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The Role of TCCS in the Assessment of the Main Anatomical Patterns of the M1 Segment of the Middle Cerebral Artery

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1. Introduction

Since the first use of transcranial Doppler sonography by Aaslid et al. in 1982 (Aaslid, R. et al, 1982), ultrasound exploration of intracranial arteries has become highly advanced. The introduction of transcranial color-coded sonography (TCCS) made it possible to use real-time B-mode imaging and Doppler-signal color coding along with conventional transcranial Doppler (TCD) sonography (Bogdahn, U. et al, 1982).

Thus, with B-mode imaging and color coding of the Doppler, vessels can be reliably identified. Theoretically, TCCS studies of the anatomy of the M1 segment of the middle cerebral artery (MCA) could have an impact on the precise localization of a blood clot site, on the potentialization of thrombolysis using ultrasound, and on the morphological profile of recanalization. Thus, TCCS morphological findings provide fundamental information that is complementary to that obtained using 3D time-of-flight (TOF) magnetic resonance angiography (MRA), which is considered to be the reference standard.

2. The M1 segment of the middle cerebral artery

2.1 Anatomical patterns

The princeps anatomical descriptions of the MCA still represent the basis of current knowledge (Duret, H., 1874; Foix, C. and Lévy, M., 1927). Later, microdissection on human cadavers led to a better understanding of the anatomical patterns of the MCA (Gibo, H. et al, 1981; Tanriover, N. et al, 2003; Umansky, F. et al, 1984; Yasargil, M.G., 1984). The proximal part of the MCA is commonly known as the M1 segment (Gibo, H. et al, 1981) although other terms, such as the horizontal segment (Herman, L.H. et al, 1963) or the sphenoidal segment (Gibo, H. et al, 1981), have also been used. The M1 segment may be defined in relation to the references to brain structures found nearby, from its origin to its end (Gibo, H. et al, 1981). As such, its origin is situated laterally in relation to the optic chiasm, at the

level of the medial end of the lateral fissure. Its course then leads laterally, behind the anterior perforated substance and towards the insula. Leaving aside the parenchyma, a definition based on angiographic references has been suggested and has often been used (Krayenbuhl, H.A. and Yasargil, M.G., 1968). The origin of the M1 segment is then located at the division of the internal carotid artery (ICA), at the same level as the anterior cerebral artery (ACA). Its diameter and direction make the M1 segment appear to be a lateral extension of the ICA. According to this definition, the M1 segment ends when the artery curves sharply back and up, at the point known as the genu of the M1 segment (Fig. 1).
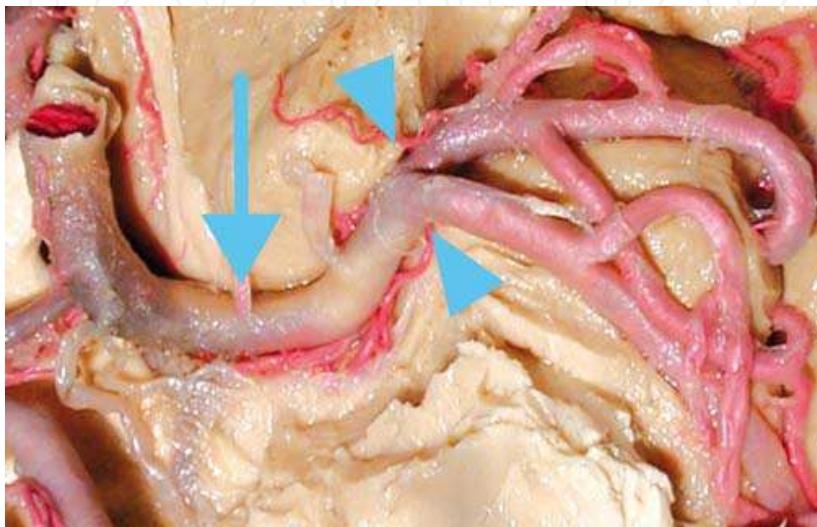

