Overview of the Manometry Machine

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Abstract

The manometry machine measures pressures from the lumen of the gastrointestinal tract using a catheter placed in the region to be studied. A number of types of manometry systems are available, but all record data digitally to a computer for analysis. The different systems utilize a variety of technologies to record pressure and to transmit the pressure signal to the computer. This determines the cost of the machine and ease of use, but in the end, all record intraluminal and wall contact pressure with acceptable accuracy for clinical diagnosis and physiological investigations, provided the properties of the machine and recording catheter are suited to the physiological and anatomical characteristics of the region to be studied. Factors to be considered include the spacing and orientation of the pressure sensors, the rate of rise of pressure to be recorded, accuracy of pressure measurement, and the rate of digitization of the signal (temporal resolution). In some situations it may be advantageous to record pressures in parallel with other data such as images or intraluminal impedance to allow correlation between pressure and transit.

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Introduction

The purpose of manometry is to record pressures from the gastrointestinal tract in order to either make a clinical diagnosis or to provide data for research studies into the function of the gut. The characteristics of the recording system required to record the pressure data can be defined in terms of the spatial resolution (distance between the recording points), temporal resolution (rate of pressure measurement sampling), and the accuracy with which pressure is measured. These characteristics vary depending on the part of the gastrointestinal system being investigated, determined by the anatomy of the region and the characteristics of the pressures generated.

Over the past 20 years, manometric recording has undergone a revolution in technology based on the use of digital recording techniques, as well as changes in the number and spacing of sensors that can be used to record pressures. Recording systems have evolved from single or low channel count pull-through systems with paper chart recorders to sophisticated digital systems with the ability to record at high resolution and display the resultant pressures as high resolution spatiotemporal plots.

Broadly, there are two general types of manometric recording systems, differentiated by whether the sensors are located within the catheter itself, or externally (in which case pressures are transmitted along a column of water perfused slowly through the catheter). Each of these systems has its advantages and disadvantages, but once the signal is digitized and recorded to the computer, the principles are very similar between the types of recording systems, as shown in Fig. 1.1 and Table 1.1.

Systems utilizing intraluminal transducers (solid state or optical catheters, Fig. 1.1) are simple to operate; the recording catheter is connected and calibrated, then passed directly into the subject. As the transducers are located at the point that the pressure being measured, the dynamic performance of these systems (as measured by the rate of rise of pressure that can be recorded) is excellent. As the solid-state catheter is an electronic device however, individual catheters are expensive and fragile, as well as being generally stiffer and wider than a water-perfused catheter. In addition, these catheters may be sensitive to temperature change, with small changes in temperature causing fluctuations in apparent pressure, which may require temperature compensation measurement, or may lead to "drift" where the recording baseline of individual channels changes with time. An optically based catheter has recently been developed which has the advantage of data being transmitted via a central optical fiber connected to all transducers, meaning that for these catheters, the diameter of the catheter is not related to the number of recording channels, and the catheter remains highly flexible and thin even for up to 96 recording points (Fig. 1.2).

