Idiopathic scoliosis: foundation for physiological treatment*

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Summary

The three-dimensional nature of the idiopathic spinal deformity has been investigated in cadaveric specimens and patients with both idiopathic scoliosis and idiopathic kyphosis (Scheuermann's disease). In both scoliotic and kyphotic deformities the essential lesion lies in the sagittal plane with apical vertebral wedging. In idiopathic scoliosis there is an apical lordosis which being biomechanically unstable rotates to the side to produce a scoliotic deformity as a secondary component. In contradistinction the kyphotic wedging process of Scheuermann's disease is mechanically stable and any associated idiopathic type scoliosis occurs above and below the region of kyphosis. When an asymmetric lordosis is created in the growing New Zealand white rabbit, a progressive lordoscoliosis is readily produced and when the thoracic kyphosis is restored the scoliotic deformity shows evidence of regression and this forms the basis of physiological treatment. In 25 patients with idiopathic thoracic scoliosis the thoracic kyphosis has been restored and this leads to enhanced correction of the deformity in all three planes.

Introduction

Those of us who have had the honour and privilege to deliver a Hunterian lecture cannot but wonder at the extraordinarily catholic knowledge of surgical science that John Hunter possessed. Moreover, this knowledge did not only include surgery in general but encompassed the whole of the musculo-skeletal system from the structure and function of articular cartilage on the one hand to the complexities of three dimensional spinal deformities on the other, interestingly, it was not just the more obvious severe deformity which attracted Hunter's attention, of which there is a classic example in the Hunterian Museum, but also the mild and seemingly innocuous deformity present in the thoracolumbar spine of the 'surprising Irish giant' Charles O'Byrne, clearly discernible at the entrance of that museum, and in at least 15% of normal schoolchildren *(1)*.

Somerville, one of the leading orthopaedic intellectuals of his generation, adopted the Hunterian approach of challenging conceptual assumptions with surgical scientific methods and thereby contributed greatly to our understanding of the nature of three dimensional spinal deformities as well as providing a strong stimulus to this research programme *(2)*.

The deformity of idiopathic scoliosis accounts for more than 95% of spinal deformities detected in the community and more than two-thirds of patients attending scoliosis clinics. Unfortunately, little progress has been made in the last fifty years towards characterising this so common deformity and treating it effectively. Orthotic devices, thought at their inception and over the next thirty years to be able to attenuate the progression of the deformity *(3)*, have recently been shown not to alter the natural history of the condition *(4)* and conventional posterior surgical techniques have been shown to provide a limited correction of the deformity in only one plane while leaving the rotational hump, with which every patient presents, essentially unchanged *(5)*. In terms of our powers of correctability we have advanced little from the days of our scoliosis surgical father figures at the beginning of this century *(6)*. Furthermore, comprehension of the nature of this three dimensional deformity has not been helped by the use of anatomically incorrect terminology. Although the time allocated for undergraduate orthopaedic teaching still sadly lags behind clinical reality, there can be few medical practitioners who have not encountered the word 'kypho-scoliosis', a condition which, as will be seen, cannot and does not exist.

The aetiology of idiopathic scoliosis is unknown but, because a rotational spinal deformity is common in neuromuscular conditions, most pathogenetic work has sought to elucidate a disorder of nerve or muscle *(7)*. No primary nerve or muscle lesion has thus far been detected and such changes as have been described are considered to be secondary to the presence of a spinal deformity *(8)*. Clearly, if by x-ray screening a majority of children can be shown to have a measurable spinal deformity, 10% with curves measuring more than 5°, 2% with curves measuring more than 10°, and 1% with curves more than 15°, then a neuromuscular condition of epidemic proportions is being postulated. In addition, if a primary neuromuscular factor is present, it ought to be so in children with straight backs in whom the noxious agent has not yet produced a detectable deformity, unless its mode of action is to suddenly produce an acute scoliosis in every case, which is not a feature of any known neuromuscular condition.

Moreover, children with idiopathic scoliosis are otherwise entirely healthy normal individuals. Even if a specific agent were detectable, it would still put us at