Fig. 1. Inferior view of the left middle cerebral artery. Its course is straight (c.f. arrow) up to the point where the artery curves sharply back and up at the genu where it divides into two branches, defined as a bipode division (c.f. arrow heads)
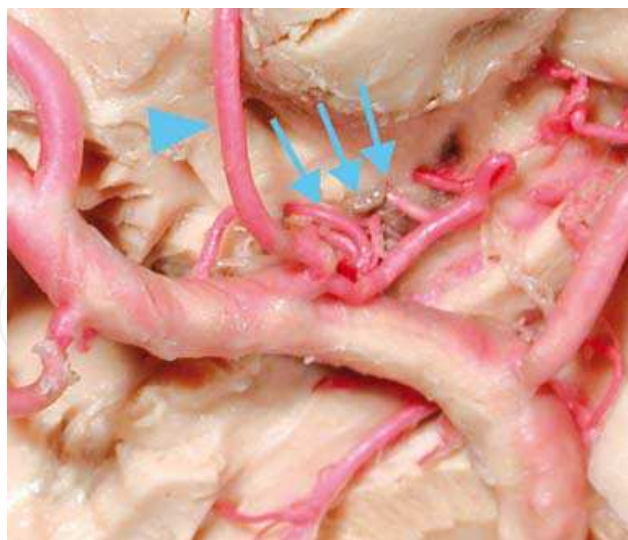

Fig. 2. Deep perforating branches of the M1 segment (c.f. arrows) arising from an early cortical branch (c.f. arrow head)

In most cases, close to the genu, the M1 segment divides into two branches, defined as a bipode division (anterior and posterior divisions). An absence of division, defined as the monopode type, or an M1 segment trifurcation with superior, middle and inferior divisions,

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are observed less frequently. The early cortical branches (ECB) are defined as small diameter arteries that usually arise almost at a right angle to the M1 segment and that run toward the cortex. The type of branch can be defined using anatomical criteria from microdissection studies, based on the diameter and direction of the branches in relation to the M1 segment (Tanriover, N. et al, 2003). Although these criteria allow us to distinguish the main division branches from the ECB in most cases, they may not be entirely accurate, particularly with regard to early proximal cortical branches that may be taken for early bifurcations (Foix, C. and Lévy, M., 1927).

The deep perforating branches of the M1 segment, defined as the lenticulostriate arteries, arise proximal to the M1 segment division. Usually, deep perforating branches are divided into medial, intermediate and lateral groups (Fig. 2).

2.2 Technical approach of the M1 segment

The use of conventional angiography, which was considered for a long time to be the gold standard in the diagnosis of intracranial arterial anomalies, has also been the source of a number of anatomical descriptions (Newton, T.H. and Potts, D.G. 1974; Nomura, T., 1970). Most of these studies have been carried out from a neurosurgical perspective with a view to contributing to improvements in the treatment of aneurysms and intracranial arteriovenous malformations. With the development of high-field-strength MR imaging, it is now possible to carry out, in vivo, a precise visualization of the intracranial arteries and, in particular, the M1 segment of the MCA, using 3D TOF MRA (Fig.3). However, 3T MRA has not been widely used, particularly in stroke patients (Choi, C.G et al, 2007). Thus, 3T MRA could help neurologists to better understand the angioarchitecture of intracranial arteries in order to optimize stroke management.
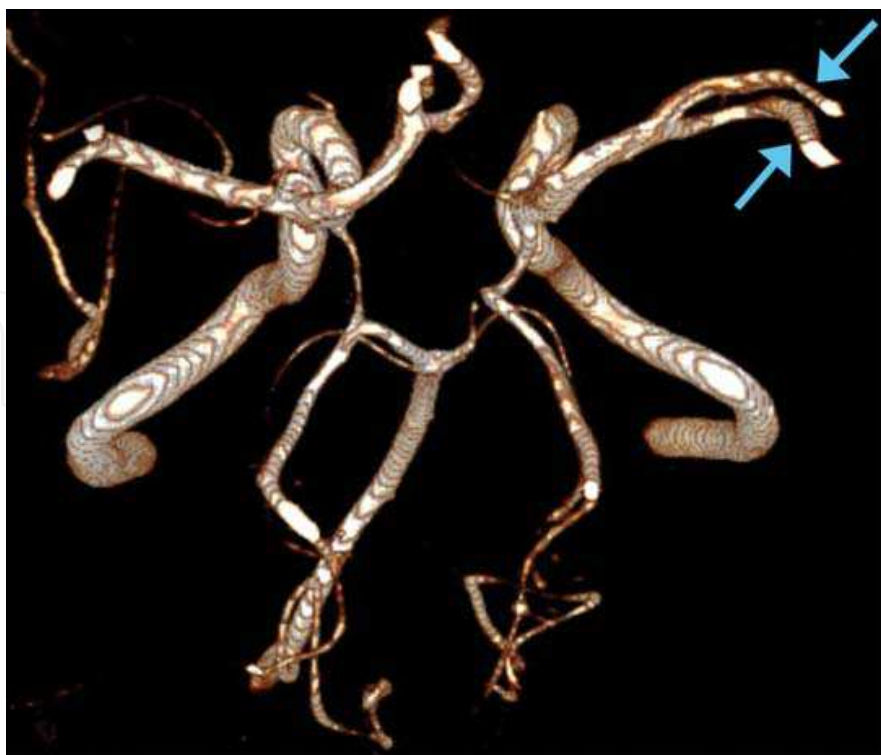

