

Treatment of spinal injuries

On relating anatomical facts to clinical practice

Henry V Crock

Spinal Disorders Unit, 2A Pennant Mews, London W8 5JN, UK. Tel +44 171 460-5646. Fax -5648
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In the neurosciences the names of Willis (1664) and Adamkiewicz (1882a, b) are known universally for their anatomical descriptions of the blood vessels of the nervous system. Willis published a small book, *Cerebri Anatome*, in Latin, in 1664 in London. Hailed as the father of the neurological sciences, he is remembered primarily for his work on the anatomy of the brain, studies which are still fundamental to the understanding of disorders such as cerebral strokes and subarachnoid hemorrhage. Arteries at the base of the brain are formed in a regular pattern termed the "Circle of Willis". The surgical treatment of intracranial subarachnoid hemorrhage still depends on the surgeon's knowledge of the anatomy of the Circle of Willis.

A Polish pathologist, Adamkiewicz, is equally well known worldwide for his description of the blood vessels of the spinal cord, some of which bear his name. These are delicate vessels of quite small caliber which are difficult to demonstrate in specimens obtained from adult cadavers. In 1882, his monograph "*Die Blutgefäße des Menschlichen Rückenmarkes*", contained most beautifully coloured drawings of the arteries and veins of the human spinal cord. Like Willis two hundred years earlier, Adamkiewicz's anatomical studies have influenced the thoughts and teachings of anatomists, of physicians, and of surgeons with interest in the spinal cord. Management of spinal disorders such as vascular malformations of the cord, the spinal deformities of scoliosis and kyphoscoliosis, and more frequently spinal injuries, is still based on his ideas of spinal cord blood supply.

Adamkiewicz taught that the blood supply of the spinal cord was dependent on a few large feeding arteries which entered the spinal canal at variable levels along the vertebral column to join arterial channels on the anterior and posterolateral surfaces of the cord. His findings were confirmed by different workers this century, by Lazorthes and colleagues in France in the 1960's and by Dommissé in South Africa in 1975. They and many other authors have agreed that the

blood supply of the human spinal cord is tenuous in certain areas such as in the mid-thoracic region and in the lower cervical spine and therefore surgeons have believed that the nutrition of the cord is poor. The attention of surgeons has traditionally focused on the arteries of Adamkiewicz on the understanding that these vessels are uniquely, if not exclusively, responsible for the cord's nutrition. Paralysis after injury is currently ascribed to damage to these few vessels and to direct cord injury or transection, although the latter is found only rarely at postmortem examinations on patients who have died of multiple injuries. Hence a viewpoint has emerged, as expressed recently in a postgraduate lecture in London on current trends in the management of spinal injuries, that "from the moment of injury, paralysis cannot be influenced" (Henderson 1994).

In 1970, Dr. H Yoshizawa from Keio University, Tokyo, came to work at St. Vincent's Hospital in the Department of Orthopaedic Surgery at the University of Melbourne. As head of this department, I began a series of anatomical studies with him, using techniques different from those which had been used by other workers to demonstrate blood vessels in bones and soft tissues.

The results of our work were published in a book entitled "*The Blood Supply of the Vertebral Column and Spinal Cord in Man*", in 1977. The research has continued up to the present time in association with Dr. M. Yamagishi, also a graduate of Keio University, Tokyo, and with Dr. Carmel Crock. A second book, dealing with the arteries and veins of the *Conus Medullaris* and *Cauda Equina* in Man, was published in 1986. Full details of the methods used for the injection, collection, processing and dissection of specimens, together with a description of the photographic techniques used to produce illustrations, have now been published for the first time in a third volume, "*An Atlas of Vascular Anatomy of the Skeleton and Spinal Cord*" in 1996. These techniques produced more complete filling of the vascular systems in adult