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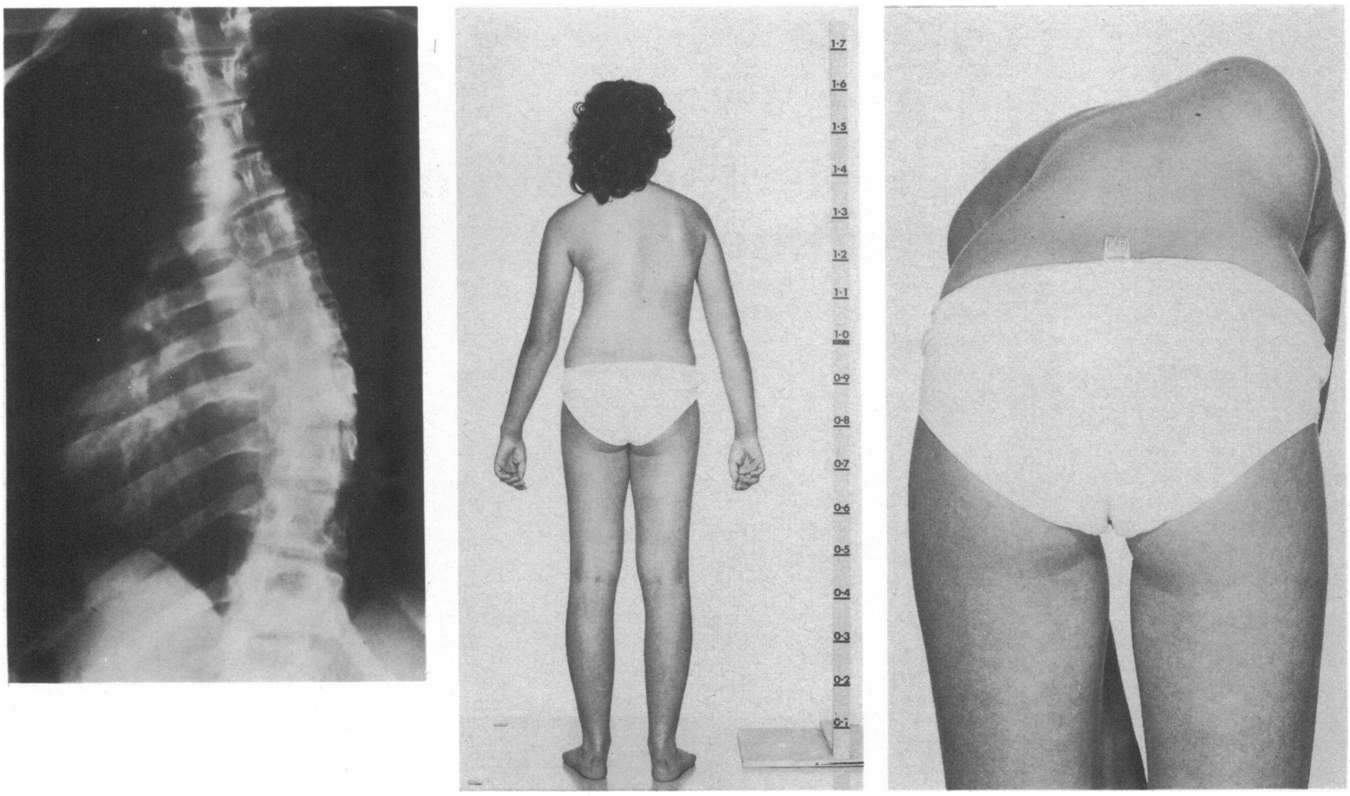

FIG. 1 (a) posterior-anterior (PA) X-ray of a patient with idiopathic scoliosis. The posterior elements are rotated into the curve concavity while the bodies are rotated into the curve convexity: the deformity must be lordotic throughout.
(b) A patient with an idiopathic thoracic scoliosis standing. The deformity is less marked.
(c) The same patient leaning forward. The rotational prominence is maximised on forward flexion.

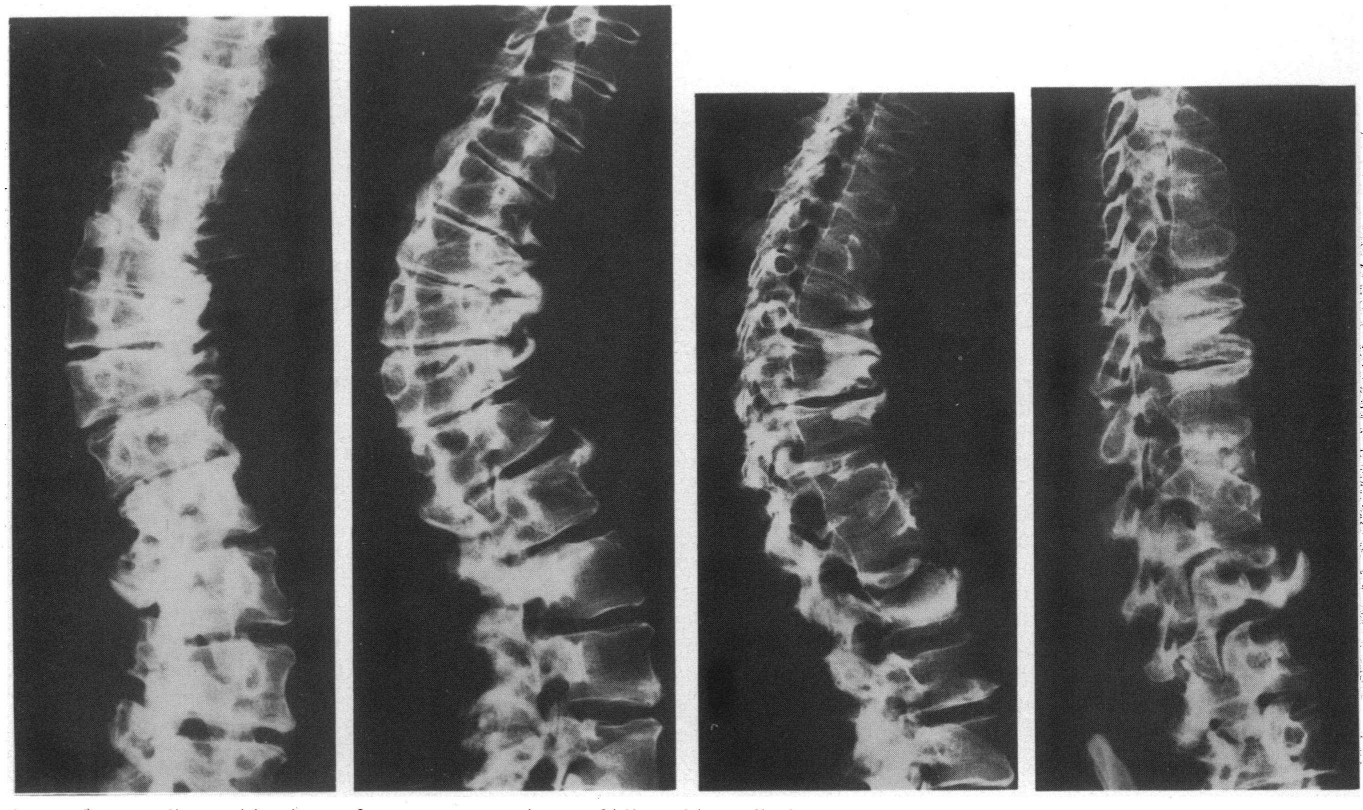

FIG. 2 Four radiographic views of a museum specimen of idiopathic scoliosis.
(a) PA view of specimen; showing PA oblique view of deformity.
(b) PA view of deformity; the scoliosis is now maximal.
(c) Lateral view of specimen; showing lateral oblique view of deformity and the illusion of a kyphosis.
(d) Lateral view of deformity; showing the apical lordosis.

