"Squeeze" vs. Resistance: An Evaluation of the Mechanism of Sphincter Competence

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Research Article

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Many articles dealing with patterns of intraluminal pressure at the gastroesophageal junction either state or imply that the high pressure recorded within the junctional zone provides a pressure barrier separating the adjacent cavities (1–12). It has also been suggested that a high resting sphincter pressure denotes a competent sphincter, and conversely, a low pressure an incompetent sphincter (1–4, 11–14).

Although the pressure barrier concept is an attractive one, the physics of pressure and flow makes it seem unlikely to us that "pressure" as such can separate two cavities. Indeed, no pressure at all should exist within the potential lumen of a closed sphincter. The fact remains, however, that intraluminal pressures are recorded from within the resting gastroesophageal sphincter, and therefore further studies to investigate the significance of such pressures seemed indicated.

Since technical problems make evaluation of the pressure barrier concept at the gastroesophageal junction difficult, we chose to study the anal sphincter. Although others have studied the mechanism of action of the anal sphincter (15–17), our design was not to study the rectum and anus as such but simply to investigate the meaning of pressures recorded from an easily accessible sphincter. Although we do not claim that our results can be directly applied to the gastroesophageal sphincter, we do feel that they may challenge the general concept that alimentary tract sphincters prevent flow by creating a barrier of pressure.

Methods

Fifteen normal adult males have been studied on 57 occasions. No bowel preparation was employed. The subjects were usually studied while they were lying in the left lateral decubitus position. Intraluminal pressures were transmitted to Sanborn transducers by two open-tipped, water-filled, side-opening, polyvinyl catheters of 1.4 mm i.d. The recording orifices were 5 cm apart and were approximately 1.3 mm in diameter. The output from the transducers was graphed on a multichannel direct-writing recorder. The transducers were leveled with a spirit level, the anal orifice being defined as the zero reference point. To permit insertion of the recording tubes without the use of a proctoscope, they were cemented to a no. 16 F polyvinyl Levin tube. The entire assembly then measured 4 mm by 6 mm in cross section.

In a preliminary study we had noted that the anal pressure profile obtained depended to a large extent on the spatial relationship of the recording orifice to the end of the assembly. When the orifice was within 1 cm of the end of the assembly, a pressure profile was recorded that varied considerably but was generally higher than a pressure profile obtained when this orifice was 5 cm from the end of the assembly. In all other respects the sphincter pressures obtained with the distally placed orifice behaved the same as those obtained with the more proximally located orifice, whether this orifice was side-opening, end-opening, or covered by a small balloon. We have employed recording tubes with side-opening, open-tipped orifices at least 5 cm from the end of the assembly because of this reproducibility and ease of construction. Pressure profiles obtained with the distally placed orifices resembled those published by Duthie and Bennett (15) and Hill, Kelley, Schlegel, and Code (16). We have not further investigated this interdependence of type of pressure profile obtained and placement of recording orifice.

Results

When both recording tips were in the rectal ampulla, pressures of 5 to 10 mm Hg were recorded (Figure 1). These pressures showed respiratory variations. As the assembly was slowly with-

drawn, the tips entered an area from which were recorded pressures that were 2 to 6 mm Hg higher than the mean ampullary pressure and were not subject to respiratory variations. This area was 3 to 5 cm long and showed little variation in pressure throughout its length. As the assembly was pulled even further, the pressure dropped to atmospheric, and the recording tip was seen to emerge from the anus. The zone of elevated pressure betwen the ampulla and the outside therefore represented the pressure recorded from the anal sphincter. This area of slightly elevated pressure was found on each of the 160 occasions the recording tip was pulled from the rectal ampulla to the outside. When the subject performed a Valsalva maneuver with the recording tips in the rectal ampulla, ampullary pressures rose. If the assembly was withdrawn as the subject continued to perform a Valsalva maneuver, sphincter pressure was commensurately higher, thus maintaining a sphincter-ampulla pressure gradient on each of the 41 times this maneuver was performed. This pressure gradient was shown over a wide range of ampullary pressures (Figure 2).

