Published in final edited form as:

Lung. 2015 February ; 193(1): 129–133. doi:10.1007/s00408-014-9662-x.

Effect of laparotomy on the swallow-breathing relationship in the cat

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Abstract

Swallow occurs predominantly in the expiratory phase (E) of breathing. This phase preference is thought to contribute to airway protection by limiting the passage of material through the pharyngeal airway with little or no inspiratory (I) airflow. This phase preference is attributed to central interactions between the swallow and breathing pattern generators. We speculated that changes in peripheral mechanical factors would influence the respiratory phase preference for swallow initiation. We induced swallowing in anesthetized spontaneously breathing cats by injection of water into the oropharynx. In animals with intact abdomens, 83% of swallows were initiated during E, 7% during I, 7% during E-I phase transition and 3% during I-E transition. In animals with open anterior midline laparotomy, only 38% of swallows were initiated during E, 33% during I, 17% during the E-I transition, and 12% during I-E. The results support an important role for feedback from somatic and/or visceral thoraco-abdominal mechanoreceptors for swallow-breathing coordination after laparotomy.

Introduction

In humans and animals, swallow occurs primarily (80%) in the expiratory phase of breathing (i.e.[1]). This pattern is consistent with phase preference, in which swallow occurs during a breathing cycle with little to no inspiratory airflow. The mechanism is thought to be due to cooperation of breathing and swallow pattern generators [2, 3]. The consequences of phase preference disruption are thought to include increased risk of aspiration, resulting from the presence of food and/or liquid in the pharyngeal airway during an inspiration.

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Financial Disclosure: There are no other financial disclosures to report.

Conflict of Interest: None for all authors.

Beginning as early as 1878 investigations began into the mechanisms of pulmonary complications following abdominal surgery. King [4], Oswald [5], Harris [6], and Mann [7] found a greater percentage of pulmonary complications (vascular emboli, edema, pleural transudates, and infections: staphylococcus, pneumococcus, tuberculosis, empyema) from high (20–66%) versus low (5–25%) abdominal surgery. Beecher [8, 9] demonstrated that the opening of the peritoneal space changes the resting peritoneal space from sub-atmospheric (negative) pressure resulting in a reduction in vital capacity, tidal volume, and expiratory reserve volume.

This is due in part to the strict division of the abdominal compartment into two components: the gastrointestinal tract from the esophageal hiatus to the pelvic floor, and the peritoneal cavity the space between the parietal and visceral peritoneum [10, 11]. The gastrointestinal tract during eupnea normally rests at a positive pressure (compared to atmospheric), however the peritoneal space rests at sub-atmospheric pressure and is known to aid in diaphragm dissention [10–12]. Upper abdominal surgery which disrupts the pressure in the peritoneal space results in a reduction in vital capacity, tidal volume, and expiratory reserve volume [8, 9, 11].

An additional consequence of swallow/breathing coordination disruption is an increasing risk for dysphagia (swallow impairment). It is common for patients with laparotomy to be placed on feeding tubes, but to the best of our knowledge there is no published data on swallow function of these at risk patients. However, the risk for pneumonia significantly increases in upper vs lower abdominal surgery. To this end, while swallow and breathing can be significantly modified by sensory feedback from alimentary tract and airways, respectively, there is relatively little information on peripheral mechanisms effects on phase preference. We hypothesized that disruption of the peritoneal cavity, altering the respiratory system would also disrupt the swallow-breathing relationship, leading to more swallows occurring during the inspiratory phase and/or respiratory phase transitions.

Methods

Experiments were performed on twelve spontaneously breathing male adult cats (5.3 ± 1.0 kg). The protocol was approved by the University of Florida Institutional Animal Care and Use Committee (IACUC). The animals were initially anesthetized with sodium pentobarbital (35 mg/kg i.v.). Supplementary doses of sodium pentobarbital were administered as needed (1–3 mg/kg i.v.). The right femoral artery and vein were cannulated to monitor blood pressure and administer fluids, respectively. Physiologic levels of end-tidal CO_2 , body temperature, and arterial blood gas composition were continually maintained and monitored. Pentobarbital sodium was obtained from Lundbeck, Inc. (Deerfield, IL), and doses were calculated as their free base. A trachea cannulation was placed at approximately the sixth tracheal ring to allow for swallow stimulation.

