PHYSIOLOGY

Dynamics of Swallowing-Induced Cardiac Chronotropic Responses in Healthy Subjects

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Translated from *Byulleten' Eksperimental'noi Biologii i Meditsiny*, Vol. 135, No. 4, pp. 377-381, April, 2003
Original article submitted December 27, 2002

Simultaneous recording of ECG and swallowing movements in healthy humans (n=23, age 20-57 years) showed that each swallow is accompanied by transient tachycardia with initial abrupt and pronounced heart rate increase. These rapid changes in heart rate (evaluation by maximum increment of heart rate over two successive heartbeats, ΔHR_{2bt}) are typical of vagal chronotropic responses. The amplitude of tachycardia induced by a single swallow was significantly higher in the supine position (13.1±5.6 bpm) compared to the standing position (8.5±3.8 bpm; $p<0.0001$). Chronotropic responses to a series of three or more successive swallows consisted of two phases, the initial abrupt acceleration and subsequent slower growth of heart rate. In the standing position, the portion of the first rapid phase significantly decreased, while the portion of the slower phase increased compared to the supine position. The amplitude of tachycardia induced by a single swallow and parameter ΔHR_{2bt} can serve as indices of the strength of parasympathetic modulation of the heart. By contrast, further slow increase in the heart rate determined by summation of responses to a series of successive swallows can result from not only inhibition of the parasympathetic influences, but also enhancement of sympathetic activity during swallowing.

Key Words: *swallowing-associated tachycardia*; *cardiac chronotropic regulation*; *parasympathetic influences*

In 1883, S. Meltzer first demonstrated a transient but pronounced acceleration of heart rate occurring synchronously with swallowing in humans [2]. In some cases it was accompanied by subsequent slight bradycardia. Development of ECG gave new impetus to investigation of this phenomenon, and soon it was established that tachycardia during swallowing is normally observed in all subjects. However, the amplitude of deglutition tachycardia (DT) is age-dependent and characterized by considerable interindividual variability. It is noteworthy that the potent tachycardiac responses were observed in dogs during eating [1]. Recently it was established that nonperiodic waves of tachycardia associated with swallowing can significantly decrease the accuracy of estimation of the power spectral components of heart rate variability [2].

The swallowing act represents a complex highly coordinated motor activity involving muscles of the tongue, larynx, pharynx, and esophagus. The main function of swallowing is effective and quick propulsion of food or saliva via the pharynx to provide rapid resumption of breathing and to protect upper airways from aspiration. The mechanisms responsible for tachycardia associated with deglutition are poorly understood. In particular, it is point at issue whether DT is a reflex response to excitation of specific receptors or it is completely of central origin. On the one

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0007-4888/03/1354-0322$25.00

hand, mechanical stimulation of superficial receptors in the posterior pharyngeal wall and the posterior pillars initiates reflex swallowing in cats, while, in humans, voluntary muscle efforts at similar pharyngeal zones induces tachycardia [2]. On the other hand, stimulation of the superior laryngeal nerve can induce long-term self-excitation in a group of brain stem neurons ("central pattern generator"). Such self-excitation ("central command") develops in parallel with contractions of swallowing muscles, but can also be generated independently of the feedback from the pharyngeal and esophageal receptors [3]. The dorsal swallowing group of neurons generating the basic swallowing pattern is located predominantly within the nucleus tractus solitarius, the first sensory relay for many autonomic reflexes [3]. It can be hypothesized that DT results from a nonspecific irradiation of excitation from the "swallowing center" to the neighboring brain stem regions. Otherwise, DT can be a manifestation of complex interactions between swallowing, respiratory and cardiovascular neuronal networks [3] during realization of the "central program" of swallowing.

According to S. Meltzer, the efferent mechanism of cardioacceleration during swallowing is transient inhibition of vagal preganglionic motoneurons and attenuation of vagal tonic inhibitory influences on the heart. Swallowing can considerably diminish bradycardia during various vagal maneuvers (diving reflex, Aschner reflex) in humans, while injection of atropine or vagotomy abolishes the ingestion-induced tachycardia in dogs [1]. These findings suggest a primary role of the parasympathetic nervous system as the efferent mechanism of DT. As vagal activity is posture-dependent, one can suppose that DT during standing will differ from that during supine rest.

