1 Ophthalmologic Imaging Methods

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1.1 Color Doppler Ultrasonography of the Eye and Orbit

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Color Doppler imaging is the significant development of the last decade in ultrasonography that allows for simultaneous two-dimensional structural imaging in the Doppler evaluation of blood flow. With this technique, it has become possible for the first time to display indirectly the fine orbital vessels such as the ophthalmic artery and its branches, the central retinal artery, the posterior ciliary artery, and the lacrimal artery. On the other hand, also the display of venous structures such as the superior ophthalmic vein, the vortex veins, and the central retinal vein is possible. In addition to this qualitative display, it also enables quantitative assessment of the hemodynamics in those vessels by looking at the Doppler spectrum and determining flow velocities during various periods of the cardiac cycle.

This technique is now being used in ophthalmology to evaluate orbital tumors and vascular lesions, intraocular tumors, carotid cavernous sinus fistulas, and hemodynamic changes in patients with retinal vascular disease such as central retinal artery occlusion, central retinal vein occlusion, and diabetic retinopathy. Several studies have even been made to study drug effects on the hemodynamics.

1.1.1 Introduction

Real time A-mode and B-mode ultrasonography has been used for the diagnostic evaluation of ophthalmic disorders since the early 1960s. Modern digital high-resolution equipment has improved diagnostic imaging and made it an essential part of certain ophthalmologic evaluations. Doppler ultrasound detects
changes in the frequency of sound reflected from flowing blood, allowing estimation of the flow velocity. Doppler ultrasonography of the carotid arteries and the periorbital vessels is frequently employed in patients with ischemic ocular disease. The technology of Duplex scanning allows for simultaneous B-mode imaging and Doppler spectral analysis. Since the diameters of the vessels in the eye and orbit are too small to be imaged with conventional Duplex scans, Doppler spectra are obtained without precise localization and without knowledge of the Doppler angle. The latest technological change in the character of diagnostic ultrasound is color Doppler imaging. To facilitate localization of vascular structures, the two-dimensional flow information in color Doppler imaging (CDI) is encoded in color and superimposed on the gray scale structural image. Since the sensitivity of detecting Doppler shifts is not limited by the resolution of the gray scale image, Doppler shifts in very small vessels can be detected, depicting the course of the vessels (Grant et al. 1989, 1992; Merritt 1987; Mitchell 1990; Mitchell et al. 1988, 1989; Powis 1988; Pozniak et al. 1992; Ranke et al. 1992).

The introduction of the so-called “power Doppler”, which represents the summation of the square from the spectral amplitudes of the Doppler signal, was an important new step in CDI technology. Hereby the coding for direction is neglected in order to improve sensitivity for very small vessels or vessels with low blood flow (Adler et al. 1995; Allard et al. 1999; Babcock et al. 1996; Bascom and Cobbold 1996; Grieweng et al. 1996a,b; Hamper et al. 1997; Martinoli et al. 1998; Murphy and Rubin 1997; Pugh et al. 1996; Rubin et al. 1994; Winsberg 1995; Wu et al. 1998). Modern broad band transducers with frequencies up to 15 MHz have greatly improved orbital gray-scale and color Doppler imaging.

The three major areas of application of CDI and its new modifications of signal processing such as power Doppler, tissue harmonic imaging, 3-dimensional CDI, as well as the use of contrast agents can be described as primarily:

1. Vascular evaluation

Application of CDI includes the detection and measurement of arterial stenosis and flow-restricting or flow-disturbing abnormalities. This can be performed for the large abdominal vessels, the aorta, iliac, femoral, and popliteal artery, and other peripheral arteries, and of course, for large vessels of the head and neck, the carotid bifurcation, and the vertebral arteries (Allard and Cloutier 1999; Bazzocchi et al. 1998; Bendick et al. 1998; Carroll 1996; Erickson et al. 1989b, Erickson et al. 1989c; Ferrara and DeAngelis 1997; Foley et al. 1989; Grant et al. 1990, 1992; Landwehr and Lackner 1990; Landwehr et al. 1989, 1990, 1991; Merritt 1987, 1989; Whelan et al. 1992)

2. Organ perfusion

CDI can be utilized to visualize the perfusion of the liver, kidneys, spleen, placenta, and brain. It can be used as a guide to obtain selective Doppler information which allows better assessment of the hemodynamics in those organs. The major indications of this category is the assessment of perfusion in kidney transplants (Bazzocchi et al. 1998; Becker and Cooperberg 1988; Deane et al. 1992; Fleischer and Kepple 1992; Lerner et al. 1990; Levine et al. 1997; Lewis and James 1989; Middleton et al. 1989; Riffkin et al. 1993; Seibert et al. 1998; Wilson and Thurston 1992; Winkler 1998; Winters 1996).

3. Tumor neovascularity

CDI adds a new dimension to the ultrasound evaluation of mass lesions (Maresca et al. 1991; Orr and Taylor 1990; Taylor et al. 1991). This technique is already being successfully used to differentiate some benign from malignant tumors of the liver (Goldberg et al. 1990), tumors of the female breast, the testicles, as well as tumors of the eye and orbit (Falco et al. 1992; Guthoff et al. 1989, 1991a; Jain et al. 1992; Lieb 1998; Lieb et al. 1990b; Wolff-Kormann et al. 1992a,b).

1.1.2 Ophthalmic Examination Technique

The ultrasound transducer is applied to the closed eyelids using sterile ophthalmic methylcellulose as a coupling gel. During the examination, the patient lies in a supine position, and care is taken not to apply pressure to the eye to avoid artifacts. Horizontal and vertical scans through the eye and orbit are performed. Depending on the direction of flow with respect to the transducer, the blood flow data displayed are either in red or blue. The colors can be arbitrarily assigned, but in this study flow toward the transducer is depicted as red and away from the transducer as blue. The color saturation in the image represents the average frequency (first moment average) from a spectral analysis performed at each sample site. These frequencies can be turned into velocities by solving the Doppler equation for velocity.