Fig. 3. MRA of the circle of Willis showing a bipode division of the right MCA (c.f. arrows)

In the field of ultrasound application, B-mode imaging and Doppler-signal color coding are used only to measure the angle of insonation in order to obtain absolute flow velocities more accurately than is possible with TCD (Martin, P.J. et al, 1995; Kimura, K. et al, 1998). Consequently, even if TCCS presents certain advantages, its main clinical applications in the assessment of cerebrovascular diseases are similar to those of TCD. Prior to our study, the ability of TCCS to provide a visualization of the intracranial arteries using a morphological approach, especially in the distal part of the M1 segment, had not been properly evaluated.

3. TCCS examination of the M1 segment

3.1 General procedure

TCCS is carried out through the left and right temporal bone window with a 2-MHz probe and can be performed at the bedside in the stroke unit within the first 48 hours of hospitalization. To achieve the best possible visualization of the M1 segment, the investigation should be carried out using power-Doppler (Fig. 4). This is the most angle-independent imaging technique and is more appropriate than color-Doppler for morphological studies on arteries (Griewing, B. et al, 1998; Postert, T. et al, 1997).
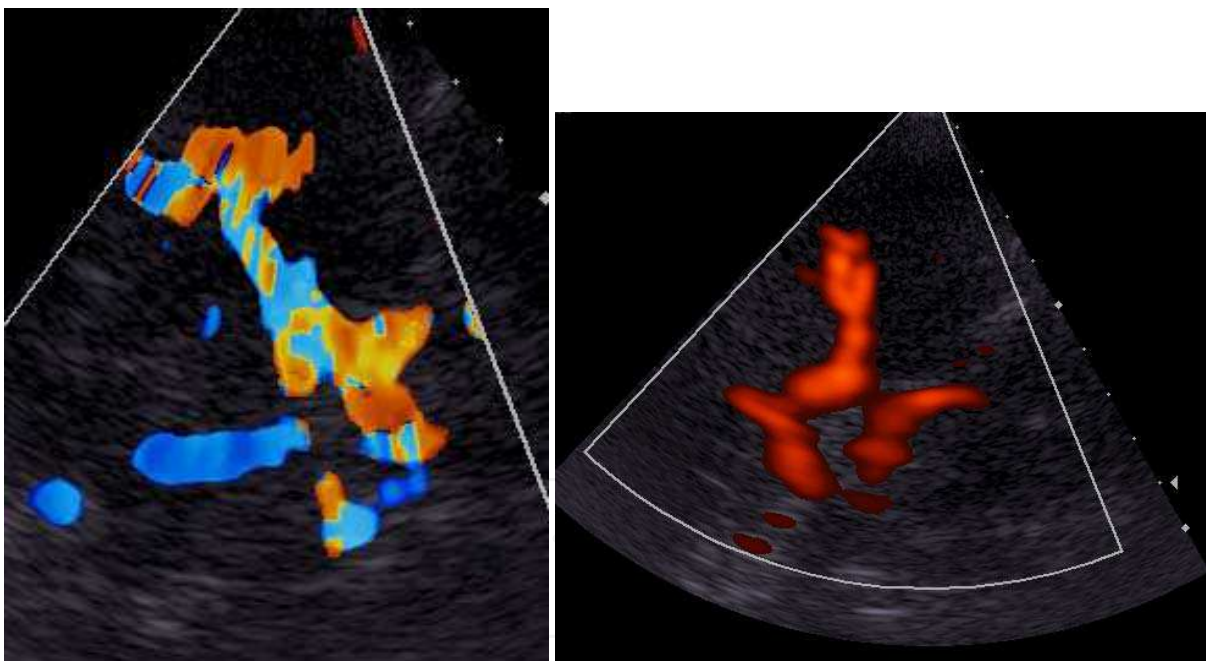

Fig. 4. M1 segment using color-Doppler (a) and power-Doppler (b)

Power-Doppler is used taking particular care to obtain a long-axis view of the M1 segment and several images of its course, end and division. This is done by tilting, rotating and shifting the transducer (Fig. 5).

