A capsule endoscopy guide for the practicing clinician: technology and troubleshooting

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The purpose of this article is to discuss the technology of capsule endoscopy (CE) in a manner that would be relevant to the practicing physician. There are inherent difficulties in eliminating bias in an article that describes technology for which only one company's product has been commercially available and when 2 of the investigators work with that company, Given Imaging. Having said that, every attempt was made by us to eliminate bias and commercialization. The reader will note references to specific Given Imaging products and features, which are used to explain the technology. In addition, we acknowledge the input from Olympus Optical Co, Ltd, Japan, for their valuable contributions. In some instances, references are made to the Olympus product. No attempt is made to compare the video capsules. The focus of the article is to explain the technology.

HISTORICAL BACKGROUND

Twenty-six years ago, in 1981, the inventor of the capsule endoscope, Gavriel Iddan, conceived of the idea of a miniature wireless camera device that would image the entire GI tract and, in particular, unchartered territory, such as the small bowel, while passing through it naturally. This region could only be assessed by small-bowel follow-through (SBFT) at this time. Because of technologic limitations then, it was not possible to create a capsule small enough to be swallowed by a human being, with all the necessary components onboard. Independently, experiments were performed on larger capsule prototypes in the mid 1990s by Swain et al[1] from London. In fact, it took almost 20 years from the time that the original idea was conceived until the first small prototype was produced by Given Imaging (Yokneam, Israel) at the end of the last century. By this time, low-power and low-cost image sensors, such as the complementary metal oxide semiconductor (CMOS) type, were small enough to fit into the earliest digital cameras and other similar devices. In addition, application-specific integrated circuit (ASIC) chips and miniature white light-emitting diode (LED) light sources then became available. An ASIC chip is a highly compact integrated circuit, with specific functionality designed for a dedicated application only. As such, the chip is very compact and robust, and most suited for CE. Since the late 1990s, more than half a million patients have ingested such a capsule. With thousands of physicians now using CE as part of the primary workup for their patients, hundreds of articles have been written describing its use for indications such as bleeding, iron deficiency anemia, inflammatory bowel disease, celiac disease, nonsteroidal damage, and small-bowel tumors.

Today there are already different types of capsules for specific anatomical regions of the GI tract. In addition to the small-bowel video capsules, innovative capsules with 2 video camera heads were developed by Given Imaging. One such capsule, which was introduced in 2005, is for examination of the esophagus and another one was recently introduced for the colon.[2-4] This latter capsule underwent clinical trials in Europe and the United States, where it is compared with routine colonoscopy. Olympus Medical Systems Corp, Japan, have, in the past few years, produced a single-head, 2 frames per second, small-bowel capsule, based on the same size as the Given capsule but with a charged-coupled device (CCD) rather than a CMOS imager. A Chinese company, Chongqing Jinshan Science and Technology, and the Korean company IntroMedic also developed video capsules for use in the small bowel. Other than with Given Imaging's products, we are not aware of any publications referring to the other capsules.

At the time of writing this article, only the video capsules of Given Imaging have U.S. Food and Drug Administration (FDA) clearance for use. The small-bowel capsule is approved for use in patients 10 years and older, and the esophageal capsule is cleared for use in patients 18 years or older. Because essentially all published clinical data (more than 500 peer-reviewed articles) refer to the Given Imaging capsules, this paper deals primarily with the CE procedure and components of the Given Imaging system.

CE TECHNOLOGY: THE CAPSULE SYSTEM

A capsule system comprises 4 primary components: (1) an ingestible video capsule, (2) a recording device, (3) a workstation, with (4) physician review/reporting