a considerable distance from understanding the three dimensional spinal configuration produced, and its behaviour. Accordingly it appears more logical to start with an analysis of the deformity and to work from there.

Patients and methods

SIMPLE CLINICAL OBSERVATIONS

Idiopathic scoliosis can be defined as a lateral curvature of the spine with rotation and, interestingly, much about the nature of the deformity and its mechanical behaviour can be discerned from a single postero-anterior radiograph of the patient and inspection of the patient standing and leaning forward, (Fig. 1). In this typical thoracic idiopathic scoliosis, as with a similar deformity in any other site, the spinous processes are rotated towards the curve concavity while the vertebral bodies rotate towards the curve convexity. In the thoracic spine there is normally a smooth kyphosis (round back) but if a kyphosis rotates then the direction of rotation will be the reverse, with the spinous processes directed towards the curve convexity. It can therefore be said with some certainty that a thoracic lordosis is an integral part of the three dimensional deformity. This is verified by the elementary geometrical observation that if the spinous processes are directed towards the curve concavity then a line joining them from the top to the bottom of the curvature will describe a shorter distance than the vertebral bodies, which are directed towards the convexity. If the line of the anteriorly situated vertebral bodies is longer than the posteriorly situated spinous processes then the whole deformity must be lordotic. In the lumbar region of course a lordosis is already present as a normal sagittal curvature.

In the erect position the rotational prominence on the convexity of the scoliosis is very much less obvious than in the forward bending position (Fig. 1), indicating that a mechanical effect has been produced accentuating the rib hump with spinal flexion. In flexion the lordotic spine is under increasing compression such that it cannot be accommodated without rotating to the side. As the deformity is one of lateral curvature with rotation, then the PA radiograph of the patient, the standard view obtained for assessment and measurement purposes, is a PA view of everything except the deformity in question, of which it is a random oblique view according to the amount of vertebral rotation, and so of course is a lateral projection of the patient and not the deformity. In order to take true planar views to analyse the deformity either the patient or the beam must be rotated according to the amount of vertebral rotation present.

CADAVERIC ANALYSIS

To establish the true planar nature of the deformity radiologically without involving ethical considerations, attention was directed to museum specimens of idiopathic scoliosis *(9)*. Unfortunately the bulk of Hunter's superb collection of scoliotic spines was destroyed by fire and the curator of the museum of our sister college in Edinburgh (Professor D C Meekie) kindly gave permission for their specimens to be studied. Each specimen was rotated through 180° and radiographed at 10° increments of rotation. Anterior and posterior vertebral body heights were also measured throughout the spine. The specimens included varying degrees of curve severity but a constant pattern emerged (Fig. 2). As the specimen was rotated from the PA position of specimen or patient, the size of the lateral curvature increased to a maximum, at which position the apex of the curve was truly PA. These observations demonstrated that the PA view of the specimen or patient underestimates the true magnitude of the deformity by 40% on average.

As the specimens were rotated further, so the size of the lateral curvature diminished and at 90° of rotation round from the true PA projection a true lateral of the curve apex was obtained, which demonstrated an average lordosis of 14°. By contrast lateral projections of the specimen or patient give the spurious impression of kyphosis measuring on average more than 40°. Thus, not only did the PA and lateral projections of the specimen or patient provide quite erroneous information concerning the true planar nature of the deformity, but were nothing more than oblique views of the same scoliotic deformity. These views at different increments of rotation also enable all the vertebrae within the curve to be identified as regards their true rotational position in space. Morphometric measurements confirmed that all vertebrae within the curve were truly lordotic, anterior vertebral height being greater than posterior.

ANALYSIS OF PATIENTS WITH IDIOPATHIC SCOLIOSIS

One hundred and fifty patients with idiopathic thoracic scoliosis have now been analysed with reference to true