For a long time, because the acoustic temporal bone window is more restricted in the elderly, and notably in women, TCCS was usually carried out on patients aged under 55 years (Itoh, T. et al, 1993). Thanks to the use of contrast enhancement, the sensitivity and specificity of diagnostic ultrasound imaging have been considerably improved (Droste,

D.W. et al, 2002). Usually, contrast enhancement (Sonovue TM) is administered, as necessary, via continuous infusion up to a total dose over 8 minutes. The temporal bone window is considered as absent when no part of the M1 segment can be detected and as insufficient when it is not possible to view the entire course of the M1 segment. In good conditions, the course and division patterns of the M1 segment can be defined and compared to the MRA results. Thus, it is now possible to carry out TCCS in the conditions encountered in most stroke patients.
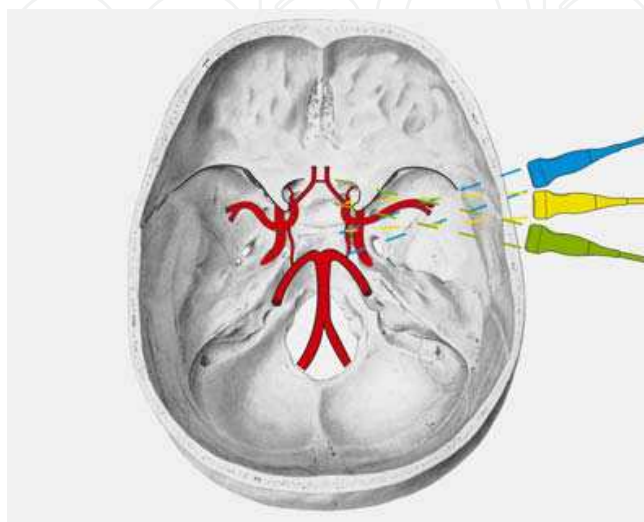

Fig. 5. Directions of the probe through the temporal bone window to obtain a long-axis view of the M1 segment and several images of its course, end and division

3.2 TCCS anatomical capacity

Using TCCS, the main anatomical features, such as the type of course and division of the M1 segment, can be determined.

As shown in Figure 6, the precise direction in the horizontal plane and the length of the M1 segment can be defined. In the majority of cases, the M1 segment is straight, which facilitates its exploration using TCCS. In some cases, however, the course of the M1 segment curves and does not always follow the same concavity direction. This type of course, and in particular a curve with a posterior concavity, has already been reported, when the M1 segment is described as being parallel to the large sphenoid ridge (Gibo, H. et al, 1981). A tendency towards an anterior concavity has been reported, although less frequently (Nomura, T., 1970). In these cases, TCCS exploration can be more difficult, requiring more complicated manipulations of the probe. The length of the M1 segment, which is usually approximately 20mm, can provide the neurologist with important information in order to identify the precise location of the clot in relation to the collateral branches and to evaluate the gradual recanalization of the M1 segment. Evaluations of the diameter of the M1 segment are usually used to judge the severity of stenosis in conventional arteriography, angio-CT or MRA. In TCCS, stenosis is usually evaluated using velocity values. The advent of ultrasound technology could enable us to evaluate the diameter of certain intracranial arteries, such as the distal part of the ICA or of the basilar artery.