Figure 2 also shows that although recorded sphincter pressure increased to maintain an apparent pressure gradient, this augmented pressure did not return to its resting level as the Valsalva procedure was terminated. Once sphincter pres-
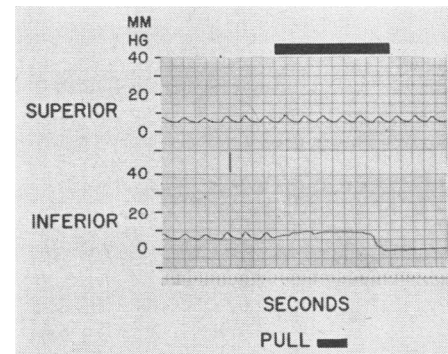

FIG. 1. ANAL SPHINCTER PRESSURE PROFILE. The superior tip is the most craniad in this and subsequent figures. As the assembly was pulled, the inferior or outermost tip entered and passed through the sphincter to the outside. The superior tip did not enter the sphincter.

sure had been elevated by this mechanism, this pressure remained unchanged if the tip was left in the sphincter, as long as 10 minutes. In terms of the pressure barrier concept it would seem unnecessary for sphincter pressure to remain elevated when ampulla pressure had returned to its base-line levels.

On each of the 74 occasions in which a recording tip was placed in the anal sphincter before a Valsalva maneuver, entirely different results were found. As shown in Figure 3, the tip in the sphincter did not record a rise in pressure
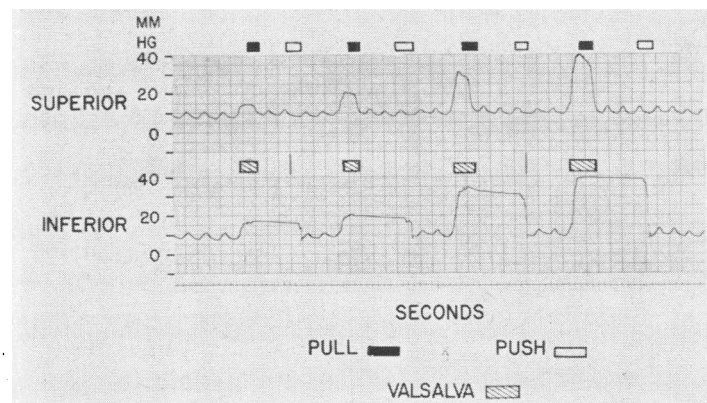

FIG. 2. EFFECT OF VARYING INTRA-ABDOMINAL PRESSURE ON SPHINCTERIC PRESSURE. In this sequence the superior tip did not enter the sphincter but only recorded the effects of Valsalva maneuvers of varying intensity. During each graded Valsalva, the inferior tip was pulled into the anal sphincter. After the Valsalva, the assembly was pushed until the inferior tip re-entered the rectal ampulla. Sphincter pressure tended to be slightly higher than ampullary pressure and remained elevated after ampullary pressure had returned to base-line levels.
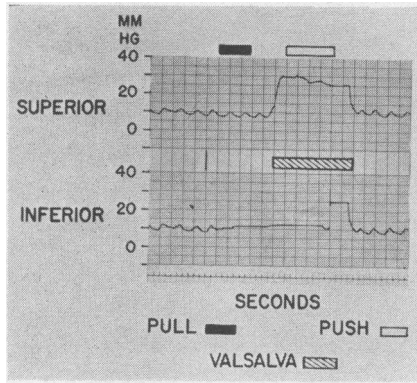
FIG. 3. LACK OF INFLUENCE OF INCREASED INTRA-ABDOMINAL PRESSURE ON SPHINCTER PRESSURE. The inferior tip was placed in the sphincter before the Valsalva maneuver was begun. No appreciable rise in sphincter pressure was recorded in spite of a 20 mm Hg rise in the ampullary pressure. When the assembly was pushed, the inferior tip entered the ampulla and recorded the elevated ampullary pressure.

during a Valsalva maneuver even though ampullary pressure did rise. Increases in ampullary pressure as high as 80 mm Hg did not cause appreciable changes in the recorded sphincter pressure. Under these circumstances, there was clearly no evidence of a pressure barrier.