Water-perfused manometry systems (Fig. 1.1) utilize external transducers which are connected to a multi-lumen silicone or PVC catheter. Water is perfused through the transducers, and then through the catheter by a pneumohydraulic pump, with the rate of flow of the water for each channel determined by the resistance of a capillary
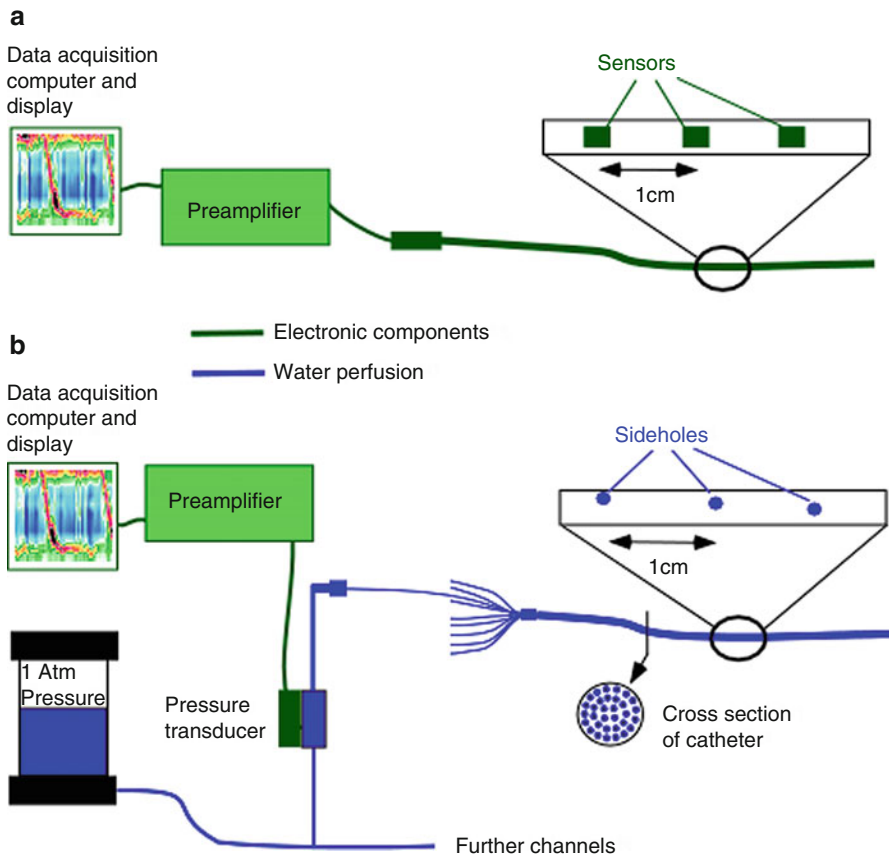
Fig. 1.1 Comparison of different types of manometry machine. (**a**) Intraluminal transducer (solid state or optical sensor); (**b**) water-perfused (silicone or PVC catheter)

Table 1.1 Comparison of intraluminal transducer and water-perfused catheters

| Characteristic	Intraluminal transducer	Water-perfused
Cost of catheter	High (US 10–20 k)	Moderate (US 1 k)
Ease of use	Good	Moderate
Catheter material	Plastics/electronic Parts	Silicone/PVC
Site of transducer	In catheter	External
Pressure rise rate	High	Medium
Minimum channel spacing	7 mm	Any
Reprocessing	Chemical	Autoclave (silicone)
Sensor orientation	Unidirectional or circumferential	Unidirectional (circumferential if multiple sideholes)
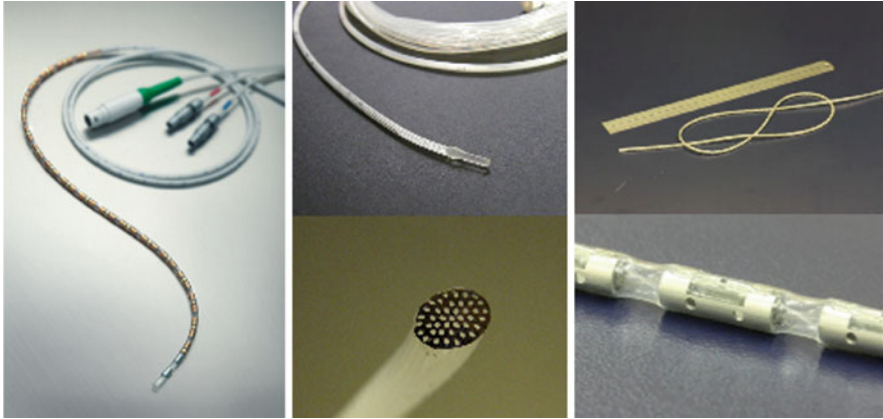
Fig. 1.2 Comparison of different manometric catheters. From *top left* to *far right*: optical catheter, demonstrating flexibility; 16-channel silicone catheter for esophageal manometry; 36-channel solid-state catheter (Image courtesy of Given Imaging). From *bottom left* to *right*: cross-section of 41-channel silicone manometric catheter; close-up of optical sensors

