Pressure Exposure and Catheter Impingement Affect the Recorded Pressure in the Manoscan 360™ System

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Abstract

Background—The accuracy of pressure measurements by Manoscan high-resolution manometry (HRM) system is affected by pressure drift (PD). The PD is partly related to temperature and study duration, but other factors that contribute to errant pressure recording have not been systematically evaluated.

Aim—The aim of this study was to investigate and quantify contributing factors to pressure recording error.

Methods—In total, 660 in-vitro experiments were conducted on seven HRM catheters to determine the effects of sustained pressure exposure, catheter impingement, temperature, duration of study, and immersion in saline or acid on recorded pressure and PD.

Results—At room temperature and without application of pressure, the PD was negligible. Application of sustained pressure significantly increased PD and catheter impingement of even 15 degrees produced remarkable increases in the recorded pressure as well as post-recording PD. There was significant variability across sensors in their propensity to develop PD with temperature. Body (37 °C) and freezing (0 °C) temperatures resulted in significantly higher absolute value of PD in the opposite algebraic direction respectively (for individual sensors). Although the overall trend was for higher PD with increasing temperature, some of the pressure sensors demonstrated inherently negative PD at body temperature.

Conclusions—In addition to the known effects of temperature, both sustained pressure exposure and catheter impingement significantly affect the recorded pressure and the magnitude of the PD observed at the end of the recording. These effects can be substantial enough to result in erroneous manometric diagnoses.

Graphical abstract

- The accuracy of pressure measurements by Manoscan system is affected by development of pressure drift (PD) throughout the recording.

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- Application of sustained pressure significantly increased PD, and catheter impingement produced remarkable increases in the recorded pressure as well as PD.
- In addition to the known effects of temperature, both sustained pressure exposure and catheter impingement significantly affect the recorded pressure and PD observed at the end of the recording. These effects can be substantial enough to result in erroneous manometric diagnoses.

Keywords

manometry; thermal compensation; hysteresis; high-resolution; pressure topography; pressure drift

INTRODUCTION

Esophageal high-resolution manometry (HRM) is currently considered the gold standard modality for diagnosis of esophageal motor disorders¹. Several hundred articles utilizing this technique have been published since 2004, resulting in the current classification schemes for diagnosing esophageal motor disorders²⁻⁴. The Manoscan 360™ (Sierra Scientific Instruments, Los Angeles, CA; acquired in 2010 by Given® Imaging, Yoqneam, Israel; purchased in 2014 by Covidien®, Dublin, Ireland; and currently Medtronic®, Minneapolis, MN) is the most commonly used HRM system in the United States (>60% market share)⁵. The manufacturer reports an in-vivo pressure measurement accuracy of 1-2 mmHg^{6, 7}. However, the accuracy of pressure measurements by Manoscan 360™ esophageal HRM system (hereto Manoscan) is potentially limited by the development of a pressure drift (PD)⁸⁻¹¹. The PD has generally been attributed to the changes in temperature caused by the warming of the sensors inside the body^{6, 7} and duration of pressure recording¹¹. During in-vivo use of this manometric system the PD is addressed by the uniform adjustment of the baseline pressure within the Manoview™ analysis software using the “thermal compensation” (TC) tool⁷.

Recent investigations have shown that the standard operating instructions and available corrective algorithms of Manoview™ software do not adequately correct PD in the Manoscan^{8, 10}. In a recent study, we observed that more than 95% of clinical manometry studies exhibit a substantial PD of more than five mmHg⁸. Investigation of the anorectal catheters of the Manoscan™ HRM system replicated these results, and added that accounting for the uncorrected portion of PD changed clinical interpretation of the manometry (normal versus abnormal) in 12.5% of studies⁹. Therefore PD not only may impact the normative data but also may alter quantitatively driven interpretation of the results exclusively based on pressure values⁸⁻¹⁰.

