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Proof of concept: differential effects of Valsalva and straining maneuvers on the pelvic floor

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ABSTRACT

Objective: To prove a basic physiological principle in healthy women, demonstrating different movement patterns of diaphragm, pelvic floor, and muscular wall surrounding the abdominal cavity during a Valsalva maneuver as opposed to a straining maneuver, by means of real-time dynamic magnetic resonance imaging (MRI).
Study design: The study was performed at Hochzirl Hospital, Austria and Department of Radiology, Medical University Innsbruck, Austria. Four healthy women underwent MRI measurements in a 1.5-T whole body MR-scanner. Coronal, sagittal, and axial slices were acquired simultaneously and a dynamic MRI sequence was used to assess cranio-caudal movements of the diaphragm and pelvic floor and of concomitant changes in anterolateral abdominal muscle thickness and abdominal diameter at the umbilical level.
Results: Both the Valsalva maneuver and the straining maneuver began with deep inspiration and downward movement of the diaphragm. During the exertion phase of both maneuvers, abdominal muscle thickness increased and abdominal diameter decreased. During the Valsalva maneuver, the pelvic floor moved cranially parallel to the diaphragm, whereas during the straining maneuver, the pelvic floor was markedly displaced caudally.
Conclusion: The Valsalva maneuver reflects an expiratory pattern with diaphragm and pelvic floor elevation, whereas during straining the pelvic floor descends.

1. Introduction

The Valsalva maneuver (VM) is named after the Italian physician and anatomist Antonio Maria Valsalva (1666–1723). His principal scientific interest was the human ear. In his original work *De aure humana tractatus* [1] he advised forceful inflation of air from the oro-nasopharyngeal cavity into the Eustachian tubes and the middle ear with concomitantly closed nostrils and mouth. Over time, the VM has become a widely used – albeit modified – medical technique mainly in otorhinology, internal medicine, and urogynecology. In internal medicine, the maneuver is most commonly applied to arrest paroxysmal supraventricular tachycardia [2] and to evaluate heart failure and heart murmurs [3]. In urogynecology, the VM is used in assessment of patients with urinary incontinence and pelvic organ prolapse, to aid diagnosis of intrinsic sphincter deficiency in urodynamic tests, and to demonstrate maximum organ descent during rising intra-abdominal pressure (IAP) [4–7]. The explanation of the VM, however, has not always been clear [8]. As Jellinek summarizes, the VM currently refers to "an acute rise in intra-thoracic and intra-abdominal pressure brought about by contraction of the trunk muscles, right down to the pelvic floor, against a 'stop', at the glottis, but also more peripherally by the tongue in the nasopharynx, or at the lips and nostrils, or even outside the body, as in the blowing up of a column of mercury in a manometer. It is done automatically, and very briefly, in coughing and sneezing; and for longer periods in bodily functions like defecation and parturition; or, more deliberately, in heavy lifting; in various sports; and in the blowing of wind instruments" [9]. Notably, this definition, as well as other generally available literature, clinical investigations, and study protocols, seems to confuse two distinct physiological maneuvers: (1) the VM, in which the abdominal contents and relaxing diaphragm are forced cranially by the effect of increasing IAP, thus increasing and directing intra-thoracic pressure cranially

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toward the glottis and nasopharynx and (2) a straining maneuver (SM), in which the abdomino-pelvic contents are forced caudally by the effect of increasing IAP against the relaxing pelvic floor (PF) in order to support defecation or delivery [10–13]. The purpose of the present study was to show differentiation between the two maneuvers in healthy women, demonstrating different movement patterns of the diaphragm and PF, and changes in anterolateral abdominal muscle thickness and abdominal diameter at the umbilical level during a VM as opposed to SM, by means of real-time dynamic magnetic resonance imaging (MRI) [12,14–16]. Additionally, MRI investigations were performed during forceful breathing, in regard to the relation of the VM and SM to different respiratory tasks.

We hypothesized that (1) the VM is associated with synchronous upward displacement of the relaxing diaphragm and concentrically contracting PF, together with contraction of the anterolateral abdominal muscles – resulting in cranially directed transmission of IAP, similar to a physiological forced expiration, and (2) the SM is associated with downward displacement of the concentrically contracting diaphragm and relaxing PF, while abdominal muscles contract – reflecting caudally directed transmission of IAP during a held inspiration.

