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AJNR Am J Neuroradiol 2001, 22 (3) 584-589
http://www.ajnr.org/content/22/3/584

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CEREBRAL ANGIOGRAPHY VIA THE FEMORAL ARTERY WITH PARTICULAR REFERENCE TO CEREBROVASCULAR DISEASE

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The therapeutic approach to cerebrovascular disease depends upon the site and extension of the vascular lesion. Detailed study of the entire vascular bed from the aortic arch to the intracranial circulation is imperative. The aim is to show the aortic arch and the brachiocephalic trunks by means of aortic injection (thoracic aortography) and then to make selective injections into each of the cerebral vessels (selective carotid, vertebral and — if necessary — subclavian angiography).

This can be done by catheterization via the femoral artery. Up to the present time however, most authors feel that this is difficult and dangerous because of the widespread atheromatous lesions which are often present in these patients.

Our experience both from Ullevål Hospital and the University of California, San Francisco Medical Center, indicates that this is the method of choice, the incidence of technical failures is small and the complication rate low.

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An *AJNR* panel was convened to select the 10 neuroradiologic articles that most represent the seminal underpinnings of our current clinical practice. Nine of the 10 ''classic'' communications chosen were full-length articles, the exception being this historical selection, only a brief abstract (1 [facing page, reprinted with permission]). The first author of this abstract on transfemoral pan-cerebral angiography (TFCA) was the pre-eminent Norwegian neuroradiologist, Per Amundsen. His pioneering of this ''integrated angiographic methodology'' has been succinctly described by his famed Swedish colleague, Torgny Greitz (2): ''Amundsen of Norway was the first routinely to catheterize and examine all cerebral vessels, carotid as well as vertebral arteries, via the femoral route, a technique he had been using at the Ullevål Hospital in Norway since 1964. Hans Newton learned about this routine use of the femoral approach when he was in Sweden in 1966. He had earlier only occasionally used this method for carotid angiography (3). Newton was actually the first to perform a catheterization of the carotid artery from the femoral artery at the Karolinska Hospital. That was in 1966 when he came back from a week's visit in Oslo'' (2).

Only a comprehensive, but relatively little known book chapter by Amundsen et al (4) on cerebral angiography (in which he elaborated his technical approach and concern for risks and procedural safeguards during TFCA) and this abstract (1) constitute his published output on TFCA. His transmission of TFCA methodology to North American neuroradiology thus occurred through two other pathways: 1) during his tenure as Visiting Professor at the University of California, San Francisco (UCSF) between 1965 and 1966 and 2) through collaboration with the distinguished North American (and other international) visiting observers and trainees in his department in Norway.

Concerning the first pathway, his UCSF tenure, Amundsen's unique contributions are clearly recalled by the two UCSF residents then assigned to neuroradiology:

''I was completing a 6-month neuroradiology rotation with Dr. Hans Newton when he left for Sweden in October 1965 on a 6-month sabbatical leave. Before he left, in the absence of neuroradiology fellows, I was given the privilege of assisting him with all neurovascular procedures. Hans asked me to spend an additional 6 months in neuroradiology in order to introduce Dr. Amundsen to the UCSF routine.

Like Hans Newton, Per Amundsen was a gentleman. He always seemed happy and upbeat. His philosophy: 'There are no mistakes, only experiences.' He never raised his voice and had no 'airs'. He solicited and considered opinions from all sides. Generous, friendly, and approachable, he quickly became a 'favorite' at UCSF. At our first meeting, Per put me at ease and requested we continue the routine Hans had established so that he could evaluate the UCSF approach. Three to five angiographic procedures were being performed each day. Per made no immediate changes, save one, creating a 'closed flush system'. The flush solution would be obtained directly from a stopcock connected to a bottle of heparinized saline rather than from an open bowl filled with the solution'' (J.R.M.).

(''Amundsen would use one heparinized saline syringe for aspirating blood through the lumen of the catheter and a second syringe of heparinized saline, meticulously cleared of blood, to forward flush the catheter. [T.O.G.]'')

''After 1 week, Per told me he understood the UCSF approach. He was now going to introduce the Amundsen technique that he had been using in Norway for some time. Cerebral angiographic procedures were now to be done by the femoral approach using catheters and a modified Seldinger technique. Instead of using the standard Seldinger double-wall arterial-puncture technique, he used a sharp, short-bevel, 18-gauge, thin-walled open needle (ie, without stylet) that he brought from Norway. He connected the needle to a one-way stopcock, the other end of which was connected to a saline-filled syringe. This assembly would be directed toward the arterial pulse at a 45-degree angle. En route, 2 mL of saline was injected to clear the needle of possible skin or subcutaneous fat. When the upper wall of the artery would be punctured, arterial blood pulsed back into the saline-filled (glass) syringe. Then the stopcock on the needle would be closed, the syringe detached, and a guidewire introduced into the hub of the stopcock before reopening it. The 'ideal entry' meant no blood had spurted onto the procedural field. He called this his 'bloodless approach.' Using only a

single-wall arterial puncture also usually precluded groin hematoma (eg, in hypertensive patients) and lessened the magnitude of digital compression of the femoral artery required after catheter removal'' (J.R.M., T.O.G., O.P.E., A.E.R.).