If the recording tip, instead of being pulled from ampulla to the outside, was pushed from the outside into the ampulla, a different sphincter pressure was recorded in each of 57 trials. Figure 4 shows a study in which the inferior tip was pulled from ampulla to the outside and then returned to the ampulla. The inferior tip successively re-
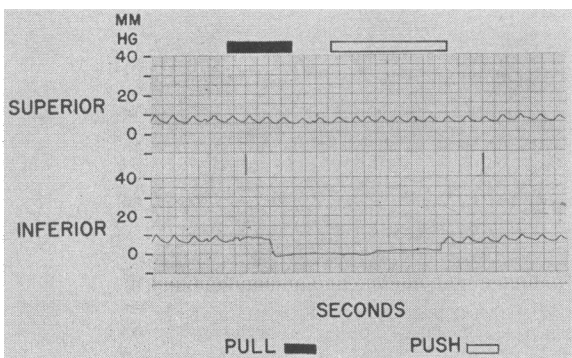

FIG. 4. "PULL" SPHINCTER PRESSURE COMPARED TO "PUSH" SPHINCTER PRESSURE. While the superior tip remained in the ampulla, the inferior tip was pulled through the sphincter to the outside and then pushed through the sphincter into the ampulla. Pull pressure and push pressure are clearly different.

corded ampullary pressure, "pull" sphincter pressure, atmospheric pressure, "push" sphincter pressure, and finally ampullary pressure again. In this study the inferior tip passed through the entire length of the sphincter in both directions, but a clear difference between the pull sphincter pressure and the push sphincter pressure is evident.

A variation of this study was performed 16 times with identical results. In this instance the tips of the recording assembly were only 2 cm apart, permitting both tips to be in the sphincter at the same time. As the assembly was withdrawn, both tips entered the sphincter and both recorded the same pressure (Figure 5). Then
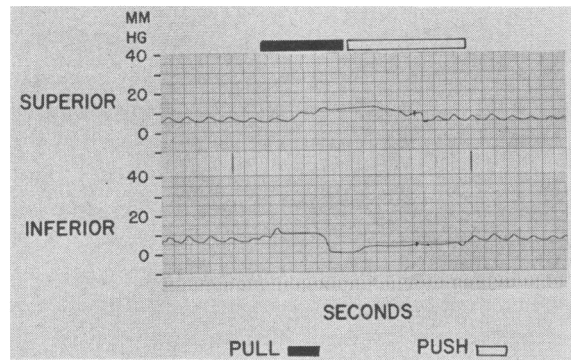

FIG. 5. PUSH AND PULL SPHINCTER PRESSURES RECORDED SIMULTANEOUSLY. The two tips were 2 cm apart. The inferior tip was pulled through the sphincter to the outside. At this point, the superior tip was in the sphincter. The inferior tip was returned to the sphincter while the superior tip remained in the sphincter. Recorded pressures are clearly different.

the assembly was slowly pulled until the inferior tip emerged from the anus. At this point the superior tip still recorded sphincter pressure while the inferior tip recorded atmospheric pressure. Then the assembly was slowly pushed until the inferior tip was again in the sphincter. Even though both tips were in the same sphincter simultaneously, one recorded pull sphincter pressure and the other push sphincter pressure. Each tip continued to record its individual pressure until it entered the rectal ampulla. This difference in simultaneously recorded sphincter pressure was more impressive if a Valsalva maneuver was performed while the tips were pulled into the sphincter (Figure 6). When the inferior tip was

brought to the outside and then reinserted while the superior tip remained in the sphincter, the difference in simultaneously recorded sphincter pressures was striking.

In each of the preceding studies, the tips were pulled into the sphincter from an area of high pressure and pushed into the sphincter from an area of low pressure. Since pull sphincter pressure was always higher than push sphincter pressure, it seemed desirable to alter these conditions to see if pulling and pushing or the effects of previous pressure were responsible for these findings. Accordingly, two subjects were studied on four occasions in such a position that the rectal ampulla was the highest portion of the abdominal cavity, i.e., while the subjects were standing on their heads. The studies of Duomarco and Rimini (18) suggested that this position would be expected to produce a negative pressure in the rectal ampulla, and therefore that atmospheric pressure would be relatively higher than ampullary pressure. Figure 7 shows that under these conditions, the rectal ampullary pressure was − 15 mm Hg. When the assembly was pushed into the ampulla, the usual push sphincter pressure of 4 mm Hg was recorded, but the pull sphincter pressure was − 12 mm Hg. This demonstrates that pulling was not always associated with higher pressures than pushing.