To date, there has been no systematic *in vitro* investigation to comprehensively address potential contributing factors to PD in the Manoscan. Previous investigations focused on factors of temperature and duration, but did not explore other physical conditions to which pressure sensors are routinely exposed during clinical manometry^{10, 11}. In addition, the effects of different physical conditions on actual pressures recorded during a study have not been investigated. Any such effects may have a critical impact on the post-recording analysis, because these conditions are likely to have considerable spatiotemporal variability during a study and thus cannot be accurately adjusted for in a post-hoc correction algorithm (TC). We hypothesized that recorded pressure and post-procedure PD may be affected by parameters such as magnitude of pressure exposure of a sensor (such as in the upper and lower esophageal sphincters [UES and LES]); catheter impingement resulting in pressure sensor angulation (such as LES in presence of a hiatal hernia/surgery or UES in presence of cervical osteophytes/hardware); duration of the pressure recording; temperature, moisture and acidity of the environment. The type of HRM catheter and the exact timing of pressure drift measurements are also plausible variables that may influence PD. The aim of the current study was to comprehensively determine the contribution of these potential variables to the development of recording error in the Manoscan.

METHODS

We performed high-resolution manometry (HRM) recordings using three different models of esophageal catheters. I) Two standard adult esophageal HRM catheters with 4.2 mm outer diameter composed of 36 solid-state pressure sensors composed of twelve circumferentially distributed pressure sensitive segments⁶ (EAN 734 and EAN 1291); II) Three esophageal combined HRM-impedance catheters composed of 36 pressure sensors (similar to above) and 18 impedance channels (EAS 357, EAS 175 and EAS 240); and III) two small-diameter adult HRM catheters with 2.75 mm outer diameter composed of 36 sensors composed of sixteen circumferentially distributed pressure sensitive segments⁶ (EAS 022 and EAS 061). All catheters were within the two-year warranty period and were maintained according to the manufacturer's guidelines⁷.

Experimental Protocol

The HRM system was operated by a single trained technician to conduct all studies in a uniform fashion across all experimental conditions. Recordings commenced after a successful system calibration (0 mmHg - 300 mmHg), and pressures were universally zeroed prior to the onset of recording. Immediately after termination of each experiment, the operator suspended the catheter in the air prior to terminating the manometric recording. In total, we conducted and analyzed 660 in-vitro experiments in the following settings:

- I. **Pressure Exposure:** We placed the HRM catheters in a sealed cylindrical pressure chamber in a vertical position connected to a computer-controlled barostat device (G and J Electronics, Willowdale, Ontario, Canada). The barostat maintained an omnidirectional pressure of 0, 10, 20, 30, 40, and 50 mmHg. The barostat device was calibrated with two different external sphygmometers to ensure accuracy of the generated pressure. Experiments for each pressure condition for every catheter were repeated once to assess the repeatability of measurements.

Catheters were also randomly exposed to step-wise ascending (10, 30, 50 mmHg *and* 0, 20, 40 mmHg) and descending (50, 30, 10 mmHg *and* 40, 20, 0 mmHg) orders of ramp pressure for a total of 15 minutes (each pressure level for five minutes) to determine if the sequence of exposing sensors to the higher pressure had an effect on the observed PD.

- II. *Catheter Impingement and Sensor Angulation:* To determine the effect of catheter bending or impingement, catheters were passed through a plastic tube that was bent under tension over two protractors affixed to a flat surface to produce 0, 15, 30, 45 and 60-degree angles exactly in two affected pressure sensors. Recordings were obtained from these two sensors while catheter was maintained at atmospheric pressure for a total duration of 180 seconds. Recordings were obtained from sensor pairs from the mid-portion of each catheter. The PD on these two sensors under tension was measured immediately after the catheters were removed from the angulated state.
- III. *Environment and Duration of Recording:* To assess the effects of moisture and acidity, catheters, were placed in the sealed pressure chamber in a horizontal orientation. The chamber was filled with saline or 0.1 normal hydrochloric acid (pH=1) to just cover the sensors. The pressure chamber was then connected to the computer-controlled barostat device and pressures were recorded with and without 50 mmHg of pressurization (10, 30 and 60 minutes of duration).
- IV. *Temperature and Duration of Recording:* To determine effect of temperature, catheters were immersed in a general purpose water bath filled with water at 3 cm depth without pressurization. Temperature was set at 0, 22, 37, and 50-Celsius degrees for duration of 10, 30 and 60 minutes.