''Amundsen had also brought to UCSF a wide variety of catheters and guidewires, which he used to great advantage. He frequently met with the ever-present salesmen to facilitate their developing more suitable catheters and guidewires for angiography. Per converted UCSF to the TCFA approach easily and painlessly. (Even when carotid studies were not successful, direct carotid catheterization [5] rather than direct carotid cannulation was performed.) The rate of complications was very low and the comfort level of patients very high. Residents and, later, fellows learned the procedure technique quickly.

When asked if we should publish what we were doing, he replied: 'John, I feel no great need to publish. I love teaching. Finding a reception for my ideas is reward enough.' Without fanfare or rancor, he quietly and efficiently ushered us forward into the vanguard of vascular neuroradiology'' (J.R.M.).

Some 8 months later, when Dr. Newton returned from sabbatical leave, this conversation with him is recalled: ''You ought to look at it [TFCA]. It's great.'' Hans responded: ''If its complication rate is low, let's do it. He was very open minded about it'' (A.J.P.).

In addition to the propagation of Amundsen's TFCA approach through the UCSF program and its visitors, his influence also extended to other major medical centers in the United States through the second pathway: North Americans he trained at the Ullevål Hospital in Oslo such as Roy D. Strand (1967–1968), who joined the Children's Hospital of Boston, Trygve O. Gabrielsen (1968) of the University of Michigan, G. Joseph Poole (1970) of Stanford University, and Joseph Sackett (1972–1973) to join the University of Wisconsin (from Cornell Medical Center). Many well-known neuroradiologists from other North American medical centers also briefly visited Amundsen's Department in Oslo and observed his TFCA methodology.

Two conditions are addressed regarding the impact of *routine* TFCA by Amundsen and the recognition he received for it:

I. How was cerebral angiography performed before *routine* TFCA?

With hope, the reader will not feel burdened in recalling how cerebral angiography was accomplished in the United States in 1965 before Per Amundsen's tenure here. Most cerebral angiographic procedures then were performed by neurologists and neurosurgeons. The common arterial accesses they chose were percutaneous needle cannulation of one or both common carotid arteries with separate (or simultaneous) hand injection(s) of contrast media for carotid angiography; to visualize the vertebrobasilar circulation, the most common technique they used was a countercurrent brachial artery injection. A right brachial injection could usually opacify both the right anterior and posterior circulations. If visualization of only the posterior circulation was clinically warranted, a left brachial artery countercurrent pressure injection could often adequately opacify that circulation alone. Anatomic variations/anomalies, contralateral vertebral artery ''washout'', or subclavian ''steal'', however, could preclude reliable and satisfactory posterior circulation opacification from a single countercurrent brachial artery injection, even with the often used higher concentrations (eg, 75–76%) of iodinated contrast material. Thus, bilateral simultaneous brachial pressure injections of 120 cc of 60% iodinated contrast media became the standard for that American institution (Mt. Sinai Medical Center, New York, NY) that provided the most detailed knowledge of the posterior fossa venous circulation at that time. (6, 7 and personal communication [Huang YP, Sept. 11, 2000])

When radiologists performed cerebral angiography by catheter techniques, they used the transaxillary, transfemoral, transbrachial, transradial (and transsubclavian) routes for nonselective or selective vertebrobasilar opacification. With right-sided access, right common carotid opacification could be achieved from the innominate artery injection, but left common carotid artery catheterization from the aortic arch was rarely achieved. In 1963, both Amundsen et al (5) and Schechter (8) reported using the Seldinger technique (9) to accomplish transcervical common carotid artery catheterization. Amundsen et al (5) described 853 direct percutaneous common carotid catheterizations and 118 vertebral artery catheterizations via the brachial or femoral arteries. One can conclude that Amundsen was technically advancing stepwise, via catheter, toward effecting routine TFCA. It is also remarkable that these authors (5, 8) accomplished selective transcervical catheterization of the internal and external carotid trunks *without the benefit of fluoroscopy* by relying on neck positioning and test injections of saline. (By hyperextending the neck and turning of the head ipsilaterally, a guidewire introduced into the ipsilateral common carotid artery would usually enter the external carotid trunk; conversely, with positioning the head contralaterally and the neck flexed, the guidewire, when advanced, would usually enter the internal carotid from the common carotid artery. On rapidly injecting a *bolus of saline* into the catheter, successful internal carotid catheterization could be confirmed by observing momentary blanching of the ipsilateral supraorbital skin or palpebral conjunctiva [versus blanching of the cheek from an external carotid injection]). Using fluoroscopy, Weidner and Hanafee (10) and Newton and Kramer (3) would further advance the clinical utility of detailed selective external carotid angiography.

