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Calculation of upper esophageal sphincter restitution time from high resolution manometry data using machine learning

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HIGHLIGHTS

- Physiological data for the restitution time of the upper esophageal sphincter are provided.
- The restitution time is determined by swallowing specialists and objectively by a Machine Learning model.
- The implemented Machine Learning model is partly independent of the input of the investigators.
- The methods provided can be a basis for a complete automatic evaluation of high resolution manometry data in the future.

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ABSTRACT

Objective: After swallowing, the upper esophageal sphincter (UES) needs a certain amount of time to return from maximum pressure to the resting condition. Disturbances of sphincter function not only during the swallowing process but also in this phase of pressure restitution may lead to globus sensation or dysphagia. Since UES pressures do not decrease in a linear or asymptotic manner, it is difficult to determine the exact time when the resting pressure is reached, even when using high resolution manometry (HRM). To overcome this problem a Machine Learning model was established to objectively determine the UES restitution time (RT) and moreover to collect physiological data on sphincter function after swallowing.

Methods and material: HRM-data of 15 healthy participants performing 10 swallows each were included. After manual annotation of the RT interval by two swallowing experts, data were transferred to the Machine Learning model, which applied a sequence labeling modeling approach based on logistic regression to learn and objectivize the characteristics of all swallows. Individually computed RT values were then compared with the annotated values.

Results: Estimates of the RT were generated by the Machine Learning model for all 150 swallows. When annotated by swallowing experts mean RT of 11.16 s ± 5.7 (SD) and 10.04 s ± 5.74 were determined respectively, compared to model-generated values from 8.91 s ± 3.71 to 10.87 s ± 4.68 depending on model selection. The correlation score for the annotated RT of both examiners was 0.76 and 0.63 to 0.68 for comparison of model predicted values.

Conclusions: Restitution time represents an important physiologic swallowing parameter not previously considered in HRM-studies of the UES, especially since disturbances of UES restitution may increase the risk of aspiration. The data presented here show that it takes approximately 9 to 11 s for the UES to come to rest after swallowing. Based on maximal RT values, we demonstrate that an interval of 25–30 s in between swallows is necessary until the next swallow is initiated. This should be considered in any further HRM-studies designed to evaluate the characteristics of individual swallows. The calculation model enables a quick and reproducible determination of the time it takes for the UES to come to rest after swallowing (RT). The results of the calculation are partially independent of the input of the investigator. Adding more swallows and integrating additional parameters will improve the Machine Leaning model in the future. By applying similar models to other swallowing parameters of the pharynx and UES, such as the relaxation time of the UES or the activity time during swallowing, a complete automatic evaluation of HRM-data of a swallow should be possible.

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1. Introduction

The upper esophageal sphincter (UES) denotes the passage between the pharynx and the esophagus. Current anatomical models assume the UES to consist of the inferior part of the pars thyropharyngea (TP) and the pars cricopharyngea (CP), which are both part of the inferior pharyngeal constrictor muscle (IPC). In addition, cranial parts of the upper esophagus muscle also form part of the closing muscles of the UES. The opening of the UES is regulated by muscles inserting from the outside into the sphincter region [1,2].

The sphincter remains closed during rest and maintains a basal resting pressure to prevent air from entering into the gastrointestinal tract during inspiration and to protect the airway from material refluxing back from the esophagus into the pharynx [3]. This resting pressure is partially created by active muscle contraction and also passively by elastic connective tissue. The resting pressure varies intra-individually, depending on the state of arousal, activity and emotional stress [1,2,4]. During swallowing the sphincter shows a complex multiphasic opening and closing pattern allowing a bolus to pass the sphincter region (Fig. 1). It also relaxes during belching and vomiting [4,5].

During swallowing, the resting pressure of the UES initially decreases to a minimum in order to allow bolus passage and then reaches very high pressures when the peristaltic wave passes the sphincter region. In order to quantify these functions, a variety of swallowing parameters related to the opening and closing process of the UES have been suggested. Among these are pressure values, such as maximum pressures before and after sphincter opening or the minimum pressure during opening, time intervals (such as the relaxation time or the UES activity time), pressure integrals or the velocity of the peristalsis [6,7]. Calculation models evaluating the sphincter function during swallowing have also been presented [7,8] and attempts have been made to mathematically distinguish normal from pathological swallows [9].