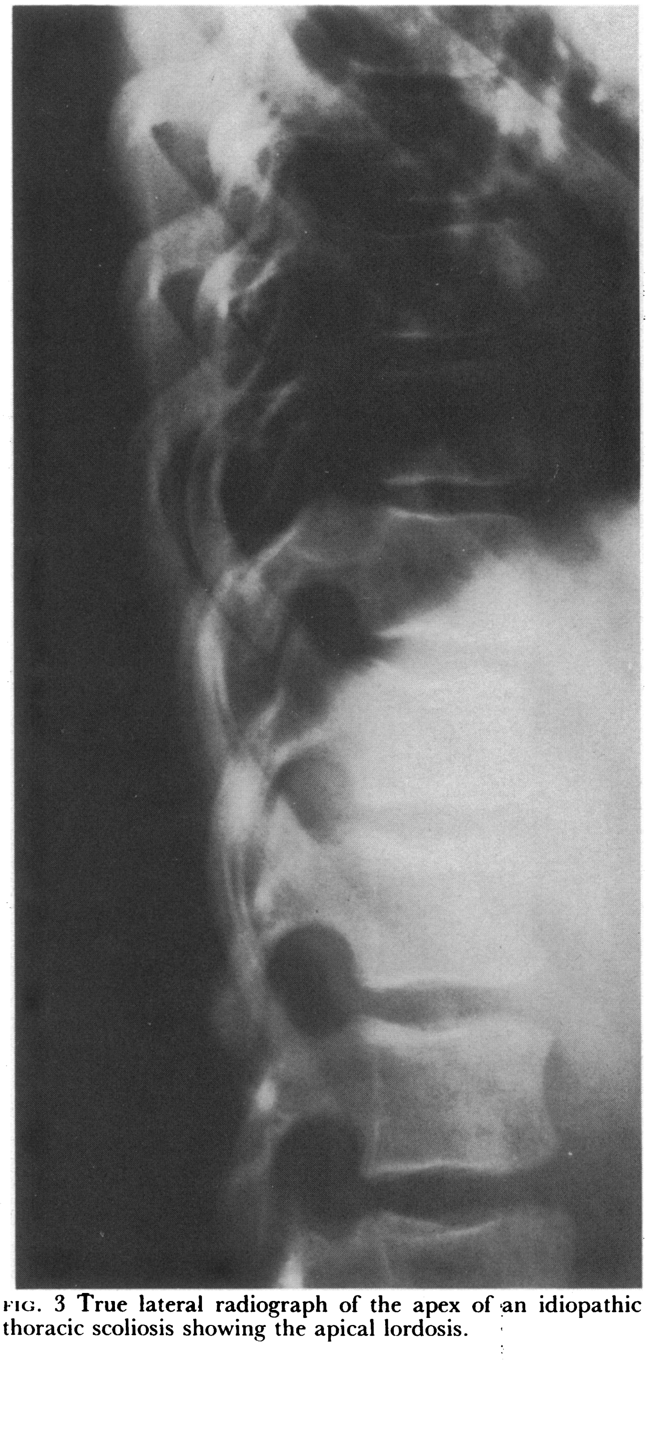

FIG. 3 True lateral radiograph of the apex of an idiopathic thoracic scoliosis showing the apical lordosis.

planar views of the apex of the deformity. Their mean age was 14 years and the female to male sex ratio was 7:1. True lateral radiographs of the apex of the deformity were obtained in all cases by fluoroscopy, computerised axial tomography or geometrical measurement *(10)*. An apical lordosis was present in all cases (Fig. 3) affecting modally the apical three vertebrae, and the angle of lordosis, which range from 4° to 18°, was significantly correlated to PA curve size ($P < 0.001$), the bigger the lordosis then the bigger the associated scoliosis deformity. The position of the lordotic apex correlated significantly with the apex of the scoliosis ($P < 0.001$), with the ninth thoracic vertebra as the mode. Computerised axial tomography demonstrated that the apical vertebral bodies were least rotated one to another and that maximal intervertebral rotation occurred in the segments well above and below the apex, and this was strictly in the nature of derotation bringing the head and pelvis neutral.

ANALYSIS OF PATIENTS WITH SCHEUERMANN'S KYPHOSIS

The similarity in sagittal vertebral wedging between the lordosis of idiopathic scoliosis and the kyphosis of Scheuermann's disease prompted an analysis of 30 consecutive cases of the latter. PA and lateral views of the thoracic and lumbar spines of these patients were obtained and all had the diagnostic criteria of Scheuermann's kyphosis with mean vertebral body wedging of 8.5° extending over four consecutive segments. Twenty one of these patients had an associated scoliosis and in five cases these lateral curvatures were in the region of the Scheuermann's kyphosis with the vertebral bodies either not rotated or rotated such that the posterior elements were directed towards the curve convexity. By contrast 60% of these lateral curvatures were true lordoscolioses with posterior element rotation towards the curve concavity. These lordoscoliotic deformities were either above or below the Scheuermann's kyphosis in the region of the compensatory lordosis which had rotated to

