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Coronary Angioscopy

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I dedicate this book to my beloved wife, Sakiko.

"Life isn't worth living, unless it is lived for someone else" was her way of life.

Kyoichi Mizuno

Preface

This book provides a long-awaited perspective on state-of-the-art coronary angioscopy. Angioscopy is a relatively new diagnostic tool that permits nonoperative imaging of coronary structures through the use of fiber optic systems. Direct visualization of the internal surface of a vessel provides detailed information about the characteristics of a plaque or thrombus. Coronary angioscopy is playing an ever-expanding role in research and in clinical practice because it provides a precise, full-color, three-dimensional image of the interior surface of the morphology of coronary arteries.

Angioscopy allows coronary macropathology during ongoing ischemia in living individuals, information that hitherto was unavailable except during autopsy. The ability to discriminate colors in angioscopy makes it relatively easy to distinguish between a thrombus and a plaque even if a clot is very small. Furthermore, angioscopy can also distinguish between the type of plaque (yellow versus white) and type of thrombus (red versus white).

It is important to learn the biological and scientific facts through angioscopy, which is useful for the recognition of vascular pathogenesis, diagnostic evaluation, and treatment. Here, it is relevant to recall the proverbs “A picture is worth a thousand words”, “Seeing is believing”, and “One eyewitness is better than many hearsay witnesses”.

We hope that this book will provide professionals in the field with a useful, comprehensive guide to modern coronary diagnostic and coronary care. The book is divided into 3 parts and 19 chapters including an overview, angioscopic procedures, and angioscopic findings after stent- and drug-based therapies. We wish to thank all the authors, who are well-known researchers in angioscopy. We also thank the editorial staff of Springer Japan, especially Ms. Tomoka Taya and Ms. Sachiko Hayakawa.

Tokyo, Japan — Kyoichi Mizuno
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Abstract A fiber-optic image guide is employed as an angioscopic image transmission in spite of almost all other endoscopes utilizing a charged-coupled device (CCD) image sensor at their tip, since an angioscope should be formed in a very thin shape less than 1.7 mm in diameter (5 Fr.) for coronary artery and disposable use to avoid sterilization issue. The silica-based image guide is a unified fiber, which contains several thousands of independent core in a common clad region. Since this silica-based image guide can be fabricated by a wiredrawing process corresponding to fit large-lot production, it should be very thin and inexpensive. Despite pixel size being limited to approximately 10 k, this silica-based image guide has been used in an angioscope due to its thinness and inexpensiveness. The recent advance of high-NA silica-based image guide can make bright and sharp angioscopic image by increasing pixel density as well as suppressing cross leakage. An image of 6000 pixels is used in the coronary angioscopic imaging. The minimum bending radius and outer diameter of the optical image guide for the coronary angioscope should be 15 mm and 0.4 mm, respectively.

Keywords Silica-based image guide • Optical fiber • Silica glass fiber • Plastic optical fiber

1.1 Principle of Image Transmission

1.1.1 Necessity to Use Optical Image Guide for Angioscope

A fiber-optic image guide is employed as an angioscopic image transmission in spite of almost all other endoscopes utilizing a charged-coupled device (CCD) image sensor at their tip, since angioscope should be formed in a very thin shape less than 1.7 mm in diameter (5 Fr.) for coronary artery and disposable use to avoid

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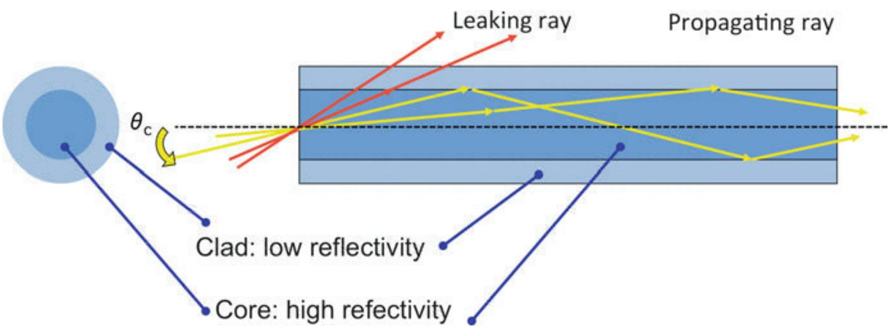

