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Teaching cardiac autonomic function dynamics employing the Valsalva (Valsalva-Weber) maneuver

Luiz Fernando Junqueira, Jr.

Clinical Medicine Area, Cardiology, Cardiovascular Laboratory, Faculty of Medicine, University of Brasilia, and Division of Cardiology, University of Brasilia Hospital, Brasilia, Brazil

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Junqueira LF Jr. Teaching cardiac autonomic function dynamics employing the Valsalva (Valsalva-Weber) maneuver. *Adv Physiol Educ* 32: 100–106, 2008; doi:10.1152/advan.00057.2007.—In this report, a brief history of the Valsalva (Valsalva-Weber) maneuver is outlined, followed by an explanation on the use of this approach for the evaluation of cardiac autonomic function based on underlying heart rate changes. The most important methodological and interpretative aspects of the Valsalva-Weber maneuver are critically updated, and some guidelines are established for simple application of the maneuver in a teaching or research laboratory setting. These include the hemodynamic and cardiac autonomic mechanisms involved, technical aspects such as the intensity and duration of the expiratory straining, frequency of maneuver sessions, training and posture of the individuals tested, different time- and grade change-dependent indexes of heart interval variation, and clinical application of the maneuver.

cardiac autonomic function testing; baroreflex heart rate control; sympathetic and parasympathetic cardiac modulation

IN RECENT YEARS, an unprecedented interest has emerged about the normal and pathological physiology and clinical evaluation of the autonomic nervous system modulation of the heart. The traditional Valsalva (Valsalva-Weber) maneuver has been commonly and widely employed for many decades for the evaluation of cardiac autonomic function, and thousands of works dealing with it in different areas of medicine have appeared in the literature. This method explores cardiac autonomic control based on tachycardia and bradycardia responses to sudden short-lasting subsequent and alternating induction and liberation of forced expiration against standardized resistance, resulting in an abrupt reduction and elevation of arterial pressure, respectively (2, 10, 12, 13, 16, 22, 23, 25, 27, 33). Thus, this maneuver allows us to analyze the homeostatic aspects of cardiac autonomic function under a condition of stressful stimuli, differently from those in the steady-state condition evaluated by modern short- or long-lasting spontaneous heart rate variability analysis in time and frequency domains (29, 44, 45).

This report provides a brief historical overview of the use of the Valsalva (Valsalva-Weber) maneuver and critically updates and discusses theoretical and practical technical aspects and also considers interpretative concerns of the maneuver, emphasizing the clinical physiology of the underlying heart rate changes and the methodology of its application. These aspects are of great importance for employment of the maneuver for cardiac autonomic testing and also for the accurate interpretation of the implied information about the autonomic nervous system that influences the heart, especially for those not fully familiar with clinical autonomic testing. Class instructors and students at different levels may find it useful as an introduction for the comprehension and demonstration of short-term cardiac autonomic modulation by means a simple, practical, and inexpensive method, which may even be used noninvasively. The present report and all the investigations conducted by the author and here referenced were performed with signed informed consent of the individuals, under the principles of the Declaration of Helsinki and the Brazilian Ministry of Health, and were approved by the Ethics Committee of Research in Human Beings of the University of Brasilia Faculty of Medicine (registry no. 007/98).

Historical Outline

In the center of the history of the expiratory straining maneuver is Antonio Maria Valsalva, a physician born of a noble family in Imola, Italy, who lived from 1666 to 1723. He was, for many years, an eminent anatomy, physiology, and surgery professor at the University of Bologna, where he was a pupil of Malpighi and a teacher of Morgagni. In 1704, he published his most remarkable work, *De Aure Humana Tractatus*, which for more than one century was a reference treatise on the medicine of the ear. In some paragraphs of this book, Valsalva described in detail the procedure that is today extensively used as a physiological maneuver consisting essentially of a sustained forced expiratory effort against the closed glottis, nose, and mouth, lasting some seconds, and at that time was employed with the therapeutic aim of expelling foreign bodies or exudates from the middle ear (6, 8, 11).