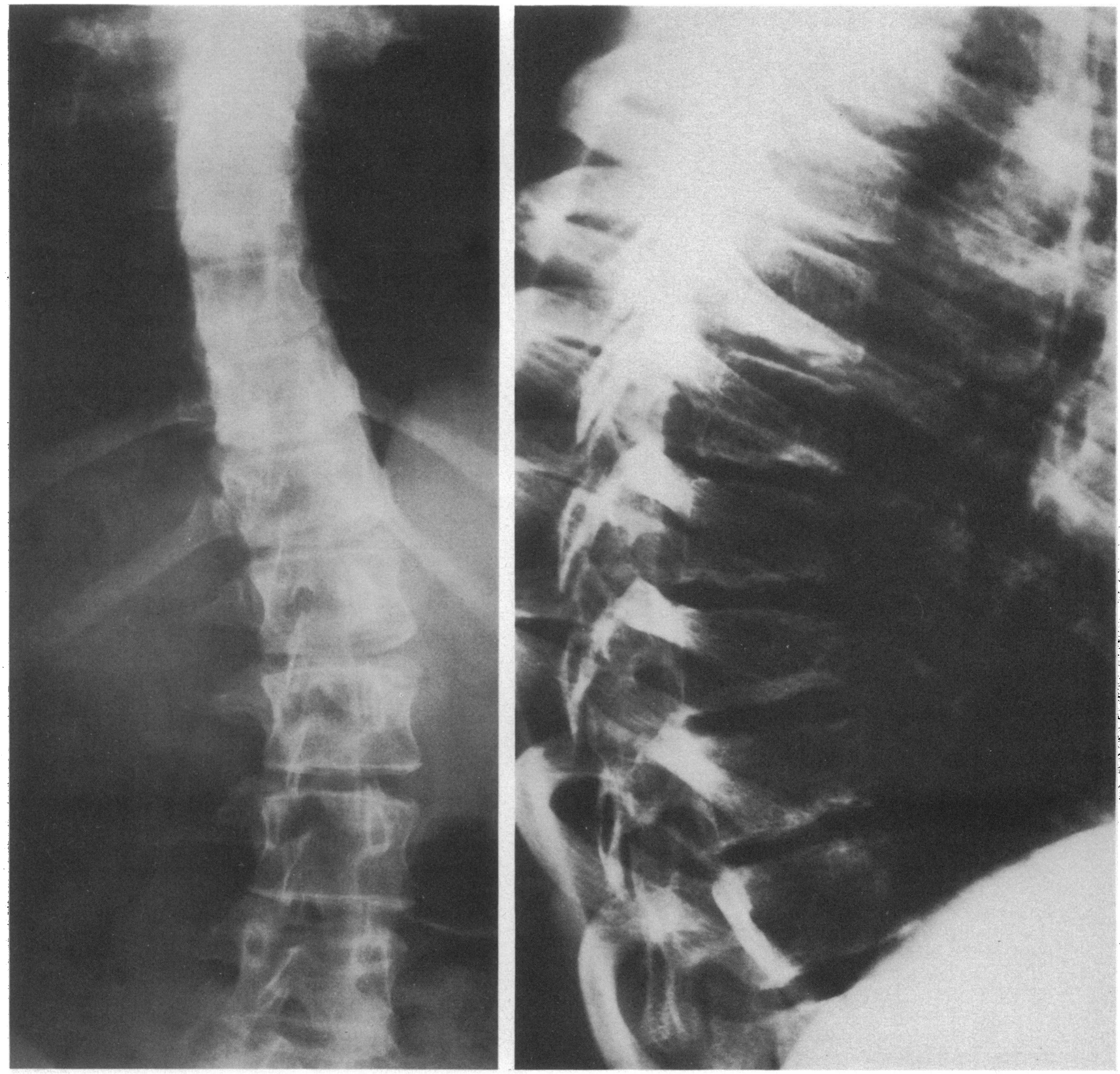

FIG. 4 (a) PA radiograph a patient with Scheuermann's disease showing an "idiopathic-type" scoliosis below the area of kyphosis. (b) Lateral radiograph of the thoracic spine of the same patient showing an increased thoracic kyphosis.