FIG. 7. PUSH FROM A RELATIVELY HIGH PRESSURE AND PULL FROM A RELATIVELY LOW PRESSURE. Subject was upside down with the superior tip in the rectal ampulla. The inferior tip sequentially recorded atmospheric, push sphincter pressure and negative ampullary pressure. When the assembly was withdrawn, pull sphincter pressure and finally atmospheric pressure were recorded. Note that pull sphincter pressure is recorded as a negative pressure, whereas push sphincter pressure is the usual 4 mm Hg.

To assess the possibility that the type of recording tubing or recording tip might influence our results, six subjects were restudied an additional 15 times. The contribution of "stiffness" of recording tubing was evaluated by comparing the polyvinyl tubing used in the main body of the study with more rigid polyethylene tubing and with a tube made of 15-gauge, thin-walled, stainless steel needle stock. All tubing was of comparable size. Additionally, small 2.5 mm × 2.5 mm water-filled balloons made of thin-walled latex were used as the pressure-sensitive tip instead of the end- or side-openings usually employed. In all subjects, neither the type of tubing used nor substitution of a balloon for an open tip caused any appreciable change in our experimental results. A balloon or a "stiff" tube, once within the anal sphincter, still did not respond to changes in intra-ampullary pressure, and the recorded sphincter pressure still bore a direct relationship to the ampullary pressure existing immediately before the device was drawn into the sphincter. The record obtained with stainless steel tubing tended to have a steadier base line than the polyvinyl or polyethylene tubing. The balloon tip tended to give a higher anal pressure profile than did the open-tipped tubes, as others
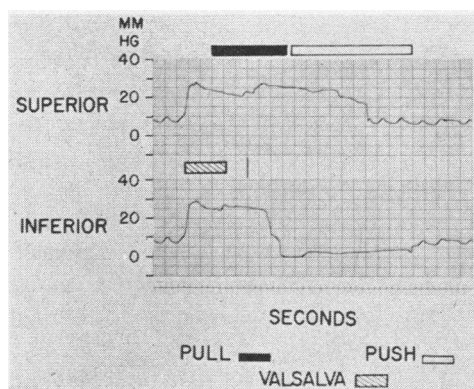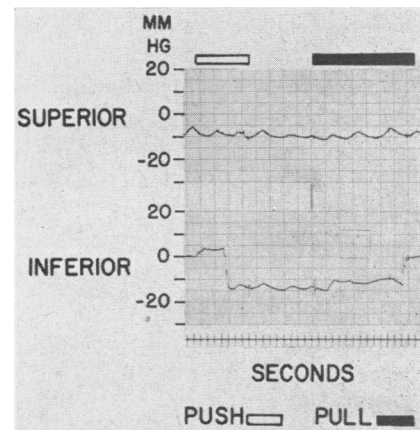

FIG. 6. MARKED DIFFERENCE IN SIMULTANEOUSLY RECORDED SPHINCTER PRESSURES. The tips were 2 cm apart. A Valsalva maneuver was performed, and both tips were pulled into the sphincter. Both recorded high sphincter pressure. The inferior tip was then brought to the outside and reinserted, while the superior tip remained in the sphincter. The two tips recorded markedly different pressures and yet were in the same sphincter at the same time.

have noted (16), and slight movements of the assembly produced variations in the base-line pressure with the balloon tip but not with the open tip. In spite of these minor differences, however, polyvinyl, polyethylene, and stainless steel tubing gave identical results, and end, side, and small balloons produced entirely comparable tracings.

Discussion

Current concepts of sphincteric action hold that a sphincter maintains closure by tonic contraction, or "squeeze." Intrasphincteric pressure has been felt to be an accurate measure of this squeeze and thus to be an accurate reflection of sphincteric tone. This tone has also been quantitated, i.e., the higher the pressure recorded from a sphincter, the better the sphincter, and vice versa. Our findings would indicate, however, that recorded sphincter pressure is not a measurement of sphincter tone, but rather is directly related to the pressure to which the recording tip is last exposed before it enters the sphincter. This is shown in Figures 2 to 7. Each figure shows that recorded sphincter pressure is equal to or exceeds ampullary pressure by a few mm Hg whether the ampullary pressure is positive (Figure 2) or even negative (Figure 7). If it is presumed that sphincter pressure reflects sphincter tone, then the negative sphincter pressure shown in Figure 7 must mean that the sphincter can exert negative tone!

