.

The indication for the use of the apparatus in this series was, in most instances, a rigid deformity associated with a marked rotational component. The average age of the patients (15.6 years) suggests that the deformity had been present for some years and had developed significant vertebral body wedging which cannot be corrected by distraction.

METHODS OF TREATMENT

Halo-pelvic distraction over an average period of nine weeks (range 3 to 10 weeks) was followed by a one-stage posterior fusion in seven patients, and a two-staged posterior fusion in one patient (case 74 with a double primary curve of 97 degrees). Harrington rods were used in five of the eight patients without further significant correction, the principle being to achieve the major correction before surgery. Following distraction, three patients had Dwyer's anterior instrumentation without posterior fusion.

RESULTS

The average curve after distraction measured 48 degrees, a correction of 42 per cent. The best final corrections were obtained in the two patients (cases 78, 85, lumbar scoliosis) who had Dwyer's instrumentation performed after distraction. Both corrected to zero. The third patient with Dwyer's instrumentation had a thoracic scoliosis which lost nine degrees of correction after surgery.

One patient (case 81), in whom the upper hook slipped out, lost 17 degrees of correction. Two patients, in whom internal fixation was not used (cases 76, 77), lost 10 degrees of correction. Case 77 actually lost correction whilst in the apparatus for a period of 10 months. Loss of correction will be discussed under Complications (Part II, Chapter II).

Nine patients had cervical spine radiographs taken - four patients (44 per cent) developed cervical spine complications as the result of the halo-pelvic distraction; these will be discussed more fully in the section dealing with complications.

SUMMARY - IDIOPATHIC SCOLIOSIS

Eleven patients with idiopathic scoliosis who had not had previous surgery had their curves corrected before fusion by the halo-pelvic apparatus. Their average age was 15.6 years and the average major curve measured 82 degrees. The average correction was 42 per cent and following this, eight patients had posterior surgery, with or without internal fixation, whilst three had Dwyer's anterior instrumentation performed.

4. CONGENITAL KYPHOSCOLIOSIS

Clinical material

There were ten patients with congenital spinal deformities, four males and six females; one patient died with respiratory failure after surgery. The average age at the time of surgery was 13.8 years (range 10 to 19 years). Two patients were paraplegic on admission; one of them became paraplegic when correction of the deformity was attempted on a standard traction table in another centre. The average time in the halo-pelvic apparatus for these patients was 5.5 months (range 3 to 9 months) (Fig. 22).

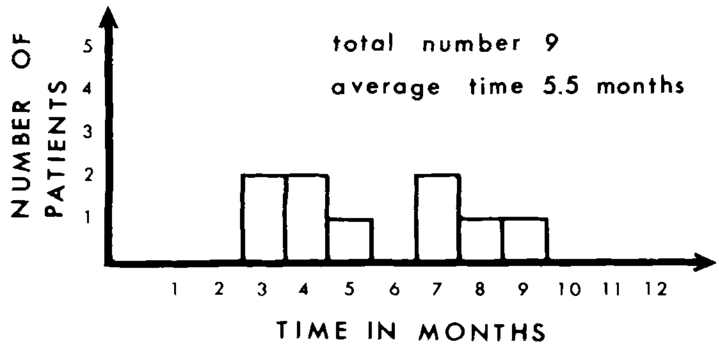

Figure 22. Congenital kyphoscoliosis. Length of time in halo-pelvic distraction.

The average degree of scoliosis measured was 98 degrees. The halo-pelvic apparatus was used as a means of external spine fixation in two patients, to provide stability after surgery, so that in neither case was any correction attempted.

METHODS OF TREATMENT

The two patients with congenital deformities and cord compression had decompression done. Eight patients had mobilising osteotomies and five subsequently had staged anterior and posterior fusions following distraction. Two patients had Harrington rods inserted and one had a Dwyer's instrumentation performed.

RESULTS

The percentage correction in the congenital deformities was 26 per cent (range from 6 to 48 per cent).

One patient developed a pseudarthrosis which required further surgery (case 97). This patient's curve deteriorated finally to its pre-operative level of deformity.

5. NEUROFIBROMATOSIS

Clinical material

Six patients with neurofibromatosis were treated with the halo-pelvic apparatus, two males and four females. Three of the six patients were paraplegic on admission, following previous surgery; they had been paraplegic for one week, three weeks and five months, respectively.

The average length of time in the halo-pelvic apparatus was 8 months (Fig. 23), the average length of follow-up was 3 years (range 2 to 4 years).

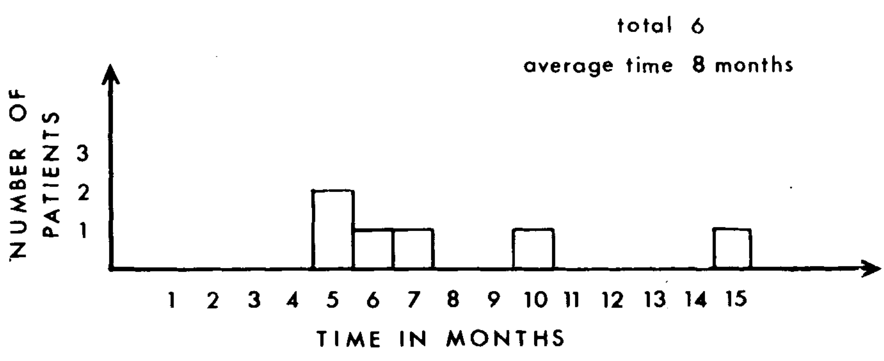

Figure 23. Neurofibromatosis. Length of time in halo-pelvic traction.

The average number of vertebrae involved in the major curve was 8; the barograph demonstrates a peak of vertebral involvement at thoracic 9, 10 levels (Fig. 24).

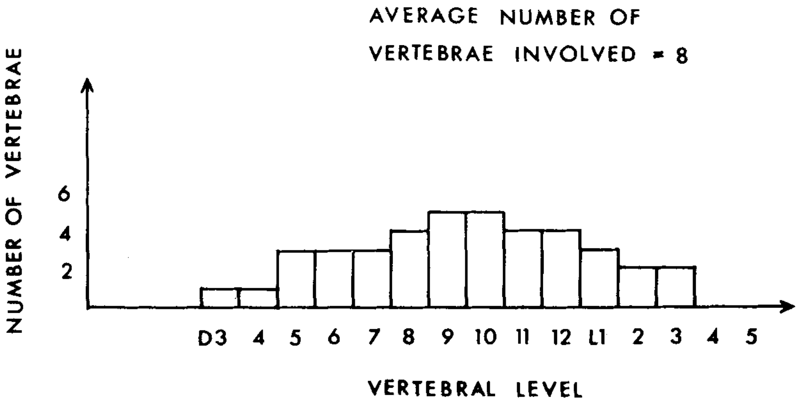

Figure 24. Neurofibromatosis. Barograph to demonstrate the vertebrae involved in the major curve.

METHOD OF TREATMENT

Of the six neurofibromatosis patients, the three who were paraplegic on admission had anterior decompression done, followed by anterior fusion (after distraction in two patients).

The three patients without cord decompression had staged anterior and posterior fusions following distraction (2 patients) and a posterior fusion following distraction (1 patient).

RESULTS

The average correction of patients with neurofibromatosis deformities was 43 per cent (range 6 to 85 per cent). Of the three patients who were paraplegic on admission, two recovered cord function and were able to walk 6 months after decompression and fusion. The third patient (case 99) had been paraplegic for five months before surgery, by which time her cord function was irreversible.

The loss of correction, even after anterior and posterior fusions, was significant. Whilst initial corrections were good, the subsequent loss of correction left much to be desired, confirming the tendency of patients with this syndrome to deteriorate, in spite of staged anterior and posterior fusions. Eighteen months after surgery, case 102 lost 50 degrees of correction with stress fractures through both anterior and posterior grafts which occurred despite radiologically sound fusions.

SUMMARY AND CONCLUSIONS - CONGENITAL AND NEUROFIBROMATOSIS KYPHOSCOLIOSIS

Fifteen patients with congenital or neurofibromatosis spinal deformities completed treatment in the halo-pelvic apparatus. One patient died after surgery because of respiratory failure. Five of the fifteen patients (33 per cent) had cord compression or frank paraplegia at commencement of treatment. Two of these patients had had previous extensive laminectomies performed. The basic plan of treatment depended on the basic configuration of the spinal deformity and the presence or not of spinal cord compression. Following decompression (when it was required) anterior and posterior fusions were used in the majority of patients. In the congenital curves the average correction of the deformity was 26 per cent and in the neurofibromatosis patients the average correction was 43 per cent. All had complete or near complete return of cord function and could walk six months after spinal surgery except for case 99 where complete paraplegia had been present for five months before treatment (5 years later she had shown no further recovery).

Many of the associated conditions represented by this group of patients present ideal indications for the use of halo-pelvic apparatus, namely: spinal cord compression, gross spinal curvatures, an unstable spine secondary to extensive laminectomies and the association of respiratory impairment.

6. SALVAGE GROUP

Eight patients with previous posterior spinal fusions for scoliosis were treated by the halo-pelvic apparatus.

The average time in the apparatus was 6.5 months. The average pre-operative curve in this group was 88 degrees. Two patients excluded from the average include case 73, who had initial correction following osteotomies with halo-femoral traction, and case 61, whose basic deformity was a kyphosis, which developed acutely at the site of a pseudarthrosis (paralytic scoliosis). The average follow-up was 2.5 years (range 1.5 to 4.7 years).

METHOD OF TREATMENT

Following fitting of the apparatus the previous fusion mass was explored and any metal present was removed. Usually a Harrington rod, if it had been used, had fractured at the site of pseudarthrosis and had caused loss of correction. Osteotomies were done at the apex of the curve and distraction was applied over the next few weeks.

At re-operation the osteotomy sites were grafted and internal fixation with the Harrington rod was used (four patients). Three patients had supplementary anterior fusions performed (Table 5).

RESULTS

The average curve after correction was 52 degrees, a correction of 40 per cent. An average of two spinal operations was performed per patient. The one specific problem in using the halo-pelvic apparatus in this group of salvage cases was that the pelvic pins precluded the use of graft from the posterior parts of the iliac crests. It is in these patients, however, that large blocks of cancellous bone grafts are often required to plug the gaps created at the levels of the fusion mass osteotomies.

This factor, however, may be of minor importance relative to the major values offered by the halo-pelvic apparatus in certain situations, particularly that of associated pelvic obliquity and respiratory insufficiency.

TABLE 5

CORRECTION OF PREVIOUS FAILED FUSIONS ("SALVAGE GROUP")

TABLE 5

CORRECTION OF PREVIOUS FAILED FUSIONS ("SALVAGE GROUP")

No.	Sex/Age	Number of operations	Operations performed	Time in HPT (months)	Correction (degrees) From	To	%	Final (degrees)	Length of follow-up (years)
A. PARALYTIC SCOLIOSIS									
43	M/11	2	SO						
			PSF	7	97	74	24%	97	4.75
61	F/18	2	ASF						
			PSF (rod)	7	28	20	29%	20	3.0
70	F/13	4	PSO (2 stages)						
			PSF (2 stages with rod)	8	110	50	55%	70	2.0
73	F/14	2	PSO) Comb. PSF)	3	Holding				1.5
			ASF						
B. IDIOPATHIC SCOLIOSIS									
75	F/18	1	PSF	12	75	33	56%	33	3.0
82	F/9	2	ASF	9	94	57	39%	57	2.0
86	F/15	1	PSO + (one stage with rod)	3	62	52	16%	52	2.0
87	F/13	2	PSO						
			PSF (rod)	4	92	48	48%	48	1.5

SUMMARY AND CONCLUSIONS - SALVAGE GROUP

Eight patients with previous posterior fusions for scoliosis had the halo-pelvic apparatus used in their treatment. In two it was used for external skeletal fixation, and in six patients to correct deformities following osteotomies and prior to fusions. Three patients had supplementary anterior fusions. The average correction with the halo-pelvic apparatus was 40 per cent.

CHAPTER II: COMPLICATIONS

INTRODUCTION

The incidence of complications has been greatly reduced by the increased experience in the use of the halo-pelvic apparatus. Improvements in the technique of fitting the apparatus and the introduction of force measurements, together with refinements in the clinical care of the patients have all contributed to a lower complication rate more recently.

There are several complications however which inevitably occur with the use of the halo-pelvic apparatus such as osteoporosis, loosening of the pelvic pins and problems with distraction in the cervical spine.

In the initial stages of experience with the halo-pelvic apparatus complications occurred which led to changes and refinements in the procedure. All the complications encountered during the treatment of the first 104 patients with the halo-pelvic apparatus have been listed (Table 6, page 80). It is hoped that discussion of past mistakes will eliminate unnecessary complications. The author believes that strict adherence to the detailed instructions itemised in Part I should prevent many of these complications from being repeated.

COMPLICATIONS RELATED TO THE SKULL HALO

Infected halo pins

These occurred in 20 out of 104 patients and required replacement. This is an easy matter with the modified halo in use, which has multiple threaded holes around its perimeter and allows a wide selection of alternative pin sites (Fig. 2, page 17). In one patient an intense cellulitis developed in a pin site and, for fear of a cavernous sinus thrombosis developing, the halo and extension bars were removed until the infection had subsided.

A chronic discharging sinus, following removal of the skull halo, occurred in 2 patients. Radiographs revealed a small bony sequestrum,

TABLE 6

COMPLICATIONS DUE TO TREATMENT WITH THE HALO PELVIC APPARATUS

	Total number of patients (104)	Per cent
1. Related to skull halo		
1. Infected halo pins	20	21
2. Chronic discharging sinus	2	2
3. Slipped halo	8	8
2. Related to pelvic pins		
1. Torn peritoneum	1	1
2. Infected and loose pins	50	50
3. Premature removal	5	5
4. Ischial tuberosity pain	5	5
5. Sensory nerve syndromes	3	3
6. Hip contractures	3	3
7. Broken pelvic pins	2	2
3. Spinal cord and nerve injuries		
Spinal cord		
Temporary spasticity	3	3
Cranial nerve neurapraxias (all temporary)		
Sixth (VI)	2	2
Tenth (X)	4	4
Twelfth (XII)	1	1
Brachial plexus lesions (all temporary)		
C5-6	2	2
T1	1	1
4. Cervical spine (77 patients with radiographs)		
Acute over-distraction		
Avulsion ring apophysis	1	0.8
Chronic distraction		
Avascular necrosis upper pole dens	13	17
Subluxation of atlanto-axial joint	5	6
Prolonged immobilisation		
Degenerative posterior joints	26	34
Spontaneous fusion upper units	1	0.8
5. Intestinal obstruction	3	3
6. Osteoporosis	100	100
7. Miscellaneous		
1. Deaths (post-operative)	4	4
2. Pressure sore over the kyphos or rib hump	5	5
3. Infection (wound)	3	3
4. Psychological disturbance	Nil	Nil

which was removed by currettage, and the drainage subsided.

Slipping skull halo

In 8 patients the halo slipped off and both the halo and extension bars needed to be replaced under general anaesthesia. The skull pins should be checked with the torque screw driver one week after fitting and tightened up if necessary. Much bone resorption will often have occurred around the point of the skull pins due to pressure necrosis and they sometimes require several turns of the screw driver to return them to 5.5 pound inches (0.06 kpm) of torque force.

Once the halo has begun to slip off it is difficult to replace, particularly if there is much tension in the extension bars. It is a painful and frightening occurrence for the patient for which he requires adequate analgesic. If only a couple of millimetres of slipping has occurred, then, with local anaesthetic infiltration, supplementary skull pins can be applied, providing that the skin around the existing skull pins is not excessively tented and ischaemic.

Should the halo have slipped further than can be accepted, it is best removed together with the extension bars, to allow the patient to settle down. It can then be reapplied several days later under local or general anaesthesia. When a patient complains of looseness or slipping of the skull halo, it is important to act immediately or the halo will continue to slip rapidly, accelerated by the high forces being used. The incidence of skull halos slipping has been greatly reduced by using six pins and by checking their tension one week after fitting. These are now used routinely for heavier patients and patients requiring longer periods of treatment.

COMPLICATIONS RELATED TO THE PELVIC PINS

Torn peritoneum

This occurred in one patient (case 71) who had a collapsing paralytic scoliosis (126 degrees) associated with pelvic obliquity of 60 degrees. His clinical picture will be given in some detail because of the serious nature of the complication.

The pelvic pin on the higher side of the pelvis could be palpated during its insertion both on the inside and the outside of the crest, indicating the thinness of the bone.

He vomited several times that evening and complained of abdominal pain. 24 hours later his temperature was 37.8°C and his pulse 100 per minute. He did not complain of much abdominal pain, but there was generalised abdominal tenderness; reflex abdominal guarding was not possible because of the extensive muscle paralysis. A plain erect radiograph of the abdomen showed some gas beneath the diaphragm.

Bowel perforation was considered likely and an exploratory laparotomy was done immediately. The pelvic hoop was removed but the two pins were left in position. A left paramedian incision was made and the findings were as follows: there was no bowel injury, both caecum and sigmoid colon were several centimetres from the pins. The right pin had torn a hole in the peritoneum measuring 2 by 2 centimetres, and approximately 30 millilitres of blood had trickled from that iliac crest through the rent in the peritoneum, producing the clinical signs of peritonitis. The left pelvic pin could be felt and seen from inside through the peritoneum. It had produced a haematoma in the iliacus muscle. The tear in the right iliac fossa peritoneum was repaired, the blood stained fluid was aspirated from the cavity and the abdominal wall closed in layers. The pelvic hoop was then re-applied. Subsequently the patient had no further problems.

After insertion of the pelvic pins, all patients must be observed closely for 24 hours, and should there be any fear of bowel perforation a general surgeon must be consulted immediately. If a laparotomy is done, it is best to leave the pins in situ until the pathology is fully identified.

The intestinal surgery required will depend on the site and extent of the gut damaged as well as the delay in diagnosis. Perforations of the small intestine, caecum or sigmoid colon, should be oversewn and the surrounding area drained. If there has been extensive injury to the caecum or sigmoid colon, a right or left hemi-colectomy should be done; in the case of the sigmoid colon, a proximal transverse colostomy or caecostomy should be done in addition to the left hemi-colectomy (49).

There has been no instance of bowel injury in this series, although it has occurred on several occasions in other centres. The danger with pelvic obliquity is apparent. The anatomy of the bony pelvis is so grossly abnormal and the bone so poorly developed and osteoporotic that a large portion of the pin may be intrapelvic.

Infected and loose pelvic pins

The pelvic pins commonly drained at some stage of treatment; this was usually a clear serous discharge, and cultures taken were often negative. The skin around the pelvic pin occasionally grows up around the pin, and in many patients the pin sites remained dry for many months. It is important, however, that they be examined and dressed each day, and cultures taken if the discharge becomes profuse or purulent; the patients' activities should then be restricted and antibiotics considered. Prophylactic antibiotic treatment should also be considered although it was not used routinely in this series.

Patients with paraplegia and anaesthetic skin around the pelvic pins had a greater tendency to infection than those with normal skin sensation.

There has been no osteomyelitis of the ilium but there have been several patients in whom a continuing discharge has become a problem. In this respect, the possibility of cross infection must be remembered and, if the patient is being nursed in a large ward, he should be isolated.

