HISTORY

The History of Neuroradiology: An Australian Perspective

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On December 28, 1895, Wilhelm Roentgen presented his classic written preliminary communication regarding x-rays to the president of the Physical Medical Society of Wurzburg, Germany, and 9 days later his discovery was announced to the world. Despite a lack of modern communication methods, within months of Roentgen's discovery, human radiographs were being produced in Australia by individual scientists, including the first known documentation by Thomas Ranken Lyle on March 4, 1896 (1), and others such as W. L. Bragg, A. L. Rogers, S. Barbour, and W. T. Rowe in Adelaide on June 1, 1896 (Oliphant Sir M, personal communication) (Fig 1). Professor W. L. Bragg continued research in x-ray spectra and the elucidation of the structure of crystals for which he was corecipient of the Nobel prize in 1915.

(5) and 1912 (6, 7), he elucidated the radiographic anatomy of the skull and suggested the best projections to show various structures.

Many future projections and variations on projections for radiography of the skull can be traced to Schüller (8). His initial observations, documented in

1912, were comprehensive. For example, he pointed out the value of observing the calcified pineal gland and noted its displacement by hemispheric tumors and also differentiated many types of normal and pathologic intracranial calcification; he also pointed out the difficulties of distinguishing between intrasellar and extrasellar tumors with plain radiography (4). Schüller's name is linked with Hand and Christian in the condition known as Hand-Schüller-Christian disease, and he is credited with the first description of osteoporosis circumscripta as a manifestation of Paget disease. Schüller's more than 300 publications covered not only radiology of the skull but also various aspects of neurology, surgery, and psychiatry (2, 4), which included the operation of anterolateral chordotomy for the relief of intractable pain and the transsphenoidal approach for the treatment of pituitary tumors (4).

Arthur Schüller spent the later years of his life in Australia (Fig 2). He was at the height of his career when for political reasons he was forced to flee Vienna in 1938 at the age of 65. He moved to Melbourne where he quietly continued his interests in the interpretation of plain films at St Vincent's Hospital, encouraged by an eminent local neurosurgeon, Frank Morgan (Gilford E, personal communication). At St Vincent's Hospital he had an association with the radiology, neurology, and neurosurgical departments, and when he died in 1957 at the age of 82, Mr Morgan wrote, "He was at once the most helpful, charming and valuable colleague that one could wish to have" (9).

Plain Radiographs

As elsewhere in the body, the initial application of x-rays in neurologic practice was the detection and location of foreign bodies and fractures (2, 3). Most would agree that the first person to study the radiography of the skull systematically was Arthur Schüller, a Viennese physician (4). Schüller is of particular interest to Australasian radiology, because he spent his later years living and working in Melbourne (Fig 2).

Arthur Schüller qualified in medicine in Vienna just after Roentgen's discovery, and he soon became interested in the radiology of the skull. In two important works published in 1905

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Fig 1. A radiograph produced in Adelaide, Australia, on June 1, 1896, by Mr A. L. Rogers and Professor W. L. Bragg of the University of Adelaide, in association with Mr W. T. Rowe and Mr S. Barbour of F. H. Faulding & Co, Adelaide, South Australia (courtesy of Sir Mark Oliphant).

Schüller has been called the “father of neuro-radiology” (4). However, in summarizing his accomplishments, Lindgren (10) stated that he is more properly described as “one of its forerunners,” because he expressed no interest in the contrast medium studies characteristic of subsequent neuroradiology.

Pneumoencephalography

For the first 20 years after Roentgen’s discovery of x-rays, neuroradiology consisted of plain radiography of the brain and spine. Although posttraumatic air “ventriculograms” had been reported earlier (11), it was not until 1918 that Walter Dandy from the John Hopkins Hospital, Baltimore, Md, described diagnostic ventriculography in his classic paper (12), which was followed several months later by his description of air encephalography (13).

In his comprehensive thesis, “A History of Radiology in Victoria,” Malcolm McKeown (14) describes the introduction of pneumoencephalography into Victoria, Australia, and in doing so identifies two distinguished Australian pioneers of these important techniques, John Fullarton MacKeddie (Fig 3) and E. Graeme Robertson (Fig 4). McKeown states in his thesis that “John Fullarton MacKeddie was probably responsible for introducing many of the new investigations in Victoria, Australia which required the use of

Fig 2. Arthur Schüller, 1874–1957, in his later years in Melbourne, Australia (2, 4).

opaque oil and air as contrast media” (13). MacKeddie apparently commenced his medical course while still a teacher at Caulfield Grammar School; after graduation in 1902 he became the first junior resident medical officer at the Alfred Hospital, Melbourne, at the age of 33. His personality was such that he ignored difficulties and pursued his objectives with energy and enthusiasm (14). He obviously maintained an interest in new developments, and he encouraged and supported the development of a research institute at the Alfred Hospital (14). In 1923 he traveled overseas, and in particular he spent time at the National Hospital for Nervous Diseases, Queen Square, London. By the time he returned to Melbourne in 1924, he was skilled in cisternal puncture and descending myelography, encephalography, and the injection of the Gasserian ganglion at the foramen ovale (14, 15).