Curiously, however, it seems that was not Antonio Valsalva who first described this maneuver. Worthington (50) credited the first description of a maneuver of forced expiration against the glottis, with the mouth and nose closed, with the objective of diagnostic or discharge fluids of a fractured skull, to Leonard of Bertapaglia in his exposition *On Nerve Injuries and Skull Fractures*, published in 1497. On the other hand, Nathan (32) noted that the maneuver was first mentioned for relief following trepanning of the skull by the Renaissance French surgeon Ambroise Paré, who lived from 1510 to 1590, in his book *An Explanation of the Fashion and Use of Three and Fifty Instruments of Chirurgery*, according to an English translation of 1634. Despite these earlier descriptions, the eponym Valsalva maneuver is accepted, honoring a great physician and

Address for reprint requests and other correspondence: L. F. Junqueira, Clinical Medicine Area, Cardiovascular Laboratory, Faculty of Medicine, Univ. of Brasilia, Brasilia DF 70910-900, Brazil (e-mail: lfjunq@unb.br).

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investigator, who was able to give practical importance to a procedure he also helped describe. Many years later, in 1851, the German physiologist Edward Weber detailed the cardiovascular alterations associated with the maneuver (8, 33), allowing its use for diagnostic or investigative objectives.

In view of the fundamental contribution of Weber, indiscriminate use of the eponym Valsalva maneuver may be considered a misnomer, as suggested by Derbes and Kerr (8). Thus, it seems more appropriate to employ the term Valsalva maneuver when the objective is a therapeutic procedure, as used in otolaryngology, urology, and other specialties, and the term Weber experiment when the procedure is used for diagnostic elucidation or to demonstrate functional mechanisms (8), as in heart clinical examinations and investigations of cardiac autonomic function. Alternatively, with the aim of simplification, correction, and justice, it would be preferable to call the procedure the "Valsalva-Weber maneuver."

A fundamental advance in the use of the maneuver was introduced many centuries following the initial description. In 1936, Hamilton et al. (19) characterized the maneuver as consisting of four well-individualized phases of cardiovascular changes reflecting in simultaneous arterial pressure modifications and heart rate reflex responses. Next, in 1947, Rushmer (38) introduced the objective measure of the intraoral pressure generated by the expiratory straining during the maneuver, using a mercury column sphygmomanometer. Thereafter, a practical adaptation of this technique was made by changing the mercury column to a more convenient aneroid manometer.

Following these refinements, knowledge about the maneuver has been greatly expanded and its clinical and diagnostic usefulness were extended, principally in the field of cardiovascular medicine and in the new area of neurocardiology, which is particularly concerned with the study of cardiac autonomic function.

Maneuver Essentials and Functional Effects

The Valsalva-Weber maneuver is a procedure executed in many functional situations in everyday life associated with expiratory straining, usually performed against a closed glottis. It is one of the most informative study methods employed to evaluate the integrity of cardiac autonomic function based on heart rate responses associated with the arterial pressure stabilizing baroreflex mechanism. Although the interpretation of the existing normal or impaired autonomic functional status is complex, the Valsalva-Weber maneuver is a very simple procedure to do by anyone, whether instructor, student, or technician; it may be carried out noninvasively in a few minutes, even without specialized laboratories in outpatient clinical settings, and it is also inexpensive and usually of very low risk. The associated transient cardiovascular changes, autonomic activity modifications, and intrathoracic, intraabdominal, and intraoral pressure increases allows the maneuver to be used as a tool in the understanding and diagnostic evaluation of several clinical conditions.

To perform the maneuver, the subject is asked to blow after a full inspiration against the resistance represented by one mouthpiece tubing connected to an aneroid manometer to maintain a constant expiratory effort equivalent to an intraoral pressure of 40 mmHg during a certain period of time, imitating a cough act without permitting the escape of air from the nose and mouth (Fig. 1). This is usually done in the supine position.

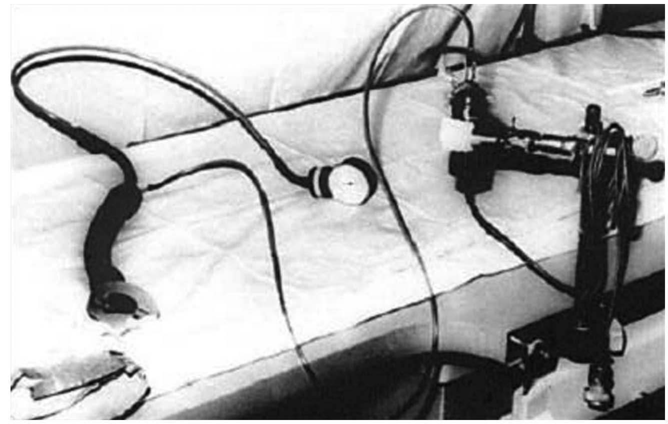

Fig. 1. Example of a device for performing the Valsalva-Weber maneuver. A mouthpiece is mounted onto flexible tubing connected to an aneroid manometer. The "Y" connection is an option for simultaneous recording of intraoral pressure by means of a pressure transducer.