(a)   (b)   (c)
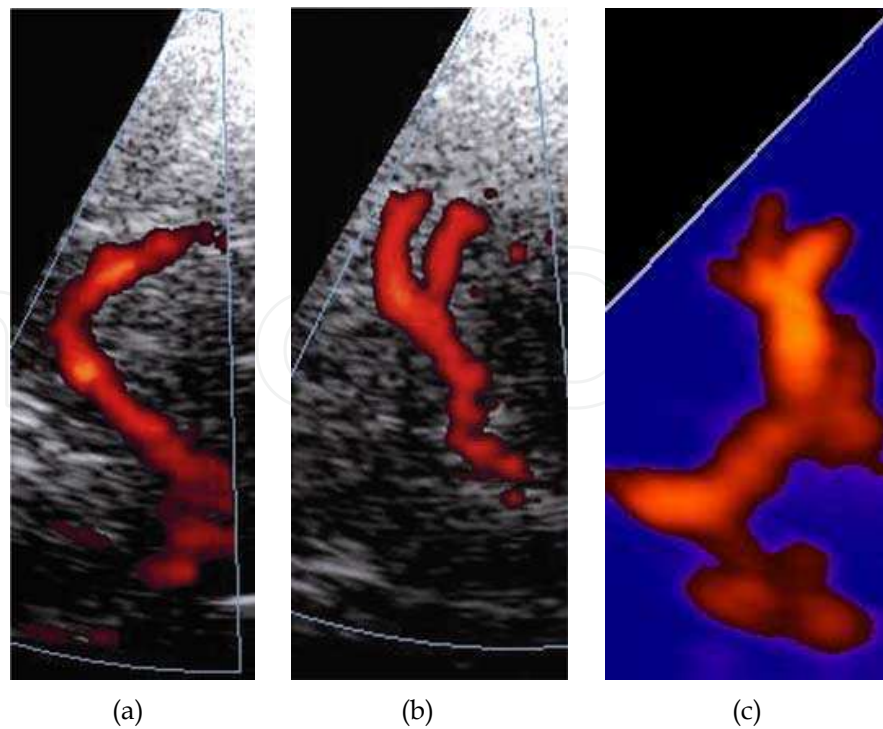
Fig. 6. TCCS using power-Doppler showing the division patterns of the M1 segment:
(a) monopode, (b) bipode and (c) tripode

TCCS is a useful tool in defining the type of M1 segment division. As in our study, TCCS was able to show that the division was monopode in 16/68 cases (23.5%; Fig. 6a), bipode in 50/68 cases (73.5%; Fig. 6b) and tripode in 2/68 cases (3%; Fig. 6c), confirming the classic data (Gibo, H. et al, 1981; Tanriover, N. et al, 2003). The type of division could not be defined in the remaining 17/85 cases (20%).

In our study, TCCS anatomical patterns of the M1 segment were compared to 3D TOF-MRA at 3 T, which is the gold standard technique used to depict the normal anatomy of the intracranial artery (Willinek, W.A. et al, 2003). Our comparisons between TCCS and MRA findings indicated concordance in most cases (67%), especially when the division was bipode (Fig. 7).

The fact that false-positive results were uncommon (positive predictive value = 87%) indicates the efficacy of TCCS in depicting bipode division. Nevertheless, in all false-negative cases, the division was taken to be monopode, whereas it was bipode on MRA. These facts illustrate the difficulty of identifying certain division branches, confirming a classic limitation of TCCS. Our results demonstrate that if TCCS is performed with care, it can provide anatomical information on the whole M1 segment. Our results also highlighted the ability of TCCS to analyze the distal part of the M1 segment, despite potential difficulties such as the insonation angle and a more superficial situation (Itoh, T. et al, 1993; Zunker, P. et al, 2002). The main technical limitation that we encountered (in 11/23 cases) was an unfavourable angle between the ultrasound beam and the division branches of the M1 segment, which led to an unfavourable insonation angle. As for the anatomical causes of discordance, we observed that the anatomical criteria could not be applied accurately in 12/23 cases. This can be explained by the difficulty of accurately evaluating the diameter of the branch and its angle of origin, because contrast enhancement creates color artefacts
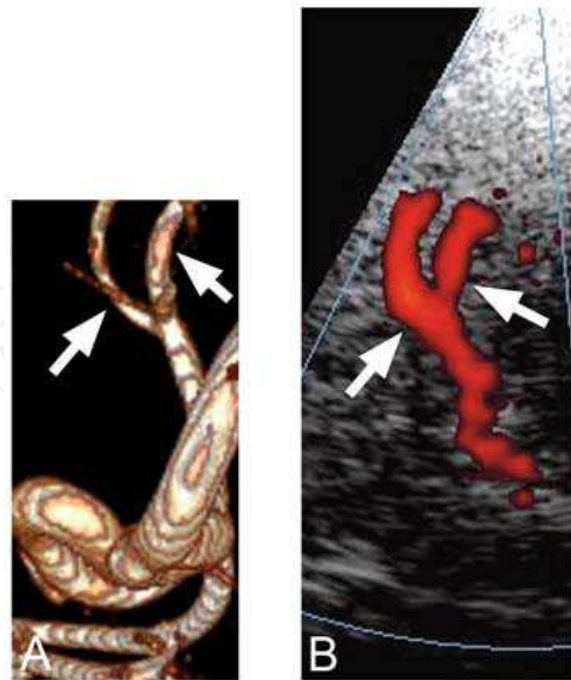
Fig. 7. MRA (a) and TCCS (b) showing a bipode division with a good correlation between
the two techniques