Electromyograms (EMG) were recorded using bipolar insulated fine wire electrodes according to the technique of Basmajian and Stecko [13]. Seven muscles used to evaluate swallow function: a) laryngeal/hyoid elevators: mylohyoid, geniohyoid, and thyrohyoid; b) laryngeal adductor: thyroarytenoid; c) pharyngeal: thyropharyngeus (inferior pharyngeal

constrictor) and cricopharyngeus (upper esophageal sphincter); and d) parasternal (respiratory and schluckatmung [14, 15]). In six of the animals additional EMG activity was recorded from the costal and crural diaphragm following open abdomen laparotomy. Correct electrode position was confirmed by visual inspection of electrode position upon implantation using known landmarks and of EMG activity patterns during breathing and swallowing. To initiate swallowing, a one-inch long, thin polyethylene catheter (diameter 2.37 mm), attached to a 6cc syringe was placed into the oropharynx. Water was injected into the pharynx via a syringe (3 cc's). Swallows which spontaneously occurred during the course of the protocol were also analyzed. Swallowing was defined as a quiescence of the cricopharyngeus with overlapping activity in the mylohyoid, geniohyoid, thyropharyngeus, thyrohyoid, thyroarytenoid and the parasternal.

Upper abdominal laparotomy

Six of the twelve animals underwent laparotomy and diaphragm EMG placement. Laparotomy was performed by an anterior midline abdominal incision extended 1.5cm distal to sternum, to the umbilicus, (total incision measuring ~ 12cm in length). Laparotomy was closed by using a continuous interlocking suture in the transverses abdominis and rectus abdominis individually, ensuring abdominal closure with glue. Time from closure of the abdomen to the swallow stimulation was from 5–10 minutes.

Data processing and statistical analysis

“Spike 2” Version 7 (Cambridge Electronic Design, United Kingdom) was used to automate the analysis process. Electromyograms were rectified and moving averages with the time constant of 50 ms were obtained. EMG data were normalized as a percent of maximum, for comparison across animals. The maximum was the largest amplitude during the swallow. Results are expressed as means $\pm$ standard error. To determine statistical significance Wilcoxon Signed Rank Test was used to examine differences between no laparotomy and open abdomen, and between open versus closed abdomen. An assigned coding system was used for the respiratory phase in which the swallow occurred: inspiratory as “1”; swallows occurring during the I-E transition as “2”; and swallow occurring during E as “3”.

Results

Injection of water into the oropharynx reliably elicited swallows. In the six animals without laparotomy 83% (30/36) swallows occurred in the expiratory phase of breathing (E), 6% (2/36) of swallows occurred during expiration with post-inspiratory discharge (I-E transition), and 11% (4/36) occurred during the inspiratory phase (I) Figure 1a.

In the six animals, with open abdomen, 40% (30/76) swallows occurred during E, 5% (4/76) of swallows occurred in the I-E transition, and 40% (30/76) occurred during I. Following abdominal closure (n=5), 48% (21/44) during E, 14% (6/44) during I-E transition, and 39% (17/44) during I Figure 1b.

To determine if there was a significant difference in swallow/respiratory phase coordination between no laparotomy versus open abdomen, and between open versus closed abdomen a Wilcoxin Signed Rank Test, with the coding system explain above, was used. A significant

difference was found between the animals without laparotomy (2.7 ± 0.3) and animals with laparotomy plus an open abdomen (2.2 ± 0.4 ; $z = -2.023$, $P=0.04$). An additional comparison was made between animals with laparotomy plus an open abdomen (2.0 ± 0.2) and no significant difference in the same animals after abdominal closure (2.1 ± 0.3 ; $z = 0.67$, $P=0.50$) Figure 2.

The average $\pm$ standard error end-tidal CO_2 (ET) and respiratory rate (RR) of control animals was an ET of 32 ± 0.8 and RR of 18.2 ± 1.2 respectively compared to animals with laparotomy ET of 35 ± 1.6 and RR of 28 ± 1.6 , and ET of 34 ± 1.1 and RR of 34 ± 2.8 following closure of the abdominal opening.

Discussion

This is the first report of the effect of upper abdominal laparotomy significantly altering the relationship between breathing and swallow. Laparotomy induced a significant shift in the normal expiratory preference of swallowing, such that more swallows occurred during I and the I-E transition. Additionally, in animals in which the abdomen was open and then later closed did not restore the normal expiratory preference of swallow. The effect of laparotomy on breathing is significant, resulting in rapid shallow breathing [in the current experiment a respiratory rate of 18 (control), 28 (abdomen open), 34 (following abdominal closure)], a decrease in vital capacity, and decreased inspiration and expiration [9]. Farkas and De Troyer [16] found, in the dog, reduced diaphragm and rectus abdominis activity; but spared or increased expiratory activity in the external oblique and the triangularis sterni (an expiratory phase chest wall muscle, which lies under the parasternal) following laparotomy. Of note the action of the expiratory muscles, while the abdomen is open, did change from two opposing forces, to all muscles having a similar effect of deflating the rib cage [16]. This alteration of the breathing pattern significantly changes the mechanics of chest and abdominal movement.