Methods of minimising the occurrence of infection include:
1) applying the pelvic pins accurately, and with a minimum of trauma;
2) the anterior point of entry chosen, at or very near the tubercle of the crest, is subcutaneous and therefore has the least volume of soft tissue to rub against the pin. If any point below this is chosen, the pin will penetrate the abductor muscle mass, and the constant rubbing of the pin against the muscle could produce continual discharge;
3) the thicker the pin, the less will be its excursion, and the less irritation it will produce in both bone and soft tissue. The quality of the pin itself is important. It must be high quality surgical stainless steel: titanium is an ideal implant, but it is too

malleable for this purpose except for the lighter patients; 4) the constant friction of skin and subcutaneous fat against the pelvic pin can be minimised by a collodin dressing which reduces the movement of the skin around the pin. The longer the pelvic pins are in position, the wider the tracks they create within the crests. This is for several reasons: a) there is constant sawing of the pin thread against the cancellous bone; b) immobilisation osteoporosis occurs above the pelvic pin, with resulting resorption of bony trabeculae. In some instances, the "windscreen-wiper" effect will be seen in radiographs after several months (Fig. 25).

Two patients early in the series had loose pins replaced, but this is felt to be unwise, as the initial pin may have produced adhesions to the pelvic viscera, and the introduction of the second pin may expose the bowel to an increased risk of injury.

Premature removal of the pelvic hoop

Five patients required early removal of the apparatus for the following reasons: one patient had decided not to continue with his treatment; three patients had inadequate purchase of the pins in the pelvic bones (these patients all had severe degrees of pelvic obliquity associated with paralytic scoliosis). Another patient with pelvic obliquity had begun to sit up for the first time, and the anaesthetic skin over one ischial tuberosity had broken down and become infected, necessitating extensive plastic surgery before spinal surgery could be considered. He, like the others, ultimately had a combined anterior and posterior correction and fusion.

Ischial tuberosity pain

This occurred in five patients. They had usually been in the apparatus for several months and complained of pain in the region of the tuberosity which was tender to palpate. There may be no sign of infection either there or around the appropriate pelvic pin. It is possible that the pin was irritating the sacro iliac joint with pain referral to the region of the tuberosity.

Sensory nerve irritation

Three patients in the later stages of distraction developed pain in the anterior region of the thigh. The femoral nerve in its course within the pelvis lies in the groove between the iliacus and psoas muscles. It is surprising how close the pin may be to the femoral nerve, if the mid part of its course is intrapelvic. One possibility is that inflammatory oedema, produced by the pin, irritates the cutaneous component of the nerve and produces pain.

The other possibility is that the lumbar nerve roots are being over-stretched with production of sensory disturbances. Sunderland (59) has noted that when a mixed nerve is stretched there is never motor disability without sensory loss: sometimes there may be altered sensation alone.

Paraesthesia of the lateral cutaneous nerve of the thigh was observed in two patients. In the first few patients in the series the pelvic pins were being inserted just lateral to the anterior superior spine, and presumably the lateral cutaneous nerve of the thigh, where it emerges just medial to the anterior superior iliac spine, was irritated at the point where it emerged from the pelvis, and produced paraesthesia. This was of no consequence, and in both the affected patients it settled within several weeks.

Hip contractures

The point of insertion of the pelvic pin is immediately above or at the upper fibres of origin of the tensor fasciae latae. In paralytic patients who have been in the apparatus for several months this tissue will contract. Alternatively, if the pin is intrapelvic in its mid portion and, therefore related to the fibres of origin of the iliacus, a flexion contracture may be produced by contracture of the ilio-psoas complex.

On three occasions flexion abduction contractures required division when the halo-pelvic apparatus was removed. Some patients favour moving about in a wheelchair during treatment; whilst this is acceptable, they must not be permitted to sit all day as severe contractures will develop. Their hip joints should be placed through a full range of passive movement each day to prevent these contractures occurring (39).

Broken pelvic pins

The pelvic pin may break either within the crest itself or externally between the skin and the pelvic hoop. There have been two fractures of a pin adjacent to its attachment to the pelvic hoop and this has not presented particular difficulties. If the pin breaks within the pelvis, then it must be replaced unless treatment is near completion when consideration may be given to removing the apparatus a little earlier than planned.

SPINAL CORD AND NERVE INJURIES

Paraplegia

No patient sustained permanent paraplegia as a result of distraction. Three patients had episodes of temporary spasticity and lower limb weakness during the course of treatment; one associated with coning of the brain stem into the foramen magnum. The circumstances under which these temporary cord signs occurred were as follows:

1. Case No. 12 developed fever, papilloedema, headaches and hypertension following anterior and posterior osteotomies and distraction to correct a previously fused severe high dorsal tuberculous kyphosis. A lumbar puncture excluded meningitis. The symptoms settled when the distraction bars were shortened by 5 millimetres. Some weeks later, he developed lower limb spasticity and this again was completely relieved by shortening the extension bars further.

2. Case No. 74 with a severe double-primary idiopathic scoliosis had some temporary motor loss in her lower limbs following posterior fusion. In retrospect the tension left on the spine during surgery resulted in a taut spinal cord which was exposed to the risk of concussion.

3. Case No. 17 with severe tuberculous kyphosis and pre-operative partial paraplegia had a short, temporary episode of increased leg weakness following posterior osteotomy.

Cases 31, 33, 34 - three patients with severe pre-operative spasticity were permanently paraplegic following surgery. In no case was distraction an etiological factor. All three had severe tuberculous kyphosis with penetration of the spinal cord by the tuberculous disease process. This phenomenon has been emphasised by Hodgson and co-workers (28) and is clinically manifest by severe lower limb clonus and spasm.

Discussion

The spinal cord begins at the lower end of the medulla oblongata and is described as extending normally to the intervertebral disc between the first and second lumbar bodies, although this is variable (29). In patients with long standing deformities, with congenital absence or infective destruction of the vertebral bodies, one cannot judge exactly where the spinal cord terminates. The cord occupies the shortest course within the spinal canal; in scoliosis it will rest against the concavity and in kyphosis it will occupy an anterior position in the canal, abutting against the internal kyphos.

The blood supply of the spinal cord has been a subject of increasing interest; the cord is nourished by three longitudinal vessels which extend from the origin of the cord to the conus medullaris: they are two postero-lateral arteries and a larger anterior spinal artery (29). This latter vessel receives contributions along its course which are not segmental, however, the most important member of these so-called feeder vessels is the artery of Adamkiewicz (1) which occurs on the left side in 80 per cent of patients and most frequently at about T10 vertebral level.

Prompted by a high incidence of paraplegia following operations for severe scoliosis in adults, Dommisse (13) investigated the blood supply of the spinal cord and the dimensions of its canal. He concluded that the blood supply is poorest and the spinal canal narrowest from the T4 to approximately the T9 vertebral level. This region he named the "critical vascular zone of the spinal cord".

Breig (2) has demonstrated that the spinal cord shortens and lengthens to accommodate relative changes in the length of the spinal canal. He analysed the relative amounts of lengthening which occurred in different areas of the cord; the thoracic cord was least extensible (one centimetre), the lumbar cord intermediate (one to two centimetres) and the cervical cord most able to be deformed (1.8 to 2.8 centimetres). Three quarters of the physiological extension was provided by unfolding of the cord and the remainder through the natural elasticity of the tissue.

The spinal cord is at risk with any form of rapid spine distraction because its axis is parallel to the longitudinal forces generated. With the cord under tension, Sunderland (58) noted mechanical failure occurring at values of 0.66 kp/mm^2 with a rate of extension of three inches per minute. Such a rate of extension in clinical circumstances could probably only be applied to the cord if the patient were forcibly corrected under general anaesthesia, whilst applying distraction with the extension bars.

The lower thoracic cord would thus seem to be its most susceptible area and it is in this region that most spinal deformities have their peaks of incidence, as the barographs demonstrate (Appendix A). It is also, normally, a rigid region of the spine where antero-posterior and side to side motion permitted are approximately only 2 to 6 degrees at each segment (62).

Several factors must be remembered if paraplegia is to be avoided. Pre-operative assessment should include myelography in order to exclude or to define an intraspinal lesion or to delineate the level and extent of cord compression, particularly in kyphoses and all congenital lesions. There may well be myelographic evidence of a narrowed spinal cord without the obvious clinical signs of an upper motor neurone lesion, as for example with tuberculosis. Should cord compression be detected it must be removed, to allow safe correction with gradual distraction.

It is prudent to carry out a daily neurological assessment whilst carrying out distraction which must be gradual and well tolerated by the patient (Table 1, page 34). Regular lateral radiographs of the cervical spine and force measurements assist in determining a safe rate and tolerable extent of distraction.

Patients with cord compression are in the greatest risk category, particularly if in the cases of tuberculosis, the disease has penetrated the spinal cord. There is a high risk of paraplegia if one operates on a patient with a spinal cord under excessive tension; therefore the tension should be released at the time of operation.

In posterior surgery this will mean removing the two posterior bars and shortening the two anterior bars by 5 to 10 millimetres each, or removing all the bars. The correction lost by releasing this tension will be negligible.

Cranial nerve neurapraxias

Seven patients developed cranial nerve palsies during treatment: the sixth cranial nerve in two patients; the tenth cranial nerve in four patients; and the twelfth cranial nerve in one patient. All were temporary and recovered rapidly except for the twelfth nerve injury (case 91) which took one year before recovery was complete.

Traction generated and transmitted during extension falls mainly on nerves pursuing vertical or obliquely vertical courses and this would explain the selection of nerves which sustain traction injuries with halo-pelvic distraction (58).

The abducent (VI) nerve runs upwards and is fixed where it leaves the ponto-medullary junction and where it crosses the apex of the petrous temporal bone. The vagus (X) and hypoglossal (XII) cranial nerves run slightly upwards to leave the skull by way of the jugular and hypoglossal foramina, respectively. Glosso-pharyngeal (IX) function is normally not tested but is closely associated with tenth and twelfth cranial nerves in the area of vulnerability at the base of the skull; it is presumably involved in many of these patients though its injury is more of anatomical than clinical significance.

Brachial plexus lesions

Two patients sustained neurapraxias of the C5-6 nerve roots and one of the first thoracic nerve root. These three temporary lesions occurred towards the end of distraction in patients with rigid deformities. The fifth and sixth cervical spine nerves are more obliquely aligned in the neck and therefore more prone to injury by a vertically transmitted distraction force. The first thoracic nerve crosses the neck of the first rib and presumably here it is tented and stretched by the distraction.

The clinical significance of these nerve injuries is that no further correction can be achieved unless one mobilises the spine with osteotomies and considers resuming traction thereafter. Even when this is done, the nerve injury is likely to recur when the same amount of distraction force is built up again, as occurred in the patient who sustained the hypoglossal nerve injury. This same observation has been made by DeWald (11). If these injuries are recognised very early and the extension bars shortened, then the prognosis for quick recovery is excellent.

The tensile strength of a nerve trunk depends essentially on its perineurium: tension in deforming nerve fibres will interfere with their blood supply. Studies in stress and strain have shown that the greatest elongation within the elastic limit is 20 per cent, except for some nerves where it may be as low as 6 per cent (59). The rate of application of deforming forces as well as their magnitude are instrumental in producing nerve lesions. When distraction is applied over a long period of time, nerves can be stretched well beyond the range of elasticity with little or no disturbance of function.

As the bundles elongate the nerve fibre deformation may produce arrest of circulation and obliteration of the vessels in the stretched nerve (59). Lundborg and Rydevik (32) demonstrated the effects of stretching the tibial nerve of the rabbit. The first vessels to be affected were the venules. There was arrest of venular flow with about 8 per cent elongation, at which stage there was the first intravasal evidence of tissue injury, granulocytosis, microthrombi and emboli.

Temporary nerve injuries involve interruption of conduction with preservation of anatomical continuity. These types of nerve injury have been termed first degree injuries by Sunderland (59) and neurapraxias by Seddon (56). In some cases conduction may be arrested on the verge of paralysis so that only a paresis results.

Most paralysed muscles will show recovery within six weeks. Sunderland (59) reported a series of patients with a duration of paralysis ranging from 17 to 60 days. Seddon (57) observed that mild distraction produces a lesion clinically indistinguishable from neurapraxia; the fibres are affected in order of their size, motor paralysis is complete, and sensory disturbance minimal. Recovery occurs rapidly and completely.

The duration of the paralysis varies from patient to patient, and bears no constant relationship to the cause or the apparent severity of the injury.

COMPLICATIONS IN THE CERVICAL SPINE

77 patients in this series had radiographs of the cervical spine taken at some stage during treatment or at the time of the follow-up. 45 patients had cervical spines which were regarded as radiologically normal; 32 patients had radiologically abnormal cervical spines. These abnormal radiological findings included:

1) Degenerative changes in the posterior joints of the cervical spine, the main features of which were diminution of the joint space, erosions and cystic lesions of bone adjacent to the joint. Such latter changes were sometimes seen whilst the patient was still in the apparatus (26 patients).

2) Avascular necrosis of the proximal pole of the dens. This was evidenced by cystic areas in the proximal end of the dens, by irregularity of the contour of the pole and adjacent sclerosis (13 patients).

3) Chronic atlanto axial subluxation. This was confirmed by lateral flexion and extension radiographs of the cervical spine and was found in five patients at the time of follow-up.

4) Avulsion of the ring apophysis of the inferior body of the second cervical vertebra occurred in one patient as a result of rapid distraction (Fig. 26).

Of those with avascular necrosis of the dens (13 patients), ten had treatment for tuberculous kyphosis and one each for idiopathic, neurofibromatosis and paralytic scoliosis, respectively (60). Of these 13 patients with avascular necrosis of the dens, 7 had associated degenerative changes in the posterior joints.

In a previous report (48) 65 per cent of the patients (44 out of 70) were observed to have developed changes in the cervical spine. Loss of normal cervical lordosis was then considered abnormal. In a later review of more radiographs many were found to have regained much of the normal lordosis and, when no other changes were apparent, and no clinical symptoms present, they were reclassified as normal.

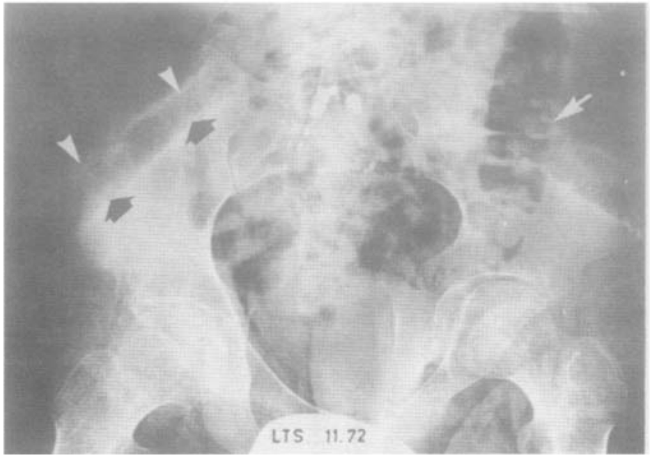

Figure 25. Case 98. Antero-posterior radiographs of pelvis after the patient had been in the apparatus for seven months. Note: 1) the widening of the pin tract within the iliac crest, the so-called windscreen wiper effect (arrows); 2) marked osteoporosis of the iliac crests above the pin tracts; 3) on the viewer's right side, gas in the sigmoid colon overlying the left pelvic pin tract provides a good demonstration of the relationship of the sigmoid colon to the iliac crest (arrow).

Figure 26. Case 16. Lateral radiograph of upper cervical spine to demonstrate avulsion of the ring apophysis of the inferior aspect of the second cervical vertebra due to rapid distraction.

Nevertheless the incidence of radiological changes in the cervical spine is high.

Four particular factors were analysed to determine their significance in relation to these above mentioned radiological cervical spine complications taken as a whole. The factors analysed were: a) the age of the patient; b) the period of time in the apparatus; c) the etiology of deformity; and d) the corrective forces used.

The age of the patient

Those patients with radiologically abnormal cervical spines were grouped mainly between 11 and 21 years. 11 patients younger than 10 years had no radiological changes at time of follow-up (range 2 to 5 years) (Fig. 27).

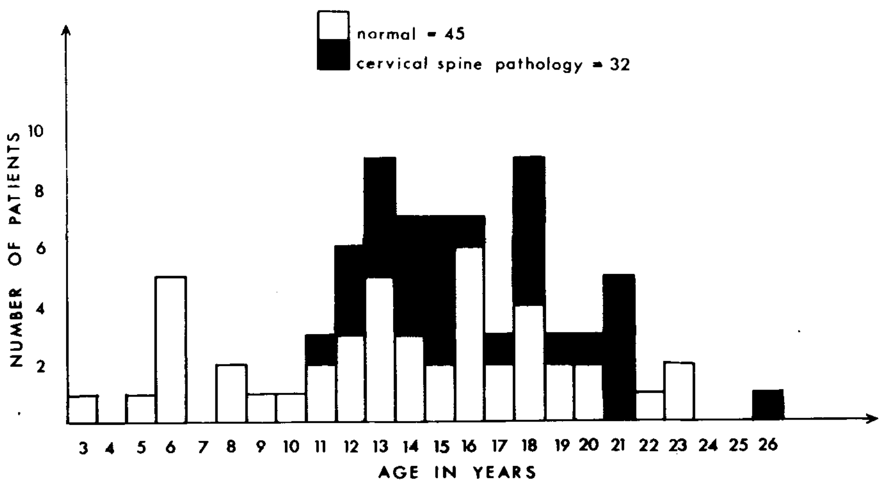

Figure 27. Barograph to demonstrate the age of patients with radiological changes in the cervical spine after treatment in the halo-pelvic apparatus.

There appeared to be a trend towards an increase in neck pathology correlating with the age of the patient (Fig. 28).

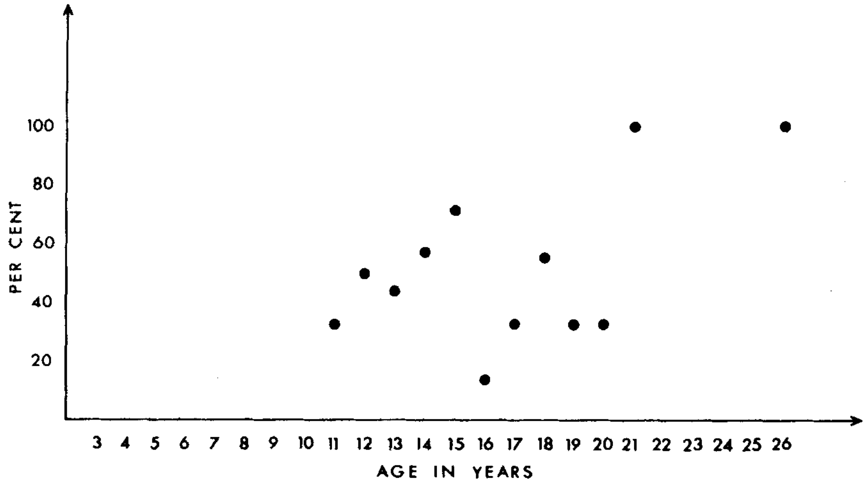

Figure 28. Plotted points to demonstrate the percentage of patients with abnormal cervical spines in the various age groups after treatment.

Period of time in the apparatus

The longer the patients were in the halo-pelvic apparatus, the higher the observed incidence of radiological pathology in the cervical spine (Fig. 29). In all groups of patients treated in the apparatus for longer than 7 months, a significant number developed cervical spine changes.

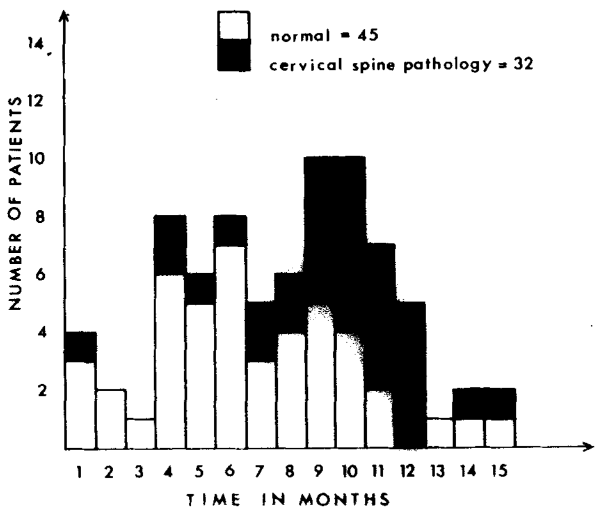

Figure 29. Barograph showing the relationship between radiologically abnormal cervical spines and the length of time in the halo-pelvic apparatus.