Data Analysis

The entire recorded pressure dataset for each manometry study was exported as an ASCII file. Each column of data in the exported file corresponds to the time series of the recorded pressure from distinct identifiable sensors labeled individually as 1-36. The PD was defined as the residual pressures measured immediately (approximately 0.5 second) after termination of the experiment when no external pressure was applied. In addition, PD was also measured at a delayed time point (approximately 5 seconds after termination) to assess the effects of timing of TC. Summary data including the PD, delayed PD and recorded pressure tracing averaged in 1 second intervals of each sensor during study was extracted from the ASCII format manometry files, and used for statistical analysis. All analyses were performed using R 3.3.0 (R Foundation for Statistical Computing, Vienna, Austria). A linear mixed effects model with random catheter, experimental run, and sensor effects was used to model the PD outcome as a function of experimental variables and their interactions. The effects were tested for linearity by comparing model fits with a linear term and as a categorical predictor. The reference condition is pressure exposure of 0 mmHg, 0 degrees angle, 10 minutes for duration, dry condition at ambient room temperature of 22 Celsius degrees. The data are presented as mean $\pm$ SEM.

RESULTS

At room temperature, without application of pressure, and in absence of sensor angulation, PD remained negligible regardless of the duration of recording and other factors (<2 mmHg).

- I. *Pressure Experience:* The actual pressure value was consistently under-recorded for all sensors. At each pressure level of the barostat device except zero, the pressure recorded by the sensors averaged 2.9 ± 0.7 mmHg lower than the barostat generated pressure persistently (Figure 1A). Four pressure sensors of a single combined pressure-impedance catheter (sensors 33- 36) showed 4.1 ± 0.8 mmHg lower pressure measurements compared to the remainder of sensors across study conditions. These sensors were excluded from further analysis to avoid data pollution by potentially defective sensors (however the outlier sensors passed the calibration test for all experiments). PD was not significantly different across the repetitions of the same experimental condition ($P > 0.5$). The PD and the variance of PD significantly increased with escalating pressure exposure (Figure 1B). The combined pressure-impedance catheters had a larger PD and variance of PD. Every 10 mmHg of sustained pressure exposure resulted in the increased PD of 1 ± 0.2 mmHg in the combined pressure-impedance catheters ($p < 0.01$). The order of pressure exposure was also associated with significantly different PD. The ascending order of pressure exposure resulted in a 3 ± 0.8 mmHg higher PD than the descending one (Figure 1C, $P < 0.001$). PD measurement obtained at 5 s after the recording period (delayed as shown in Figure 1D) were significantly lower than those obtained at 0.5 s (the time interval recommended by the manufacturer).
- II. *Catheter Impingement:* HRM catheter impingement associated with angulation of pressure sensors resulted in the recording of pressure values that linearly correlated with increased angulation for both combined pressure-impedance and standard catheters (Figure 2A). In addition, increasing the angle of catheter impingement resulted in significantly higher PD and higher variance of PD, that were most noticeable for the standard adult catheters (Figure 2B). Each fifteen degrees of increased sensor angulation was associated with average 13.5 ± 4.1 mmHg of PD in the standard adult HRM catheter ($P < 0.01$).
- III. *Environment and Duration of Recording:* The effects of recording environment and study duration on the PD were more variable, and thus less predictable, than that of constant pressure application or catheter impingement (Figure 3). Compared to recording in air, recording in the presence of acid or saline resulted in a modestly higher PD (1.2 ± 0.4 mmHg, $P < 0.001$). The effect of duration was more consistent in the small diameter catheter, and longer duration of recording (60 minutes) was associated with 1.1 ± 0.5 mmHg higher PD ($P < 0.05$).
- IV. *IV. Temperature and Duration of Recording:* All sensors recorded atmospheric pressure with little error at room temperature. Increasing temperature significantly increased PD, but the effects were highly variable among individual