After this period, the expiratory straining is suddenly released, and the respiration should be maintained as regularly as possible without gasping.

By increasing the intrathoracic and intra-abdominal pressure, the straining results in a decrease in the venous return of blood to the heart with an increase in venous pressure, progressive arterial pressure reduction, and, consequently, a progressive compensatory baroreflex-mediated heart rate increase. Following cessation of the straining phase, these functional changes are abruptly reversed, resulting in an overshoot of arterial pressure that is accompanied by a rapid and progressive baroreflex bradycardia lasting some seconds until the return of blood pressure and heart rate to basal levels (8, 12, 18, 40, 46).

The maneuver may be done invasively, by recording the arterial pressure by means of an indwelling needle directly in a peripheral artery, with the continuous recording of the electrocardiogram in one lead for heart rate or heart interval series acquisition. Alternatively, it may be also performed noninvasively, by only recording the conventional electrocardiogram. Exclusive employment of the heart rate change evaluation without the simultaneous direct recording of arterial pressure has been shown to be a reliable method to assess cardiac autonomic function, in addition to the advantage of being noninvasive and very easily executed (3, 12, 16, 22, 25, 27, 37).

The maneuver should be considered effective when facial flushing and plethora, neck vein engorgement, and increased muscle tension in the abdominal wall are observed in addition to the full expansion of the thoracic cage (Fig. 2). These signs are very important to be observed when subjects perform the maneuver noninvasively without blood pressure being recorded.

The Valsalva-Weber maneuver consists of four phases of acute short-lasting heart rate and arterial pressure simultaneous and sequentially alternating changes (19), as shown in Fig. 3 from a maneuver taken invasively showing arterial pressure and heart rate changes (*top*) and noninvasively showing only equivalent heart interval changes (*bottom*): *1*) rapid inspiration and onset of the expiratory straining with a variable bradycardia associated with a transient systolic arterial pressure rise (phase I); *2*) maintenance of the straining with an incremental relative tachycardia secondary to a progressive decrease in arterial pressure (phase II); *3*) release of the strain with pro-

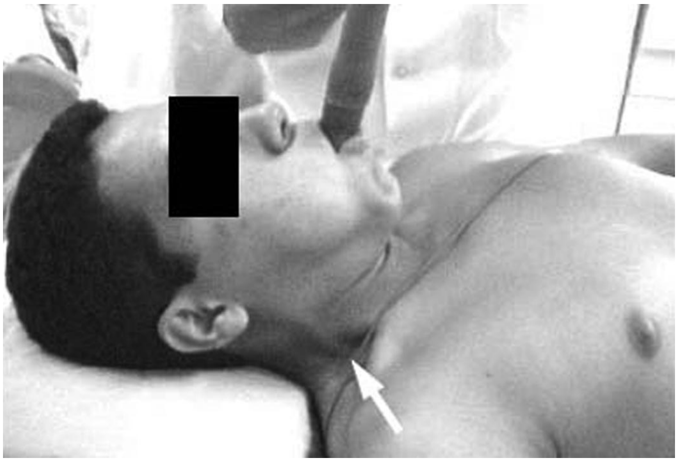

Fig. 2. Exteriorized manifestations of the expiratory straining period of an effective Valsalva-Weber maneuver. The subject exhibits facial flushing and plethora extending to the ear and nose as well as congested and distended external jugular veins (arrow).

gression of the tachycardia to the maximum level following an additional sudden dip in arterial pressure (phase III); and *4*) poststraining reversion of the tachycardia and onset of the progressive relative bradycardia in response to the rapid arterial pressure overshoot, which lasts several seconds until the complete recovery to the basal level (phase IV). A conspicuous bradycardia response instead of the expected tachycardia during the expiratory straining (phase II) can be observed in normal subjects with a marked vagotonic state, particularly when a low strain pressure is employed (26).