This work was aimed at elucidation whether DT depends on the baseline level of parasympathetic chronotropic influences of the heart. For these purposes, we studied the dynamics and amplitude of deglutition tachycardia in healthy subjects induced by a single swallow or a series of successive swallows in both supine and standing positions.

MATERIALS AND METHODS

Changes in cardiac sinus rhythm during swallowing were studied in 23 healthy volunteers (12 men and 11 women) aged 20-57 years. All tests were performed before the morning meal, excluding smoking after sleep. ECG potentials were recorded in the chest lead CS1 (similar to standard lead II) and, simultaneously, the swallowing movements were recorded, using a thin-walled rubber capsule fixed on the neck above the thyroid cartilage. Amplified ECG signals and electric signals from a transducer, which measured pressure oscillations within the rubber capsule during swallowing, passed to a computer via a Biola 12-bit analogue-to-digital converter.

Recordings were started after 10-min relaxation in the rest supine position. First, the participant was asked to make a swallow every 30 sec (5-6 trials), then triple swallows (4 trials, pause 1 min), and 5 swallows one-by-one (without repetition). This protocol provided high reproducibility of swallowing-induced tachycardiac responses. Drinking water through a tube (7-10 small swallows) completed this set of tests (Fig. 1, *a*). Afterwards, the subject stood up and all tests were repeated.

The data were processed off-line using original software. This processing included transformation of ECG signal into cardiotachogram (Fig. 1, *a*), automatic search for 40-sec fragments containing swallows and sorting by the number of swallows in a series. The selected fragments were plotted synchronously by the start of swallows (t=0, Fig. 1, *b*, *c*) and averaged. The method of coherent averaging allowed clearing up the dynamics of deglutition-induced changes in the heart rate by reduction of respiratory and other oscillations of non-swallowing origin. The amplitude of DT was evaluated from average responses by measuring the difference between the peak value of heart rate during response and the mean heart rate calculated for 10 sec before swallowing. In addition, the maximum increment of heart rate during two successive heartbeats (ΔHR_{2bt}, Fig. 2) was determined. Individual parameters were averaged and the means and standard deviation for the group of participants were calculated.

The differences between the means were statistically analyzed by paired Student's t test.

RESULTS

In the supine position at rest, pronounced DT clearly seen against the background of respiratory arrhythmia was observed in 21 of 23 subjects (Fig 1, *a*). In two other subjects (22 and 25 years old) tachycardia induced by a single swallow (DT_1) was masked by respiratory oscillations. Even in these cases, the dynamics of heart rate changes associated with swallowing was successfully revealed by the method of coherent averaging. The magnitude of DT_1 varied in a wide range from subject to subject (4.8-24.3 bpm), but was characterized by stable dynamics and amplitude in the same individual (Fig. 1, *a*, *b*).

The characteristic feature of DT in healthy humans is an abrupt heart rate acceleration at the beginning of the response. A single swallow induced a brief tachycardiac response with fast recovery to the baseline level (Fig. 2, *2*). Entire duration of the response was less than 10 sec. Mean amplitude of DT_1 in the