sensors. The initial temperature shock generally equilibrated after a couple of minutes into the recording. Higher and lower temperatures resulted in pressure errors that were highly variable from sensor-to-sensor on a given catheter, as well as between catheters of identical and different design (Figure 4A). The smallest PD and variance of PD were noted at room temperature. Both higher and lower temperatures resulted in significantly higher PD values but in the opposite algebraic directions (Figure 4B). The colder (0° C) and the warmer (50° C) temperatures were associated with -4.8 ± 1.2 mmHg and 7.9 ± 1.9 mmHg of PD difference from room temperature PD respectively. Although the overall trend was for higher positive PD with increasing temperature, some of the pressure sensors inherently demonstrated paradoxical negative PD at 37° C body temperature and a positive PD at 0° C (Figure 4C). PD measurement obtained at 5 s after the recording period ended (delayed as shown in Figure 4D) was significantly higher than those obtained at 0.5 s (opposite effect of PD measurement timing to pressure-induced PD).

Increased duration of recording significantly increased PD. Effect of study duration was more noticeable in the warmer environment ($P < 0.05$). For example at body temperature (37° C) the overall PD after 60 minutes of recording was 3.6 ± 1.0 mmHg higher than after 10 minutes of recording. However, the effect of study duration on PD at different temperatures was variable, and the trend for larger PD values with longer recording duration was not seen with every catheter.

DISCUSSION

Both temperature⁷ and duration of recording¹¹ are known to affect the PD and cause inaccurate pressure measurement in the Manscan 360™ esophageal HRM system. This study extends those findings through an *in-vitro* investigation of additional parameters: i) sensor pressure experience, ii) catheter impingement, iii) recording environment, iv) catheter type, and v) timing of PD measurement. At room temperature and without application of pressure (or catheter impingement), the PD remains negligible irrespective of the environmental acidity/moisture and duration of recording. However, as our data show, performance of the catheter in the unperturbed condition is unlikely to reflect actual catheter performance in-vivo. The effects of sensor pressure exposure and catheter impingement/sensor angulation, which vary with catheter type, can impact the accuracy of pressure measurements substantially. Since some of these effects are not accounted for in the manufacturer's recommended post-procedure TC correction algorithm, it is not possible to achieve the advertised accuracy of this system (2 mmHg). Other existing recording systems are also likely to experience similar difficulties.

Impingement of the HRM catheter with even minor angulation of the sensor (15 degrees for 180 seconds) altered pressure measurements in the sensors of the Manoscan. Our data during bending of the HRM catheters indicate that impingement results in angulation of the tactile sensing technology¹² resulting in an elevated pressure being recorded (coupling of the bending and tensile stresses to the tactile sensor) that could be incorrectly interpreted as representing the true luminal pressure. This phenomenon affected HRM catheters

differentially and affected standard adult and combined impedance catheters (EAN and EAZ) at higher angulations (30-60 degrees) more prominently than small diameter (EAS) catheters (Figure 2A). We contemplate that smaller electrodes (0.54 mm) of the smaller sensors (sixteen circumferential co-axially aligned surface electrodes) are less amenable to angulation deformity than larger electrodes (1.10 mm) of the larger sensors (twelve circumferential co-axially aligned surface electrodes)^{6, 12}.

The effects of impingement/angulation are not corrected immediately by straightening the catheter, as there is a persistent PD (Figure 2B), whose magnitude depends on the preceding degree of angulation in the standard adult catheters. The residual PD in combined impedance and small diameter catheters was similar for angles 15–60 degrees and significantly less than standard adult catheters. The lower PD in small diameter catheters can be explained by lower angulation deformity and reduced pressure experience during catheter impingement. On the other hand, combined impedance catheters have similar size electrodes to adult standard sensors and display similar angulation deformity and pressure experience during catheter impingement. The incorporation of metal impedance rings (and related hardware) palpably adds to the rigidity of combined impedance catheters. We speculate that additional stiffness and core support may contribute to rapid elimination of angulation deformity after straightening of the catheter, and explain the reduced post-recording PD in these catheters.