Heart rate responses to the Valsalva-Weber maneuver are the result of reflex mechanisms, predominantly of baroreceptor origin, which involve principally the parasympathetic autonomic nervous system but also the sympathetic division (10, 14, 25, 37, 43). Cardiopulmonary and chemoreceptor reflexes appear to be also involved to a lesser extent, interacting with the baroreflex (41). The phase III to IV progressive bradycardia that follows the liberation of straining is thought to be due to parasympathetic activation alone, because of the very rapid functional action of this autonomic division or possibly combined with some sympathetic inhibition. The mechanism of the tachycardia during the maneuver remains controversial, with some authors suggesting exclusive slow enhancement of the sympathetic activity, others crediting it to exclusive rapid depression of parasympathetic outflow, and still others attributing it to combined synergistic opposing autonomic effects (4, 10, 43).

Clinical Physiology Application

The quantification of heart rate or heart interval variations associated with the Valsalva-Weber maneuver has been used as a sensitive, reliable, reproducible, and very simple method for characterizing the suddenly acting cardiac autonomic modulation. This approach has helped characterize particularly the parasympathetic nervous function in healthy subjects and patients with different clinical conditions, such as diabetes mellitus (3, 4, 9, 16, 20), systemic arterial hypertension (47), coronary disease (48), heart failure (1, 36), chronic Chagas' disease (2, 17, 21, 22, 30, 31, 34), neurological diseases (7, 28, 49), and renal failure (15, 39), among many others.

Different time- and grade change-dependent indexes of R-R interval variations can be calculated from the various phases of the maneuver (10, 16, 21, 22, 25, 27, 30), as shown in Fig. 3, *bottom*. Grade change-dependent indexes are those indicating relative changes in R-R intervals and include the following: *1*) relative tachycardia, defined as the percent difference between the shortest R-R interval during the maneuver or immediately after it (maximum tachycardia in phase III) and the longest control R-R interval observed immediately before the

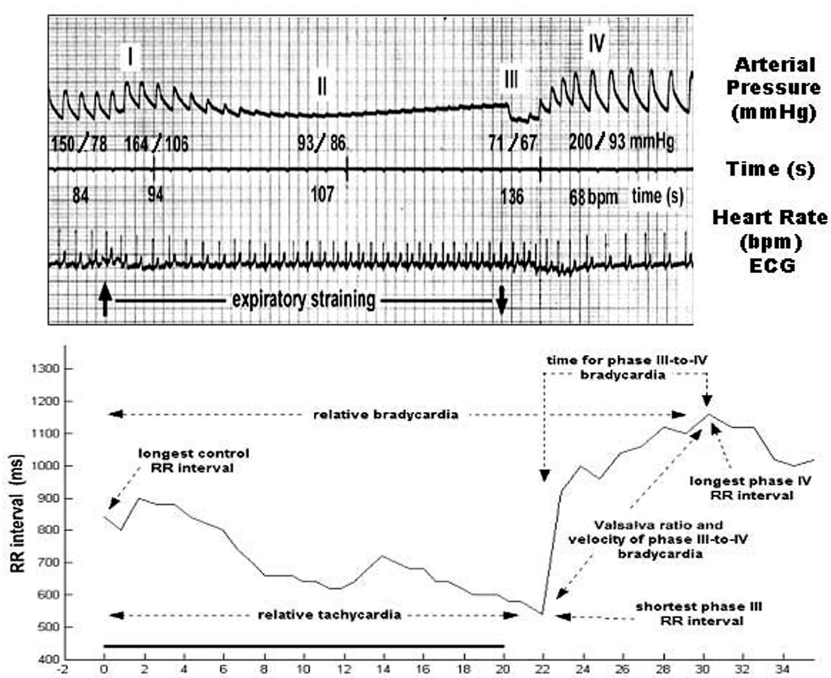

Fig. 3. Recordings of a typical normal pattern of heart rate or heart interval baroreflex responses to arterial pressure changes associated with phases I–IV of one Valsalva-Weber maneuver performed during 20 s of expiratory strain (arrows and bar) at an intraoral pressure of 40 mmHg by the same subject in the supine position. *Top*: recordings of femoral arterial pressure directly obtained and the DII lead electrocardiogram (ECG) recorded at a paper speed of 12.5 mm/s with heart rate changes. *Bottom*: equivalent R-R interval changes that may be obtained noninvasively without the arterial pressure recording, with time - and grade change-dependent indexes. Arterial pressure values are given in mmHg, heart rate values are given in beats/min (bpm), and heart intervals are given in ms.