After Dandy’s description of diagnostic encephalography in 1919, there were several reports in the *Medical Journal of Australia* suggesting the performance of ventriculography, including one in 1926 reporting that “diagnostic ventriculography is carried out in Australia by one or two radiologists,” and it was suggested that a paper would be forthcoming within a few weeks (14). However, no such paper appeared, and the first definite reference to encephalography was probably made at a meeting of the Victorian Branch of the British Medical Association held at the Alfred Hospital on September 21, 1927, at which John MacKeddie described pneumoencephalography performed by both lumbar and cisternal puncture. This was subse-

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Fig 3. John Fullarton Mackeddie, 1868–1944.

Fig 4. E. Graeme Robertson, 1903–1975.

quently reported in the *Medical Journal of Australia* (14, 16).

MacKeddie's expertise and enthusiasm for diagnostic pneumoencephalography attracted attention and was probably at least partly responsible for the appointment of the first surgeons with an interest in neurosurgery at the Alfred Hospital and St Vincent's Hospital, Melbourne (14). Although individuals and institutions associated with enthusiasts such as MacKeddie embraced pneumography as a useful diagnostic modality, its use was not uniform either in Melbourne or elsewhere in Australia (14). However, after 1935 the influence of another outstanding Australian physician, E. Graeme Robertson, led to the more uniform acceptance of pneumography as a practical, valuable, and essential aid to diagnosis in neurology and neurosurgery.

Edward Graeme Robertson graduated from the University of Melbourne in 1927 and following the influence of Sir Sidney Sewell, a physician at the Melbourne Hospital, astute in all branches of medicine but with a special interest in neurology, he pursued postgraduate training in neurology in London, working at the National Hospital for Nervous Diseases, St Bartholomews Hospital, and at the London Postgraduate Teaching School, Hammersmith. In 1934 he returned as an honorary physician to outpatients at the Melbourne Hospital and was finally appointed as honorary neurologist at the Mel-

bourne Hospital and the Children's Hospital in 1944. He states in the forward to one of his publications (17) that "work on pneumoencephalography began in 1935." In his first significant publication on encephalography in 1941 (18), he describes in detail the intracranial movement of air during encephalography. In particular he confirmed Laruelle's statements of 1931 and 1933 (10) in regard to the significance of the position of the head during the injection of air. He also pointed out that the fourth ventricle and aqueduct were more easily studied while the air passed into the ventricular system than while it flowed out. He advocated the withdrawal of cerebrospinal fluid before the injection of air, and he stated that 20 mL of air was sufficient for an examination of the ventricular system, whereas he used up to 100 mL for demonstration of the basal cisterns and the subarachnoid space over the convexity of the brain. Although his first monograph on encephalography was published in 1941 (17), general knowledge of his views seems to have been delayed (10), possibly because of the conditions that prevailed immediately after World War II. Subsequent techniques described some years later (19) did not differ essentially from that of Robertson (10). Therefore, it is reasonable to suggest that Robertson was the first to describe the fractional introduction of air and the alteration of the position of the head during, as well as

Fig 5. John Bryant Curtis, 1914–1990.

Fig 6. William S. C. Hare.

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after, the injection of air into the lumbar region to direct air to different parts of the intracranial cerebrospinal fluid pathway. After the initial important observations in 1941 (17), Robertson maintained his interest in pneumoencephalography, developing glass models to investigate further the movement of air within fluid and in relationship to position. His basic observations, together with his extensive clinical experience of pneumoencephalography performed at the Royal Melbourne Hospital, The Royal Children's Hospital, and the Heidelberg Military Hospital, led to a major publication on pneumoencephalography in 1957 (16) and a second edition in 1967 (20). As a result of his publications, he established a worldwide reputation for his work in pneumoencephalography. His final monograph on the subject in 1967 (20) was probably the definitive tome on this subject. Recognition of his enormous contribution in this important development in the history of neuroradiology should continue, despite the technique of pneumoencephalography's being superseded by computed tomography and magnetic resonance imaging.

Cerebral Angiography

In 1927, a Portuguese neurologist, Egas Moniz, first reported the technique of cerebral angiography (21). His determination and persistence in developing this important technique

was described in detail by Bull in 1961 (4). Moniz used a surgical cut down to expose the internal carotid artery, and although he described the first 90 cases in 1931, it was the introduction of direct percutaneous carotid artery puncture in 1936 by Loman and Myerson that led to the more universal acceptance of cerebral angiography as a useful technique (22). Loman and Myerson already were skilled in the technique of carotid puncture, which they used in the treatment of neurosyphilis (10). Other reports soon followed, but the work of the Scandinavian centers (10) led to the wider acceptance of this technique.