There were quite a definite trend regarding the incidence of neck pathology and the length of time in the apparatus (Fig. 30).

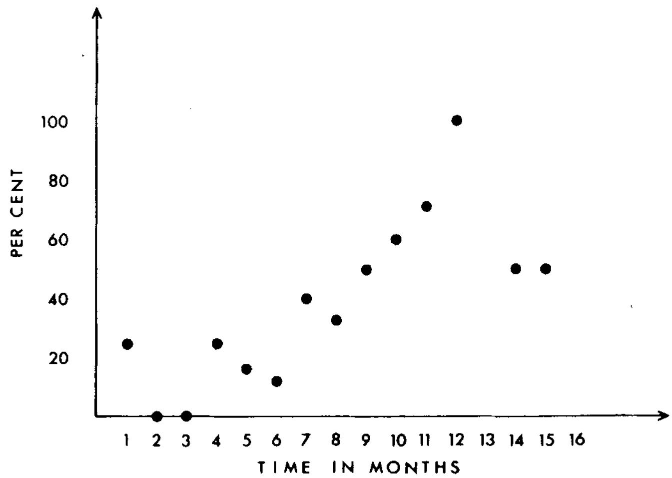

Figure 30. Plotted points to demonstrate the percentage of patients with radiologically abnormal cervical spines tending to increase as the length of time in the halo-pelvic apparatus increases.

The etiology of deformity

Patients with radiological changes in the cervical spine were classified according to the various etiologies as follows: tuberculous kyphosis 47 per cent, paralytic scoliosis 40 per cent, idiopathic scoliosis 45 per cent, congenital kyphoscoliosis 15 per cent, and neurofibromatosis kyphoscoliosis 50 per cent.

The barograph (Fig. 31) confirms that there were more significance in the tuberculous kyphosis and paralytic scoliosis groups because of the larger samples available.

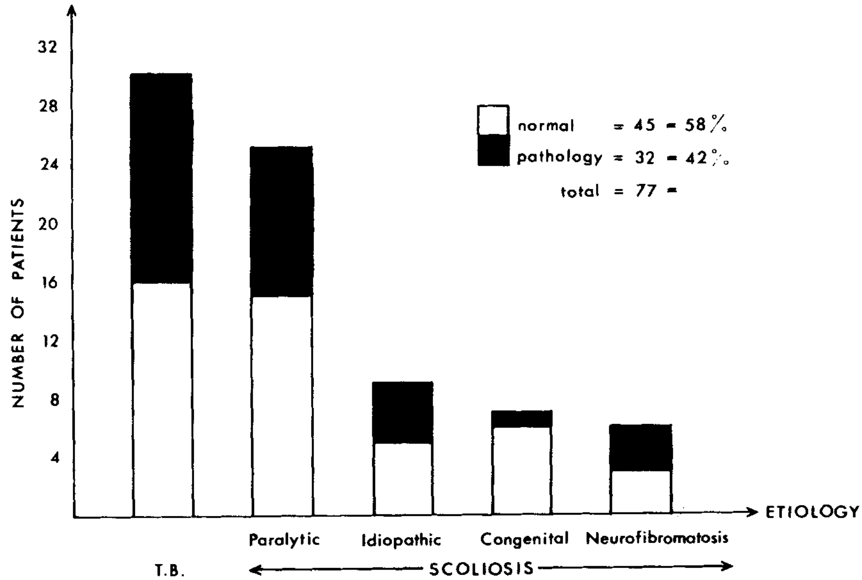

Figure 31. Barograph to demonstrate the incidence of radiologically abnormal cervical spines according to the etiology of the spinal deformity treated.

Force measurements

Those who had force measurements and cervical spine radiographs available (42 patients) suggested that the higher the forces applied to the spine the greater the incidence of radiologically abnormal cervical spines. The forces were recorded for this purpose as a percentage of the patient's body weight. The critical level seemed to be 60 per cent of the patient's body weight, beyond which there was a higher incidence of neck pathology.

Lengthening in the cervical spine with distraction occurs mostly at the upper two levels: they are the most mobile, devoid as they are of protective intervertebral discs. Case 71, a twelve year old male patient with a severe paralytic scoliosis, had lateral radiographs of the neck soon after treatment began and three months later (Figs. 33 a and b). The amount of elongation which has occurred at the upper two levels with distraction is evident.

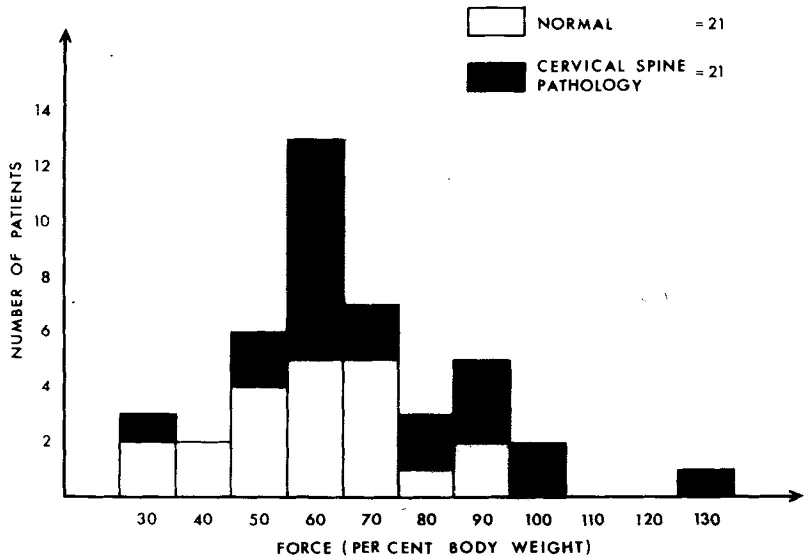

Figure 32. Barograph to demonstrate the relationship between radiologically abnormal cervical spines and the forces used in correction of the deformities.

Neck pain is often experienced at some stage due to stretching. If one examines the patient clinically whilst he has pain one can localise by palpation the segmental level at which the pain occurs. The normal cervical lordosis disappears early and widening of the posterior synovial joints occurs more than in the intervertebral disc spaces which widen only slightly even with marked distraction. Thus the neck not only loses its lordosis but becomes slightly kyphotic.

It should be emphasised that absence of pain in the cervical spine during gradual distraction does not necessarily mean that all is well. Very slow rates of distraction are compatible with freedom from neck pain. Extensive damage to the cervical spine due to over-distraction can thus occur silently without either patient or surgeon being aware of it.

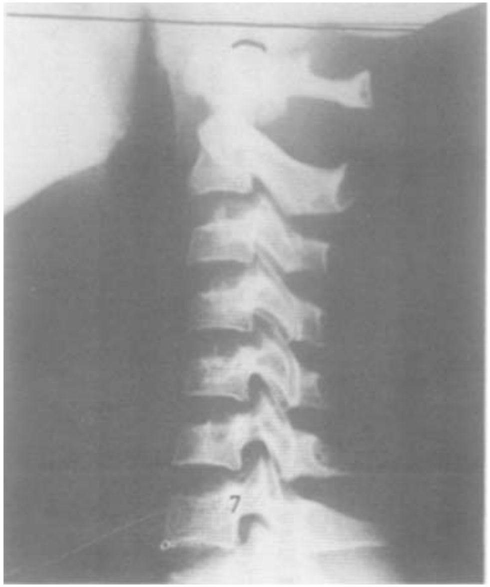

Figure 33 a. Lateral radiograph soon after distraction commenced. Note the distance between the dens and McGregor's line.

Figure 33 b. Three months later, there has been marked distraction of the cervical spine, particularly at the upper two levels. Note the increase in distance between McGregor's line and the top of the dens (arrow). Posterior joint spaces have widened more than the intervertebral disc spaces resulting in a slight kyphosis.

Figures 33 (a) and (b). Case No. 71. Lateral radiograph of cervical spine after fitting of the halo-pelvic apparatus and three months later after completion of distraction. Patient had a severe collapsing scoliosis of 126^{o} reduced to 63^{o}.

The actual amount of cervical spine lengthening can only be judged with any accuracy from a lateral radiograph. Clinically it is obvious that the neck has lengthened a good deal and the posterior arch of the axis, initially not easily palpable because of the overlying muscle mass, becomes readily felt through the stretched posterior soft tissues of the neck.

There are numerous factors which determine how much the cervical spine itself will lengthen during spine distraction: these include the patient's age, the strength and volume of his neck musculature, the rigidity of the spine deformity, the effectiveness of a mobilising osteotomy, if indicated, and the rate and extent of distraction.

The combination of a rigid deformity with rapid distraction is likely to produce an acute injury; case 16 had a severe tuberculous kyphosis. Following excision of the internal kyphos, distraction commenced at a rate faster than usual resulting in acute neck pain. A lateral radiograph several days later demonstrated an anterior avulsion of the ring apophysis of the inferior aspect of the second cervical vertebra (Fig. 26, page 92). He subsequently developed spontaneous fusion of the upper cervical units.

<u>Simultaneous correction of the deformity and lengthening of the cervical spine</u>

Four unselected patients with tuberculous kyphosis had serial lateral radiographs of the correcting kyphos and the lengthening cervical spine compared (Table 7).

Fixed points were selected on the limbs of the kyphos of the pre-operative films and of those at the completion of treatment. These were compared with lateral cervical spine films before and at the end of distraction. An estimate of the simultaneous amount of lengthening of the cervical spine could thus be made.

There were differences in each patient: the "best" ratio was case 27; for one centimetre of measured neck lengthening there was 6.4 centi-metres of lengthening at the internal kyphos. The "worst" ratio was case 23: for 2 centimetres of neck lengthening, 2.7 centimetres of lengthening at the internal kyphos was produced. So many and varied are the factors involved that one can only rely finally on regular radiographs and clinical judgements of the patient's reponse to treatment.

TABLE 7

Case number	Lengthening at internal kyphosis (in centimetres)	Simultaneous lengthening of cervical spine (in centimetres)
	(Measurements from lateral radiographs)	
13	6.0	3.0
21	2.7	1.0
23	2.7	2.0
27	6.4	1.0

Corresponding simultaneous lengthening at the internal kyphos and cervical spine, measured from lateral radiographs at the end of distraction.

Continuing lengthening without actual distraction

A significant lengthening of the cervical spine can often be measured in patients held in the apparatus who are no longer undergoing active distraction. If one measures the length of the cervical spine from a radiograph after the last operation and before the removal of the apparatus this lengthening may be as much as 5 millimetres. This is more likely when several months have elapsed between the last operation and the removal of the apparatus and in patients with paralytic neck muscles. Although one is not actively lengthening the spine it is continually deforming (or "creeping") with the passage of time (6). A typical example of this phenomenon is case 18, a patient with a severe lumbar tuberculous kyphosis, who was corrected by staged procedures and then remained in the apparatus for a further 8 months. On comparing identical lateral radiographs of the neck at the time of fusion and at the time of removal of the apparatus 8 months later, there had been an increase in length of 0.5 centimetres in the cervical spine (Figs. 34 a and b).

There are two separate mechanisms which singly or together produce the pathological changes in the cervical spine. They are 1) deformity

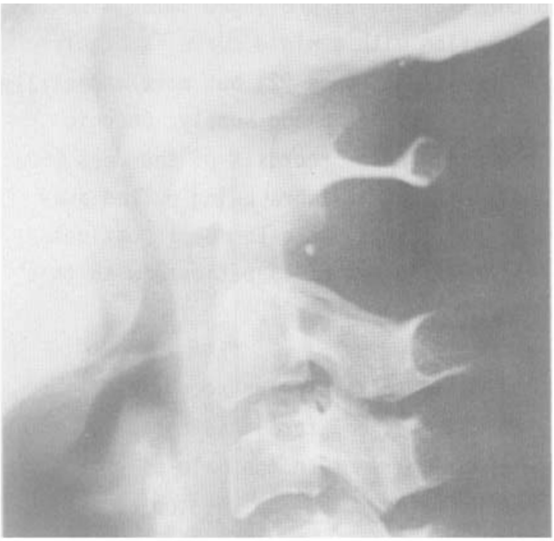

Figure 34 a. Taken at the completion of surgery.

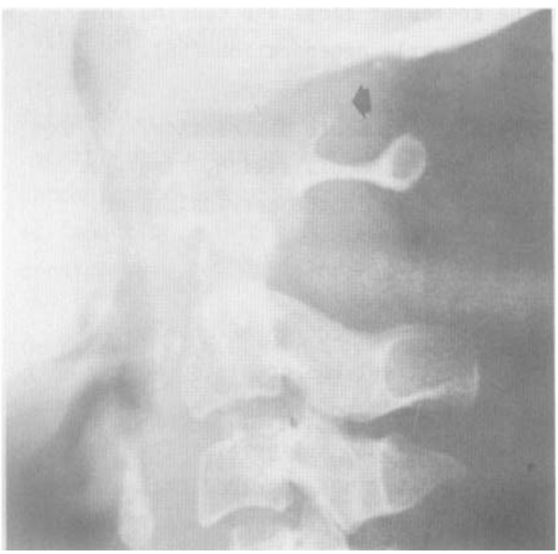

Figure 34 b. Taken eight months later when the patient was still in the apparatus but without any distraction. Note the increase in width at the atlanto occipital joint without active distraction having taken place.

Figures 34 (a) and (b). Case 18. Lateral radiograph of upper cervical spine.

(distraction) both acute and chronic, and 2) prolonged immobilisation. Acute over-distraction in association with a rigid curve is highly dangerous to the cervical spine (Fig. 26, page 92) but more especially to the integrity of the spinal cord and its blood supply. Chronic over-distraction accounts for the avascular necrosis of the dens (60). This is due to the proximal pole of that vertebra being pulled away from its blood supply. It was significantly more common in patients with marked lengthening of the neck (10 out of 13 patients with this lesion had tuberculous kyphosis).

A detailed account of the complication of avascular necrosis of the dens has been made recently (60). When the lateral radiograph of the cervical spine was examined with the patient in the halo-pelvic apparatus and the distance from McGregor's line to the top of the dens was greater than the vertical height of the posterior aspect of the third cervical vertebra, there was a high risk of avascular necrosis of the proximal pole of the dens occurring.

Prolonged immobilisation together with persistent deformity of the posterior joints produces degenerative joint changes (20). Pannus grows into the joint across the articular cartilage causing interference with its nutrition and its early degeneration (55).

The available evidence suggests that (a) acute distraction, (b) excessive lengthening, and (c) prolonged immobilisation, singly or in combination, produce deleterious effects in the cervical spine.

Clinical evaluation

Detailed measurements of neck motion were made in 56 unselected patients at least one year after treatment was complete. Nearly half (26 patients) had practically normal neck movements. Those with radiologically abnormal cervical spines had a significantly higher incidence of reduced motion (Fig. 35). It has appeared that with time and use neck movements continue to improve for up to 12 months after treatment.

The average patient, several years after treatment, had a painfree neck with loss of up to 30 degrees of rotation. As most rotation occurs in the upper cervical units because the greatest distraction occurs here, the greatest residual disability will be due to loss of motion at these levels.

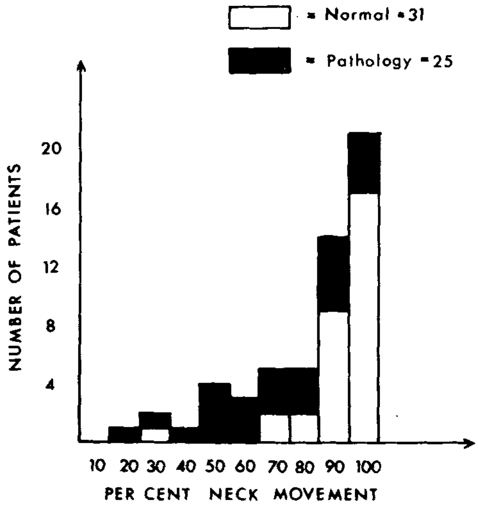

Figure 35. Barograph to demonstrate the relationship between radiologically abnormal cervical spines and clinical motion.

INTESTINAL OBSTRUCTION

Three patients developed an acute duodenal obstruction of the type recently described by Evarts et al (21). They all had marked compensatory lumbar lordoses. As in nerve injuries, early diagnosis is important, since a delay in diagnosis affects the prognosis considerably.

Occasionally small bowel obstruction may occur after the patient has had the extension bars fitted. The constricting band can be removed from the compressed anterior duodenal wall by adjusting the extension bars, thus reducing some of the lordosis.

Diagnosis was promptly made when the patients started vomiting after the fitting of the extension bars. A plain erect antero-posterior radiograph of the abdomen showed distension of the stomach and the first half of the duodenum. To confirm the level of the obstruction, a small volume of soluble gastrografin was used; this is unnecessary in the established case as the gas shadows in the radiograph will usually become conspicuous by their absence beyond the end part of the duodenum.

OSTEOPOROSIS

Osteoporosis is an inevitable accompaniment of the immobilisation produced by the halo-pelvic apparatus (Fig. 25, page 92) (4). Radiologically it is evident in all bony tissues between the skull and the pelvic pins. Radiographs of the pelvis taken several months after completion of treatment with halo-pelvic distraction confirm that bone lost above the pelvic pins has not been fully replaced.

The clinical problems encountered with osteoporosis have been difficulties with internal fixation, notably seating the hooks for the Harrington rod, the vertebral body screws in Dwyer instrumentation and the pelvic pin fixation in paralytic patients.

MISCELLANEOUS

Deaths

There were four deaths in the series. Three patients died within five days of anterior spinal surgery, two within twenty-four hours of the operation. One patient died within twenty-four hours of multiple posterior spinal osteotomies. All had severe respiratory insufficiency and a moderate to severe degree of blood loss at the time of surgery. The causes of death were paralytic ileus and pneumonia in one patient, acute respiratory failure and blood loss in one patient and acute respiratory failure in two patients.

Pressure sore over the kyphos or rib hump

It is surprising how large an area of skin is made temporarily anaesthetic by the combination of posterior vertical and oblique skin incisions. These patients with double skin incisions must be watched carefully, particularly if the back winder is being used. This requires releasing every hour and the skin checked regularly for signs of redness or early breakdown.

Infection

Bone graft was taken from the iliac crest above the pelvic pins in many patients; in some of them the donor wound was slower in healing, but there was no significant problem. There was one posterior wound infection following the use of iliac crest bone but it settled with irrigation and drainage. If this bone is used, however, prophylactic antibiotics are necessary as the graft is potentially infected.

Continuing spinal growth in the apparatus

In the presence of an intact posterior fusion mass and continuing growth of the vertebral bodies, an increase in the deformity was observed in three patients despite being held in the apparatus. Case No. 52 was a nine-year-old male patient with a collapsing paralytic scoliosis of 112 degrees (Fig. 36 a) which was corrected by halo-pelvic distraction to 21 degrees (Fig. 36 b). Although he was maintained in the apparatus for a further 12 months after surgery, the curve when the apparatus was removed measured 47 degrees, an exploration of the fusion mass six months after fusion having previously confirmed that it was solid (Figs. 36 c and d).

In the presence of marked rotational deformity, present in many of these patients, growth from the vertebral bodies would actually increase the length of the curve on the convex side whilst the concave or fused part of the spine is being bent by this continuing convex growth. The fusion mass is thus acting as if it were an unsegmented bar.

The other explanation in this situation is that because of the visco-elastic properties of tissues, gradual sagging of the fused spine and continuing lengthening of the cervical spine takes place even though no active distraction is taking place.