Figure 1. Cervical spinal cord from a woman aged 20 years (ant. view; arterial injection, Spalteholz-cleared specimen). The anterior median longitudinal arterial trunk of the spinal cord is duplicated in a number of areas, while in the lower cervical segment it is present as a single large vessel. In its unretouched state, the specimen supports the claim that contributions from the anterior radicular arteries to the anterior median longitudinal arterial trunk of the spinal cord are segmental in the adult, as they were shown to be in the fetal spinal cord by Willis. The size of individual radicular arteries varies considerably but the blood supply remains, nonetheless, strictly segmental. The dural sac has been stretched to separate it from the sides of the spinal cord, and the vertebral artery on each side has been divided into segments, from each of which the radicular branches arise.

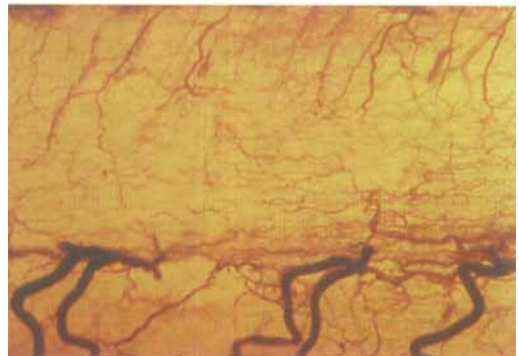
spinal cords than had been achieved previously (Figure 1). The dissection of specimens that proceeded after their lengthy processing was performed without

Figure 2. A mid-sagittal section from the thoracic spinal cord of an adult (arterial injection, Spalteholz-cleared, x10 approximately). The sulcal arteries are shown at the bottom of the picture.

damaging even very fine arteries. In *Cerebri Anatome*, Willis commented on the ease with which arteries in the fetal spinal cord could be studied but he suggested that it might prove impossible to demonstrate the same vessels in the adult.

With my co-workers, Yoshizawa, Yamagishi and Crock, I was able to demonstrate that the arterial supply of the human spinal cord remains segmental throughout life. Feeding arteries enter through each intervertebral foramen to join the main arterial channels on the anterior and posterolateral aspects of the spinal cord so that the arteries of Adamkiewicz are not exclusively responsible for its nutrition. It follows that if these "arteria magna" of Adamkiewicz were to be damaged, the smaller segmental arteries might still carry enough blood to prevent irreversible loss of spinal cord function. Yoshizawa et al. (1995) have provided important experimental evidence, albeit in live dogs, to support this proposition. The argument which stresses the importance of these smaller segmental arteries can be taken a step further. Imagine that after injury they were not damaged but had simply closed down in spasm. Modern microvascular surgery often depends for its successful outcome on the control of vascular spasm and hematoma formation by the systemic or local use of drugs, the application of live leeches or the drainage of hematomas. It could be postulated that similar measures might find a place in treating damaged spinal cords.

The functions of the veins that drain the spinal cord are still incompletely understood, as is the cause of the technical difficulties encountered in attempting to fill them by injection at postmortem. Despite this lack of knowledge, it is well known that the veins on the outer surface of the spinal cord are tethered to it by the encircling arachnoid membrane and that they receive tributaries from within the cord, where the veins are disposed in close relation with the arteries of supply (Figure 2), though they are larger in dimension (Figure 3). Each nerve root emerging from or entering



Figures 1-3 are reproduced from *An Atlas of the Vascular Anatomy of the Skeleton and Spinal Cord*, Martin Dunitz, London 1966 with permission from H V Crock.

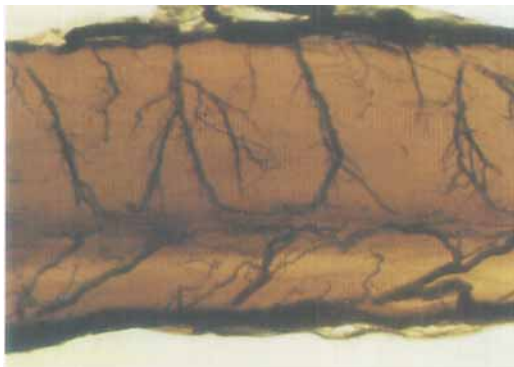


Figure 3. Thin mid-sagittal section from the thoracic spinal cord of a man aged 21 years (venous injection, Spalteholz-cleared specimen). The dorsal surface is at the top. The veins of the spinal cord have a characteristic pattern, being of larger calibre than the corresponding arteries, with radicles entering their main stems obliquely.