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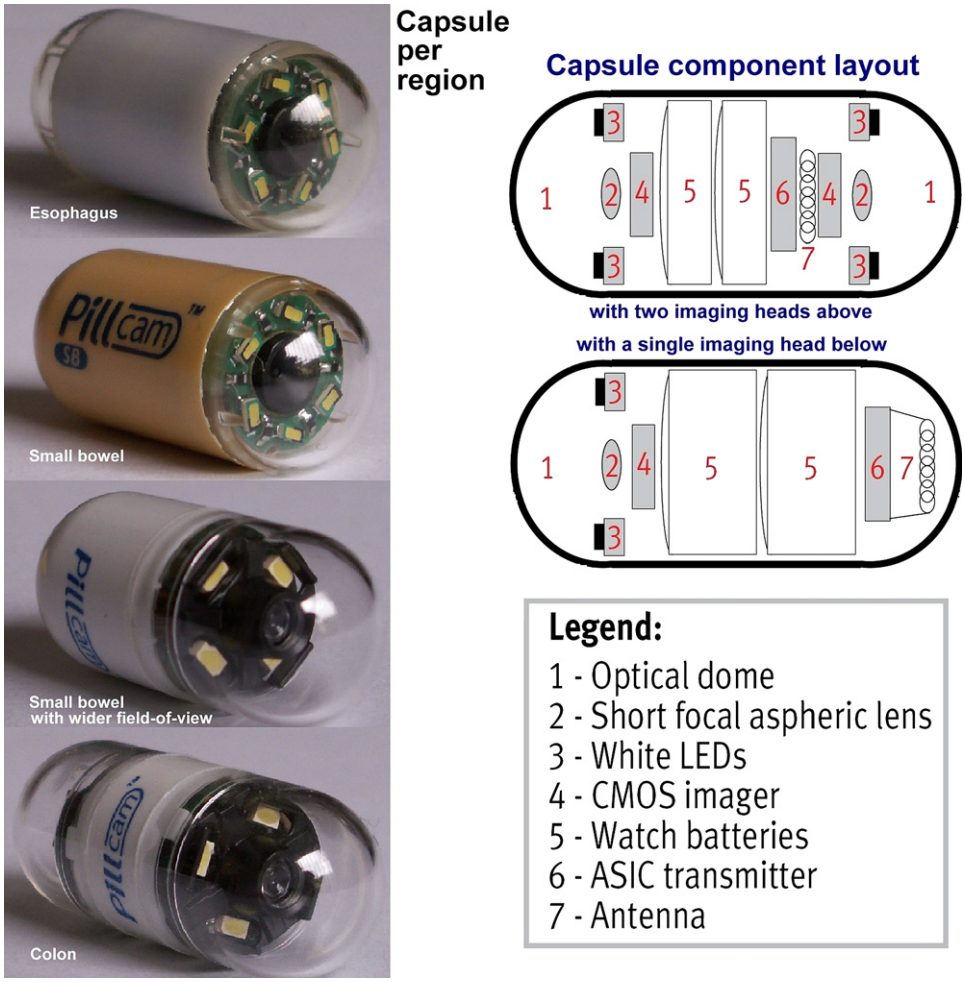

Figure 1. Range of Given Imaging capsules and typical component layout.

software. The capsule as a single-use device is not recovered for reuse. Hence, the images it captures are transmitted immediately to an external recorder worn by the patient. This recording device is designed to be compact, easily used and handled, and remains with the patient as part of an ambulatory examination throughout the day. The images received and stored by the recording device are transferred, after the examination, to the workstation, which has software that supports the recorder, transfers its data to local memory, compiles data into a video, and review/reporting functions for the physician.

Capsule

Given Imaging's PillCam SB capsule is the size of a large vitamin pill (26-mm long, 11-mm wide). It weighs 3.4 g, has a field of view of 140°, uses 6 white LEDs, and has a battery life of 8 hours. The esophageal capsule is also 26 × 11 mm. The colon capsule is a little longer (31-mm long × 11-mm wide), with a field of view of 156°. All small-bowel video capsules have 1 video camera head, whereas Given Imaging's esophagus and colon capsules have 2. The idea to add a second head to the latter capsules was based on maximizing the surface area coverage for larger organs (those wider than the width of the capsule, such as in the colon) and in regions where the capsule is expected to travel through the tract very quickly, which minimizes image capture (such as in the esophagus). Each video capsule contains a tiny pair of batteries, an ASIC transmitter with antenna, and a set of LEDs with each video camera head, all encapsulated in a biocompatible plastic casing. The range of Given Imaging capsules is shown in Figure 1.

The EndoCapsule (Olympus) for the small bowel has undergone preliminary testing in the United States, Japan, and Europe. It uses CCD technology for the imager. CCD technology is well known by endoscope manufacturers who use the technology in video endoscopes. The Olympus capsule is 26 × 11 mm, weighs 3.8 g, has a field of view of 145°, uses 6 white LEDs, and has a battery life of 8 hours. The EndoCapsule is shown in Figure 2.

CCD and CMOS imagers are 2 different technologies for digital capture of images. CMOS technology is most suited for small devices because of its high integration capability and low-power consumption. CCD imagers are