The practical points raised here are: 1) Internal fixation should be used with scoliotic deformities when possible. 2) The period of time in traction should be kept to a practical minimal period compatible with the patient's general physical state, particularly his respiratory function.

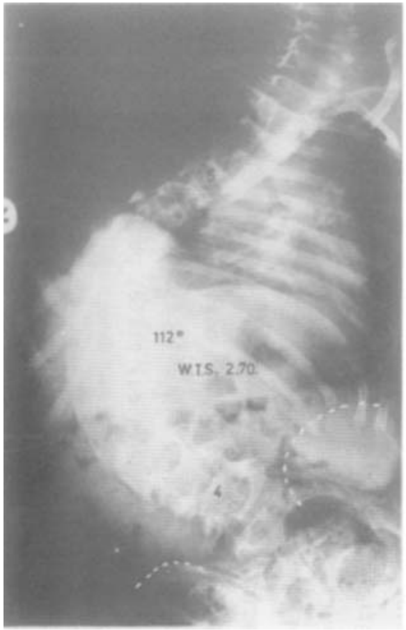

Figure 36 a. Antero-posterior radiograph with the patient seated. Note extent of pelvic obliquity.

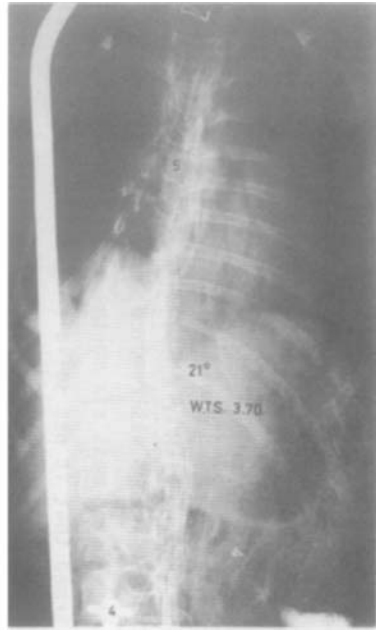

Figure 36 b. Following gradual correction, extensive posterior spinal fusion was performed from the first thoracic vertebra to the sacrum, curve then measured 21°.

Figures 36 (a), (b), (c) and (d). Case 52. A nine-year-old male patient with severe collapsing paralytic scoliosis measuring 112°; no walking potential because of severe four-limb involvement.

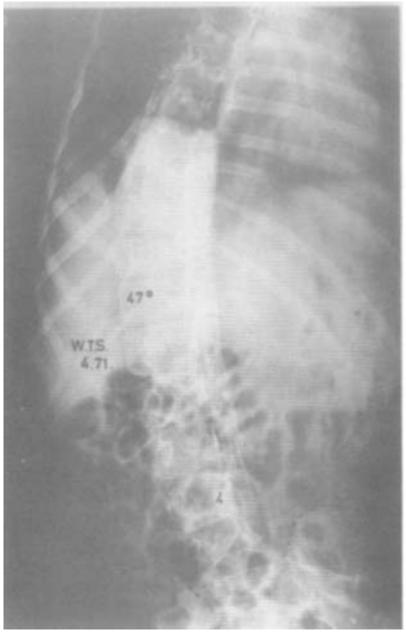

Figure 36 c. Thirteen months later, curve has deteriorated to 47^{0} despite being held during this period of time in the halo-pelvic apparatus. The likeliest explanation for this phenomenon is continuing growth in the vertebral bodies. (See text.)

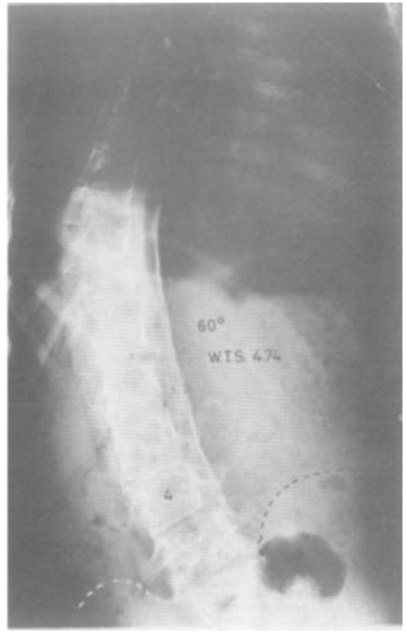

Figure 36 d. Antero-posterior radiograph of same patient four years after spinal fusion. Further loss of correction in the fused spine, the curve now measures 60^{0}. Note the recurrence of the pelvic obliquity. Internal fixation was not possible because of soft bone and the thinness of overlying soft tissues.

Psychological disturbances

These were minimal and in fact non-existent when the method of treatment was explained fully to the parents and to the patient. The recommended approach is to introduce a patient under treatment in the halo-pelvic apparatus to the parents and the patient and permit them to talk the matter over. It is helpful to demonstrate the results before and after with radiographs and rarely will the parents of a child or the patient himself not consent to corrective surgery.

One constant feature has been the dramatic improvement in the psychological attitude of the patient when he has seen the correction of his spinal deformity being obtained. Supportive psychological therapy is an all important part of the overall technique with these patients and it requires the skill and gentle care of all physicians and paramedical personnel involved with the patient.

DISCUSSION

When reviewing these results they must be assessed bearing in mind that 21 per cent of the patients had cord compression or frank paraplegia at the onset of treatment (tuberculous kyphosis 16 patients, congenital 2 and neurofibromatosis deformities 3 patients). In addition more than fifty per cent of all patients had significant respiratory impairment for which two required elective tracheostomy (tuberculous kyphosis).

Thus a large number of these patients had, in addition to severe spinal deformities, associated poor lung function and a compromised and severely threatened spinal cord.

The actual average corrections achieved were tuberculous kyphosis 31 per cent; paralytic scoliosis 51 per cent; idiopathic scoliosis 42 per cent; congenital kyphoscoliosis 26 per cent; neurofibromatosis kyphoscoliosis 43 per cent and the salvage group (osteotomies of previous posterior fusion masses) 40 per cent.

The correction of the tuberculous kyphosis series is better than it appears: the average apex of the kyphos was at the ninth thoracic vertebra (Fig. 11, page 45) and a natural kyphos of twenty to forty degrees exists in this region of the spine.

The average correction of the patients with idiopathic scoliosis (42 per cent) was not as good as expected. Significant derotation of the major curve does occur with the halo-pelvic apparatus when it is used in conjunction with the back winder (Fig. 4, page 18). However, whilst the average curve was moderately severe (82 degrees) it would seem that the halo-pelvic apparatus in idiopathic scoliosis should be reserved for patients with rigid curves over 100 degrees, ideally with associated respiratory insufficiency making longitudinal traction in bed or on a frame unwise.

The complications of greatest concern were pathological changes in the cervical spine mainly degenerative changes in the posterior joints, avascular necrosis of the dens and chronic atlanto-axial subluxation. Most of the other problems encountered were temporary or avoidable; pelvic pin tract infection was common but was usually managed without difficulty. There were no instances of osteomyelitis of the ilium nor of a case where the infection necessitated a change in the patient's management other than the three patients with pelvic obliquity who required early removal of the apparatus. The problem and the difficulties and dangers with pelvic obliquity for the pelvic pins have been stressed. The torn peritoneum in one patient has been emphasised in order to avoid its recurrence.

The principle in using the halo-pelvic apparatus is to follow a planned technique to observe the patient closely, to organise a team approach for the patients' management and to anticipate problems so that they are dealt with early and effectively.

SUMMARY AND CONCLUSIONS

One hundred and four patients with severe spinal deformities commenced treatment in the halo-pelvic apparatus. There were four post-operative deaths; the etiology of the spinal deformities was: tuberculous kyphosis 42 patients; paralytic scoliosis 31 patients; idiopathic scoliosis 15 patients; congenital kyphoscoliosis 10 patients, and neurofibromatosis kyphoscoliosis 6 patients. The average time in the apparatus was 7.5 months.

Eleven patients with paralytic scoliosis had associated pelvic obliquity. Twenty-one per cent of patients had cord compression or frank paraplegia at the commencement of treatment. Respiratory insufficiency was a common accompaniment of the spinal deformity especially in those patients with tuberculous kyphosis and paralytic scoliosis.

The average corrections of the deformities were as follows: tuberculous kyphosis 31 per cent; paralytic scoliosis 51 per cent; idiopathic scoliosis 42 per cent; congenital kyphoscoliosis 26 per cent, and neurofibromatosis kyphoscoliosis 43 per cent. An analysis of a "salvage group" previously failed posterior fusions for scoliosis leading osteotomies, distraction and fusion revealed a correction of 40 per cent.

Many complications due to distraction were easily remedied but the more serious were temporary spasticity in the lower limbs 3 per cent; temporary brachial plexus paresis 3 per cent, and cranial nerve palsies 7 per cent.

Of seventy-seven patients who had cervical spine radiographs taken, thirty-two had radiologically abnormal cervical spines. The most common neck complication was degenerative changes in the posterior synovial joints. These appeared more commonly in the older patients, with excessive distraction and with prolonged time in distraction.

The halo-pelvic apparatus is an effective instrument for the correction of severe deformities of the spine particularly for patients with poor respiratory function and cord compression or frank paraplegia. Its use requires judgement and team work, close observation and attention to detail, in view of the complications encountered.

PART III

THE HALO-PELVIC APPARATUS - AN ANALYSIS OF ITS STABILISING EFFECT AND OF THE FORCES BEING APPLIED THROUGH THE SPINE WITH ITS USE

by

John Patrick O'Brien
Gösta Elfström
Alf Nachemson

INTRODUCTION

The aims of this project are (1) to analyse the stabilising effect of the halo-pelvic apparatus on the deformed spine and (2) to determine what proportion of the tension developed by halo-pelvic distraction is actually transmitted to the spine itself.

Halo-pelvic distraction is becoming more widely known as a method for gradually correcting severe spinal deformities. Complications due to over-distraction have been reported, notably injuries to the cervical spine, paraplegia, and temporary nerve lesions (34, 48).

Considering these complications and the ignorance of the corrective forces being applied to the spine, a spring system on each of the four extension bars was developed in 1970 in conjunction with Clark and Kesterton of the Department of Mechanical Engineering at Hong Kong University (5). This gave a measure of the forces being used during treatment of the patients; the distraction forces were readily calculated from the extent of compression of the springs, but, there was no indication of what proportion of the measured forces was actually transmitted to the spine itself.

In April 1971 Nachemson and Elfström reported their results of intra-vital wireless telemetry of forces in four patients with idiopathic scoliosis using a modified Harrington rod (41). The information obtained from this work permitted a more rational approach to the post-operative management of the scoliosis patient (17, 18).

If this special Harrington rod was used in patients in conjunction with the halo-pelvic apparatus, the inherent stability of the latter could be assessed and the external forces, applied with lengthening of the extension bars and measured on the springs, could be checked against the internal measuring rod to give an assessment of the tension actually transmitted to the spine (Fig. 37). This work was carried out at The Duchess of Kent Children's Orthopaedic Hospital, Hong Kong, in October-November, 1972 (19).

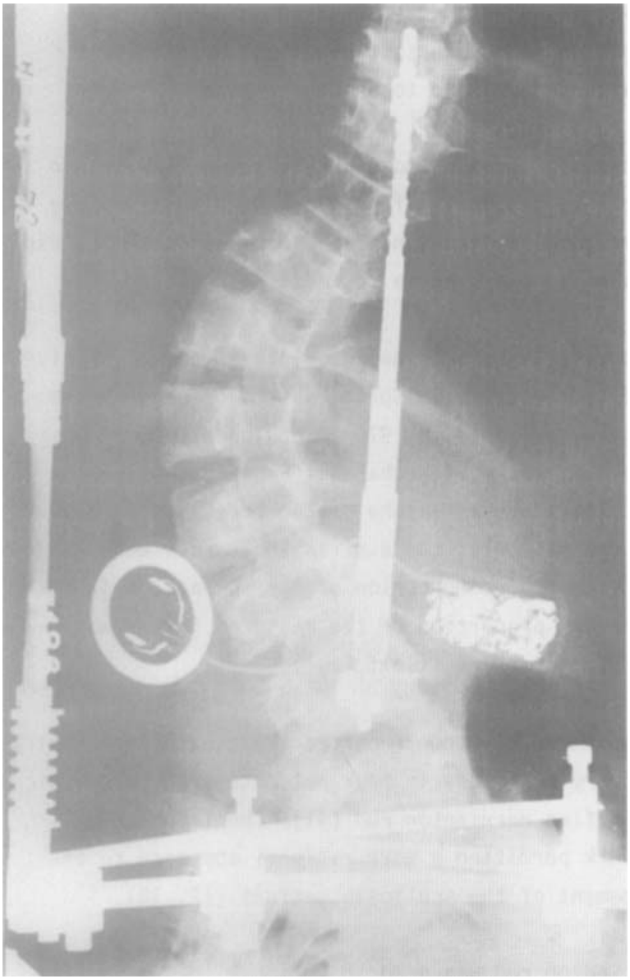

Figure 37. Patient No. 1. Antero-posterior radiograph of patient with paralytic scoliosis. Note the extension bar of the halo-pelvic apparatus with the compression spring at its base in addition to the telemetry rod with the coil and transmitter.

CLINICAL MATERIAL (Table 8)

There were four patients with severe paralytic scoliosis requiring preliminary traction before extensive spinal fusion with Harrington rodding. Three of these were males and one female with ages ranging from 12.5 to 16.5 years. Two of the patients' curves were thoraco-lumbar and two were thoracic in type; all four were convex to the right side. The curves varied in extent from 95 to 145 degrees (average 112 degrees). The major curves involved from five to nine vertebrae; the angle of 'kyphosis' ranged from 63 to 142 degrees.

OUTLINE OF TREATMENT

The following steps were taken: 1) fitting of the halo-pelvic apparatus; 2) insertion of the special Harrington rod; 3) removal of the rod, standard posterior fusion and fitting of a standard Harrington rod; 4) removal of the halo-pelvic apparatus, approximately six weeks later.

Preliminary investigations were the routine tests prescribed for all patients with spinal deformities, and these included full radiographs and respiratory function tests.

Details of treatment

1. The skull halo, pelvic pins and hoop were fitted in exactly the same manner as has been previously described (48). Fitting the extension bars several days later, with the patient seated and comfortably suspended by the skull halo, is easier, both for the surgeon and for the patient.

2. The special Harrington rods were inserted by the method previously described (41). Normally at operation the two anterior bars are left in position on the apparatus, removing only the posterior bars to allow access to the spine. In these patients all four bars were removed, so that the forces could be evaluated whilst the bars were being applied. The operations were done with the patient prone on the Relton-Hall frame (53).

TABLE 8

Case number	Age/Sex	Body weight* (pre-op.) (kg)	Pre-operative details of major curve, all convex to right side: Extent**	Pre-operative details of major curve, all convex to right side: Angle of scoliosis (Cobb) (degrees)	Post-operative curve measurement (AP film.) (degrees)	Correction (per cent)	Period of time between fitting of H.P.T. and insertion of special Harrington rod (days)	Force on spine measured from springs before surgery (patient standing) (kp)
1	13.5/M	46	T11-L3 (5)	105	54	48	27	14.2
2	12.5/M	26	T4-T12 (9)	105	85	19	29	7.7
3	16.5/M	32	T11-L3 (5)	145	60	51	29	16.5
4	16/F	28	T5-T12 (8)	95	46	51	2	2.2

*Body weight may change significantly if patient is in the halo-pelvic apparatus for a prolonged period.

**Number of vertebrae in major curve.

A midline vertical posterior incision and the standard subperiosteal exposure of the concave bony elements was made. The upper and lower Harrington hooks were inserted in the routine manner. The special rod was then placed in position and the coil and transmitter put into an adjacent, subcutaneous pocket. A force-gauging distractor (40) was used to distract the rod. Initial readings were taken from the special rod at this stage and continued during the operation. Over the next seven to ten days three sets of readings were taken at different times, (a) from the halo-pelvic springs, (b) from the special Harrington rod, and (c) from a spring balance suspending the halo with the extension bars removed.

3. At re-operation, approximately two weeks later, the telemetry rod was replaced with a standard Harrington rod and further distraction attempted. The convex side of the curve was also dissected free of soft tissues and a routine posterior fusion done. A two-stage correction was routine at the Department of Orthopaedic Surgery I in Göteborg (18). Supplementary anterior fusions were done in two patients (Nos. 1 and 3) because of the 'kyphotic' component in their deformities.

4. The halo-pelvic apparatus was removed approximately six weeks after the spine fusion and full length body casts fitted to the patients.

RESULTS

A. During the operation
B. At the end of operation
C. Lifting the patient from the operation table to the bed

A. During the operation (Table 9)

When the concave aspect of the scoliosis had been exposed and the upper and lower hooks placed in position, the modified Harrington rod was then connected up and the manual force gauging distractor used to extend the rod. The distraction forces varied from 15 to 40 kp. Patient No. 2, in whom the 15 kp reading was made, had low readings throughout because of the osteoporotic bone which was unable to hold the upper hook. Consequently, a firmer purchase for the seating of

TABLE 9

Demonstration of the forces, measured with the manual distractor and the special Harrington rod during operation, in four patients. Measurements also obtained both during reapplication of the four extension bars to the halo-pelvic apparatus and during lifting and turning the patients at completion of the operation.

Case number	Maximum force used during operation		Forces in the rod when H.P.T. applied at end of operation			
	Manual distractor (kp)	Special Harrington rod (kp)	Patient prone and before bars fitted (approx. 60 min. later) (kp)	Anterior bars fitted (kp)	Posterior bars fitted (kp)	Lifting and turning maximum force (kp)
1	40	20	11	(i)[+] 10 (prone)	(ii)[+] 11 (prone)	14 (+3)
2	15	7	5	(ii) 2 (supine)	(i) 3 (prone)	3 (+1)
3	40	13[*]	7	(ii) 6 (supine)	(i) 6 (prone)	9 (+3)
4	30	18	7	(i) 6 (prone)	(ii) 3 (supine)	Reading not taken

[+] (i) and (ii) signifies the sequence in which the bars were placed in position between the skull halo and pelvic hoop.

[*] Figures measured from the special rod are usually about half of those measured with the force gauging distractor (adjacent column). The discrepancy here was due to a gross kyphotic element (in this patient, 142 degrees). This tended to bend the rod and thus produced a large element of friction.

the hook was obtained by using acrylic cement.

The first readings taken from the telemetry rod ranged from 7 to 20 kp (column 3). In general terms, the force in the rod was approximately 50 per cent of those measured with the manual distractor. However, in patient No. 3, a gross 'kyphotic' element (142 degrees) produced a large element of friction between the rod and the hooks creating readings on the distractor which were higher than would otherwise have been anticipated.

The differences in these two sets of readings (manual distractor and telemetry rod) might be due to the fact that the manual distractor measures total force of distraction including friction between hook and rod whereas the telemetry rod registers only the axial component of that force. It will always therefore have a lower reading than the manual distractor.

The forces in the special rod were again measured at the end of the operation. By this time the stability of the two hooks had been checked and both the transmitter and the power transfer coil had been placed in pockets developed between the subcutaneous tissue and the dorso-lumbar fascia. The wound was closed in layers and continuous suction drainage was used. Readings at this stage varied from 5 to 11 kp (Table 9, column 4), an average of 60 minutes having elapsed between the first and the second readings from the rods.

The progressive decline of forces registered in the rod is evident, notably in patient No. 4 where, over this 60 minute period, the rod readings fell from 18 to 7 kp. The average initial reading from the Harrington rod was 14.5 kp and the average reading after 60 minutes at the end of the operation was 7.5 kp. In broad terms, approximately 50 per cent of the force through the rod had vanished at the end of the operation, similar to the results previously reported (18, 41). There is an inevitable decline in forces due to the visco-elasticity of the stretched tissues; later readings will always be lower than the initial ones.