John Bryant Curtis (Fig 5), later to be a leading neurosurgeon at the Royal Melbourne Hospital, was an important person in introducing percutaneous carotid angiography to Britain (23) and subsequently to Australia on his return to Victoria in 1949. While a Nuffield Dominion Scholar in Surgery at Oxford, he visited Norway with James Bull to learn the technique from Engeset. He reported the Oxford experience of 720 cerebral angiograms performed by the direct percutaneous puncture. In 1951, his article in the *British Journal of Surgery* (23) was acknowledged as the definitive article in the British literature describing the scope of percutaneous carotid angiography (Hare W, personal communication). This voluminous article contains a history of the development of the percutaneous technique and complications, contrast

media, radiographic technique, normal angiographic anatomy, and the variety of shifts and different patterns of "stains and blushes." Another important contribution to neuroradiology by John Curtis was the development of a rapid serial changer using roll film (24).

On his return to Australia, Curtis taught William Hare (Fig 6) to perform percutaneous carotid angiography at the Royal Melbourne Hospital. At the same time other Australians were embracing this new exciting technique. These included the first neurosurgeon, James Ainslie, and the first neuroradiologist, Arthur Merritt, at the Royal Perth Hospital (ApSimon T, personal communication). Although not documented by a specific publication, it has been stated that the first carotid angiogram was performed at the Royal Perth Hospital in 1946 by James Ainslie and Arthur Merritt (25). Merritt was certainly performing percutaneous direct puncture of the carotid artery in 1949, after gaining experience in Malmo and Stockholm (ApSimon T, personal communication). Subsequently, other Australians including John Varey and Charles Stuart of Perth, Lance Perrett of Adelaide, Stan Lamond of Sydney, and Eric Gilford and Hal Luke of Melbourne gained experience in this important technique in various overseas centers, including The National Hospital for Nervous Diseases, Queen Square, London, and those in Scandinavia.

Direct puncture vertebral angiography was described at the Symposium Neuroradiologicum in Rotterdam in 1949 (26), and this technique was quickly embraced by those Australians who were performing percutaneous carotid angiography. Seldinger's ingenious but simple method for percutaneous catheter insertion of the femoral artery in 1953 (27) was followed by the development of transfemoral cerebral angiography (28). In 1959 William Hare of Melbourne spent 3 months in Oslo with Per Amundsen learning the catheter approach to cerebral angiography, and he was probably the first to use this method in Australia in 1960. Initially the vertebral system was outlined via catheter, while percutaneous direct puncture of the carotids was maintained (Hare W, personal communication).

Being trained at percutaneous puncture, many neuroradiologists in Australia persisted with the technique during the 1960s, but with the introduction of newer catheter material (29), Hare had switched almost entirely to catheter

Fig 7. H. Trevor ApSimon.

angiography by 1966 (30). He was followed by others such as Bernard Vaughan and John Vary in Perth in 1967 (ApSimon T, personal communication) and those Australian radiologists returning from overseas, where the technique was being actively introduced. In particular, the morbidity associated with percutaneous cerebral angiography was reported (31, 32), and the advantages of transfemoral catheter angiography was recognized (32, 33). The catheter technique also was more easily performed in the pediatric age group (34).

The general acceptance and application of transfemoral catheter angiography in the early 1970s led to the development of new exciting interventional techniques (35). Trevor ApSimon of Perth (Fig 7) recognized the importance of this new aspect of neuroradiology, and he performed embolization of external carotid malformations, spinal arteriovenous malformations, and dural arteriovenous fistula in 1977 and 1978. The first intracranial interventional procedure performed by ApSimon was the closure of a traumatic carotidocavernous fistula using the Debrun detachable balloon technique in 1979. ApSimon's meticulous approach to interventional neuroradiology led to its rapid acceptance by his neurosurgical colleagues, and in association with others, a very active interventional neuroradiology service has been established at the Royal Perth Hospital (36). Using overseas experience and information, they introduced various interventional techniques, including transarterial bucrylate embolisation of brain arteriovenous malformation and dural fistula in 1983, and they were the first to introduce the Guglielmi detachable coil in July 1992 for the treatment of cerebral aneurysms (ApSimon

Fig 8. William J. Garrett.

T, personal communication). A formal interventional neuro-radiology unit was established at the Royal Perth Hospital in 1992. Interventional neuroradiology techniques also now are performed by other Australian neuroradiologists.