The present study shows that sensors of the Manoscan develop substantial *pressure-induced* PD in a dose-dependent manner even only after ten minutes of recording, which is a required duration for overwhelming majority of clinical HRM studies. Two distinct findings in the current study support this hypothesis: 1) the effect of order of pressure exposure, such that when the highest pressure was applied near the end of study the PD was higher and 2) the observation that PD measurements at 5 seconds after pressure experiments were lower than PD measurements at 0.5 second.

We and others have shown that during clinical manometry, pressure sensors recording in the high-pressure zones (HPZ) display significantly higher susceptibility for PD (retained pressure memory) compared to the sensors recording in non-sphincteric segments of the lumen^{8, 9}. Together these studies proposed that nearly half of PD variability could be explained by pressure experience of a sensor throughout a study^{8, 9}. Incidentally both sustained pressure exposure and catheter impingement scenarios may coexist in the esophageal HPZ regions (such as cervical osteophytes deforming the UES or anatomic distortions of the LES related to hiatal hernia). During clinical manometry in a given patient we do not know what percentage of PD is potentially temperature-induced and what portion is due to pressure or angulation events occurring throughout the study. It is currently impossible to determine how the PD is varying at different times throughout the recording or the degree to which catheter angulation and impingement are affecting the pressures being recorded. Furthermore, if the catheter changes in position and angulation during the course of the study (such as during repositioning of the patient), then different sensors will experience different PD effects from HPZ at different times and for different intervals, making the current uniform correction applied at the end of the study inaccurate (Figures 5).

Since residual deglutitive pressures of the UES and LES are arguably the most critical metrics of the motility assessment and a few mmHg of difference may alter the manometric interpretation (integrated relaxation pressure)¹, more caution is needed when inferring clinical diagnoses from these manometric parameters even after application of prescribed TC. For example, inaccuracy due to the factors identified in the current study (and not corrected by TC) may help explain findings that an abnormal elevated integrated relaxation pressure of the LES recorded on clinical manometry is often not predictive of an actual problem (Figures 6)^{13–15}. We suspect that catheter impingement in large part may explain the frequent finding of a high IRP value in patients with anatomic abnormalities in the region, in situations where relaxation would be expected to be normal^{16, 17}. Indeed, it is noteworthy that the latest criteria for identifying transient lower esophageal sphincter relaxations do not rely on the value of residual pressure at the EGJ¹⁸.

Our data confirm that pressure-induced PD is always in the positive algebraic sign (Figure 1B) unlike the temperature-induced PD that could in some sensors develop in the negative algebraic direction (Figure 4C) within the warmer body temperature environment. During clinical manometry, the temperature invariably affects all pressure sensors of the HRM catheters, but this effect is considered constant over time. However, this requires the maintenance of a constant temperature during the study. Given the additional degrees of PD with warmer and colder temperatures (and high degree of variability of direction of drift among individual sensors), there is the potential to have recording errors during clinical studies that might instigate the effects of warmer or colder swallowed bolus (for example during rapid water swallow) on esophageal motility. Since such PD effects would not be consistently present over the entire study, a post-hoc TC algorithm may not account for them accurately (Figure 7).

A recent study reported that PD in Manoscan catheters resulted from an initial “thermal shock” plus a sensor-dependent baseline drift that increased during prolonged recordings¹⁰. While this drift was pressure dependent, it was felt to be linear over the course of the recording, and so could be adjusted for by a two-step “interpolated thermal compensation” algorithm within the system software. However, that study only examined very low pressures (2.9 and 6.6 mmHg) that were applied over the course of the recording. Thus, that study could not have detected the significant effects of higher pressure application on PD that were identified in the current study. In addition, inspection of the raw pressure recordings in this earlier study show that, while overall the pressure drift is linear with time, individual sensors can be highly non-linear during portions of the recording, making any post-hoc linear compensation algorithm subject to substantial error.