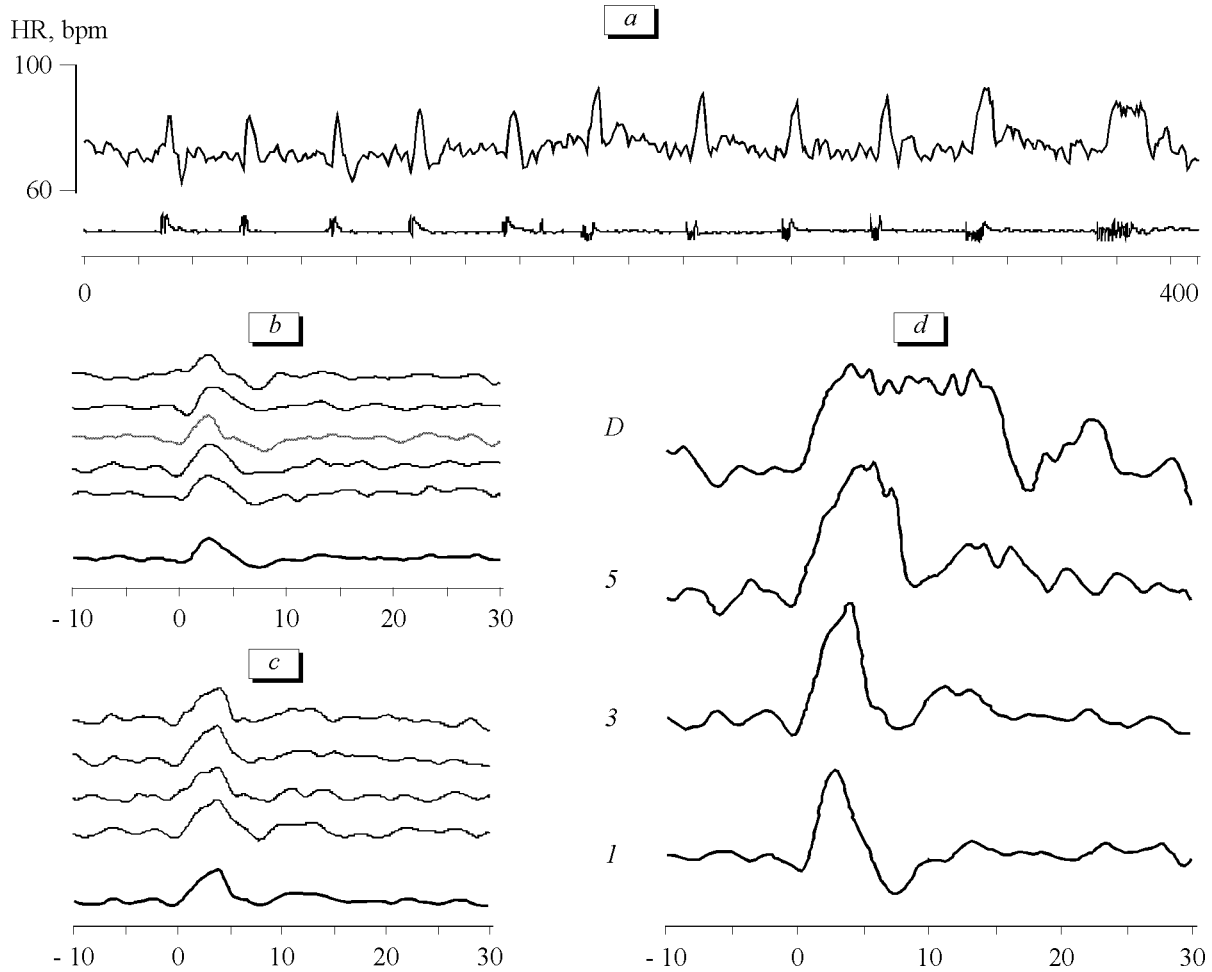

Fig. 1. Tachycardia induced by single or serial swallowing in a supine subject (44 years old). *a*) cardiotachogram of a 6-min ECG record (upper trace) containing swallowing-induced responses and synchronous record of swallowing movements (lower trace). *b*) 40-sec fragments, each contains a heart rate response induced by single swallow; thick line: average response. *c*) 40-sec fragments, each containing a heart rate response induced by a triplet of swallows; thick line: average response. *d*) average responses induced by different number of swallows (figures on the left side of each graph, D — drinking). Horizontal: time, h. Vertical: HR, bpm.

supine position was 13.1±5.6 bpm, which was practically identical to the maximum increase in heart rate during two beats, ΔHR_{2bt} (12.9±5.1 bpm). If swallows went on one by one, heart rate continued to grow, but not so rapidly as initially (Fig. 2, *1*). Three phases of heart rate changes can be easily separated in DT induced by a series of 3 or more successive swallows: an abrupt increase, slow growth, and recovery phase (Fig. 2). The initial abrupt increase in heart rate lasted only 2-3 heartbeats. In supine subjects, the amplitude of this phase constituted the most part of the entire amplitude of the response. The maximum DT was attained after 5-10 swallows. This maximum depended to a great extent on the rate of swallowing.