After the initial description of cerebral angiography by Moniz, one of the factors that initially hindered wider acceptance of cerebral angiography was the lack of a suitable contrast medium. Contrast media such as Thoratrast and Diotrast have significant side effects, and it was not until the introduction of the water-soluble iodinated contrast media in the 1950s that a level of toxicity was acceptable. Throughout the years research to develop a suitable contrast medium has continued, and after Almen's work (37) contrast media with minimal neurotoxic side effects are now available. At Flinders Medical Centre in Adelaide, a group of radiologists and scientists have played a role in demonstrating that the nonionic contrast media are less neurotoxic than the equivalent iodine concentration of ionic contrast media (38).

Cranial Ultrasound

Leskell coined the term *echoencephalography* in 1956 when reporting the use of ultrasound in brain trauma (39). Although Ian Donald obtained echoes from the fetal head in 1958 (Garrett W, personal communication), and Brinker and Taveras demonstrated early cross-sectional images of the brain (40), two Australians, William Garrett (Fig 8) and George Kossoff, played the major role in the early development of ultrasound and its applications to neuroradiology and elsewhere in the body. Working at the Royal Hospital for Women and the National Acoustic Laboratories in Sydney, they established a research program in 1959, leading to their first "echoscope" in 1960, designed by Kossoff. Concentrating initially on an-

tenatal studies, they first demonstrated the cranial bones with a bistable system (41). In 1969, Kossoff developed film echoscopy, now known as gray scale, leading to a detailed description of normal antenatal intracranial structures (42, 43) and, subsequently, intracranial pathology (44).

In early 1973, Garrett had an opportunity to perform a study on a newborn child with hydrocephalus diagnosed antenatally. Images of the lateral ventricles were obtained by placing a liter bag of saline at the side of the neonate's head as a stand-off for the contact scanner (Garrett W, personal communication). Air studies also were performed on the same neonate, and this provided an opportunity to compare the two studies. Subsequently, they described the normal ultrasound anatomy of the infant brain (45). Their publication in 1975 correlating ultrasound and air studies of the infant brain (46) clearly established the clinical role of cranial ultrasound in the neonate and infant, in most cases making invasive air studies obsolete in this age group. A presentation by Garrett and Kossoff in 1976 clearly established their leading role in the development of B-mode gray scale ultrasound and its application to neuroradiology of the neonate and infant (47). With the subsequent development of real-time ultrasound scanners, Garrett, Kossoff, and others maintained their interest in intracranial ultrasound (48), along with a rapid expansion in international interest in ultrasonic techniques.

Radionuclide Studies

George Moore's initial report in 1948 (49) and subsequent publications in the early 1950s (50) led to an increasing role for radionuclides in neuroradiology. During the 1960s and early 1970s, nuclear medicine played an important role in investigating diseases of the blood-brain barrier, cerebrospinal fluid circulation, and cerebral blood flow in Australia (51, 52). Several original developments were pursued, such as the automated cerebral radioangiogram (53), but in general, overseas experience was applied in clinical studies.

Modern Era

With the introduction of techniques relying on computer technology, such as computed to-

mography, magnetic resonance imaging, single-photon emission computed tomography, and positron emission tomography, the scope of a major international contribution to neuroradiology from Australia, such as those made by Schüller, Robertson, Curtis, Garrett, and Kossoff in the past, has been perhaps reduced because of the lack of adequate research and development funds. This is illustrated by the major contribution a New Zealander, Graham Bydder, has made to the development of magnetic resonance imaging while working in the United Kingdom (54). Such a contribution would have been difficult to achieve in Australia or New Zealand.

Nevertheless, Australian neuroradiologists are very proactive in adapting overseas developments to the local scene, and they maintain a significant academic profile by presentations and attendance at national and international scientific meetings. An Australian and New Zealand Society of Neuroradiology has been established to promote clinical, teaching, and research activities in the field of neuroradiology and the neurosciences. The Australian and New Zealand Society of Neuroradiology is one of the founding members of the World Federation of Neuroradiological Societies.

Editor's note: The author's modesty prevented him from mentioning his own contributions. Professor Sage and his colleagues at Flinders University, where he is chairman of the Department of Radiology, have contributed significantly to the understanding of the blood-brain barrier. In September 1994, Professor Sage was elected the first secretary-general of the World Federation of Neuroradiological Societies.

Acknowledgment

This historical account has relied heavily on personal communications received. Therefore, there may be important omissions, and I apologize for these. However, the purpose of the paper is to highlight the contributions of certain individuals working in Australia to the development of neuroradiology without in any way meaning to detract from the efforts of others.

I thank those medical colleagues who responded to a request for historical information, in particular, William S. C. Hare, William A. Sorby, Eric J. Gilford, H. Trevor ApSimon, William J. Garrett, Barry E. Chatterton, and Michael S. Huckman.

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