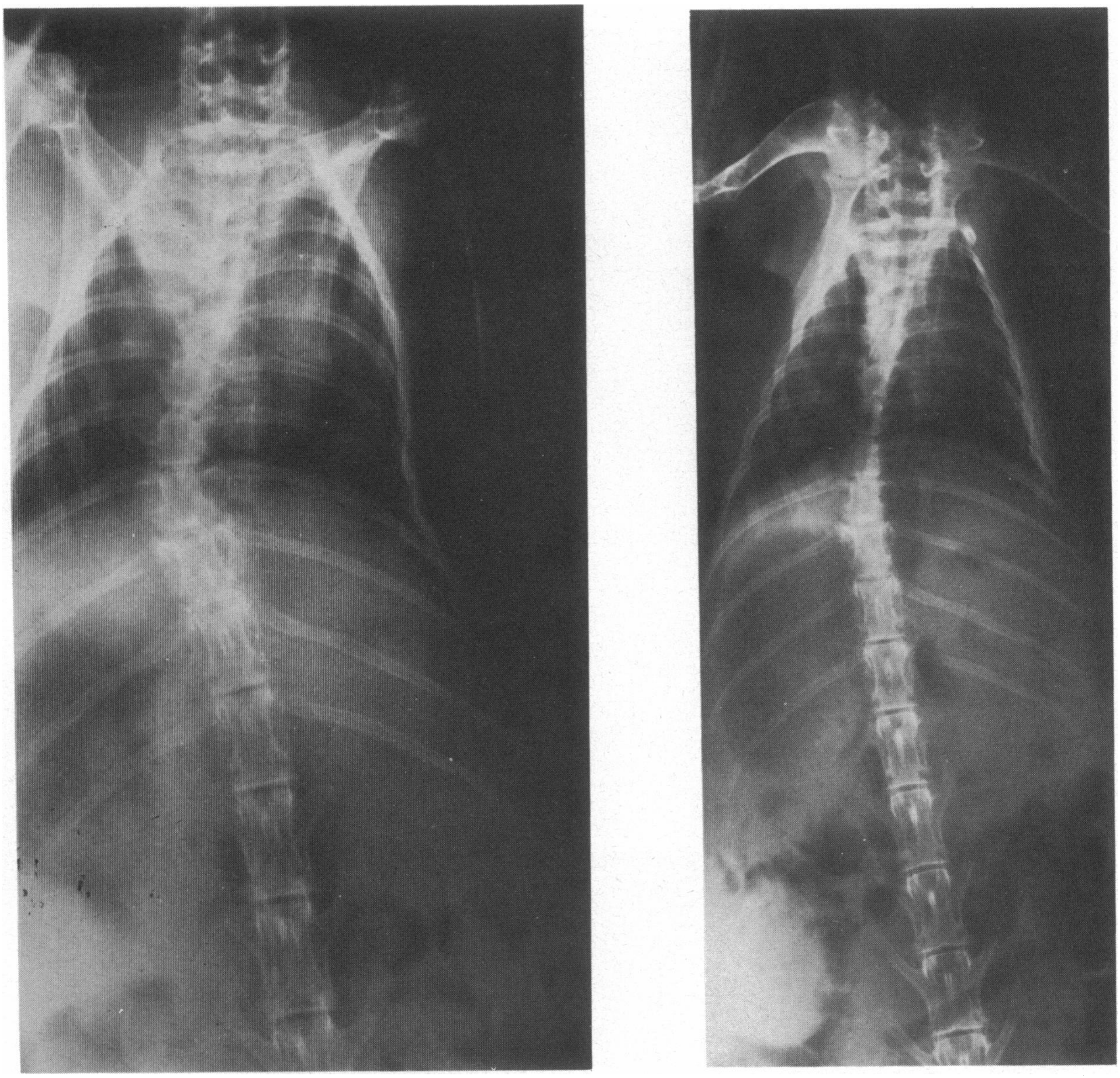

FIG. 5 (a) PA radiograph of a rabbit spine in which experimental idiopathic scoliosis has been produced.
(b) PA radiograph of the same spine four weeks after recreation of the thoracic kyphosis. The deformity has considerably improved.

the side (Fig. 4). Interestingly, there was a significant preponderance of females and right sided curves only in the lordoscoliotic group ($P<0.05$).

EXPERIMENTAL SCOLIOSIS

The crucial nature of the thoracic lordosis was tested in the experimental animal using the growing New Zealand white rabbit as the model. In freshly weaned animals a short segment thoracic lordosis was created by approximating the posterior elements of the lower four thoracic vertebrae using strong suture material. Despite the persistence of the lordosis with growth, a rotational lordoscoliosis was not produced. Rabbits, unlike so many normal childen, do not possess any inherent spinal asymmetry in another plane to impart directional instability to the mechanically unstable lordosis. Accordingly the thoracic lordosis produced was then rendered asymmetric by creating at the same time a few degrees of coronal plane asymmetry when the suture material was tightened. In a controlled experiment this biplanar asymmetry was created in ten animals and the subsequent fate of the spine compared with two further groups of animals, one group having coronal plane asymmetry only and the other the lordosis only. Only in the biplanar group did a progressive lordoscoliosis occur with subsequent growth (Fig. 5).

After the biplanar procedure rupture of the lordosis-maintaining suture occurred in one animal, which spontaneously reconstituted a normal thoracic kyphosis. The early lordoscoliotic deformity resolved over the next four weeks. To confirm this important observation ten animals with biplanar spinal asymmetry had the lordosis-maintaining suture deliberately removed when the lordoscoliotic deformity so produced had reached a magnitude of 30°. Subsequent regression of the deformity occurred in six animals, while in the remaining four the rate of progression was attenuated. Curve magnitude at the time of lordosis release was on average 20° less in those subsequently regressed.

CONCEPT OF A MORE PHYSIOLOGICAL APPROACH TO TREATMENT

From the cadaveric, clinical and experimental studies evolved the concept of restoration of the thoracic kyphosis as an integral part of a surgical procedure aiming to correct all three planes of the idiopathic de-