maneuver; *2*) relative bradycardia, as the percent difference between the longest R-R interval after the maneuver (maximum bradycardia in phase IV) and the longest control R-R interval; and *3*) the Valsalva ratio (25), which is the ratio between the longest R-R interval after the maneuver (maximum bradycardia in phase IV) and the shortest R-R interval (maximum tachycardia in phase III). Time change-dependent indexes, as introduced by the author, are those indicating the duration of R-R interval changes and include the following (21, 22): *1*) time for the maximum R-R interval variation, or time for phase III to IV bradycardia (Valsalva delay), expressed as the time from the maximum tachycardia in phase III (the shortest R-R) to the maximum bradycardia in phase IV (the longest R-R); and *2*) velocity of the maximum R-R interval variation, or velocity for phase III to IV bradycardia (Valsalva sensitivity), which is the rate of the total bradycardia attained corrected by their duration, defined as the ratio between the percent difference of the maximum bradycardia in phase IV (the longest R-R interval) to the maximum tachycardia in phase III (the shortest R-R interval) and the time for attaining the change. This last index can be considered to be an indirect estimate of baroreflex bradycardia sensitivity or an alternative expression of that, since it estimates the grade of the bradycardia response corrected for the stimulus, expressed in terms of time.

In a large series of 52 healthy subjects aged 17–49 yr (39 men and 13 women) examined by the author (22), the percent decrement of the R-R interval (relative tachycardia) showed a mean ± SD value of 35 ± 7.8% ms. The increment in heart interval (relative bradycardia) showed great individual variability, with a mean ± SD value of 23.7 ± 15.6% ms, and so it is not a good and reproducible index. The Valsalva ratio has been the more commonly employed index, and its mean ± SD value in a different series of normal individuals ranged between 1.62 ± 0.12 and 2.10 ± 0.30 (3, 13, 16, 17, 22, 31, 34, 37). Based on a large number of individuals examined by different authors, the value of 1.50 has been considered the lower limit of normality for the Valsalva ratio (25, 27). Time-dependent indexes as mean ± SD values derived from the same reported series of individuals were 11.1 ± 5.2 s for the time for phase III to IV bradycardia and 10.3 ± 5.1%/s for the velocity of this response. The normal upper limit for the first index was 24.7 s, and the normal lower limit for the velocity was 2.4%/s (21, 22).

In the case of cardiac autonomic dysfunction associated with different clinical conditions, grade- and time-dependent alterations of the indexes of tachycardia and bradycardia responses are related to the distinct phases of the maneuver. These heart rate responses demonstrate distinct patterns of subtle or gross disturbances in parasympathetic and sympathetic modulation of the sinus node due to damage to the autonomic nervous system at different levels.

Time change-dependent indexes, such as the time for phase III to IV bradycardia and the velocity for attaining this bradycardia, appear to be more sensitive for the detection of subtle cardiac autonomic dysfunction than grade change-dependent indexes, such as phase III tachycardia and phase IV relative bradycardia responses and the very commonly used Valsalva ratio (21, 22). Therefore, changes in these two time-dependent indexes may be the only subtle early alterations encountered in particular individuals. In contrast, one can say that when alterations in grade change-dependent indexes are established, time-dependent indexes should also be altered.

Direct noninvasive evaluation of the baroreflex sensitivity employing the Valsalva-Weber maneuver has been also conducted alternatively to phenylephrine injection and neck chamber methods. From the correlation between each systolic pressure peak and the corresponding subsequent R-R interval during the hypertensive overshoot in phase IV of the maneuver, an index of the baroreceptor reflex sensitivity can be calculated. These methods for calculating the baroreflex gain have been demonstrated to be useful, reliable, accurate, and well correlated with other methods (24, 35, 36, 51).