Since sphincter pressure is a function of the pressure recorded just before the recording tip enters the sphincter, a simple pull-through, or "pressure profile" does give the impression of a pressure barrier. The concept of a pressure barrier, however, demands that sphincter pressure must always be higher than the pressure existing in the cavities on either side of the sphincter if the sphincter is to remain competent. The maneuvers summarized by Figure 3 show that this demand is not met, since no change in sphincter pressure is recorded if the recording tip is placed in the sphincter before ampullary pressure is varied.

Our results might be explained if the recording tip, once within a sphincter, was mechanically sealed and therefore no longer able to act as a functional recording device. Once sealed, the sys-

tem would continue to record the pressure contained within it regardless of pressure changes in the area of the recording tip. Thus, the pressure barrier could still exist, but our pressure device would simply be incapable of recording it. If the sphincter were able to collapse the tubing, it would then behave as if it were sealed. This possibility of collapse is eliminated by the fact that records obtained with stainless steel tubing are identical to those obtained with polyvinyl tubing. Another possibility might be that the recording orifice is sealed by mucus, stool, or mucosa. Since most pressure transducers, including ours, require the displacement of very small quantities of fluid into or out of the transducer to record changes in pressure, this seal would allow no further fluid displacement and therefore no pressure change. Our use of small, fluid-filled balloons would seem to eliminate this possibility also, since ample fluid is available for displacement from the balloon after the balloon enters the sphincter.

We are left, then, with the problem of being unable to reconcile our findings with current concepts of the mechanism of action of sphincters. Therefore, we propose an alternative concept: the sphincter does not depend upon tonic contraction or squeeze to remain competent, but simply closes, and then resists being opened. In essence, we are emphasizing the disassociation of squeeze and resistance to distention. An analogy in nature that shows this disassociation is the adductor muscle of the clam (19). The action of this muscle can be clearly separated into two functions, a relatively weak ability to contract but great resistance to forceable elongation. The well-known ability of the clam to remain closed depends on this latter function. This adductor muscle consists of nonstriated muscle that histologically appears homogeneous, but which functionally can be separated into closing and holding components. If we envision sphincter function as being divided into closure and the ability to remain closed, then we would envision the following sequence. After a bolus has passed through the open sphincter, the sphincter would then contract or squeeze until the lumen was just obliterated. Active contraction would stop at that instant, so that there would be no added squeeze and therefore no pressure in the obliterated lumen. The muscle fibers would then remain at

this new length and resist stretching, so that the lumen would be kept closed even though the sphincter muscle was not actively contracting. When the proper stimulus was received, the sphincter fibers would then lengthen or relax and the sphincter would no longer prevent the flow of material through it.

A sphincter that did not depend upon squeeze but rather upon resistance to distention would not only explain our experimental results but would be entirely compatible with the results of other workers. As the recording tip with its fluid meniscus (whether or not covered by a balloon) was brought into the sphincter, the sphincter would close about the tip but not squeeze on it. Since fluid would not be further displaced from the meniscus, pressure recorded from the sphincter would be expected to be simply a reflection of the last pressure to which the tip was exposed before it entered the sphincter. When intra-ampullary pressure is now elevated, there would be no need for the sphincter to squeeze more tightly, since it does not depend upon squeeze for competence. Therefore no increase in recorded sphincter pressure would be expected in response to elevated ampullary pressures, and indeed none is found.

Although the elevated pressure usually found in a sphincteric zone might still be useful in locating the sphincter, quantitation of the pressure within the sphincter would not be expected to give an indication of the strength of sphincter closure. Since it is desirable to measure this strength in order to tell a good sphincter from a bad sphincter, other technics must be employed. Our concept of sphincter action states that resistance to distention is the prime determinant of sphincteric strength. Therefore, it would seem logical that measurement of the radial force applied from within the sphincter that is necessary to open the sphincter might offer a more meaningful guide to evaluation of sphincter effectiveness.

Summary

1) Anal sphincteric pressure as measured with water-filled open-tipped catheters did not change as rectal ampullary pressure varied widely, making the concept of a barrier of pressure to explain sphincteric competence untenable.

2) Pressure measured from the anal sphincter was a function of the last pressure to which the catheter tip had been exposed before entering the anal sphincter rather than an expression of sphincteric contraction or force.

3) Simple intraluminal pressure measurements cannot be used to assess anal sphincteric competence and possibly not the competence of other alimentary sphincters.

4) A concept of sphincteric function has been formulated that stresses resistance to distention rather than squeeze or tonic contraction as the basis of sphincteric competence.

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