Fig. 1.1 Principle of the optical fiber. Circumference material should be a water-containing fluid, so that refractive-index matching is assumed. Refraction on the tip of fiber is omitted. Incident angle θ does not correspond to incident angle on the boundary between core and clad. Actual incident angle for this boundary should be $(2/\pi)$-θ. The reflectivity of the core and clad are n_1 and n_2, respectively. This figure is based on geometric optics. Surface-wave propagation in the clad can be explained by wave optics

sterilization issue. A thin CCD endoscope around 5 Fr. may be possible to fabricate, for example, a pancreas duct endoscope, but it is never produced at a cheap cost to be used in a disposable operation. This is the reason why the optical image guide is equipped in the angioscope.

1.1.2 Principle of Light Transmission by Optical Fiber

The principle of optical fibers is shown in Fig. 1.1 [1]. Total reflection at the boundary between high-refractive-index material (core) with n_1 and low-refractive-index material (clad) with n_2 by incidence angle θ on the fiber tip surface occurs when the incidence angle is less than the critical angle θ_c defined as follows: $\pi/2$ – arcsin (n_2/n_1). This kind of optical transmission line is named a dielectric surface waveguide. The optical transmission phenomena (i.e., pointing vector of electromagnetic field) occur not only in the core region but also in the clad region, since an electromagnetic field named surface wave is formed in the clad by the total reflection. Because propagating optical rays in the optical fiber on radial direction forms a standing wave, certain incident angle is allowed to transmit in the optical fiber to form the standing wave, that is, these discrete allowable propagating angles express optical transmission mode in the optical fiber. The optical fiber of which the core diameter is over approximately 20 μm allows to transmit a lot of transmission modes. However, when the core diameter is less than 10 μm, a few transmission modes are allowed. In this case, since the allowable mode number is small, the small fluctuation on the optical fiber condition, for instance, the core diameter, may greatly change propagation mode (see Sect. 1.2.1). The incident angle and output angle in the optical fiber are usually expressed by a numerical aperture (NA) described as follows: $n_1 \sin \theta$. The NA is also used to indicate a view angle for the optical waveguide. The standard NA of silica glass optical fiber is around 0.20. The high-NA silica glass optical fiber contains large amount of high-refractive-index material, in particular Ge in its core. The high-NA silica fiber has up to 0.35 of NA. The NA of the plastic optical fiber is ranging from 0.5 to 0.63.

1.1.3 Pixel Separation Method for Image Transmission

Optical images that contain information of color and figure can be transmitted through rigid optics, such as an objective lens and telescope, in general. Despite the optical fiber of which refractive-index distribution forms a quadratic function being equivalent to a series of convex lenses, this fiber is not able to deliver images precisely because of mode transformation, i.e., turbulent wave front by the bending of the optical fiber as well as imprecision of refractive-index distribution on radial direction of the optical fiber. Therefore, a picture element (pixel) separation method should be used to transmit images by the optical fiber. Each pixel in the picture can be delivered through an individual optical fiber. Figure 1.2 shows example of an image set at various pixel sizes. Obviously, fine pixel resolution is better for diagnostic use, but it is restricted by other factors, in particular the diameter of the optical fiber (image guide). The required amount of pixels is dependent on an observation area and desired resolution for an observation. Three or six thousand pixels have been used in the coronary angioscopic imaging.

1.2 Optical Image Guides

1.2.1 Silica-Based Optical Waveguide

The production technology of silica-based image guide had been established by Japanese engineer Atsushi Utsumi who had been working with Mitsubishi Cable, Co. Ltd [2]. A cross-sectional schematic structure of his waveguide is illustrated in Fig. 1.3, comparing it to conventional optical fiber bundle used in a fiber endoscope. The optical fiber bundle is basically a human-work assembling fiber, which contains several thousands of independent pixel fibers. Because the optical fiber bundle was expensive and its pixel size is limited to 20,000–40,000 pixels, a CCD endoscope had been replaced. In contrast, the silica-based image guide is a unified fiber, which contains several thousands of independent core in a common clad region. Since this silica-based image guide can be fabricated by a wiredrawing process corresponding to fit large-lot production, it should be very thin and inexpensive. Despite pixel size being limited to approximately 10 k, this silica-based image guide has been used in an angioscope due to its thinness and inexpensiveness. Technical challenges