At the time of Amundsen's arrival at UCSF in 1965, Hans Newton (J.R.M.) had been using the

Seldinger technique for transfemoral cerebral angiography in about one third of cases since 1963–1964. It had become the routine approach for vertebral, bronchial, and parathyroid angiographies. Occasionally, in young patients, transfemoral right carotid angiography could also be performed. Although neck ''sticks'' for direct vertebral angiography had been abandoned because of their complications, direct left carotid cannulations persisted. The neuroradiologic technique for assessing multiple cerebral vessels (A.J.P.), eg, in clinically presumptive cerebrovascular disease was via the right transaxillary approach—arch aortography would be performed followed by biplane filming of the neck and head. If additional intracranial vascular detail were needed, the catheter would be withdrawn from the arch into the innominate artery for opacification and filming of the right carotid and vertebral circulations. The right common carotid and right vertebral arteries might even be selectively catheterized from the innominate and right subclavian arteries, respectively. For left common carotid angiography, percutaneous cannulation that day, or the next, transpired. When the catheter curve had been situated in the aortic arch, it could occasionally be directed into the proximal left common carotid artery. The arch catheter caliber then was 0.086 in (outer diameter) and the catheter was made from non-radioopaque polyethylene. Any patient undergoing cerebral angiography required hospitalization to include recovery time. Catheters and guidewires were in short supply and expensive. (J.R.M.) Also in 1965, commercially available ''cerebral'' catheters were usually large (7F to 8F), radioopaque, stiff, not readily shapeable, and had the undesirable characteristic of losing their ''curves'' intravascularly. Smaller caliber polyethylene catheters (PE 160 and PE 210) were available, but they were not radioopaque and had limited torque control. Hanaffee convinced one manufacturer (Becton-Dickinson, Inc., Franklin Lakes, NJ [in 1965, Rutherford, NJ]) to lower the ''opacifying'' barium content of its 5F product from 10% to 5% (Personal communication: Hanafee W, 1982) to avert its inherent brittleness and predilection to split (Personal communication: Hanafee W, Sept. 7, 2000). Amundsen visited UCLA from San Francisco and learned of this radioopaque catheter and of fluoroscopic advances during catheterization (Personal communication: Hanafee W, Sept. 7, 2000). During this UCSF period, he adopted B-D's Hanafee tubing, which also became very popular with Hans Newton and his subsequent trainees. The catheter ''curve'' Amundsen typically applied to the 5F. radioopaque polyethylene catheters for younger patients was ''hockey stick–'' or ''C-shaped''; in patients over 40 years old, various ''S-shaped curves were used. (T.O.G.) The later-developed, Mani double curve (11) further reduced the difficulties in achieving left common carotid origin catheterization. An optimal guidewire and catheter armamentarium, which would contain various tapers, graded flexibility, numerous calibers, lengths, and coatings, was yet to evolve.

Amundsen's introduction of TFCA at UCSF offered visualization of all pertinent cerebral arteries extracranially and intracranially through a single femoral artery entry site, via a one-wall puncture, preferably using a small (5F) catheter, in one session. Yet unanticipated was that TFCA could be performed safely as an outpatient procedure.

II. Why has there been scant historical recognition of Amundsen's seminal development of TFCA?

Prime among the reasons may be his extraordinary modesty and the lack of Norwegian institutional or professional requirements for him to have published broadly.

Academic appointments in Norway were very few. The only Norwegian academic appointment in neuroradiology was held by Arne Engeset at the Rikshospitalet (the national and main teaching hospital). Although Amundsen was involved in some teaching of medical students, he did this without financial compensation or academic appointment (T.O.G., O.P.E.). His daily clinical workload was very heavy and he lacked adequate office staff support; garnering secretarial assistance occurred in part ''after hours'', and was then paid for from his private funds because his sole medical transcriptionist's main function was the typing of departmental radiologic reports (T.O.G.).