Based on the user’s manual of Manoview analysis TM software, the “thermal compensation” (TC) correction should be applied to prepare the study for analysis. The vertical time bar is placed after the “waterfall image” and in the beginning of the atmospheric dangle to adjust the baseline pressures. We have observed situations in which clinicians have applied the thermal compensation tool while viewing the screen in a low temporal resolution (zoomed out mode), which resulted in the time being chosen for the thermal compensation baseline to fall several seconds after the “waterfall image”. We tested PD at 0.5 and 5 seconds after termination of all experiment. We found that PD is significantly different at these two-time

points and this difference is different for pressure-induced and temperature-induced hysteresis. While the pressure PD (i.e. deformity related) quickly fades, temperature PD may even grow in amplitude over time. Therefore, placing the vertical bar exactly at the end of the “waterfall image” becomes important.

In summary, pressure exposure, temperature variation, and catheter impingement of a degree likely to be encountered during clinical manometry alter pressure recordings reported by the Manoscan in a manner that cannot be accounted for by the currently available post-procedure compensation algorithms.

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Figure 1. Sustained pressure exposure and development of the pressure drift (PD)

A) Average recorded pressure over ten minutes. Each colored line represents the average values from a single catheter trial. Note individual sensor deviations from average measured pressure that was lower than barostat generated pressure. *B) Effect of applied intraluminal pressure on PD.* Each dot in the box-whisker plot (interquartile range) represents the data from a single sensor. Each colored line represents the average values from a single catheter. EAZ catheter showed significantly higher PD and variance in PD values with escalating pressure exposure compared to the other two types of catheters (EAN and EAS). PD always increased with increasing pressure application. *C) Effect of pressure application order.* Ascending order of pressure exposure was associated with a higher and more variable PD for all catheter types. *D) Effect of timing on PD measurement.* Colored lines represent a fitted regression line for data over all sensors of respective catheter type. Immediate PD measurements at 0.5 seconds were significantly higher than delayed PD at 5.0 seconds after study termination. Greater differences are seen with higher PD values.

Figure 2. Effect of catheter impingement and sensor angulation on the recorded pressures and development of pressure drift (PD)

A) Effect on recorded pressure. Each dot represents a single sensor and colored lines represent average values for a single catheter. Increasing angle of catheter impingement resulted in increasing pressures being recorded while at atmospheric pressure. *B) Effect of angulation on post-study PD.* The EAN catheter showed significantly greater and more variable PD compared to the other two types of catheter. Angulation-induced PD always possessed a positive algebraic sign similar to pressure-induced PD.

Figure 3. Effect of moisture and acidity on pressure drift (PD)

Box-whisker plots represent data from all sensors and all recording durations (10, 30 and 60 minutes). Exposure to 50 mmHg pressure (gray filled bars) in all recording environments showed significantly higher PD than 0 mmHg pressure exposure (white filled bars). Saline and acid showed higher PD in small diameter catheters (EAS) that was not significantly different from each other.

Figure 4. Effect of temperature and duration of recording on recorded pressure and PD

A) Average recorded pressure over ten minutes without pressurization. Each colored line represents the average values from a single catheter. B) Effect of temperature and recording duration on PD. Each colored line represents mean value from a single catheter trial. Each dot in the box-whisker plot represents the data from a single sensor. Lowest PD is observed at ambient room temperature. Warmer and colder temperatures always resulted in higher absolute value of PD but in the opposite algebraic directions. Effect of duration of pressure recording was not consistent except for EAS catheters where prolonged recording was

associated with higher PD. *C) Variability in effects of temperature on direction of PD change in different sensors.* In left panel each line represents data from a single sensor. Brown and green lines indicate sensors with a negative and positive PD at body temperature respectively. In the right panel each dot represents data from a single sensor. Sensors with a positive PD at lower temperatures have a negative PD at higher temperatures, and vice versa. *D) Effect of timing on PD measurement.* Colored lines represent a fitted regression line for data over all sensors. Immediate PD measurements at 0.5 seconds were significantly lower than delayed PD at 5.0 seconds after study termination. Greater differences are seen with higher PD values.