Fig. 8. In 8a, the top of the head is at the left of the image and the probe is placed at the top
of the image. MRA (a) and TCCS (b) showing an ECB arising from the M1 segment at a right
angle (c.f. arrows)

(blooming). Our study showed that TCCS can be used to obtain anatomical information on the M1 segment of the MCA. Nevertheless, the resolution of TCCS to detect MCA branches needs to be improved through technical developments.

Regardless of the technique used, it is quite possible for the main division branches to be taken for cortical branches and vice-versa (Tanriover, N. et al, 2003). In good conditions, TCCS enables the visualisation of the ECB despite their small diameter. The identification of these ECB using TCCS is also possible thanks to the application of anatomical criteria, in particular the almost 90° angle at which they branch from the M1 segment (Fig. 8).

Finally, it is also possible using TCCS to determine the site of the division as being before, at the level of, or distal to the genu.

To our knowledge, our study was the first to compare anatomical patterns as shown on MRA and TCCS images.

4. Pathological applications

The benefits of TCCS in detecting MCA stenosis or occlusion have been widely demonstrated (Kimura, K. et al, 1998; Baumgartner, R.W. et al, 1999; Tang, S.C. et al, 2005), particularly when contrast enhancement is used (Gerriets, T. et al, 2000; Ogata, T. et al, 2005). Similarly, as TCCS is a bedside tool that can be used easily and as required, it has become the test of choice for evaluating the recanalization of the M1 segment after thrombolysis (Gerriets, T. et al, 2000; Ogata, T. et al, 2005). These clinical applications of TCCS are based exclusively on an evaluation of flow velocities, particularly for the proximal part of the M1 segment. Yet with improvements in image quality, thanks to the recent advent of harmonic imaging and contrast enhancement (Burns, P.N., 1996), it is now possible to obtain precise morphological knowledge of various vascular lesions. Wherever the stenosis or occlusion in the M1 segment is located, it can now be identified and located more accurately with respect to the origin of the division of the branches of the M1 segment. It is also possible to specify the consequences of occlusion with regard to the ECB. These morphological data are essential in achieving a good understanding of the functional consequences of stenosis or occlusion.

Obviously, the same applies regarding the quality of recanalization of the M1 segment and the consequences of recanalization on its division branches, which can also be determined using morphological patterns. In addition, more precise localization of the blood clot can improve the capacity of low intensity ultrasound to accelerate thrombolysis (Alexandrov, A.V. et al, 2000; Molina, C.A. et al, 2004) or better guide the thrombectomy procedure. Hence, there is a need to pursue further TCCS studies with an increased focus on morphology. Moreover, the use of TCCS in pathological conditions and in the elderly population should now be easier. This would make it possible to implement clinical applications such as the localization of lesions and the time course of the morphological parameters of reperfusion, both of which may improve treatment strategies for stroke in the future.

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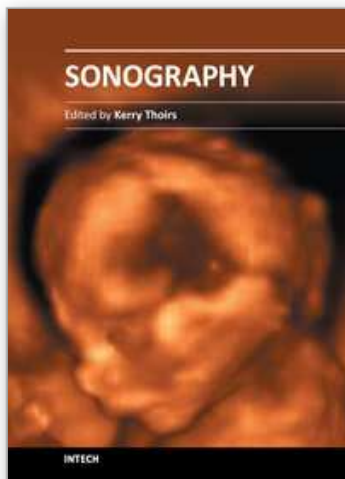
Sonography

Edited by Dr. Kerry Thoirs

Medical sonography is a medical imaging modality used across many medical disciplines. Its use is growing, probably due to its relative low cost and easy accessibility. There are now many high quality ultrasound imaging systems available that are easily transportable, making it a diagnostic tool amenable for bedside and office scanning. This book includes applications of sonography that can be used across a number of medical disciplines including radiology, thoracic medicine, urology, rheumatology, obstetrics and fetal medicine and neurology. The book revisits established applications in medical sonography such as biliary, testicular and breast sonography and sonography in early pregnancy, and also outlines some interesting new and advanced applications of sonography.

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