Methodological and Interpretative Concerns

A critical question when the maneuver is done noninvasively is the comparability of the results among distinctive groups of individuals, since the R-R interval changes are not quantified in relation to the simultaneous recordings of blood pressure alterations. In fact, as indicated by Eckberg (10), difficulties can arise in interpreting R-R interval or heart rate responses to the Valsalva-Weber maneuver for subjects tested when appropriate control subjects are not used or if rigorously similar methodological aspects are not observed. To avoid theses difficulties, stimuli associated with the maneuvers should be comparable in both groups studied. That is, the maximum depth of inspiration before straining, the duration of straining, and its magnitude dictated by the magnitude of the intraoral pressure should all be well controlled. An important point in doing the maneuver is that the procedure is not a held deep inspiration but a forced expiration acting against a resistance (5).

Although the Valsalva-Weber maneuver has been employed for a long time and is a well-established investigative and diagnostic tool, the duration of the expiratory straining has been variably applied and is still under dispute, with several authors employing 15 s, others employing 20 s, and some applying as few as 10 s or much as 30 s. The 15-s duration of strain is the most common protocol employed, but the alternative 20-s protocol for maneuvers applied invasively or noninvasively has been standardized and systematically used for many years by some researchers (10, 22, 30, 31, 33, 37).

The question regarding which protocol to employ may be raised on the basis of three aspects: the capacity of the subject to sustain a continuous strain, the presence of potential risks capable of resulting in possible undesirable effects, and sufficient stimuli to detect subtle autonomic disturbances.

The 20-s protocol provokes a more potent and long-lasting stimulus and arterial pressure changes, inducing conspicuous and reliable heart rate baroreflex responses and marked modifications in parasympathetic and sympathetic activities. These responses are critical to evaluate the cardiac autonomic nervous system modulation in conditions of variable and frequently subtle autonomic dysfunction, such as may occur in forms of chronic Chagas' disease, diabetes mellitus, and other conditions with primary or secondary cardiac autonomic involvement. Healthy controls, chronic Chagas' disease patients, and other individuals the author has tested over many years were able to sustain the expiratory strain for 20 s very well. There were never any difficulties with this protocol, and it has proved to be pertinent, valid, reliable, and safe for the individuals that the author has examined. The maintenance of a constant intraoral pressure of 40 mmHg must be rigorously controlled, thus generating uniform and persistent elevation of intrathoracic pressure during the straining.

Therefore, for the purpose of cardiac autonomic evaluation, both the 15- or 20-s straining durations may be used. No strong reasons exist, however, for establishing the 15-s protocol as advantageous and the standard one. The 20-s protocol seems to be more reliable to warrant unquestionable and sufficient stimuli for evaluating subtle or variable impairment of the cardiac autonomic nervous system modulation in any clinical condition. The 10- and 30-s protocols have no practical or functional interpretative advantages and should be abandoned for less diversity of protocols or other difficulties; the 10-s duration is unreliable, and the 30-s protocol may be unexpectedly dangerous. Despite these considerations, no study has yet been published comparing the cardiovascular responses derived from maneuvers employing different durations of expiratory straining period in the same subject.

Although the maneuver very uncommonly results in undesirable or deleterious effects, the clinical condition of the subject examined should be also considered for the choice of the protocol to avoid health risks. This is important as potential complications may happen associated with the marked arterial pressure decrease in phases II or III, the increase in phase IV, and tachycardia or bradycardia, respectively. Potential adverse events can include retinal hemorrhage, urinary incontinence, syncope, chest pain, arrhythmias, severe hypertensive or hypotensive reactions, or cerebral stroke, among others. Subjects who are sensitive to transient changes of arterial pressure and heart rate or who are prone to arrhythmogenesis, such as individuals with hypertension or hypotension, coronary disease, valve disease, cardiac congenital disease, heart failure, cardiovascular asthenia, previous syncopal attacks, and supposed autonomic insufficiency, should perform the maneuver very cautiously, preferentially using the 15-s straining protocol. In all cases, approval for applying the maneuver should be obtained from an institutional protocol review board. A minimum of common emergency equipment or tools, such as a cardiac monitor with cardioverter/defibrillator, ambu bag, oxygen, drugs, and general materials, should be also readily available at the laboratory or ambient where the maneuver will be done.