2. Materials and methods

2.1. Study subjects

After approval of the study by the local ethics committee and after obtaining written informed consent, two young nulliparous and two perimenopausal female healthy volunteers were investigated. One of the latter was nulliparous (subject 1) the other (subject 2) had had two normal vaginal deliveries. Preceding the MRI, clinical assessment of pelvic floor muscle (PFM) function was performed in a supine position according to the guidelines of the International Continence Society [17]. PFM performance was graded according to the PERFECT scheme by Laycock [18]. Table 1 shows the subjects' demographic characteristics and results of clinical PFM assessment. The women knew about basic mechanisms of diaphragmatic breathing and the role of PF in this context as they had participated in prior related studies [14]. Except for subject 2, none knew about differences between the VM and SM. Instructions given targeted everyday activities: (1) to inflate air into the ears with closed mouth and nostrils as commonly practiced to counteract atmospheric pressure changes, and (2) to strain toward the PF with the intention to defecate. The women did not receive any instructions regarding contraction or relaxation of abdominal muscles or PFM.

Table 1
Characteristics of the study participants ($n = 4$) and results of the PFM assessment – performed according to the PERFECT scheme by Laycock.

	Subject 1	Subject 2	Subject 3	Subject 4
Age (years)	50	50	25	25
Body mass index (kg/m^2)	21	24	22	23
Number of childbirths	0	2	0	0
PFM contraction strength[a]	Strong	Normal	Strong	Normal
PFM endurance (s)	10	10	10	10
PF elevation during PFM contraction	Yes	Yes	Yes	Yes
Co-contraction of the lower abdominal muscles during PFM contraction[b]	Yes	Yes	Yes	Yes

[a] PFM contraction strength was graded according to the International Continence Society (ICS) terminology [13] as absent – weak, normal or strong.
[b] Co-contraction of the lower abdominal muscles during PFM contraction was observed visually and palpated at their suprapubic insertion region [14].

2.2. Dynamic MRI protocol

MRI examinations were carried out on a 1.5-T whole body MR scanner (Magnetom Avanto, Siemens, Germany). Imaging was performed in a supine position. No intravenous contrast medium was administered. Two body-phased array coils were combined with a spinal array coil integrated into the patient table, in order to cover both diaphragmatic and PF motion within one acquisition. After localization, participants were asked to perform three different tasks for 10 s, respectively: (1) to "breathe forcefully three to four times within 10 s without accentuating inspiration or expiration", (2) to perform the VM described as follows: "take a breath, then close the mouth, pinch the nostrils with the thumb and the index finger, than blow air forcefully toward the blocked mouth and nostrils and direct the increasing pressure into the ears", (3) to perform the SM, described as follows: "take a breath, then contract the abdominal muscles and strain downwards with the intention to evacuate stool or urine". A pause of at least 3 min was interposed between tasks. For dynamic imaging, a saturation-recovery spoiled gradient echo-sequence (TurboFLASH) was used with the following parameters: $T_R = 2.7$ ms; $T_E = 1.07$ ms; $T_I = 100$ ms; flip-angle: 12°; acquisition matrix: 160×128; parallel imaging acceleration factor: 2 (*k*-space reconstruction mode: GRAPPA); field of view: 450 mm × 338 mm; slice thickness: 10 mm; acquisition time for one slice: 176 ms. Five slices were measured simultaneously, whereby three slices were directed in coronal orientation, one slice in sagittal orientation, and one slice in transversal orientation. The slices were positioned so that the coronal images contained the apex of the diaphragm as well as the PF. The sagittal slices contained symphysis and os coccygis. The axial slices were performed at the umbilical level.

The above sequence was repeated 12 times; total dynamic measurement time was 11 s in each condition (forceful breathing, VM, SM). The high temporal resolution necessary for dynamic imaging reduced contrast and image quality, nevertheless, the anatomical structures of interest were clearly visualized.

2.3. Analysis of the MRI

Images were analyzed on an external console with zoom facilities and electronic calipers using Image J [19]. In *coronal planes*, cranio-caudal displacements of the diaphragmatic cupolae were measured as described in Fig. 1a. The reference line transecting the basis of the intervertebral disc L4/5 was arbitrarily selected because of its relatively stable position and its consistent and well identifiable presence in coronal images. In *mid-sagittal planes* (Fig. 1b), the pubococcygeal line (PCL) and the M-line were used to define the level of the muscular PF. The PCL is drawn from the inferior point of the pubic symphysis to the last visible coccygeal intervertebral disc [12,20,21]. The M-line is defined as a line perpendicular to the PCL, crossing the posterior anorectal junction [12,20]. The anorectal junction is formed by the U-shaped puborectalis muscle behind the rectum, and can be identified in MRI images between the rear edge of the rectum and the anteroinferior edge of the midline anococcygeal raphe of the iliococcygeus muscle, also known as the levator plate [12,20]. Displacements of the puborectalis muscle along the M-line were measured in order to evaluate PF elevation or descent [12,20]. In *axial planes*, the transverse horizontal abdominal diameter and changes in anterolateral abdominal muscles thickness were measured at the umbilical level as described in Fig. 1c.

During forceful breathing as well as during VM and SM, visually selected images with maximum inferior diaphragmatic positions