In contrast to the various studies focusing on the swallowing process itself, however, only little attention has been paid to the sphincter function after swallowing. In particular, the time interval between reaching the maximum pressure during swallowing and returning to the state of rest (resting pressure), which we here refer to as "restitution time" (RT), has, to our knowledge, not previously been described.

We consider the post-swallowing phase to be of considerable clinical relevance, since phenomena such as globus sensation, impaired bolus passage, regurgitation or peristalsis disturbances might be linked to dysfunction of the UES after swallowing. In particular, it is not known, if a reduction in RT leads to regurgitation or an extension as in a sphincter spasm to globus sensation. Since these disturbances have not been considered in the context of the post-swallow time interval, RT needs to be evaluated as a first parameter.

It is known that a certain amount of time is needed for the UES to return to its resting pressure. Therefore, it is a general practice in swallowing studies to wait for at least 30 s between swallows in order to avoid interference [10]. However, the exact time span necessary for the UES to return to its state of rest has not yet been determined. This might be due to the irregular decrease of UES pressures and the difficulty in defining the exact point in time when a basal resting pressure is reached again. A manual definition of the end point of restitution time is possible, but is always examiner-dependent and time consuming.

The aim of this paper was to determine the period between the maximum pressure in the UES during swallowing and returning to the state of rest (restitution time/RT) in healthy participants. Given the predicted difficulties in doing this manually, we set out to develop a Machine Learning model to collect data in a more objective way. Using this automated model, normative values of restitution times in physiologic swallows are established. They will help clinicians in the future to evaluate UES function more precisely and possibly to identify dysfunctions of the sphincter in relation with aberrant restitution times, e.g. globus sensation or regurgitation.

2. Materials and methods

2.1. Study design

Retrospective analysis of swallowing data from healthy subjects.

2.2. Ethical approval

Permission to reuse data obtained in a previous experimental study (#5905/2012) has been granted by the ethics committee of the

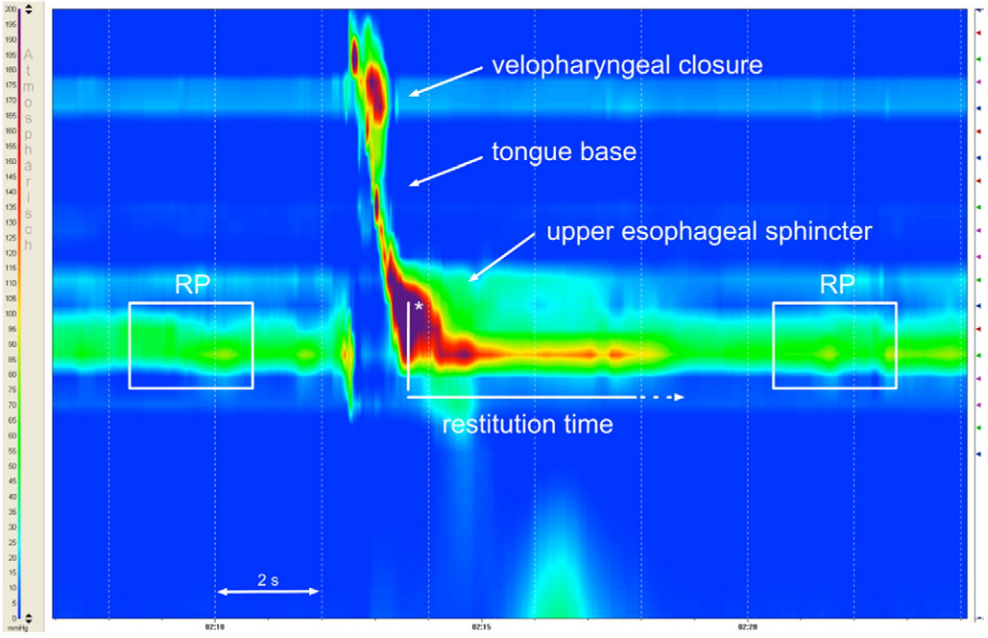

Fig. 1. Pharyngeal spatio-temporal pressure plot of a regular swallow with time on the x-axis (double-headed white arrow indicates 2 s), and distance from the nostril on the y-axis. Each pressure is assigned to color (color bar on the left). Anatomical landmarks of the velopharynx, the tongue base and the upper esophageal sphincter are marked. RP indicates the regular resting pressure of the upper esophageal sphincter before and after a swallow. The beginning of the restitution time is indicated by the straight white line (*).