which is placed "upstream" of the catheter. As the catheters do not contain any electronic components, they are considerably cheaper, and generally thinner and more flexible (hence more comfortable for the patient) than the solid-state catheters, however the dynamic performance (pressure rise rate) is not as high, which may be a limiting factor where pressures increase rapidly (e.g., in the pharynx). In addition, the need for a pneumohydraulic pump to perfuse the catheter requires some extra steps to prime the pump with water prior to, and empty the pump after, a series of studies.

Regardless of the mechanism by which the pressure is measured, once the signal is digitized, it is transmitted to a computer for display and recording. Generally, the rate of digitization and number of digitization steps should not be limiting, and a sampling rate of 25 Hz, with a 16 bit analog to digital converter (providing about 65,000 digitization steps) should be adequate for most GI physiology studies, being less limiting in accuracy than the mechanical and other factors described above. The exact details of the digitization, display of the digitized signal, and interpretation is specific to the software and recording system, but the general principles are discussed below.

Spatial Resolution

The general principle to be followed in determining the adequacy of spatial resolution for manometry in the GI tract is that the spacing of sensors should be such that they record all mechanically significant pressure events and, if interpolation between channels is being used to generate a spatiotemporal topographic plot (Fig. 1.3), the channels should be sufficiently closely spaced to ensure that this is a valid
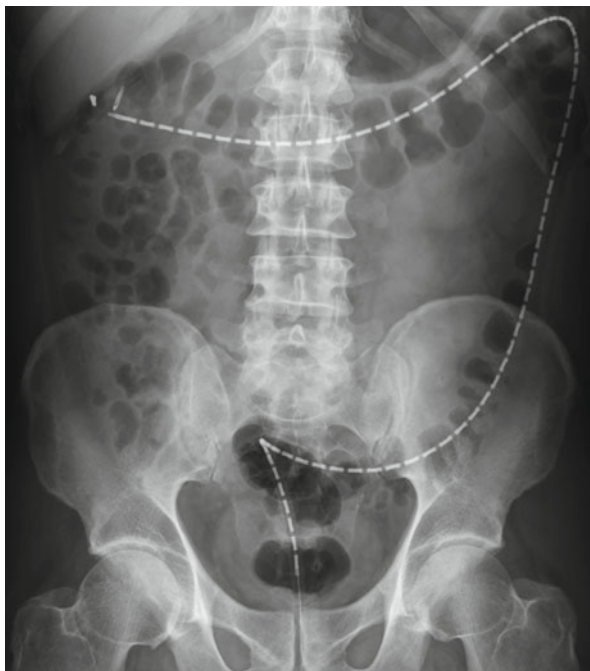
assumption. Ideally, pressure would be measured continuously along the manometric catheter, but at present this is not possible, and in all systems available at present, pressure is measured at discrete points, sometimes with a specific radial orientation on the manometry catheter. Generally, recording at 1 cm intervals is considered adequate across the lower esophageal sphincter and in the pharynx. In the body of the esophagus the optimum distance has not been determined, but commercially available systems record at distances of 1–3 cm. The advantage of recording at 1 cm intervals throughout the pharynx and esophagus for esophageal manometry is that the precise position of catheter placement and movement during a study are less critical than if a specific region of the catheter needs to be positioned in the lower esophageal sphincter. In specific regions such as the pylorus or sphincter of Oddi, spacings at less than 1 cm intervals may be required, for example at the pylorus spacings of 3 mm are required to ensure that all mechanically significant pressures are recorded. In the colon, spacings of 5 cm have previously been considered adequate (based on what could be achieved using the available technologies), but more recent studies using more closely spaced sensors have shown that the data obtained with the larger sensor spacings may have significantly misinterpreted the direction of some propagated events. The effects of the radial orientation of the sensor depend on the structure being examined—for example, there is significant radial asymmetry of the upper and lower esophageal sphincters, however, exactly how this should be interpreted, and whether this makes a difference to the interpretation of physiological events or clinical diagnosis, is not certain.