The changes in chestwall mechanics could also alter swallow mechanics. Bolus movement during swallow is accomplished by a combination of positive pressure from the mouth and oropharynx and negative intra-esophageal pressure. This negative intra-esophageal during swallow has been described (i.e [15, 17]) referred to as the “schluckatmung” a German word meaning “swallow breath”. Disorders such as COPD and lung cancer (large tumors) create changes in resting intra-thoracic pressures that result in a significant mechanical disadvantage for execution of swallowing. This mechanical disadvantage is often overcome with shifting swallow phase to inspiration (as seen in these results), which would move the occurrence of swallow to the respiration phase with the greatest negative intrathoracic pressure.

The effect of the schluckatmung would theoretically also be altered if the diaphragm is higher in the chest and without the benefit of the negative peritoneal aiding in diaphragm distention. To determine the range and effect of pressure changes of the sub-diaphragmatic pressure Wagoner [12] underwent a series of investigations. First he recorded sub-diaphragmatic pressure in the following animals: cats (-8 to -14 cmH_2O), monkeys (-2 to -6 cmH_2O), and rabbits (-30 to -55 cmH_2O). He then, examined 50 patients with body mass

ranging from extreme emaciation, to obesity and pneumonia with significant intestinal distension. He described 3 broad categories: normal (-2 to -20 cmH₂O), pathologic increases in subdiaphragmatic pressure (4 to 150 cmH₂O) with obesity, and pathologic decreases (-30 to -106 cmH₂O) with emaciation. The comparable results across species lead to possibility of translation of these results to the clinic.

There is an additional question of duration of time necessary for the abdominal pressure to return to pre-surgical levels. Wagoner[12] tested this in dogs and found positive pressure immediately following closure, relative atmospheric pressure 12 hours post, and 25–36 hours were necessary for the values to return to pre-surgical pressure levels. Therefore closing the abdomen does not restore the original thoraco-abdominal mechanical status. In our experiments, opening the abdominal cavity was an initial condition and upon closure there was no significant change to the abrogated swallow/breathing pattern tested in the next 10 ± 5 minutes.

A limitation of the experimental design was the use of anesthesia, and its effects on respiratory motor drive. However, the anesthetic level was equivalent across animals testing using the end-tidal CO₂ and reflex testing. Warner and colleagues [18], in the dog, demonstrated acute change in expiratory motor drive during breathing, but the effects were ameliorated over time. The second limitation is the use of a single stimulus modality to induce swallow. It is conceivable that swallow induced by various bolus types (size, texture, taste, etc) would be coordinated. However, we hypothesize that these coordinating mechanisms are primarily central in nature, and not dependent on afferent modality. Third, by nature of the current experiment, it was not possible to test swallow 25–36 hours following laparotomy.

The expiratory phase preference for swallow has been intensely studied in humans (i.e [1]). Conditions which affect the central pattern generator such as stroke and more peripheral conditions such as chronic obstructive pulmonary disease can alter the swallow-breathing relationship with significantly more swallows occurring during inspiration (i.e [19, 20]). However, it is unknown whether the phase preference is a solely central/brainstem mediated phenomenon, or if continuous feedback from chest-wall, vagal, and/or abdominal afferents regulate swallow occurrence. Conditions which result in altered sensory feedback may arise from disruption of transdiaphragmatic pressure by the laparotomy. This evidence supports a hypothesis for a *peripheral* mechanism controlling swallow-breathing coordination, likely arising from thoracic-abdominal somatic and/or visceral mechanoreceptors.

Acknowledgments

NIH HL 89104, HL103415, HL109025, and HL111215.

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Figure 1.

Electromyogram of breathing and swallow in two animals. Vertical cursors delineate respiratory phases: inspiratory (I), inspiratory-expiratory transition (E1), and expiratory (E2). A. Swallow during the E2 phase of breathing in an animal with an intact abdomen. B. Swallow in the I phase of breathing in an animal post-laparotomy and placement of the costal diaphragm.

Figure 2.

Histogram of swallow initiation and termination within the phases of breathing. The occurrence and termination of swallows were plotted across breathing phases that were segmented into quartiles. Swallow initiation as demarked by elevation of the hyoid and relaxation of the upper esophageal sphincter, and swallow termination was identified by increased tone to the upper esophageal sphincter following relaxation. The solid line is animals with an intact abdomen, the black segmented line is animals with open laparotomy, and the grey segmented line is animals in which the laparotomy was closed. Swallows occurred significantly later in the breathing cycle in animals without laparotomy than in animals with an open abdomen. There was no significant difference for swallow occurrence during breathing between animals with an open abdomen and the same animals once the

abdomen had been closed. Boxes delineate respiratory phases: inspiratory (I), inspiratory-expiratory transition (E1), and expiratory (E2).