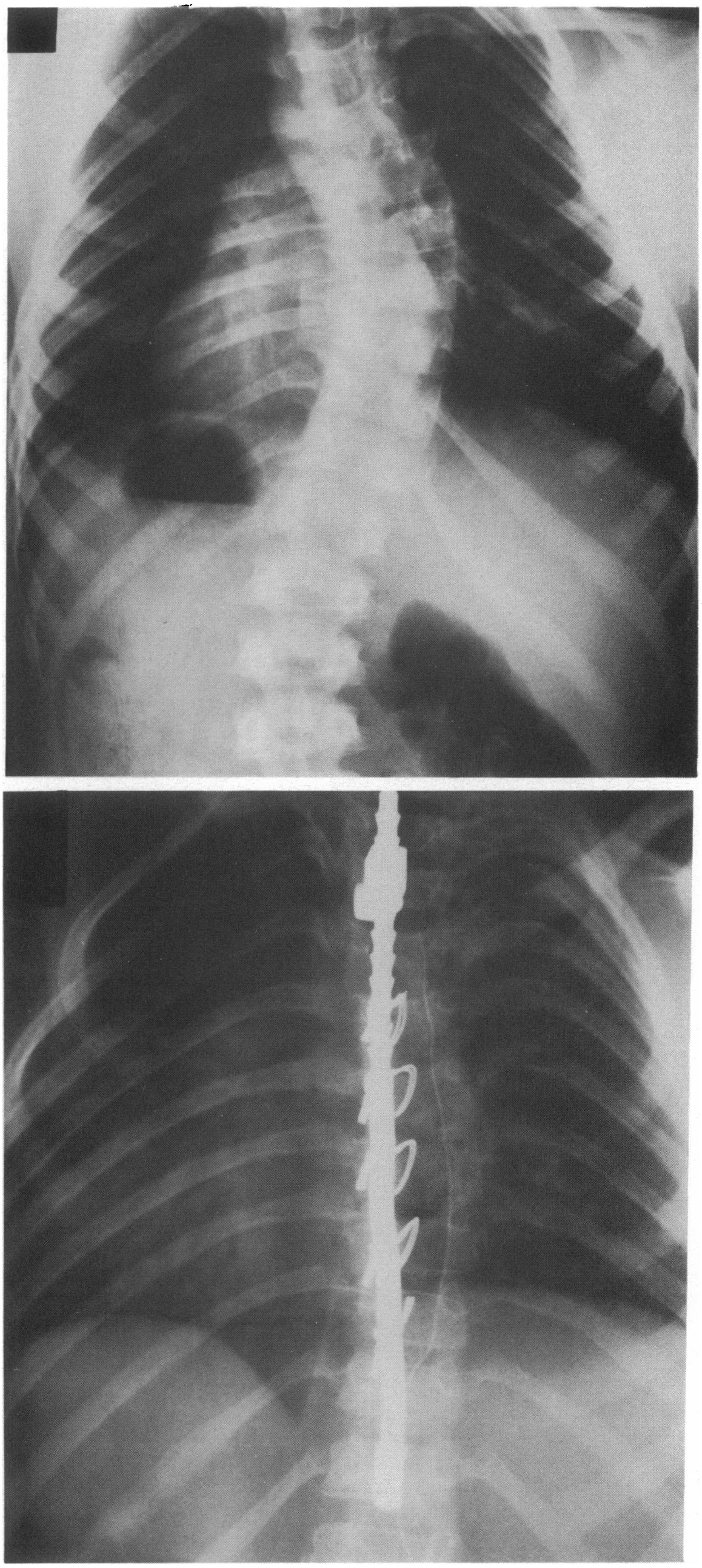

FIG. 6 (a) PA radiograph of a patient with idiopathic thoracic scoliosis before surgery.
(b) PA radiograph of the same patient after concave kyphotic rodding and concave sublaminar wiring. The deformity has been markedly improved.

TABLE 1 *Results of 'physiological' treatment*

No. of patients	*Mean curve size (Degrees)* Before	After	*Correction %*	*Mean apical rotation (Degrees)* Before	After	*Correction %*
20 (Curves < 70°)	46	16	65	28	13	54
5 (Curves > 70°)	100	40	60	46	32	30
25 Total	62	22	65	33	18	45

formity and to possibly allow in the younger child with much growth to go an opportunity for further regression of the secondary deformities of lateral curvature and rotation with the passage of time. The development of segmental spinal instrumentation *(11)*, wiring all the vertebrae in the curve to longitudinal rods, has focussed on the coronal plane, but by bending a longitudinal rod into a normal thoracic kyphotic configuration and drawing the rotated vertebrae to this by tightening concave sublaminar wires enables all three planes of the deformity to be dealt with at one time *(12)*. Necessarily this can only be performed in one stage if the deformity is flexible and not too severe; with significant rigidity a preliminary shortening procedure anteriorly in the nature of multiple disc removal is required to provide room in which the correction can take place and to minimise spinal cord tension. Thus far 25 patients have been operated upon using this technique, 20 with late onset idiopathic scoliosis in whom a posterior spinal fusion has also been performed, and five infantile idiopathic progressive scoliosis in whom posterior fusion has been withheld lest the already too short back of the spine is further tethered in bone. No operative or postoperative complications have been observed in this small group of patients and Table I shows the mean corrections obtained in all three planes. The maximum follow-up period is only 15 months and only one of the four infantile cases, the mildest curve, is showing any evidence of curve regression, and that is minimal. The deformities in the other 21 cases have not changed since the early postoperative position (Fig. 6).

Discussion

This cadaveric, clinical and experimental study emphasises the three dimensional nature of the idiopathic scoliotic deformity and implicates the thoracic lordosis as the essential lesion in idiopathic thoracic scoliosis. The simple mechanical concept of the fundamental nature of the lordosis could not be new and indeed is not, being described 120 years ago by Adams *(13)*, whose classic essay, before x-rays were available, introduced the hypothesis. The precocious minds of Somerville *(2)* and Roaf *(14)* lent further support to the lordosis necessitatis; neither could conceive of the deformity occurring in any other way. Indeed Somerville created the first animal model of 'idiopathic' scoliosis in which the lordosis produced must have been rendered asymmetric. Roaf went further and stated that, in terms of simple geometry, if the spinous processes are rotated less than the bodies then there must be a lordosis. He further strictured, "If kyphosis means an increase in the length of the posterior elements of the vertebral column relative to the anterior elements, the use of the term is certainly erroneous in idiopathic scoliosis." He also made a plea for the study of the morphology of scoliotic spines. In effect, the results of these studies do little more than confirm the views of Adams, Somerville and Roaf, although it is now possible to explain the clinical behaviour of the idiopathic deformity and its response to treatment *(15)*.

The normal cervical and lumbar lordoses are protected from rotation by considerable available intersegmental flexion before the limits are reached, by exceedingly strong posterior supporting musculofascial systems, and by the prismatic shape of the vertebral bodies in the transverse plane, whose anteriorly directed bases confer considerable rotational stability *(16)*. By contrast the thoracic vertebral bodies in the transverse plane are prismatic with their apices anteriorly and this potentially unstable situation is protected by a kyphosis with an axis of rotation well in front. Accordingly, in the presence of a thoracic lordosis rotation is inevitable. Non-structural deformities are due to causes extrinsic to the spine, but while a leg length inequality will induce a mild nonprogressive lumbar scoliosis by way of compensation, the secondary coronal plane component is applied to an area where there is naturally a lordosis and thus a true lordoscoliosis is produced. This is why children with leg length inequality are detected in such numbers in school screening programmes, which use a forward bending test in order to demonstrate rotation *(1)*.