Temporal Resolution

The frequency with which pressure samples are taken and recorded should generally not be an issue, as most current recording systems are capable of sampling at frequencies able to detect the changes in pressure encountered in the upper GI tract. Generally, recording at 25 Hz or above will provide excellent temporal resolution in the measurement of changes in pressure within GI tract.

Accuracy

The accuracy with which pressures are measured is vital to accurate interpretation of physiological events and is affected by a number of factors, including the characteristics and placement of the transducers, mechanical factors, transducer drift, and pressure artifacts. The differences in transducer and catheter measurement characteristics are discussed above. Mechanical factors affecting accuracy in water-perfused systems include changes in the pressure driving the pneumohydraulic pump, as well as the effects of perfusion of bubbles or particles through the capillary resistors, and changes in the resistance of the lumina of the catheter. These factors are preventable by the use of optimal technique, however this is more time-consuming than the use of solid-state catheters.

Transducer drift can affect any type of recording system and relates to instability in the "baseline" pressure recorded by a transducer, usually due to electrical issues with the transducer which may be faulty, or subject to a changing environment (e.g., temperature difference between where the catheter is "zeroed" and the subject in systems using intraluminal transducers). Changes in temperature affect the electrical characteristics of transducers, and intraluminal transducer catheters may need to be "compensated" for the effects of the difference between the ambient temperature and body temperature.

As pressure gradients are being measured along a catheter, an accuracy of 1–2 mmHg is required. The accuracy of pressure measured can be tested in a system by applying a known pressure to the transducers, generally utilizing the manufacturers' system supplied for calibration, and applying known pressures during recording. Pressures should rise in each transducer equally, and should be stable over a recording period of 20–30 min. Catheters can be placed in water baths to simulate placement in the gastrointestinal lumen, and recordings made over prolonged periods to determine whether electrical or mechanical drift is occurring.

Combining with Other Data Streams

One of the longstanding issues in the interpretation of manometry data is that the variable that is measured (pressure) does not directly correlate with transit. Indeed, quite large volumes of intraluminal content can move with minimal pressure change, provided resistance is sufficiently low, and conversely if resistance is

increased, high pressures may be required to move relatively small volumes. This has led to the concept that the value of pressure data can be enhanced by a concurrent measure of transit, and some manometry systems are capable of synchronizing pressure measurement with other data streams such as intraluminal impedance or X-ray images. This data is recorded to the same data file and can be analyzed with the pressure recording, allowing correlation between pressure and the transit of intraluminal contents.

Artifact Detection

The measurement of pressures within the gastrointestinal tract is subject to many potential artifacts. Some of these may arise from mechanical factors within the gastrointestinal tract such as compression by adjacent structures (e.g., vascular or the liver), or the catheter itself impinging on a wall of the gastrointestinal tract as it traverses a bend. Other artifacts are due to mechanical or electrical factors within the recording system, such as a faulty transducer or electronic components, or an incorrect or unstable electrical connection. Generally, artifacts will be recognized when one channel appears to be behaving differently to other recording channels, sometimes with a different baseline pressure, or lack of responsiveness to physiological changes such as coughing (which raises intra-abdominal and intrathoracic pressure, and should increase in the pressure in all transducers in those areas approximately equally). If it is unclear whether the artifact is due to a transducer or to a mechanical factor, the catheter can be repositioned. If the artifact moves with the recording channel, it is due to a problem with the electrical or mechanical factors affecting measurement in that channel; if the artifact changes recording channels, it is likely to be due to mechanical effects from the gastrointestinal tract; and if the artifact disappears with repositioning of the catheter, it is likely to have been due to pressure of the catheter on a mucosal surface.