B. End of operation - reapplying the extension bars (Table 9)

The four extension bars were reapplied during which time readings of the internal force were taken. The anterior extension bars were reapplied first in patients No. 1 and No. 4 and the posterior bars first in patients No. 2 and No. 3. The patient in each case was prone for the fitting of the first bars; in patient No. 1 the prone position was maintained but the other three patients were turned to the supine position on the table before the second set of bars was reattached to the halo and pelvic hoop. The length of the bars was not altered in any way from their pre-operative length.

During the refitting of the extension bars seven of the eight readings were less than those taken before the bars were attached. In patient No. 4 a significant reduction in the force on the rod (from 6 to 3 kp) was recorded with the fitting of the posterior bars in the supine position with the anterior bars already in place. There are two explanations for this. The refitting of the bars tends to unload the rod slightly and, with the progress of time, there is still further decline in the forces on the rod.

C. Lifting the patient from the operating table to the bed (Table 9)

The patient was lifted from the operating table and placed on his ward bed. Patient No. 1 needed to be turned to the supine position and then placed on the bed; the other patients were already supine on the operating table, the spinal frame having previously been removed. Readings were taken whilst the patients were transferred from the table to their beds (except for patient No. 4 where readings were not taken at this stage).

All three patients measured registered an increase in forces on the rod when compared with the last readings taken during the fitting of the second pair of extension bars (Table 9, columns 5 and 6). Patients No. 1 and No. 3 showed an increase of 3 kp force in the rod, patient No. 2 an increase of 1 kp. There was little influence on the rod in the patients during refitting of the extension bars, nor did there seem to be any consistent difference in the forces of the patients who had the anterior bars fitted before the posterior ones or those who had the bars fitted in a prone or supine position. It is important, however, that this fitting be done carefully.

TABLE 10

A demonstration of the inherent stability of the halo-pelvic apparatus. Comparison of measurements during and immediately following surgery (in kiloponds).

Group A*: "Non halo-pelvic group". First four patients in whom special rod was used.

Group B: "Halo-pelvic group". Four patients in this series.

Group	Case No.	Maximal reading during distraction (manual distractor) (kp)	Reading in special rod after 60 minutes (kp)	Reading in special rod after all four halo-pelvic bars are applied (kp)	Maximal reading in special rod lifting and turning (kp)	Change in reading in special rod (kp)
A	1	42	31		43	+12
	2	25	18		32	+14
	3	21	12		16	+4
	4	20	14		23	+9
B	1	40	11	11	14	+3
	2	15	5	2	3	+1
	3	40	7	6	9	+3
	4	30	7	3	-	-

*Reference: Elfström & Nachemson, Clin. Orth. 93, 158-172, June, 1973.

The stability of the apparatus is apparent when comparing this group of patients with a previous group who were not in the halo-pelvic apparatus (41). They had the telemetry rod applied and measurements were taken when the patients were lifted from the table to the bed.

Table 10 shows two such groups, a "non halo-pelvic" and a "halo-pelvic" group. In the "non halo-pelvic" group (Group A) the changes in the rod forces during lifting and turning varied from an increase of 4 to an increase of 14 kp; in three of these four patients the increase at this stage exceeded the highest forces registered during the operation itself, when the rod was first inserted. With the stability of the halo-pelvic apparatus in the three patients where readings were taken (Group B), the maximum increase in the rod force during lifting and turning varied from 1 to 3 kp.

D. Readings in the rod after surgery and during the first three post-operative days (Table 11)

Day of operation:

Coughing or straining during recovery from anaesthesia produced a mean increase of 2 kp in the rod (range 1 to 3 kp). One patient vomited during recovery (patient No. 4) and an increase of 4 kp was recorded. These figures are more meaningful when compared with the mean increase and range in forces measured with the special rod in the group of patients who were not in the halo-pelvic apparatus (Table 11). This "non halo-pelvic" group had a mean increase of 5 kp (range 0 to 14 kp) during lifting and turning from the operating table to the bed.

In the recovery phase after surgery, the "non halo-pelvic" group had a mean increase of 3 kp recorded in the rod (range 0 to 6 kp). In one patient (41) an increase of 30 kp was observed when vomiting occurred during the post-operative period.

Comparing these two groups of patients, with and without the support of the halo-pelvic apparatus, demonstrates the stability and protection for the implanted rod provided by the halo-pelvic apparatus. The greatest difference was recorded in the two patients who vomited during recovery; the patient without external support had an increase of 30 kp recorded in the rod as opposed to the patient in the halo-

TABLE 11

Mean increases and the range in forces measured with special rod (in kiloponds).

	Activity performed	GROUP A: NON HALO-PELVIC		GROUP B: HALO-PELVIC	
		Mean	Range	Mean	Range
Day of operation	Lifting and turning from operating table to bed	5	0 to 14	2	1 to 3
	Coughing during recovery (first four hours)	3	0 to 6	2	1 to 3
	Vomiting during recovery	30* (one patient)		4 (patient No. 4)	
Day 2 to 3 post-operatively	Positive pressure breathing (Bird respirator)	1	0 to 2	1	0.5 to 1.5
	Bicycle exercises in bed	2	0 to 5	No increase	No increase
	Arm exercises	7	5 to 10	No increase	No increase
	Turning in bed to convex side	3	2 to 4	3	1 to 7
	Turning in bed to concave side	1	0 to 2	0	0 to +1

*Cf. patient L.K.; J. Bone Joint Surg. (A), 53A, 445-465, April, 1971.

pelvic apparatus in whom an increase of only 4 kp was measured.

Day 2 to 3 post-operative

On the second or third day after surgery the patients used the Bird respirator for positive pressure breathing. In the halo-pelvic group mean increases of 1 kp were recorded (range 0.5 to 1.5 kp). When compared with group A (non halo-pelvic) there was little difference, for, in this group, the mean increase was the same (1 kp) and the range of increase similar (0 to 2 kp). It would seem that using the respirator places little stress on the spine.

On the third day after surgery the following activities were performed by the patients:

1. Cycling exercises in bed
2. Arm exercises
3. Turning in bed to the convex side of the major curve
4. Turning in bed to the concave side of the major curve

1. Cycling exercises in bed

No increases were recorded in the halo-pelvic patients whereas in group A (non halo-pelvic) mean increases of 2 kp (range 0 to 5 kp) were recorded with this manoeuvre.

2. Arm exercises

The patients were encouraged to lift weights with both hands and also to exercise against the resistance of a spring type chest expander. In the halo-pelvic group no increase in forces was observed. In the non halo-pelvic group mean increases of 7 kp were measured during the same exercise (range 5 to 10 kp).

The stability provided by the halo-pelvic apparatus is probably best demonstrated in this particular series of exercises, where no increase in forces on the rod were recorded.

3 and 4. Turning in bed to the convex and concave sides of the major curve

The patients were assisted to turn in bed so that the convex part of the instrumented curve was lowermost and readings were taken during this change in position. There was a mean increase of 3 kp in the halo-pelvic group (range 1 to 7 kp).

They were then assisted back to the supine position and turned to the opposite side so that the concave side of the deformity was facing downwards. The mean increase during this manoeuvre was zero (range 0 to 1 kp).

Similar increases were observed in both groups of patients, namely a larger increase in forces on the rod when the patient was turned to the convex side (Table 4).

E. <u>An assessment of the tension transmitted to the spine with the halo-pelvic apparatus</u>

Two separate investigations were carried out. Firstly, the springs at the base of the extension bars were measured with a vernier caliper in the routine manner and the forces calculated as described in Part I. This was done with the patient seated. All four extension bars were then lengthened by increments of 2 millimetres, and after each extension the springs were measured again and readings were taken from the special Harrington rod.

The lengthening was done over approximately 20 to 30 minutes, and in each patient 8 to 10 millimetres of lengthening of the bars was tolerated without discomfort. The external and internal force readings at various increases in spine length were taken and the respective points were plotted.

Secondly, a spring balance, with cords and small hooks, was connected to the skull halo and upward traction through the halo was applied, approximately equal to that measured on the springs. The four extension bars were then removed. The force in the spring balance was then altered gradually in stages, and at each stage readings were taken from the spring balance and simultaneously from the internal rod. These points were similarly plotted.

DISCUSSION

As would be expected, there is a direct relationship within certain limits between the external force applied either by the spring balance or the halo-pelvic apparatus and the internal forces on the spine measured simultaneously on the special rod. One should not draw definite conclusions from these curves because of the multitude of variables such as: age, body weight and height, site of deformity, pattern of muscular imbalance, to mention only some of them. The measuring systems do appear to be consistent, although the differences in each patient are vast.

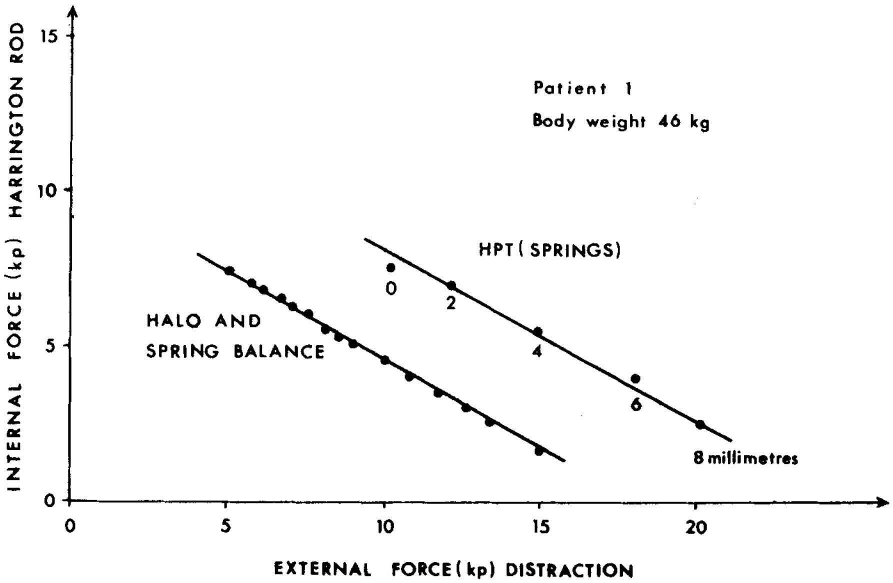

Figure 38. Patient No. 1. Plotted curves of internal force against external force measurements. The external force systems included:
left curve: the skull halo with the spring balance suspending it with the extension bars removed.
right curve: the springs compressed at the bases of the four extension bars.

In patient No. 1, with an internal force of 5 kp (Fig. 38), the halo and spring balance registers 9 kp and the halo-pelvic springs 16 kp, a difference of 7 kp between the two external readings for the same internal measurement. The difference can be explained by friction in the halo-pelvic spring measuring system and the error of the force readings of this system. Furthermore, patient No. 1 was a tall boy on whom long extension bars had to be used. This creates difficulties in the alignment of the four bars and there is a greater risk of friction in the system. The spring balance applies its force directly on the halo, axially on the spine, and without either friction or bending moments.

In patient No. 4 (Fig. 39) for the same internal reading (5 kp) the halo-pelvic springs register 6 kp and the spring balance springs 7.5 kp. Note in this patient that the plotted curves have changed their position relative to one another: the halo-pelvic spring curve has the lower offset. In this patient, a small female, the bars were easy to align and no friction was noted. The difference between the two curves can be explained by the error in spring measurements.

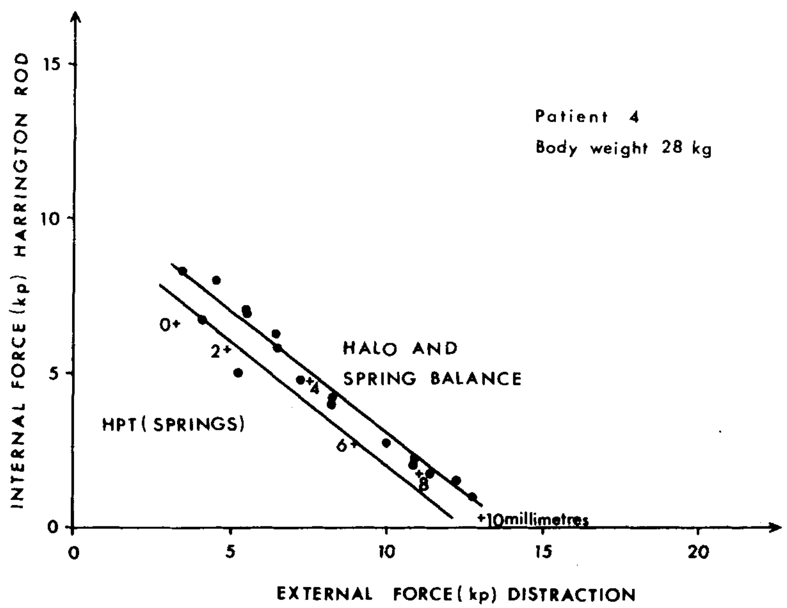

Figure 39. Patient No. 4. Plotted curves of internal force against external force measurements. The external force systems included:
<u>left curve</u>: the springs compressed at the bases of the four extension bars.
<u>right curve</u>: the skull halo with the spring balance suspending it with the extension bars removed.

Perhaps the wider scatter of the points in patient No. 4 (Fig. 39), when compared with patient No. 1 (Fig. 38), is due to the fact that the external readings extend over a range from 3 to 12.5 kp. In patient No. 1, they vary from 5 to 20 kp. It is likely that the springs will tend to be more accurate once their initial slack has been taken up.

For an increase in length of 8 millimetres for patient No. 1 (Fig. 38) the halo-pelvic springs registered an increase of 10 kp (from 10 to 20 kp). In patient No. 4 (Fig. 39) for the same increase in length, the external force increase was 7.8 kp (from 3.2 to 11 kp).

In the plotted curves the offsets are different in both patients for both external measuring systems when plotted against the force on the rod. (The offset is found by extending the curves to where they meet the vertical axis, i.e. the external force is zero.) In patient No. 1, the offset is 10 kp for the halo and spring balance and 14 kp for the halo-pelvic springs. For patient No. 4, the offset for the halo-pelvic springs is 10 kp, and for the halo and spring balance it is 11 kp but again the slopes for each patient are the same.

In patient No. 1, the internal force is equal to 60 per cent of the externally applied distractive force. In patient No. 4, the internal force reduction was equal to 80 per cent. In other words, for these two patients over this range of forces and under these specific circumstances, 60 and 80 per cent of change in the external force, respectively, appears as a change in the internal force. The linear relationship between the force (stress) and deformation (strain) demonstrates the elastic properties of tissue (22).

In Fig. 40 (halo-pelvic springs and internal readings) the curves for both patients are linear, the measured points fall nearly along straight lines and these lines fairly closely approximate equal slopes.

In Fig. 41 (halo and spring balance and internal readings) the curves are more or less linear and the two slopes are reasonably close to each other considering the differences between the patients' ages, heights, body weights, and their site and extent of deformity.

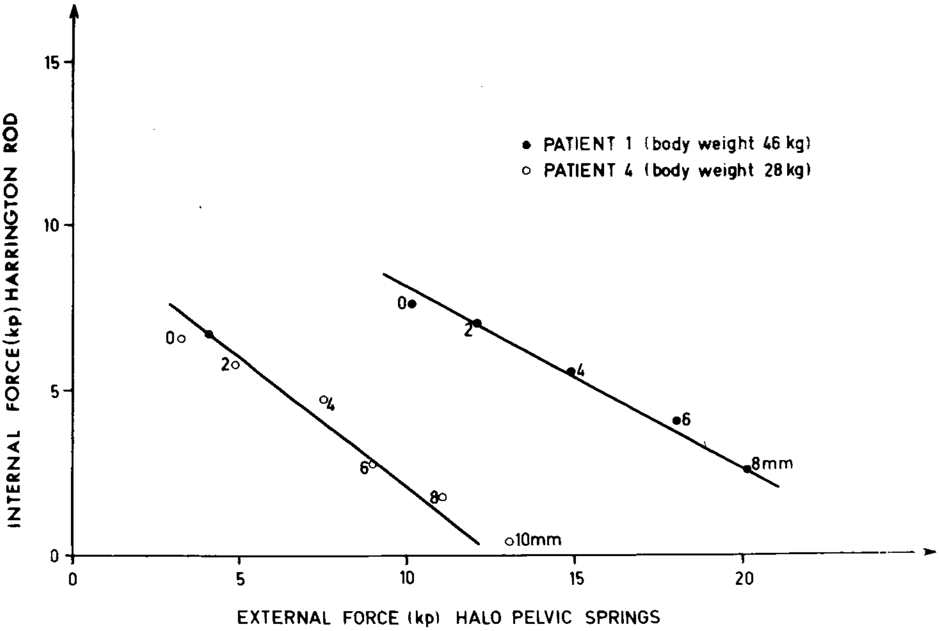

Figure 40. Plotted curves of the external force measurements for both patients (halo-pelvic springs), and the internal force measurements (telemetry rod).

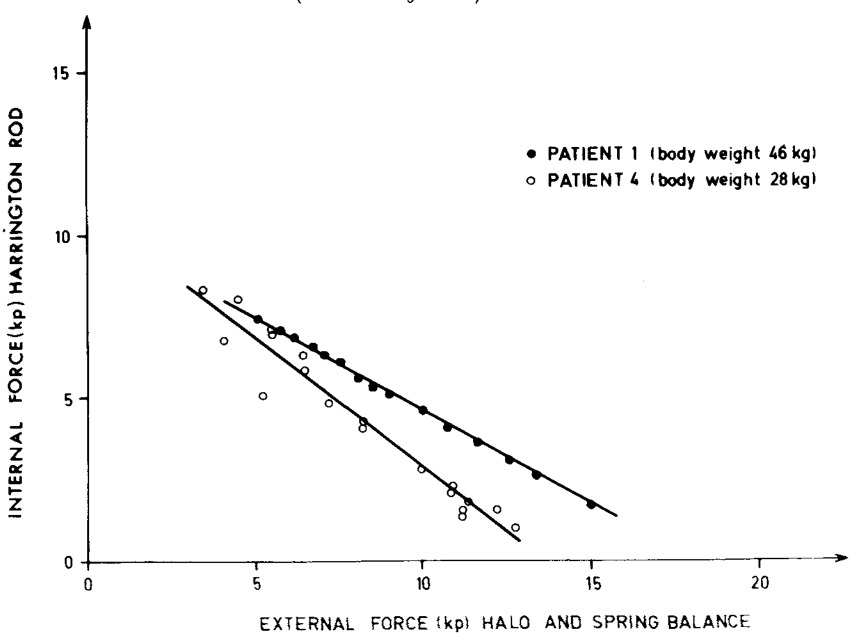

Figure 41. Plotted curves of the external force measurements for both patients (the halo and spring balance system), against the internal force measurements (telemetry rod).

SUMMARY AND CONCLUSIONS

Four patients with severe paralytic scoliosis requiring preliminary pre-operative halo-pelvic traction had a specially designed telemetry rod inserted during treatment and over the next 10 to 14 days measurements were taken from the telemetry rods and from the compressed springs at the base of the extension bars as well as from a spring balance suspending the skull halo with the extension bars removed.

Readings from the telemetry rod were taken from the time of its insertion at operation and an early decline in forces on the rod was observed. Replacing the extension bars at the end of surgery did not have a significant effect on the forces on the spine measured from the rod. Lifting the patient from the operating table and placing him on his ward bed, which was done without any particular precautions, produced a mean force increase of 2 kp in the rod.

Coughing during recovery from anaesthesia produced a mean increase of 2 kp in the rod. Vomiting (one patient) produced an increase of 4 kp and positive pressure breathing with a Bird respirator a mean increase of 1 kp in the rod.

Cycling and arm exercises in bed three days after surgery produced no increase in rod measurements. Turning the patient in bed to the convex side of the major curve produced a mean increase of 3 kp and to the concave side no increase was observed.