As for other technical aspects, the supine position adopted during the maneuver by the subject and the level of 40 mmHg for the intraoral expiratory pressure against the manometer appear to be consensual, and they have not been disputed. When necessary, the sitting or orthostatic position and another level of intraoral pressure have been employed. In these cases, it should be stressed that posture has a significant influence on arterial pressure changes and baroreflex sensitivity associated with the Valsalva-Weber maneuver; upright positions result in more pronounced effects in arterial pressure during phases II and IV of the maneuver and a reduction of baroreflex gain (42). Therefore, some of the indexes of heart interval responses to the Valsalva-Weber maneuver may be critically influenced by the posture adopted.

A technical concern with respect to the simplicity of employment of the maneuver is the difficulty or impossibility of some individuals to adequately attain the standard intraoral pressure with straining or to maintain it for a sufficient time. These restrictions, however, can be usually avoided by providing the subject with some training sessions prior to performing the maneuvers.

Finally, in view of the variable intensity of the effects that may occur due to the nonuniformity of the respiratory stimulus applied and of the variable technical adaptation, a certain dispersion of the data obtained from a group studied is a possibility. Thus, for a more precise functional evaluation, the Valsalva-Weber maneuver should be sequentially performed in a subject usually for three to four times on the same occasion, and the individual mean values of the isolated indexes should be obtained, even when the maneuvers are well controlled. Despite the occurrence of relative dispersion, the indexes of heart rate changes obtained with the application of the Valsalva-Weber maneuver in different times have been demonstrated to be very reproducible in both normal and diabetic subjects (3).

Summary Application Guidelines

For practical application of the Valsalva-Weber maneuver and acquisition of unbiased valid results to evaluate cardiac autonomic function, the following standardized guidelines are suggested:

1. The maneuver may be performed invasively by registering continuously and simultaneously the heart rate or R-R intervals obtained from the conventional electrocardiogram and the arterial pressure directly taken from a peripheral artery or it may be alternatively done in a noninvasively manner by only registering the electrocardiogram for heart rate or R-R interval measurements.

2. The maneuver should be preferentially performed with the subject resting in the supine position with a slight inclination of the head in an ambient without any interference.

3. At least three maneuvers should be sequentially performed to obtain individual mean indexes of heart rate responses. Sufficient time, ~5–10 min, should be allowed for the return of variables to baseline levels following each maneuver.

4. Stimuli associated with the maneuver, namely, the depth of inspiration before straining, the duration of straining, and its intensity (expressed by the magnitude of the intraoral pressure of 40 mmHg), should be all controlled as much as possible.

5. In doing the maneuver, a held deep inspiration not followed by a forced expiration against a resistance should be avoided.

6. The duration of the expiratory strain period of the maneuver does not seem to be critical in the interpretation of the cardiac autonomic function and mechanisms based on heart rate responses except for conditions where the autonomic disturbance evaluated is expected to be subtle and variable. In these conditions, the 20-s duration of the expiratory straining period seems quantitatively more reliable, since there are no clinical restrictions that require performance of the maneuver more cautiously. Otherwise, the 15-s duration of straining is an adequate and safer alternative to be applied.

7. To avoid the difficulty of some individuals in adequately performing the maneuver, training sessions should be conducted before valid testing sessions.

Concluding Remarks

The Valsalva maneuver or Weber experiment, or Valsalva-Weber maneuver, has a long history of useful employment in multiple fields of physiology and medicine. Regarding the cardiac autonomic function investigation in healthy individuals and in subjects with different clinical conditions, the maneuver has greatly contributed, respectively, to our understanding of normal and abnormal underlying functional mechanisms. Baroreflex tachycardia due to simultaneous sympathetic activation and parasympathetic inhibition in response to acute transient and progressive hypotension during the expiratory straining phase of the maneuver is first induced, followed by baroreflex bradycardia of almost exclusively parasympathetic origin consequent to the suddenly evolving hypertension after the release of straining. In general, the technical aspects involved are well uniform and standardized. The maneuver consists of an expiratory effort after a full inspiration, against tubing connected to a manometer, to maintain an intraoral pressure of 40 mmHg during 15 or 20 s of strain. Other levels of intensity and durations of the expiratory effort may eventually be employed but are not justified since these may induce practical or interpretative difficulties and should be abandoned for uniformity, safety, and reliability. With respect to the evaluation of heart rate or heart interval responses, different time- and grade change-dependent indexes may be calculated, which present good reproducibility and distinct sensitivities and specificities in the characterization of normal and altered cardiac autonomic function.

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