Figure 5. Pressure drift (PD) error in clinical manometry

Top and bottom panels show identical esophageal pressure topography (EPT) plots before (A, B, C) and after application of thermal compensation correction algorithm (A', B', C') respectively. The panels will be explained in clockwise sequence to facilitate communicating the concept of generated pressure errors related to PD. A) The EPT displays presence of an elevated residual deglutitive pressure in the upper and lower esophageal sphincter (UES and LES) regions before application of thermal compensation (TC). B) The HRM catheter has been repositioned so that both UES and LES are on more distal sensors. Note that horizontal “pressure memory bands” retained on the sensors previously recording from the UES and LES regions as shown in A. C) The EPT plot after removal of the catheter. Considerable PD in multiple sensors is seen. The two highest PD horizontal bands correspond to the “retained pressure memory” of original location of UES and LES in the beginning of the recording. C') The identical EPT plot as in C, but after TC is applied showing adjusting the baseline by zeroing of the PD bands in C. B') EPT shows that TC performed well for new UES and LES regions after catheter repositioning. Note however that artefactual horizontal sub-atmospheric pressure bands have developed due to overcorrection of previous retained pressure memory bands shown in the corresponding panel B. A') The artefactual horizontal sub-atmospheric pressure bands overlap with the UES and LES regions in the earlier swallows (before catheter repositioning). The resulting overcorrection of the PD in the UES region is masked under the existing UES tone but remains apparent in the LES region. As a consequence, deglutitive pressures in the UES and LES regions are now erroneously recorded as sub-atmospheric.

Figure 6. Effects of catheter impingement and sensor angulation on the clinical manometric recording

Two swallows in a patient with a large hiatal hernia are shown before and after catheter repositioning. A) Shows EPT plot of a swallow early in the study. Distal end of catheter is bowed within the hernia sac, causing catheter impingement and sensor angulation at the EGJ. Note the appearance of a sustained high-pressure zone (HPZ) at the EGJ that is not substantially relaxing with swallow resulting in elevated integrated relaxation pressure (IRP=20). Intrabolus pressure (IBP=7) is not consistent with the elevated IRP. B) The EPT plot of the same swallow with impedance (magenta overlay) to show normal bolus transit. Despite apparent presence of an abnormal IRP, the bolus passes through the EGJ without any impediment (arrow). Moreover, after termination of peristaltic wave impedance displays an episode of reflux back into the esophagus (dashed arrow) as if EGJ barrier of > 20 mmHg is nonexistent (suggesting artefactual HPZ). C) The EPT from a swallow later in the study after patient and catheter repositioning. Note the resulting reduction in recorded pressure at the EGJ (baseline and swallow period) which now shows a normal deglutitive relaxation (IRP=9). Clinical, endoscopic and radiographic findings were consistent with a diagnosis of GERD in a known patient with large hiatal hernia (and not suggestive of outflow obstruction).

Figure 7. Effect of errors in thermal compensation (TC) algorithm on manometric diagnosis

A) EPT plot of two swallows early in the study before application of TC (IRP=7). B) EPT plot of rapid water swallows in the middle of study before application of TC. Note appearance of multiple horizontal bands of sub-atmospheric pressure immediately after rapid water swallows of 6 ounces of tap water (Arrow). C) EPT plot showing period immediately after catheter removal and before application of TC. Several bands of both positive and negative PD are observed. However, these were not present earlier in the study (panel A) before application of TC. C') EPT plot showing period immediately after catheter

removal following application of TC, zeroing the positive and negative bands of PD. D) EPT plot showing the same two wet swallows of panel A after application of TC (standard operation recommended by manufacturer). Artefactual non-physiologic horizontal bands of sub-atmospheric and supra-atmospheric luminal pressure are now visible that inversely correspond to the PD bands in panel C. Manometric findings are erroneously now consistent with type I achalasia (IRP=17). E) Three swallows are shown sometime after rapid water swallows in the second half of study (after TC applied). Artefactual horizontal sub-atmospheric and supra-atmospheric bands are not present and manometric findings are consistent with absent contractility (IRP=3). The results from panels A and E are consistent with endoscopic and radiographic findings in this patient with known systemic sclerosis.