With acute distraction (over 15 to 20 minutes), there was a linear relationship demonstrated between the externally applied force and the force simultaneously recorded on the telemetry rod in the spine. This existed for both external systems - the halo-pelvic apparatus and the forces applied through the skull halo and spring balance with the extension bars removed.

The direct relationship between stress and strain was demonstrated, illustrating elasticity as one of the mechanical properties of biological tissue.

In the two patients who were assessed, 60 and 80 per cent, respectively, of changes in the externally applied force appeared as changes in the force measured in the spine itself by the telemetry rod.

PART IV

AN ANATOMICAL AND MECHANICAL STUDY OF SKULL AND PELVIC FIXATION RELATIVE TO THE USE OF THE HALO-PELVIC APPARATUS

INTRODUCTION

When this clinical project commenced in 1969, studies were done both in the autopsy room and on cadaver specimens to determine the points of relative safety for inserting the pelvic pins. Complications related to skull and pelvic fixation have occurred (see Part II, Chapter II): the skull halo slipped and required replacing in eight patients; the apparatus was removed early in five patients because of insecure pin fixation. There was tearing of the peritoneum in one patient. Loosening of pins, with prolonged immobilisation, was commonly seen.

This present study was therefore expanded to define more clearly the preferred anatomical landmarks and the mechanical aspects relative to the use of the halo-pelvic apparatus.

The following subjects were explored:
1) Fixation of the skull halo and the advantages, if any, of using supplementary skull pins.
2) The anatomy of pelvic pin insertion with particular emphasis on defining safe landmarks.
3) Basic mechanical studies of the bony ilium.

1. SKULL HALO FIXATION

An autopsy study was carried out to determine the forces required to dislodge a skull halo which had been applied by the standard clinical method (Part I). The ages of the four subjects ranged from 60 to 68 years and all had died of non-malignant diseases. Each was firmly secured to the autopsy table and the skull halo applied with the pins inserted by a torque screw driver, which recorded five and one half pounds of torque force (0.06 kpm). The pins used were of the same dimensions as those used by the Rancho group (43).

A rope and pulley system was connected to the halo in such a way that the distraction force applied would be equally distributed amongst the four (or six) pins. A spring balance, registering up to 200 kiloponds, was placed between the rope and pulley and a fixed point on the wall. Traction forces were applied gradually for up to five minutes or until the halo slipped from the skull.

Four pins were used routinely; when the halo slipped from the skull it was reapplied in two subjects; new points of fixation, adjacent to those previously used, were chosen and two supplementary pins inserted two centimetres behind the posterior pins. The traction was then gradually reapplied.

As for routine autopsy purposes, the upper part of the calvarium was then removed. The thickness of the region of the cranium where the pins had been inserted and the depth of the pits which lodged the pins in the outer table were measured.

RESULTS (Table 12)

With four skull halo pins in place, a force equal to body weight or more was applied before the halo pins cut through bone and the halo slipped off. In the first subject the halo could not be dislodged with a 200 kilopond force (three times the body weight) although the posterior pins had commenced to slip. The anterior skull pins slipped first in the other three subjects.

When two supplementary pins were added an additional 50 kiloponds of force was required to shift the halo in case 3, and in case 4 fixation could not be disturbed with 200 kiloponds of force.

The depth of penetration of the skull pins varied from 0.3 millimetres to 1.2 millimetres with the same amount of torque force applied; it was most commonly 0.5 millimetres. The deepest pin had lodged in the squamosal suture, which had not fused, and only the pin shouldering had prevented further penetration. The average thickness of the skull at the points of pin insertion was 5 millimetres.

DISCUSSION

Skull halo pins are usually inserted into the lateral aspects of the frontal bones and the posterior aspects of the temporal bones, regions which are safe because of the thickness of the skull.

TABLE 12

SKULL HALO FIXATION. RESULTS

Number	Age & sex	Body weight	Force required to detach skull halo (applied over five minutes)	Number of skull pins used	Depth of penetration of skull pins (millimetres)		Comments
					Anterior	Posterior	
1	68/F	65 kg	200 kp plus	4	0.5, 0.5	0.5, 0.5	Halo in position with forces 3 times body weight; posterior pins had commenced to slip.
2	66/F	80 kg	80 kp	4	0.3, 0.5	0.7, 0.5	Anterior pins slipped first with force equal to body weight.
3	60/M	65 kg	100 kp	4	1.0, 0.7	0.3, 0.5	Anterior pins slipped first with force over body weight.
			150 kp	6	1.0, 0.7	0.5, 0.7 0.5, 0.5	50 kp more force needed to dislodge halo with 6 pins.
4	68/M	65 kg	150 kp	4	0.5, 0.3	0.5, 0.7	Anterior pins slipped first with force over twice body weight.
			200 kp plus	6	1.0, 0.7	1.2, 1.0 0.7, 0.5	Significantly greater hold with two extra pins. Deep pin (1.2 mm) was in squamosal suture.

In the temporal region, the frontal and temporal bones do not quite meet because of the interposition of the parietal and sphenoid bones. This region of skull, termed the pterion, is 3.5 centimetres behind, and 1.5 centimetres above the lateral margin of the bony orbit (8). It lies deep to the temporal muscle and may be paper thin; on its deeper surface is the middle meningeal artery, which may produce a potentially lethal extra-dural haemorrhage if damaged. Skull pins inserted in the temporal region may be hazardous. The elected sites used clinically and in this present study, are preferable for reasons of safety, as the bone is so much thicker and denser.

Perry (51) observed at post-mortem the pits made by the skull pins in the cranium of a patient with complete paralysis, who died after having a halo on for one month. They had penetrated less than two millimetres. Skull bones in children are less dense and presumably the pins would penetrate the outer table to a greater depth than observed in this study.

Nickel and associates in 1968 (44) reporting on the use of the skull halo in 204 patients observed only 3 cases where the halo had slipped. Many of the halos, however, had been fitted together with a body plaster and not a pelvic hoop. It is likely that the forces applied through the skull halo with halo-pelvic distraction are much greater than without the halo traction system. This would explain the much higher incidence of skull halo slipping that we have had in our clinical experience with the halo-pelvic apparatus.

Clinically the problem of the slipping skull halo has been met by 1) routine tightening of the skull pins one week after their fitting (to overcome loosening from pressure necrosis of the bone), and 2) the use of six pins when treatment is to be prolonged.

2. THE ANATOMY OF PELVIC PIN INSERTION WITH PARTICULAR EMPHASIS ON DEFINING SAFE LANDMARKS

The standard clinical method of inserting the pelvic pins (47) was employed on 10 adult subjects at the time of routine autopsy. Their ages varied from 40 to 70 years. The instruments used included the drilling jig, the carpenter's brace and two diameters of pelvic pin

(6.35 and 8 millimetres). All the pins were inserted, with the aid of the jig, antero-posteriorly with the subject secured in the lateral position on the table. The pins were inserted blindly on or near the iliac crest and their positions subsequently inspected relative to the soft tissues in the corresponding iliac fossa and in their relationship to the bone. In several instances two or three pins were drilled into the crest on the same side but from different points of entry. Twenty-four separate pins were inserted. The bony pelvis appeared clinically normal and not misshapen in any of the subjects.

RESULTS (Table 13)

The safest combination of entry and exit points was the tubercle of the crest and the posterior superior iliac spine (Fig. 42, page 143). Commonly, these pins stayed intraosseous throughout their entire course, this depending to a large extent on the relative thickness of the bony iliac fossa at its centre. In 5 out of 24 instances, the pin raised the inner cortical table of the iliac fossa; sometimes the middle portion of the pin was just within the fossa. Here it was usually safe as the iliacus muscle forms the fossa bed. When this situation arose the more flexible smaller pin was often deflected for up to 2 centimetres, by the curved posterior region of the iliac fossa and the adjacent sacro-iliac joint, before reengaging bone and penetrating the anterior sacro-iliac ligament. Such pins finally emerged one or two centimetres more medial than anticipated. The larger and more rigid pin steered a more direct course under these circumstances and was not deflected as far by the bony curve.

Several pins were inserted inferior to the tubercle of the crest, through the tensor fasciae latae, and the outer table of cortical bone between the crest and the hip joint. They were equally safe but at their point of entry they penetrate more soft tissue and are thus more likely to produce infection.

In five cases (1R, 2L, 3R, 5R, 9L) the pin was medial to the iliacus, and in one of the subjects (2), it had wrapped the peritoneum around itself. These five pins were all inserted near the anterior superior spine although one of them (2L) was inserted on the crest midway between the anterior spine and the tubercle of the crest. In three

TABLE 13. PELVIC PIN INSERTION. RESULTS

Series number + side	Age/Sex	Point of pin entry	Point of pin exit	Observations	Comments
1L	55/M	Tubercle of crest	PSIS*	2 cm of length intra-pelvic. Raised inner table of fossa by 2 mms	Firm purchase in crest, safe
R		Below crest 1 cm from ASIS*	PSIS	5 cm of length intra-pelvic, in mid course 2 cms from iliac fossa	Unsafe, medial to iliacus
R		2 cm below and lateral to ASIS	PSIS	2 cm of length intra-pelvic in mid course	Relatively safe, within iliacus
2R	60/M	2 cm from ASIS on crest	Medial to PSIS	6 cm of length intra-pelvic, 1 cm from iliac fossa	Relatively safe, at mid point only 2 cm from femoral nerve
R		Tubercle of crest	PSIS	6 cm of length extra-pelvic, i.e. external to the crest	Safe, rigid hold in bone
L		Between ASIS and tubercle of crest	PSIS	6 cm of length intra-pelvic, 2 cm from sigmoid colon	Had wrapped peritoneum around it Unsafe, 3 cm from femoral nerve
L		Tubercle of crest (7 cm from ASIS)	PSIS	Raised inner table of iliac fossa over 3 cm	Safe, secure purchase
3R	66/M	2 cm from ASIS on crest	1 cm medial to PSIS	6 cm of length intra-pelvic, medial to iliacus, 2 cm from caecum	Unsafe
L		Tubercle of crest	1 cm medial to PSIS	Entirely within crest	Safe

TABLE 13 cont.

Series number + side	Age/Sex	Point of pin entry	Point of pin exit	Observations	Comments
4R	50/M	Tubercle of crest	PSIS	8 cm of length intra-pelvic (half pin diameter only)	Pin within iliacus, safe
L		2 cm anterior to tubercle of crest	PSIS	7 cm of length intra-pelvic, raised inner table	Subperiosteal, safe
5L	40/M	1 cm below tubercle of crest	PSIS	Mid portion of pin raised outer table of iliac fossa	Safe, secure purchase
L		Tubercle of crest	PSIS	Entirely within crest	Safe, secure purchase
R		1 cm posterior to ASIS	2 cm medial to PSIS	6 cm of length intra-pelvic, and medial to iliacus	In contact with caecum, unsafe
R		Tubercle of crest	PSIS	Raised inner table of iliac fossa in mid course by 3 mm	Safe, secure
6R	67/F	2 cm below tubercle of crest	PSIS	Entirely within crest	Safe, secure purchase
L		Tubercle of crest	PSIS	Raised inner table, subperiosteal	Safe, secure purchase
7R	67/F	Mid way between ASIS and tubercle of crest	2 cm medial to PSIS	2 cm of length intra-pelvic in mid course	Within iliacus, safe
		Tubercle of crest	PSIS	Entirely within crest	Safe, secure purchase

TABLE 13 cont.

Series number + side	Age/Sex	Point of pin entry	Point of pin exit	Observations	Comments
8R	51/M	Midway between tubercle and ASIS	1 cm medial to PSIS	Intra-pelvic over 4 cm of course	Deep to iliacus, safe
L		Tubercle of crest	PSIS	Visible beneath periosteum of iliac fossa, entirely within bone	Safe, secure purchase
9R	74/F	2 cm below tubercle of crest	PSIS	Entirely within bone	Safe, secure
L		1 cm posterior to ASIS	2 cm medial to PSIS	5 cm medial to iliacus	<u>Unsafe</u>, poor purchase
10R	74/F	Tubercle of crest	PSIS	Raised outer table by 5 millimetres in mid course	Safe, secure
L		2 cm below tubercle of crest	PSIS	Entirely within bone	Safe, secure purchase

* ASIS Anterior superior iliac spine

PSIS Posterior superior iliac spine

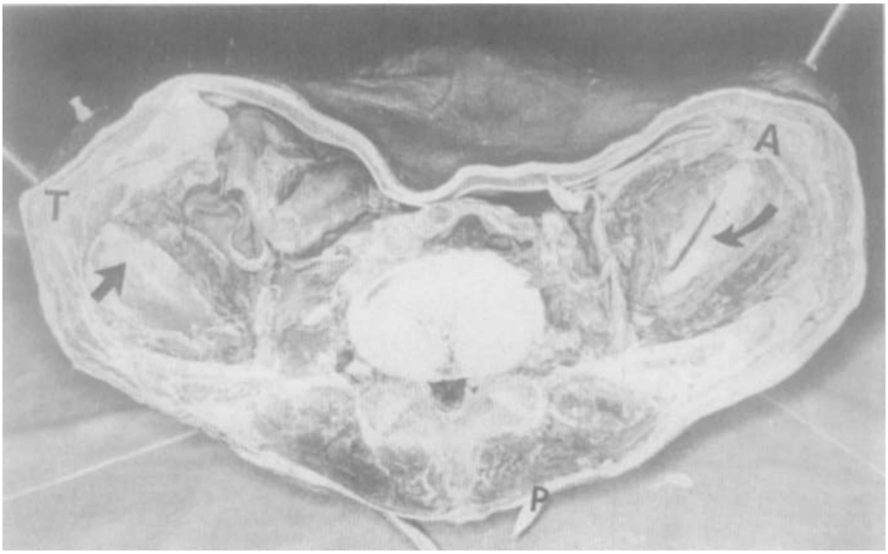

Figure 42. A section through the pelvis of an adult anatomy dissection specimen. The transverse section has been made through the lumbo-sacral disc; with the aid of a drilling jig, pelvic pins have been inserted through both iliac crests. On both sides, the pelvic viscera, peritoneum, iliacus muscle and the periosteum of the iliac fossae have been stripped medially. Note that:
(a) On the reader's right, the pelvic pin has been inserted through the right iliac crest beginning at the anterior superior iliac spine (A) and emerging at the posterior superior spine (P). The pin is intra-pelvic in the middle of its course (arrow).
(b) On the reader's left side, a second pin has been inserted through the left iliac crest beginning at the tubercle of the crest (T) and emerging at the posterior superior spine. Note that the pin is intraosseous throughout its course and it can be seen beneath the cortical bone of the inner table of the iliac fossa (arrow). The left anterior superior spine is marked.

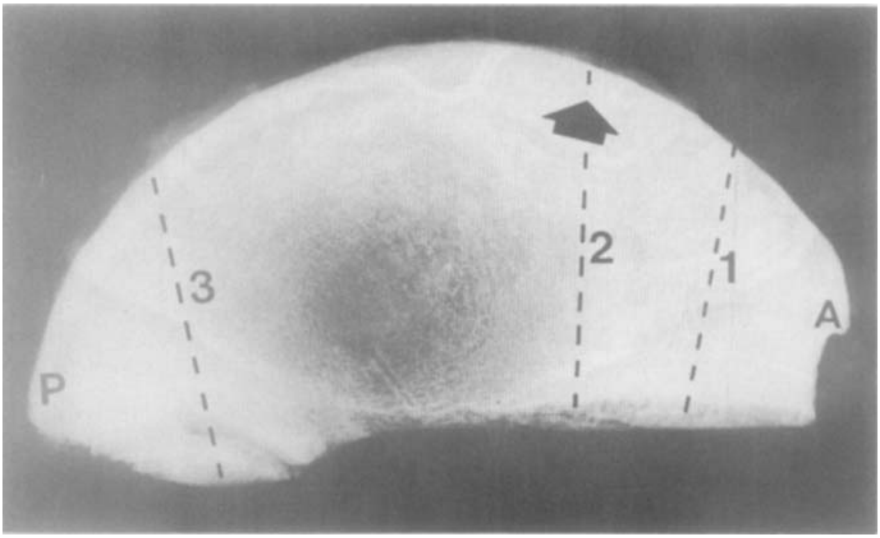

Figure 43. A lateral radiograph of an iliac crest removed at autopsy from a patient who died by accidental death. Note the following points: (A) the anterior and (P) the posterior superior iliac spine and the tubercle of the crest (arrow). Observe the thickness of the cortex at this point. Also note the deficiency in the mid portion of the bone between two relatively thick anterior and posterior columns. Bone samples 1, 2 and 3 used in the study of strength of the iliac crest have been taken from areas designated 1, 2 and 3, respectively, in this specimen.

cases (2R, 5L, 10R), the pin was seen external to the outer table over as much as 4 centimetres of its course. Provided the purchase in the strong anterior and posterior bony columns was adequate, these were considered mechanically acceptable.

DISCUSSION

The ideal pre-requisites for pelvic pin insertion should be:

1) They should be inserted safely without exposing the iliac crest, thus reducing the early incidence of infection.
2) There should be no risk to the pelvic viscera.
3) They should be inserted percutaneously, thus minimising the amount of soft tissue exposed to the pin.
4) There should be good mechanical fixation, sufficient to withstand several months of treatment.
5) The pins should be tolerated by the patient.

The present investigation has obvious limitations, the main one being that patients requiring the halo-pelvic apparatus for treatment often have a poorly developed pelvis, commonly osteoporotic and occasionally oblique. Secondly, this study has been done on a much older age group; nonetheless, guidelines emerge which might serve as an appropriate anatomical baseline.

The crest of the ilium is cartilagenous at the time of birth. With the process of ossification by the age of 9, it has been reduced to a cap of cartilage one centimetre in height (Fig. 46, page 150). In this appear secondary centres of ossification at puberty (Fig. 47, page 151), which fuse with the underlying bony crest by about twenty years (Fig. 43). The iliac crest is then converted into a strong cortical cap particularly at the tubercle, which was demonstrated by the slab radiographs (Fig. 44).

The bony ilium includes the upper part of the acetabulum and the flattened area above it. Three parts of it are subcutaneous, the upper end, which is the crest itself, and the two projecting anterior and posterior spines. The crest is convex upwards when viewed from the side; viewed from above it describes a sigmoid curve, the longer medial anterior component being the iliac fossa, and the smaller

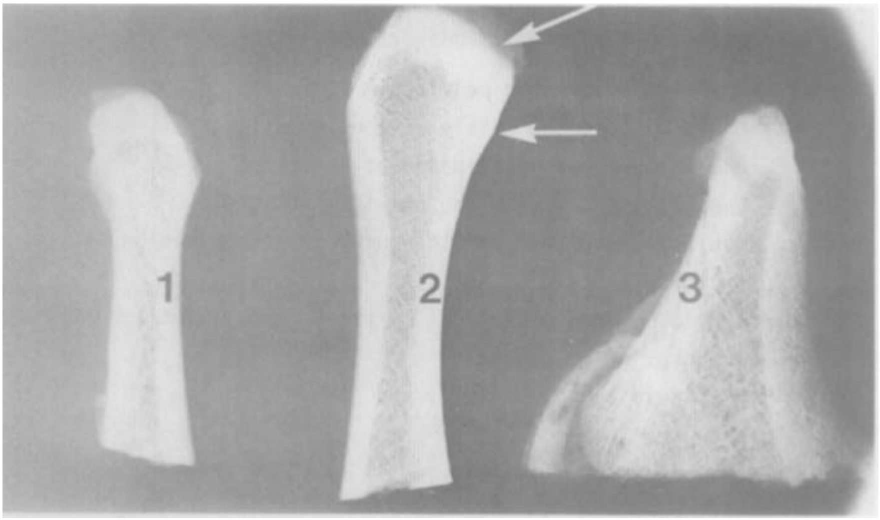

Figure 44. Slab radiographs of transverse sections of the iliac crest shown in Fig. 43 and removed from the areas of the bone designated 1, 2 and 3, respectively.