Abrupt cardioacceleration in the initial phase of DT suggests inhibition of vagal activity. Our findings show that this initial phase is completely determined by the fist swallow in a series, and does not depend on the subsequent swallows (Fig. 3, *a*, *2*). Further increase in heart rate during the slow phase corresponded to summation of responses to a series of successive swallows. This summation has a non-linear character, because the contribution of each subsequent swallow is lower than that of the previous one (Fig. 2 and 3, *a*, *1*). After the end of swallowing heart rate rapidly decreases, indicating strong reactivation of vagal motoneurons just after the end of swallowing (Fig. 1, *d*; Fig. 2). In some participants, tachycardia was followed by slight bradycardia (heart rate decreased below the initial level).

The dynamics of DT differed significantly in the standing and supine positions. In standing subjects both DT_1 and ΔHR_{2bt} (8.5±3.8 and 7.6±2.3 bpm, respectively) were about 1.5-fold lower than in supine subjects ($p<0.0001$, Fig. 3). On the contrary, the contribution of slow phase to DT in the standing position considerably increased. As a result, despite a considerable decrease in the amplitude of the initial abrupt

phase the maximum response amplitude (DT_{5-10}) remained in standing subjects as high as in supine ones.

The abrupt increase in heart rate (during 1-2 sec) at the beginning of DT can be attested only to inhibition of vagal firing during swallowing, because slow adrenergic synapses can not effectively provide transmission of sympathetic signals over so short intervals (1-2 sec) [4]. By contrast, during the slow phase of DT, it can not be excluded a possible contribution of the sympathetic drive to the heart rate increase. In fact, the duration of the tachycardiac response induced by three or more swallows is sufficient for the development of a potential sympathetic component. There is evidence that sympathovagal interaction can also influence the dynamics of chronotropic response. Thus, the bradycardiac response to vagal stimulation is progressively blunted as the frequency and duration of the antecedent sympathetic stimulation increases [7]. In addition, slowing of carotid-cardiac baroreflex with standing was established [5]. By analogy, blunting of the dynamics of tachycardiac response to reported swallowing or drinking observed in the standing position could also be related to sympathovagal interaction under enhanced sympathetic influences. However, the dynamics of chronotropic cardiac responses can depend on the state of central structures of autonomic regulation, and, particularly, on interactions between sympathetic and vagal cardiac afferent inputs in the nucleus tractus solitarius [6].

In two subjects, we studied the effects of local anesthesia of the oropharyngeal mucosa with lidocaine spray (10%) on DT. Under local anesthesia, one subject experienced some difficulty in swallowing at the command of investigator. This attests to impairment of swallowing control and confirms published data on

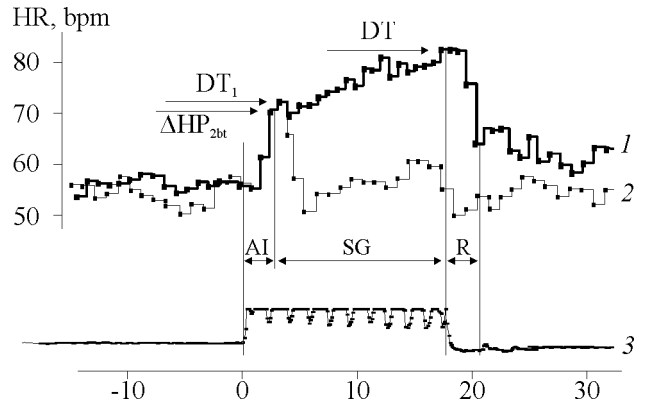

Fig. 2. Beat-by-beat dynamics of tachycardiac responses induced by swallowing and measured parameters. Cardiotachograms corresponding to single swallow (*1*) and to a series of 10 successive swallows (*2*) synchronized by the start of first swallow (*t*=0). Arrows indicate ΔHR_{2bt}, DT_1, DT, and phases of abrupt increase (AI), slow growth (SG), and rapid recovery of heart rate immediately after the end of swallowing (R).