Because Amundsen's publications on TFCA were few, today most neuroradiologists familiar with his life work recall him principally as the leading clinical investigator of the first clinically applied non-ionic contrast agent, metrizamide (12) and its second-generation successor, iohexol (13), rather than for TFCA or for high definition gas encephalography (14). Those privileged to have seen Amundsen's original images (T.O.G., O.P.E., A.J.P., R.L.M., J.R.M., A.E.R.) were positioned to understand his credo of demonstrating anatomy and disease through superb clinical imaging. He focused on generating exceedingly sharp and very aesthetic images. In his view, high-definition imaging, as a first step, should improve the likelihood of making the correct diagnosis as a logical second step. What he achieved with TFCA imaging also carried over to his achieving similarly exquisite detail on pneumoencephalograms through the use of hypocycloidal tomography (14) and on myelograms (15, 16).

There are also other explanations for his relative anonymity in having pioneered routine TCFA. Omissions of Amundsen and his collaborators regarding publications on TFCA are presumed inadvertent, but explicable. One is unlikely to uncover ''historical facts'' that have not been written, taught, or observed, so that most neuroradiologists seeking such information must rely on what has already been recorded. In the 1971 second edition of Abrams' *Angiography* (17), the chapter on cerebral angiography's technique and hazards cites catheter introduction from the femoral artery for

cerebral angiography in 1963 by Amundsen et al (1) and in 1968 by Newton and Gooding (18) for pediatric cerebral angiography. Later authors, however, in the 1997 fourth edition of Abrams' *Angiography* no longer cite Amundsen (19). Other sources also omit linking Amundsen with TFCA (20, 21).

Amundsen's initial TFCA publication, in 1967 (1), is cited under ''Historical Aspects'' in the chapter on techniques of catheter cerebral angiography in Newton and Potts' *Radiology of the Skull and Brain* (22). Amundsen (1) appears first (and alphabetically) alongside two other 1967 references (23, 24) for having ''stressed the value of femoral catheter techniques in carotid angiography''(24), interestingly, not for routine *cerebral* angiography. There is no additional commentary regarding Amundsen's earlier experiences at UCSF noted from that abstract (1). Moreover, interrelationships among these four references (1, 22–24) extend beyond mere juxtaposition and time. As Greitz had mentioned (2), Newton had visited Amundsen's department in 1966. Examination of the signatures in the guest book (*Neuroradiologisk Avdeling Ullevål Sykehus*—A bound book containing signatures of Departmental visitors and Fellows-in-training between 1964 and 1998) from Amundsen's department in Oslo reveals that three of the four authors of those same two 1967 papers (22, 23) had visited Amundsen before 1967: Hinck, in September of 1965 (and 1967), Judkins, in May of 1965, and Hare, in November of 1966. No mention of Amundsen's TFCA or his department was cited in one of them (23), whereas in the other (24), Hare proffers from his 1966 visit that: ''Amundsen is an advocate of catheter cerebral angiography, and having seen the frequency with which he is able to catheterize selectively the cerebral arteries from the groin it was decided to examine the feasibility and advantages of utilizing this technique in the study of patients admitted with subarachnoid haemorrhage''.

Alternatively, Judkins did develop another technique for TFCA (which he does not appear to have published, but which he demonstrated to William Hanafee [Personal communication: Hanafee W, Sept. 7, 2000] by 1965). This technique for TFCA used right or left coronary angiography catheters (25), which Judkins advanced to the ''closed'' aortic valve. By further advancing the catheter at the groin, the catheter end would form a loop on itself and the catheter tip could be directed backward to the aortic arch to afford cervical catheterization of cerebral vessels (Personal communication: Hanafee W, Sept. 7, 2000] by 1965).

Per Amundsen is described by those who knew him as an ingenious and genuine physician ''whose results you could trust''(J.R.M.,T.O.G.). His gracious and genial nature characteristically underplayed his contributions. This was exemplified once again during his day-long return visit to UCSF in 1969. There he delivered a lecture on the complications he had experienced in having performed 5000 TFCAs. In this huge series, he described only 19 complications, and only one death had occurred. However, he began this lecture on TFCA by stating he felt embarrassed to speak on this topic at UCSF because: ''[He] believed he was carrying coals to Newcastle''(A.E.R.).

In our present era, on considering the imaging of anatomy and pathologic abnormalities made possible by TFCA, one readily also recognizes the foundation it laid as the reference standard for interpreting noninvasive neurovascular imaging generated by MR angiograpy, CT angiography, and sonographic angiography.

Dr. Amundsen died in 1983 after a relatively brief illness that he endured bravely and quietly, quite true to his character.

Acknowledgments

The authors are very grateful for the consummate advice, acumen, and experience shared by Doctors William N. Hanafee, Yun Peng Huang, Anton S. Hasso, and Richard S. Pinto. Dr. Samuel Wolpert graciously provided editorial advice, special insights, and commentary in his capacity as generator and editor of this historical series.

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