Figure 4. Thin transverse section through the thoracic spinal cord of a young adult. The overall pattern of venous drainage is radiate. Centrally placed veins drain anteriorly and posteriorly into median longitudinal veins on the respective surfaces of the cord. The other radiate branches join the tributaries of the vasa corona on the surface of the cord, lying beneath the pia mater.

the spinal cord has veins accompanying it. Many run quite long intradural courses in the thoracic segment of the cord, having V shaped terminations, from the apex of which smaller single radicular veins pass out through the dural root sleeves to join the internal vertebral venous plexus. The direction of venous outflow from the cord is almost exclusively centrifugal, as valve-like mechanisms, described by Suh and Alexander (1939), prevent the flow of venous blood from the epidural veins backwards intradurally.

With this basic knowledge it can be assumed that subpial hematomas following injury to veins on the surface of the cord may impair its function. Likewise, cord contusion may result largely from venous bleeding within the substance of the cord (Figure 4). Finally, if a massive epidural hematoma were to develop after spinal injury, on anatomical grounds alone, it would have the potential to force the dural sac against the side of the cord, thereby occluding the V-shaped intradural veins, leading to infarction of the spinal cord.

An American orthopaedic surgeon delivering a guest lecture to the British Orthopaedic Association in London in 1991 (Chapman 1991) reported on current practice in the management of multiple injuries: using evacuation techniques learned during the Vietnam War, it was possible for people with multiple injuries sustained in motor vehicle accidents in America to be on the operating table within thirty minutes of the accident. Surgical treatment continued uninterrupted until the various injuries had been treated, sometimes lasting for as long as eighteen hours. Each injury was allotted an order of priority on which the sequence of operations was determined and spinal injuries were relegated to the end of the list.

Conclusion

Based on the anatomical facts discussed in this paper, and recognizing that experimental models of spinal injury in animals do not reproduce the patterns of injury resulting from trauma in man, it is nonetheless clear that the time has come for further changes in the methods of treating spinal injury, aimed at limiting paralysis.

If the knowledge of the segmental distribution of blood vessels of the spinal cord is to be applied to the treatment of spinal injuries, it will involve significant changes in the management of patients with multiple injuries. New logistical arrangements will need to be set up for transporting patients with spinal injuries from the site of accident directly to designated spinal centers.

On admission, resuscitation and imaging studies should be co-ordinated with the aim of getting the patient into the operating room in times approaching those currently achieved in America. Spinal fractures should be fixed internally as a first priority, ahead of the management of all other injuries, except those deemed to be life threatening. Once the fractures are fixed, the spinal canal can be safely opened to deal with the problems created by extra- and/or intradural vascular injuries—applying some of the logistical and technical skills already in use by our specialist colleagues in cardiac, transplant and microvascular surgery.

The myeloscopic equipment which is now available in Japan, developed over the past 25 years by Professor Y. Ooi and co-workers, may prove invaluable in assessing these vascular injuries (Ooi et al. 1990).

My remarks in the context of this paper are based on anatomical studies of the circulatory systems of the human skeleton carried out over many years. The knowledge gained from some of our research applied to the practice of spinal surgery in general has proved useful in reducing the hazards of spinal canal explorations. Bearing in mind that the impetus for changing approaches to clinical practice may spring from reflections on basic sciences—it is my firm belief that knowledge of the vascular anatomy of the spine and spinal cord should now be put to practical use in the management of spinal injuries.

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