the role of pharyngeal receptors in the swallowing act [3]. DT in this subject was significantly reduced by anesthesia (9.1 *vs.* 13.7 bpm in the control) and was hardly seen against the background of respiratory oscillations of heart rate. Other participant did not experience difficulties in swallowing and demonstrated even higher amplitude of DT under local anesthesia. Thus, DT depends not only on the strength of parasympathetic influences, but also on functional properties of the pharyngeal receptors, and on coordination of swallowing movements. Hence, the state of cardiac parasympathetic regulation can not be assessed only by DT (similarly to other indirect indices, for example, respiratory sinus arrhythmia). At the same time, inherent stability of DT due to highly coordinated and stereotyped pattern of swallow-related muscle

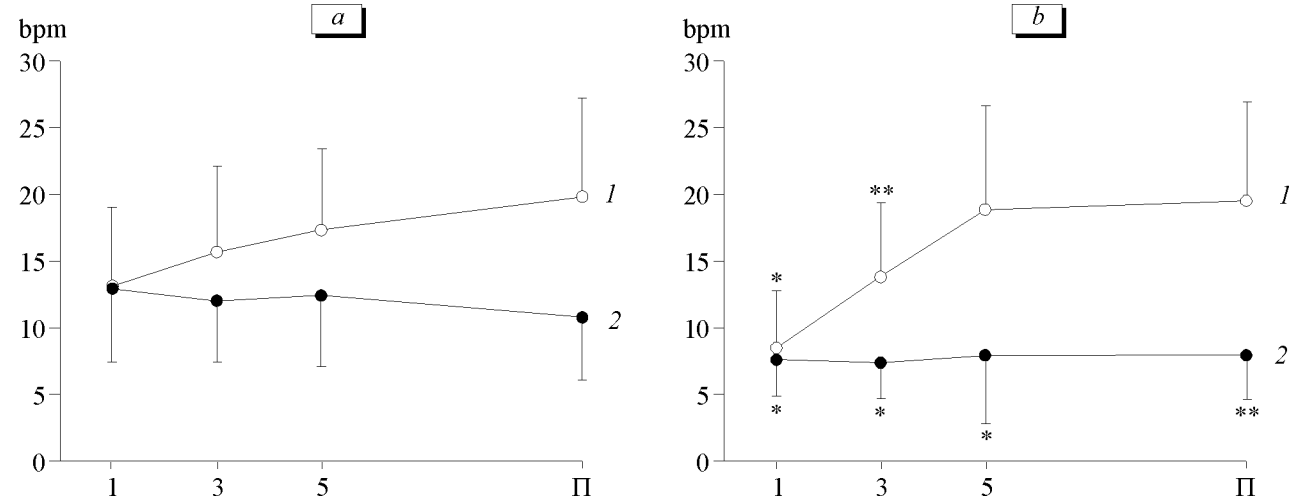

Fig. 3. Amplitude of deglutition tachycardia (*1*) and maximum increment of heart rate during two successive heart beats (*2*) as a function of the number of swallows in a series (figures on abscissas, D: drinking water) in healthy subjects in supine (*a*) and standing positions (*b*). The data are presented as means±standard deviations for the group of subjects (*n*=23). **p*<0.0001; ***p*<0.05, compared to the supine position.

activity can be used for monitoring of cardiac parasympathetic regulation and during physiological probes in the same individual. Parameters DT_1 and ΔHR_{2bt}, reflecting rapid changes in heart rate can serve as indices of vagal chronotropic regulation of the heart.

In conclusion, swallowing is a gentle natural stimulus, which disturbs autonomic regulation of the heart for a short time. Regular swallowing is not a load for organism, and it can be easily reproduced many times. Thus, swallowing is a convenient physiological probe to study autonomic nervous regulation of heart rate.

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