Section 1 is a transverse section midway between the anterior superior spine and the tubercle of the crest.

Section 2 is at the level of the tubercle of the crest. Note the well developed cortex at both the tubercle and forming the lateral table (arrows). Note that the iliac apophysis has completely fused to the iliac crest indicating full skeletal maturity.

Section 3 is taken through the posterior part of the iliac crest, 3 centimetres anterior to the posterior superior iliac spine. Note the medial part of the specimen includes a section through the sacro-iliac joint. Note particularly the absence of strong cortical bone in this specimen.

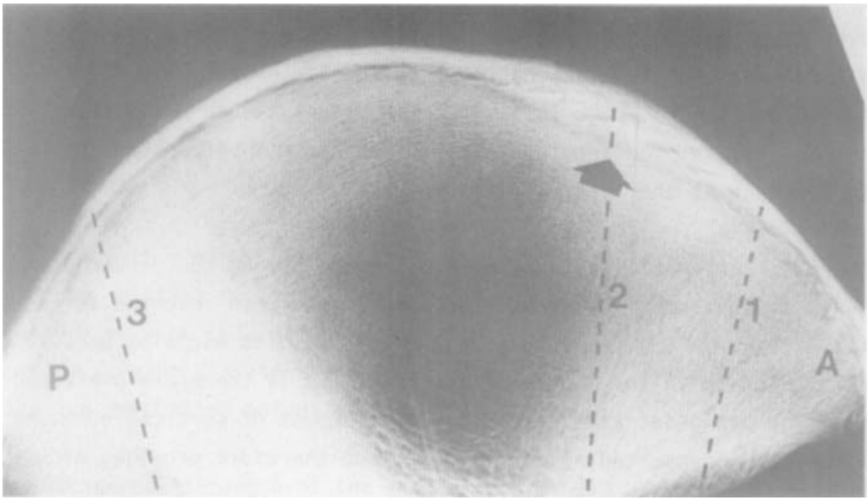

Figure 45. A lateral radiograph of an iliac crest removed at autopsy from a seventeen year old male who died by accident. The anterior and posterior superior iliac spines are marked 'A' and 'P', respectively. The tubercle of the crest is the thickest part of the crest (arrow). Note that the iliac apophysis has not yet fused with the underlying crest. Note also the strong anterior and posterior columns of bone within the crests separating a large deficiency of bone in the middle of the iliac fossa.

posterior laterally directed curve being the gluteal surface. Even in young children, the anterior column of bone in the crest between the tubercle and the acetabulum can comprise a reasonable thickness of bone (7).

The ilium has a well developed anterior and posterior pillar of bone separated by a thin area where the cortical surfaces may be almost in contact. Cunningham (8) states that the centre of the iliac fossa may even be defective. The radiograph of the ilium removed at autopsy from a 17 year old patient demonstrates this deficiency in the middle of the bone (Fig. 45, page 147). The iliac apophysis in this subject has completely ossified around the crest but has not yet united to it; it is thickest at the tubercle of the crest.

There is thus not always the possibility of having the pelvic pin in contact with bone throughout its course; even when inserted as suggested, it may be inside or outside the ilium at its midpoint because of this thinness in the middle of the ilium. It is therefore preferable that the pin penetrates a reasonable thickness of cortical bone, as it may be unsupported at its midpoint and therefore provides mechanically, relatively poor fixation.

The iliac fossa gives origin to the iliacus muscle from the upper two thirds of its surface (8). This muscle is flat and triangular and fills the fossa. It is covered by a fascial sheath, medial to which is the extraperitoneal fat, separating sheath from peritoneum. On the right side is the caecum and on the left side the iliac part of the descending colon. At the medial border of the iliacus is the psoas major and in the groove between the two lies the femoral nerve, branches of which supply the iliacus muscle (L2 and L3).

There is a reasonable degree of safety permitted, when inserting the pelvic pins, because of this cushion of iliacus muscle. This cannot always be relied upon; it will be, occasionally, very thin, particularly in paralytic conditions affecting this muscle, and so every effort should be made to keep the pin within the bony ilium itself.

3. BASIC MECHANICAL STUDIES OF THE BONY ILIUM

Initially the forces exerted by the pelvic pins on the surrounding iliac bone during distraction are mainly vertical. With time there is resorption of bone around the pins for two reasons: 1) immobilisation osteoporosis and reduction of the natural compression forces reduce the number of cancellous trabeculae above the pins and there is a corresponding alteration of the surface area of bone in contact with the pin due to pressure necrosis; 2) the constant sawing effect of the pin thread wears away the surrounding bony trabeculae. When the original track housing the pin has been enlarged, there will be an increase in the transverse forces and the pin will move to and fro widening the pin track even further.

The aim of this study was to evaluate the holding strength of the tubercle relative to other points on the subcutaneous iliac crest. An Alwetron machine (63) was used for this purpose. At the same time, pins of varying diameters and threads were tested to ascertain their relative purchasing potential within the bone.

The mechanical strength of the iliac crest in several regions was assessed. Both crests in their entirety were removed from 7 patients who had died accidental deaths, their ages ranging from 16 to 30 years.

A fixed length (2 centimetres) of the standard pelvic pin was inserted into the iliac crests at three different levels: a) halfway between the anterior superior spine and the tubercle of the crest (sample 1); b) at the tubercle of the crest itself (sample 2); c) several centimetres anterior to the posterior superior spine (sample 3) (Fig. 44, page 146). Blocks of bone encasing the pins were then excised from the crests.

The length of pin was clamped in the Alwetron machine and the bone block firmly secured in a brass cylinder. The pin was then distracted at a standard strain rate (one centimetre per minute). A continuous paper tracing provided a force-deformation curve and evidence when the pin had dislodged.

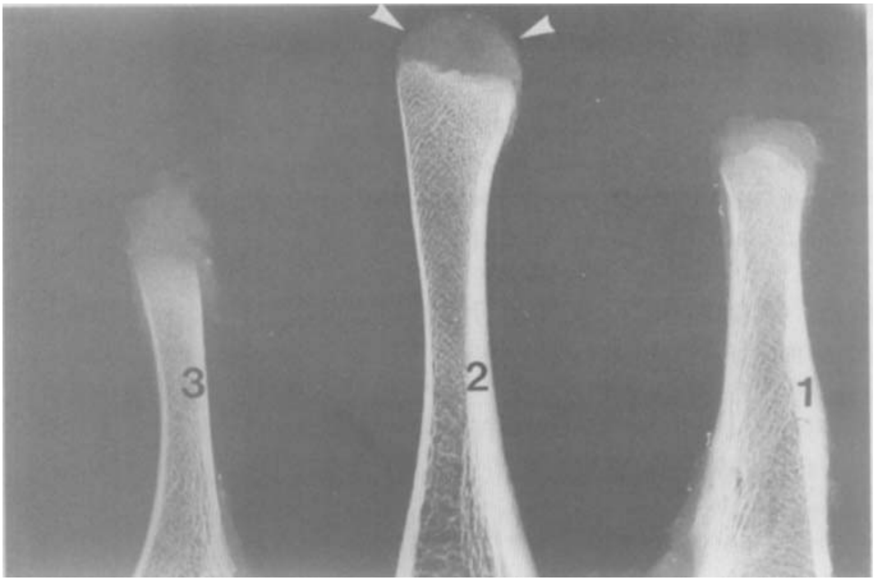

Figure 46. Slab radiographs of vertical sections of bone removed from areas 1, 2 and 3, respectively (see legend Fig. 44). Patient was a sixteen year old male who died by drowning. Note the large cartilagenous cap of iliac crest (arrows). Note also in the radiograph of section 2, the well developed lateral cortical table.

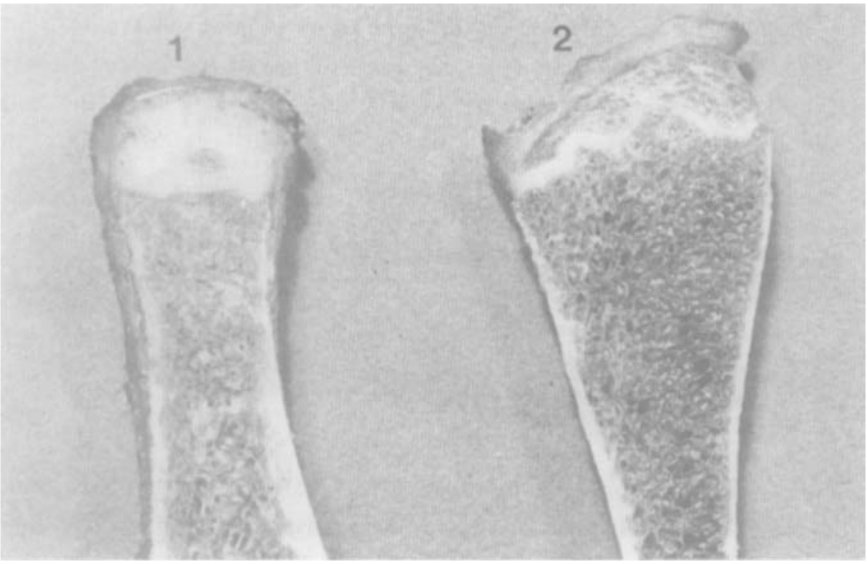

Figure 47. Photographs of vertical sections of iliac crest removed at autopsy from a seventeen year old female patient who died by accident. Section 1 was cut from the anterior part of the iliac crest and section 2 is the posterior part of the same crest. Note in section 1, the cartilagenous iliac crest in which the ossific centre has appeared. This represents a slightly later stage of development than that demonstrated in the previous radiographs (Fig. 46).

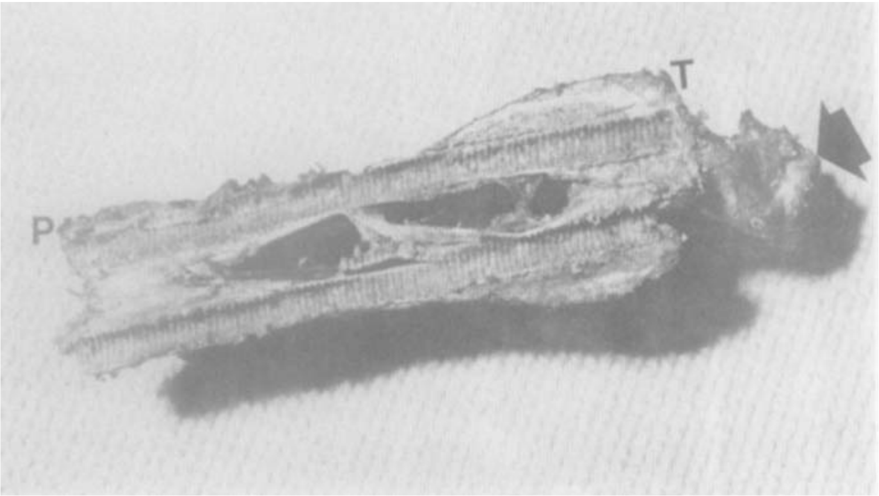

Figure 48. Photographs of a male adult's left iliac crest viewed from above. The crest was removed at autopsy, placed in a bench vice and with a drilling jig, a standard sized pelvic pin was inserted through the crest. The crest was then cut open, and the pin removed to demonstrate the thread created within the bone. The arrow points to the anterior superior spine. The pelvic pin was introduced at the tubercle of the crest (T) and it emerged at the posterior superior spine (P). Note particularly that the pin has stayed intraosseous throughout its course.

RESULTS

The bone at the tubercle of the crest (sample 2) held the pin longer than either of the other two areas examined (Table 14, page 154). The anterior sample (sample 1) was intermediate in holding ability in five of the seven specimens, equal to the posterior sample in one (No. 7) and weaker than it in one specimen (No. 2).

The ultimate holding power of bone to any testing by this method depends on the volume of bone present, particularly cortical bone. When the iliac apophysis has fused with the underlying crest at skeletal maturity, there is a strong ridge of cortical bone on the crest particularly at the tubercle (Fig. 44).

The pins were extracted with the lowest forces in bone samples from the two adolescent subjects (cases 4 and 5). This is not surprising considering that the bony crests at this age have not yet fully ossified and still consist of a large proportion of cartilage (Fig. 46).

Bench studies were done on four samples of iliac crests removed at routine autopsy. They were fixed in a vice and pelvic pins inserted into them with a drilling jig. The ilium was then cut down to the pin thread on one side and the bone was opened like a book (Fig. 48, page 152). In each specimen tested the pin was intraosseous throughout its course. The thread within the bone was firm to testing with a probe and had not been stripped by the drilling (the volume of bone replaced by the pin could be seen with a hand lens packed into adjacent cancellous trabeculae).

Pre-drilling a sample of bone crest was next evaluated. This is a standard engineering procedure where the hole is tapped first before the pin is inserted. This method was assessed three times. It produced excessive heat, with the bone actually smoking from the thermal insult. When the drill went outside the bone in its course, the fine teeth were stripped from its end when it attempted to reengage the cortical inner table.

TABLE 14

THE MECHANICAL STRENGTH OF ILIAC CREST

Case number	Sex/Age	Site of bone sample	Force required to dislodge pin from bone (kiloponds). Constant strain rate 1 cm/per minute
1	M/21	1	100
		2	210
		3	55
2	M/24	1	90
		2	220
		3	145
3	M/30	1	135
		2	210
		3	75
4	M/17	1	50
		2	90
		3	40
5	F/16	1	70
		2	110
		3	50
6	M/25	1	100
		2	190
		3	70
7	M/24	1	120
		2	190
		3	120

Legend

Site of sample: 1 Iliac crest - half-way between anterior superior spine and tubercle of crest

2 - midpoint on tubercle of crest

3 - crest 3 cm anterior to the posterior superior spine

DISCUSSION

In the skeletally mature patient the top of the crest is a thick cap of cortex. In the younger patient, while this cortical cap is still developing, there is always a well developed outer cortical layer of the ilium which is best developed between the tubercle of the crest and the upper region of the acetabulum (Fig. 46, page 150). This is firm enough for pelvic pin fixation, but it has one disadvantage in that it is not subcutaneous but covered by the muscular fibres of the tensor fasciae latae.

White and Hirsch (63) demonstrated that the strongest bone of the iliac crest, when subjected to acute compression testing, was in the region of the tubercle of the crest. The ultimate ability of bone to hold a threaded pin is a reflection of the volume of cortical bone present and at the tubercle it is thicker than at other regions of the crest. Currey (9) noted that the density of cortical bone is about 2, whilst that of cancellous bone varies from 0.25 to 0.8 (although the holding power of cortical bone is roughly thirty times stronger than that of cancellous bone).

It would seem that, providing the crest is wide enough at the tubercle, the pin should be inserted here. Measurements of the width of the crest in the region of the tubercle in 20 samples from subjects 16 years or older varied from 15 millimetres to 25 millimetres. The pelvic pin we have used regularly is 6.35 millimetres in diameter. A larger, stiffer pin (8 millimetres) has been used in the larger patients without any technical problems and with the added advantage of reduced movement in the bone. It is therefore more likely to be tolerated by the patient for a longer period of time without movement or infection.

SUMMARY AND CONCLUSIONS

1. Under acute experimental conditions in adult cadavers, firm purchase of the skull halo is provided by four skull pins and is even greater when six pins are used. With five and one half pound inches of torque force (0.06 kpm) the average skull pin penetrates 0.5 millimetres (average) of the outer table of the skull.

2. Insertion of the pelvic pins is a safe procedure if a drilling jig and carpenter's brace are employed. The recommended point of entry of the pin is on the tubercle of the crest or just inferior to this area, the exit point the posterior superior iliac spine. If a pin is inserted near the anterior superior spine it is likely to be intrapelvic and therefore dangerous.

3. With ossification of the cartilagenous iliac apophysis, a strong cap of cortical bone appears, covering the crest at skeletal maturity. This is mechanically strongest in the region of the tubercle of the crest.

GENERAL DISCUSSION AND SUMMARY

GENERAL DISCUSSION

The halo-pelvic apparatus is not a casual alternative method of treating spinal deformities; it is and should always be part of a carefully planned approach to the management of severe spinal curvatures. It is a technique which demands discriminate selection of patients, precise observation and attention to nursing care.

The patients selected should have severe curves, not sufficiently or efficiently corrected by any other methods in current use.

The main indications for the use of the halo-pelvic apparatus in this series were tuberculous kyphosis and scoliosis following poliomyelitis. If one or more of the following associated phenomena are present: 1) anaesthetic skin, 2) respiratory insufficiency, 3) spinal cord compression, 4) a spine rendered unstable by tumour, multilevel laminectomies, etc., 4) pelvic obliquity (provided due care is taken with insertion of the pelvic pins) - then serious consideration should be given to using the halo-pelvic apparatus.

Great attention has been focused on pelvic obliquity and the correction achieved with the halo-pelvic apparatus. Only two of the eleven patients with pelvic obliquity had complete initial correction of the pelvic deformity. It must be stressed again that these patients are in a high risk category because of the abnormal anatomy of the iliac crests and the subsequent possibility of perforation of intestines with pelvic pins. When pelvic obliquity has been present for a long period there is such bony overgrowth on the convexity of the vertebral bodies of the scoliosis that adequate correction of the obliquity is not possible without anterior surgery.

The importance of correcting the pelvic obliquity and thus providing adequate cover for the hip joint on the higher side will be fully appreciated. If one chooses the right patient and plans and executes treatment with skill and judgement the halo-pelvic apparatus is uniquely effective.

This is not to presume that there are no problems. These have been dealt with in detail in Part II. The complications must be weighed against the results which could not have been achieved by other conventional methods of correction. Careful patient selection and the close observation recommended should ensure that the more serious complications do not occur. Likewise, pathological changes in the cervical spine will be minimised by restricting the use of the apparatus to those patients requiring it when there is no other satisfactory means of treatment available for obtaining an acceptable result.

Due consideration should be given to using the lowest corrective forces possible for the shortest period of time which is reasonable.

The unique work in spinal instrumentation was commenced by Paul Harrington in 1948. It was many years later, however, before his method was fully accepted and now it is regarded as the treatment of choice for most forms of scoliosis. It takes time and experience in many centres of the world to establish the reputation, indications and precise place for a new form of treatment.

The available evidence suggests that the halo-pelvic apparatus is a powerful and effective method of correcting severe spinal deformities. Because of the risk of pathological changes in the cervical spine its use should be restricted to those patients with deformities which cannot be effectively treated by the other methods in use today.

SUMMARY

Part I

1) The history of the development of the halo-pelvic apparatus is discussed together with a general description of the apparatus. The fitting of the apparatus is described in detail with emphasis laid on the accurate insertion of the pelvic pins, the use of the drilling jig and precise points of entry and exit in the iliac crest being the tubercle on the crest and the posterior superior iliac spine, respectively.

2) During the post-operative period the four extension bars are placed connecting the patient's skull halo to the pelvic hoop. For reasons of safety this is not done at the time of the fitting of the

halo and hoop.

3) Any patient with a spinal deformity severe enough to require treatment with the halo-pelvic apparatus should have pre-operative myelography and respiratory function studies done.

4) The four base lines which must be used to monitor the patients during distraction are: a) regular clinical observation, b) daily neurological assessment, c) regular lateral radiography of the cervical spine, and d) the use of force measurements.

5) When the halo-pelvic apparatus is removed, a plaster body cast is applied until the bone graft has consolidated.

Part II

6) One hundred and four patients with severe spinal deformities commenced treatment with the halo-pelvic apparatus. The most common etiologies of the deformity treated were tuberculous kyphosis and paralytic scoliosis. There were four deaths following surgery in the series. The average time the patients spent in the apparatus was 7.5 months. 21 per cent of the patients had cord compression or frank paraplegia at the onset of treatment.