It is not therefore surprising to find that conservative treatment does not alter the course of the condition of idiopathic scoliosis *(5)*. What would be required to correct the essential lordotic lesion would be an orthosis which would flex the lordosis but this is when the lordosis is rotationally unstable and immediately produces the secondary features of scoliosis and rotation. The kyphotic deformity of Scheuermann's disease being uniplanar and rotationally stable is eminently suitable for conservative treatment and any means which provides thoracic hyperextension can lead to a true physiological improvement of the kyphosis *(17)*. The lordotic deformity of idiopathic thoracic scoliosis can only therefore be effectively treated surgically. The traditional longitudinal distraction techniques of Harrington, with forces applied to the top and bottom of the curve, will only affect the coronal plane component of the deformity and cannot be expected to have much influence on the apical rotation *(5)*. Furthermore, as Roaf also warned, the younger the child when posterior fusion surgery is performed, the more likely the unstable lordosis is to be augmented, thus producing the distinct possibility of further rotational deterioration in the future with growth *(14)*.

The essential nature of the lordosis is confirmed by the animal experiments which show that an asymmetric lordosis readily produces the 'idiopathic-type' deformity with growth. Importantly, when the thoracic kyphosis is reconstituted there is evidence of curve resolution, provided the deformity is not too great and there is plenty of growth to go. The concept of physiological treatment therefore arises, the principle of which is to recreate the thoracic kyphosis which re-sites the axis of spinal rotation in its normally protective position *(12)*. This would clearly have more important implications for the younger child with more growth remaining, in whom instrumental restoration of the kyphosis is performed but fusion is withheld so that subsequent growth will now be more in the patient's favour. There is clearly no need to withhold fusion in the older child with much less growth to go whose newly reformed kyphosis ought to be stabilised in bone.

It was in some ways tempting to leave out the small series of 25 patients with their short follow-up and indeed the main thrust of these investigations concerns more the nature and behaviour of the idiopathic spinal deformity. There are, however, important and serious short term implications derived from these cases. The instrumental advances of Luque in bringing segmental spinal instrumentation into the armamentarium of the scoliosis surgeon is primarily referable to the patient with the neuromuscular spinal deformity in whom the greater spinal stability afforded by rods and wires obviates the need for postoperative support *(11)*. Rightly, however, the use of two rods and two sets of sublaminar wires is considered too much of a risk to the spinal cord for the idiopathic deformity in the otherwise normal child. The risks are clearly going to be less if only one rod and one set of sublaminar wires are used and as there is no means via a posterior approach to achieve the necessary correction of the deformity in all three planes the absence of neurological problems or any other complications in this series is important. Furthermore, that there is a safe operative technique that can improve both rotation and lateral curvature by two-thirds as well as restoring the thoracic kyphosis is also important. While the future of the young child with the instrumented spine without fusion is uncertain, the longer the definitive fusion can be postponed, the better will be the final result. For the later onset case, however, the condition is primarily one of deformity and this procedure affords a very satisfactory correction of the rotational prominence with which every patient presents.

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Notes on books

Essentials of Thoracic Surgery by Raymond Hurt and Michael Bates. 270 pages, illustrated, paperback. Butterworths, London. £24.50.

For the past two decades there has been a tendency for the excitements of open heart surgery to overshadow the sister specialty of thoracic surgery. This book should do much to redress the balance. Based on the course in thoracic surgery which has been held each year at the North Middlesex Hospital since 1963 for candidates for the English FRCS examination this book, in a clear and concise text, deals didactically with the complex issues of thoracic surgery. The intention throughout has been to discuss and describe techniques and operations which are acceptable to the majority of surgeons. It is well illustrated with an abundance of radiographs and line diagrams and should appeal enormously to all FRCS candidates as well as their teachers. Sir Keith Ross contributes a lone chapter on the surgery of coronary artery disease.

1986 The Year Book of Vascular Surgery edited by John J Bergan and James S T Yao. 379 pages, illustrated. Year Book Medical Publishers, Chicago (distributed by Wolfe Medical Publications). £38.

The importance of vascular surgery as a specialty in its own right is now widely accepted and is reflected by the arrival of this new volume in the Year Book series. For the first time vascular surgery has its own volume containing abstracts of several hundred papers published in the year ending July 1985. Editorial comments are appended to most of the summaries and there is little doubt that this new series will rapidly establish itself as required reading by vascular surgeons everywhere. The journals covered include many from Europe as well as the USA.

Cancer Immunology: Innovative Approaches to Therapy edited by Ronald B Herberman. 229 pages. Martinus Nijhoff, Boston. £39.95.

This volume contains chapters relating to monoclonal antibodies, lymphokines, tumour vaccines and natural killer cells. It also covers aspects of transplantation immunity, the mechanism of cytotoxicity by NK cells and the mechanism of tumouricidal activity of macrophages.

Atlas of Orthopaedic Exposures by Detlef Von Torklus Toufick Nicola. 2nd edition. 240 pages, illustrated. Urban and Schwarzenberg, Munich. £55.25.

First published in 1966, this atlas has been very much enlarged and the number of illustrations has nearly doubled. Exposure of each part of the bony skeleton is clearly shown by a variety of approaches. The text is succinct and clear and the line illustrations, generally three to a page, are models of clarity. A third edition will surely be required in due course.

Practical Guide to Free Tissue Transfer by Martyn H C Webster and David S Soutar. 125 pages, illustrated. Butterworths, London. £22.50.

Free tissue transfer is now established as a valuable and important technique in the field of plastic and reconstructive surgery and microsurgeons constantly devise new methods and new techniques. This volume, written by two experienced plastic surgeons in Glasgow, describes 20 such free tissue transfers. Each can be read without reference to any other section of the book and each is illustrated with clear line diagrams. A concise and easy to read volume which will certainly be required reading not only for microsurgeons in training but also for those who are more experienced.