Recording/Display Software

The function of software during the recording phase of a manometric study is to display the pressures that are being recorded in a way that allows the operator to ensure that the catheter is correctly placed and recording accurately, without artifact. The catheter must initially be calibrated according to the instructions of the manufacturer of the recording system, it is then placed within the subject and positioned by ensuring that the pressure data displayed on the screen allows the identification of particular physiological structures, usually sphincters, as these demonstrate increased pressures (e.g., lower esophageal sphincter in esophageal manometry, anal sphincter in anorectal manometry) that are easily recognizable. Other maneuvers, such as deep breathing, or swallowing during esophageal manometry, or squeezing or coughing during anorectal manometry, can accentuate physiological features such as the position of the diaphragm or a sphincter. The recording

software needs to be able to display these changes in pressure in real time to allow appropriate adjustments of the catheter or other troubleshooting maneuvers to ensure an optimal recording. Generally, the data will be displayed in much the same way as it will be analyzed, usually in the form of a spatiotemporal topographic plot scrolling across the recording screen. Sometimes, it is helpful to visualize pressures as a line plot, or numerically. Once the catheter is positioned and the study commences, the recording software saves the data to a file for subsequent analysis.

Analysis Software

The analysis software used will be specific to the recording system, however the same general principles apply to all systems. Analysis software needs to allow users to move through the recording period, viewing pressures either as absolute pressures with respect to atmosphere, or internally referenced (e.g., to intragastric pressure in the case of esophageal manometry). Pressures are generally displayed as spatiotemporal topographic plots in which the Y axis represents the distance along the recording catheter, the X axis represents time, and pressures are displayed in the Z axis, either as a color plot or a contour plot. Displaying the pressures in this form requires interpolation between the individual pressure points, which must be appropriately spaced (see Spatial Resolution section). Users should be able to move a cursor around in the data to determine pressures at specific points in space and time. Most commercial software for clinical studies includes the ability to measure specific aspects of gastrointestinal function relevant to the region (for example lower esophageal sphincter relaxation), and to classify specific events (e.g., swallowing). Reporting software is included in commercial systems and, again, is specific to be region being examined.

Infection Control

Some catheters are disposable and hence do not need reprocessing. However, the use of disposable catheters will generally be more expensive, and high channel counts are not available. Most manometry catheters will therefore be used on many patients, and it is vital that there are appropriate systems for ensuring that pathogens are not transmitted between patients. The exact method of catheter reprocessing depends on the type of catheter. Water-perfused catheters constructed from silicone can be autoclaved to achieve sterilization, however the electronic components of solid-state catheters are too sensitive to allow the use of steam sterilization, and some form of chemical-based reprocessing, as for gastrointestinal endoscopy, must be used. In addition, some solid-state catheters utilize a sheath to cover the catheter during placement within the patient. The integrity of the sheath is tested afterwards

to ensure that there has been no leakage that might contaminate the catheter. In any case, the method of reprocessing to ensure that pathogens are not transmitted between patients needs to be robust, and in accordance with local policies.

Conclusion

The manometry machine records pressures from the gastrointestinal tract for diagnostic or research purposes; pressure is recorded using catheters (water-perfusion or solid state), transducers that convert physical signals to digital signals, and a computer with software that analyses the data. Different recording systems may have different spatial resolution (distance between the recording points), temporal resolution (rate of pressure measurement sampling), and the accuracy with which pressure is measured. Though the solid-state system, —in which the sensor is located in the catheter itself—has some advantages, such as simplicity in operation and high sensitivity, the catheters are quite expensive, fragile, and often thicker than the water-perfusion catheters and are quite temperature-sensitive, requiring thermal compensation of the recorded data. In both the systems, once the signal is digitized and recorded to the computer, the principles are very similar. Different manometry machines have different recording and analysis software, to which the operator needs to familiarize himself/herself, however, the principles of the most of the recording and analysis software are quite similar. All software currently uses the Chicago system for analysis and reporting of the recorded data.

Suggested Reading

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