7) The average correction of the deformity was as follows: tuberculous kyphosis 31 per cent, paralytic scoliosis 51 per cent, idiopathic scoliosis 42 per cent, congenital kyphoscoliosis 26 per cent, and neurofibromatosis kyphoscoliosis 43 per cent. These patients who had osteotomies for previously failed posterior fusions had an average correction of 40 per cent.

8) The most common significant complication due to the use of the halo-pelvic apparatus was associated with distraction of cervical spine (77 patients with radiographs of cervical spine were examined). Degenerative changes in the posterior joints of the cervical spine (34 per cent) and avascular necrosis of the upper pole of the dens (17 per cent) were the most common neck complications. Some of the patients with changes in the axis also had posterior joint changes; therefore these percentages should be interpreted accordingly. Cranial nerve neurapraxias occurred in 7 per cent of the patients and brachial

plexus palsies in 3 per cent of the patients. Temporary spasticity in the lower limbs occurred in the 3 per cent of patients. A torn peritoneum occurred during insertion of the pelvic pins in one patient. Laparotomy confirmed that no other damage had been done. Although many patients had discharge associated with the pelvic pins, it was unusual for them to present clinical problems.

Part III

9) In four patients with severe paralytic scoliosis a study was done to determine the amount of force which was transmitted through the spine by the halo-pelvic apparatus. This was done by comparing force measurements on the halo-pelvic compression springs with the internal readings from the specially designed telemetry rod.

Replacing the extension bars onto the halo and pelvic hoop at the end of posterior spinal surgery did not have a significant effect on the forces on the spine measured from the rod. Lifting the patient from the operating table produced a mean force increase of 2 kp in the rod. With acute distraction over 15 to 20 minutes a linear relationship was demonstrated between the externally applied force and the force simultaneously recorded on the telemetry rod in the spine. The direct relationship between stress and strain was demonstrated confirming elasticity as one of the properties of biological tissue. In the two patients who were assessed 60 per cent and 80 per cent, respectively, of changes in the externally applied force appeared as changes in the force measured in the spine by the telemetry rod.

Part IV

10) With autopsy experimentation, using five and a half pound inches of force on the torque screw driver (0.06 kpm) the average skull pin penetrates 0.5 mm (average) of the outer table of the skull.

Insertion of the pelvic pins is safe if a drilling jig and a carpenter's brace are used. The ideal point of entry for the pin is at the tubercle of the crest or just inferior to this area, and the ideal exit point is the posterior superior iliac spine. If a pin is inserted near the anterior superior spine it is likely to be intra-pelvic and therefore dangerous.

Mechanical studies of the iliac crest confirmed that the bone in the region of the tubercle of the crest is stronger than in other regions of the bone, providing yet another reason why that area should be used for inserting the pelvic pins.

APPENDIX A

SUMMARY OF CLINICAL MATERIAL

	TUBERCULOUS KYPHOSIS	KYPHOSCOLIOSIS			
Etiology	Tuberculous	Paralytic	Idiopathic	Congenital	Neurofibromatosis
Number of patients	42	31	15	10	6
Age of onset of deformity (average)	1.5 yrs.	2 yrs.	14 yrs.	birth	12 yrs.
Age treatment commenced (average)	16.1 yrs. (3-26 yrs.)	14.1 yrs. (6-25 yrs.)	15.6 yrs. (6-21 yrs.)	12.8 yrs. (6-19 yrs.)	13.8 yrs. (10-19 yrs.)
Length of time in apparatus in months (average)	8.4	7.6	6.4	5.5	8
Peak level of deformity	T9	T10, 11	T10, 11	Thoraco-lumbar	T9, 10
Degrees of deformity	117°	111°	82°	86°	98°
Correction at follow-up	87°	59°	48°	61°	71°
Correction in degrees/pound of traction	.75	1.32	.52	.65	1.4
Number of operations per patient	3	2	1	2	2
Radiological changes in the cervical spine (77 patients)	14 (47)	10 (40)	4 (45)	6 (15)	3 (50)
Length of follow-up (yrs.)	2.9	3.3	2.4	2.1	3

APPENDIX B

CLINICAL DATA OF 104 PATIENTS

TUBERCULOUS KYPHOSIS

No.	Sex/Age	Level extent of deformity	Previous surgery	Pre-op. cord compression	Spinal operations	Time in apparatus (months)	Correction From	To	%	Final	Follow-up (years)
1	F/15	T8-L1	Fusion	+	3 - A.S.O.) P.S.O.) A.S.F. P.S.F. (late)	12	106°	70°	34%	105°	4.5
2	M/15	T4-T9		+	3 - A.S.O. A.S.F. P.S.F.	6	135°	90°	33%	92°	4
3	M/6	T5-T9	Debride-ment	+	2 - A.S.O. A.S.F.	4	70°	46°	34%	50°	4
4	F/6	T5-T9		-	3 - A.S.O. A.S.F. P.S.F. (late)	5	81°	40°	51%	62°	4
5	F/16	T8-T12	Fusion	-	3 - A.S.O.) P.S.O.) A.S.F. P.S.F.	5	125°	90°	28%	105°	4
6	M/13	T9-L1		-	2 - A.S.O. A.S.F.	6	120°	105°	13%	115°	4
7	M/21	T8-T12	Fusion	+	3 - A.S.O.) P.S.O.) A.S.F. P.S.F.	3	134°	103°	23%	113°	3.75
8	M/20	T6-L2		+	3 - A.S.O.) P.S.O.) A.S.F. P.S.F.	11	133°	90°	32%	90°	3.75

TUBERCULOUS KYPHOSIS

No.	Sex/Age	Level extent of deformity	Previous surgery	Pre-op. cord compression	Spinal operations	Time in apparatus (months)	Correction From	To	%	Final	Follow-up (years)
9	M/16	T8-T11		-	3 - A.S.O.) P.S.O.) A.S.F. P.S.F.	10	125^0	92^0	24%	93^0	3.75
10	F/19	T8-L4		+	4 - A.S.O. P.S.O. A.S.F. P.S.F.	16	142^0	81^0	43%	105^0	3.75
11	M/15	T9-L1		-	3 - A.S.O.) P.S.O.) A.S.F. P.S.F.	12	103^0	75^0	26%	81^0	3.5
12	M/22	T2-T9	Fusion	-	4 - A.S.O. P.S.O. A.S.F. P.S.F.	12	126^0	82^0	35%	82^0	3.5
13	M/19	T8-L1	Fusion	-	4 - A.S.O. P.S.O. A.S.F. P.S.F.	15	137^0	98^0	28%	100^0	3
14	F/5	T2-T4		-	2 - A.S.F. P.S.F.	6	59^0	40^0	32%	45^0	3.25
15	M/18	T6-T10		-	4 - A.S.O. P.S.O. A.S.F. P.S.F.	11	138^0	102^0	26%	120^0	3.25
16	M/15	T10-L1	Fusion	-	5 - A.S.O. P.S.O.x2 A.S.F. P.S.F.	12	91^0	68^0	25%	81^0	3.25

17	F/20	T6-L2		+	4 - A.S.O. P.S.O. A.S.F. P.S.F.	12	146^0	93^0	36%	93^0	3
18	F/21	T6-L2		-	3 - A.S.O. A.S.F. P.S.F.	12	107^0	15^0	86%	42^0	3
19	M/19	C7-T5	Fusion	-	4 - A.S.O. P.S.O. A.S.F. P.S.F.	10	118^0	62^0	47%	62^0	3
20	M/15	T6-L1		+	4 - A.S.O. P.S.O. P.S.F. A.S.F.	10	121^0	63^0	48%	63^0	2.75
21	M/18	T11-L2		-	4 - A.S.O. P.S.O. A.S.F. P.S.F.	11	112^0	97^0	13%	97^0	2.75
22	M/6	T9-L4		-	2 - P.S.F. A.S.F.	8	85^0	55^0	35%	65^0	2.75
23	F/20	T7-T12		-	3 - A.S.O. P.S.O.) P.S.F.) A.S.F.	8	134^0	76^0	43%	77^0	2.5
24	F/23	T7-T10	Fusion	-	3 - A.S.O. P.S.O.) P.S.F.) A.S.F.	10	89^0	70^0	21%	72^0	2.5
25	M/3	T11-L2		-	2 - A.S.F. P.S.F.	7	70^0	44^0	37%	54^0	2.25

TUBERCULOUS KYPHOSIS

No.	Sex/Age	Level extent of deformity	Previous surgery	Pre-op. cord compression	Spinal operations	Time in apparatus (months)	Correction From	Correction To		Correction Final	Follow-up (years)
26	F/26	T8-L3		-	4 - A.S.O. P.S.O. P.S.F. A.S.F.	9	123^0	73^0	41%	73^0	2.25
27	M/23	T9-L2	Fusion	+	4 - A.S.O. P.S.O. P.S.F. A.S.F.	10	133^0	94^0	29%	94^0	2.25
28	F/6	Holding*		-	3 - A.S.O. A.S.F. P.S.F.	4	Holding*				3
29	M/16	T7-T10		+		1	Early removal				3
30	M/11	L3-L5		-	2 - A.S.F. P.S.F.	1	Early removal				2.25
31	M/18	T6-T10		+	3 - A.S.O. P.S.O.) P.S.F.) A.S.F.	9	147^0	109^0	26%	109^0	2.25
32	F/11	T2-T8		+	2 - A.S.F. P.S.F.	5	99^0	91^0	8%	91^0	2
33	M/17	T5-T8		+	4 - A.S.O. P.S.O. A.S.F. P.S.F.	8	105^0	93^0	12%	93^0	2
34	M/19	T5-L2		+	4 - A.S.O. P.S.O. A.S.F. P.S.F.	9	136^0	125^0	8%	125^0	2

35	M/18	T6-T12		Debride-ment	+	4 - A.S.O. P.S.O. A.S.F. P.S.F.	7	144^{o}	44^{o}	70%	44^{o}	1.75
36	M/18	T10-L1			-	4 - A.S.O. P.S.O. P.S.F. A.S.F.	7	137^{o}	110^{o}	20%	130^{o}	1.75
37	M/22	T8-L1			+	2 - A+P.S.O. A+P.S.F.	9	134^{o}	125^{o}	7%	130^{o}	1.5
38	F/18	T6-T11			-	3 - A.S.O. P.S.O.+F A.S.F.	3	128^{o}	110^{o}	14%	110^{o}	1.5
39	F/14	T6-L2			-	4 - A.S.O.x2 A.S.F. P.S.F.	12	125^{o}	108^{o}	14%	108^{o}	1.25
Deaths						Cause of death						
40	F/19	T6-T12	132^{o}	Fusion	-	Paralytic ileus and pneumonia						
41	F/20	T5-T12	145^{o}		+	Respiratory failure						
42	F/18	C2-T5	109^{o}		-	Respiratory failure						

*The apparatus was used as a means of external spine fixation, not distraction.

PARALYTIC SCOLIOSIS

No.	Sex/Age	Age onset	Level extent of deformity	Previous surgery	Pre-op. cord compression	Spinal operations	Time in H.P.T. (months)	Correction From	To	%	With Dwyer	Final	Follow-up (years)
43	M/11	10/12	T5-T12	Fusion	-	S.O. P.S.F.	7	97^0	74^0	24%	-	97^0	4.75
44	F/11	5	T4-T10		-	P.S.F.+rod	4	82^0	38^0	53%	-	49^0	4.75
45	M/14	2	T6-T12		-	P.S.F.	4	110^0	77^0	30%	-	86^0	4.75
46	M/17	1	T10-L5		-	P.S.O. Dwyer	2	120^0	53^0	57%	73^0	90^0	4.5
47	F/12	4	T4-T10		-	P.S.F.	1	59^0	25^0	59%	-	56^0	4.5
48	M/12	1	T11-L5		-	Dwyer P.S.F.	1	Early removal					4.5
49	F/12	1	T3-L2		-	P.S.F.x2 Rib excision	11	142^0	55^0	65%	-	78^0	4.25
50	F/25	3	T5-T12		-	P.S.O. Dwyer Rib excision	5	105^0	80^0	24%	42^0	58^0	4
51	F/14	5	T3-T11		-	P.S.F.x2 Rib excision A.S.F.	11	135^0	56^0	57%	-	68^0	3.75
52	M/9	9/12	T5-L5		-	P.S.F.	13	112^0	21^0	81%	-	60^0	3.75
53	F/18	-	T3-T11		-	P.S.F.	9	118^0	88^0	25%	-	103^0	3.75
54	M/8	3/12	T10-L5		-	P.S.F.	12	100^0	44^0	56%	-	40^0	3.5
55	F/21	3	T4-T10		-	P.S.F. Rib excision	9	136^0	85^0	47%	-	98^0	3.5

56	M/13	2	T10-L5		-	P.S.F. Dwyer	11	116^0	37^0	68%	37^0	46^0	3.5
57	M/20	6	T6-L1		-	P.S.F.+rod Rib excision A.S.F.	10	144^0	68^0	53%	-	68^0	3.25
58	F/11	2	T5-T11		-	P.S.F.x2 Rod	10	74^0	29^0	61%	-	37^0	3.25
59	F/16	6/12	T7-L3		-	P.S.F. Rib excision	11	92^0	55^0	48%	-	59^0	3.25
60	M/17	3	T11-L5		-	P.S.F.x2 Dwyer	9	72^0	28^0	60%	-	30^0	3.25
61	F/18	13	T4-L5	Fusion	-	A.S.F. P.S.F.+rod	7	28^0	20^0	29%	-	20^0	3
62	F/14	1	T10-L4		-	Dwyer P.S.F.x2	9	117^0	68^0	42%	32^0	37^0	3
63	M/16	4/12	T10-L5		-	A.S.F. Dwyer P.S.F.x2	14	151^0	76^0	49%	65^0	70^0	3
64	M/16	10/12	T12-L4		-	Dwyer P.S.F.+rod P.S.F.	9	83^0	41^0	51%	24^0	24^0	3
65	M/13	3	T5-T12		-	P.S.F.x2	10	100^0	48^0	52%	-	65^0	2.75
66	F/13	4	T12-L5		-	P.S.F.x2 Dwyer	2	Early removal					2.5
67	F/14	2	T11-L5		-	Dwyer P.S.F.x2	9	108^0	61^0	40%	29^0	28^0	2.5
68	M/6	2/12	T4-L5		-	No op.	2	Early removal					2.5

PARALYTIC SCOLIOSIS

No.	Sex/Age	Age onset	Level extent of deformity	Previous surgery	Pre-op. cord compression	Spinal operations	Time in H.P.T. (months)	Correction From	To		With Dwyer	Final	Follow-up (years)
69	F/16	10/12	T5-L5		-	P.S.F.x4	15	164^0	78^0	52%	-	98^0	2
70	F/13	1	T5-L3	Fusion	-	P.S.O.x2 P.S.F.x2	8	110^0	50^0	55%	-	70^0	2
71	M/11	1	T7-L5		-	Dwyer P.S.F.x2 Rods	4	126^0	63^0	50%	35^0	45^0	2
72	M/13		T6-L2		-	Dwyer P.S.F.+rod	5	120^0	65^0	46%	34^0	40^0	1.75
73	F/14		T10-L5	Fusion	-	P.S.O.+F. A.S.F.	3	Holding					1.5

IDIOPATHIC SCOLIOSIS

No.	Sex/Age	Level extent of major deformity	Previous surgery	Time in H.P.T. (months)	Spinal operations	Correction From	To	With Dwyer	Final	%	Follow-up (years)
74	F/14	T4-T11;T11-L4		10	P.S.F:x2	97^0	35^0	-	35^0	64%	3
75	F/18	T7-L4	Osteotomy	12	P.S.F.	75^0	33^0	-	33^0	56%	3
76	F/12	T10-L4		12	P.S.F.	74^0	33^0	-	43^0	55%	3
77	F/15	T6-T11		10	P.S.F.	90^0	39^0	-	49^0	57%	3
78	F/16	T11-L4		2	Dwyer	70^0	30^0	0^0	0^0	57%	3*
79	F/21	T6-L1		11.5	P.S.F.+rod	98^0	71^0	-	71^0	28	2.75
80	M/15	T3-T10		2	Dwyer	90^0	59^0	40^0	49^0	34	3
81	F/16	T5-T10		6	P.S.F.+rod	77^0	60^0	-	77^0	22	2
82	F/19	T9-L2	Osteotomy	9	P.S.F. A.S.F.	94^0	57^0	-	57^0	39	2
83	F/18	T5-T12		4	P.S.F.+rod	80^0	63^0	-	65^0	21	2*
84	F/16	T6-T12		6	P.S.F.+rod	80^0	55^0	-	57^0	31	2*
85	F/14	T11-L4		1	Dwyer	47^0	35^0	0^0	0^0	25	2
86	F/15	T4-T11	Fusion	3	Osteotomy of P.S.F.+rod	62^0	52^0	-	52^0	16	2
87	F/13	T8-T12	Fusion	4	Osteotomy of P.S.F.+rod	92^0	48^0	-	48^0	48	1.5
88	F/13	T5-T11		4	P.S.F.+rod	95^0	53^0	-	58^0	44	1.5

*Reference for treatment from outside Hong Kong.

CONGENITAL KYPHOSCOLIOSIS

No.	Sex/Age	Level extent of deformity	Previous surgery	Pre-op. cord compression	Spinal operations	Time in H.P.T. (months)	Correction From	To		With Dwyer	Final	Follow-up (years)
89	M/8	Thoraco-lumbar		+	Excision hemivertebrae	4	Holding[x]					4*
90	F/6	Thoraco-lumbar		-	A.S.O.+F. P.S.F.	4	Holding[x]					3*
91	F/12	T11-L4		-	P.S.O. Dwyer P.S.F.	7	67^0	32^0	48	11^0	13^0	3
92	M/13	T9-L1		-	P.S.O.+F. A.S.F.	9	125^0	60^0	48	-	65^0	2
93	M/19	T9-L4		-	A.S.O. P.S.O.+F. A.S.F.	8	104^0	77^0	26	-	82^0	2
94	F/12	T1-T7		-	P.S.F. P.S.F.+rod	5	84^0	65^0	23	-	70^0	2
95	F/17	T4-T10		-	P.S.O. P.S.F.	3	85^0	72^0	15	-	-	2*
96	F/15	T8-T10		-	Died	-	-	-	-	-	-	
97	F/14	T11-L4		-	P.S.O. P.S.F.+rod	3	75^0	64^0	15	-	75^0	2
98	M/12	T11-L4		+	A.S.O. A.S.F. P.S.F.	7	63^0	59^0	6	-	-	1*

[x]The apparatus was used as a means of external spinal fixation, not distraction.

*Reference for treatment from outside Hong Kong.

NEUROFIBROMATOSIS KYPHOSCOLIOSIS

No.	Sex/Age	Age onset	Level extent of deformity	Previous surgery	Pre-op. neurological status	Spinal operations	Time in H.P.T. (months)	Correction From	To		Final	Follow-up (years)
99	F/13	9	T3-T12	Fusion	Paraplegia	A.S.F.	5	72^0	59^0	18	79^0	4.5
100	F/13	6/12	T5-T10			P.S.F.	5	100^0	53^0	47	71^0	4
101	F/15	1	T5-L3			A.S.F. P.S.F.	10	85^0	35^0	59	45^0	3.5
102	F/13	5	T9-L1			P.S.F. P.S.F. A.S.F.	7	131^0	20^0	85	70^0	3.5
103	M/10		Holding[x]	Laminec- tomies	Paraplegia	A.S.F. P.S.F.	6	Holding[x]				2*
104	M/19		T8-T10	Laminec- tomies	Paraplegia	A.S.O. A.S.F. P.S.F.	15	105^0	99^0	6	99^0	5

[x]The apparatus was used as a means of external spinal fixation, not distraction.

*Reference for treatment from outside Hong Kong.

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