
Choking Clinical Studies: Maneuvers to Modern Technology

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The purpose of this manuscript is to detail the topic of choking, including an outline of the historical progression of treatment, a review of the current body of research knowledge, and the leading opinions on the most efficacious interventions. Thorough PubMed queries, meticulous analyses of leading medical institutions such as Mayo Clinic and Johns Hopkins, and evaluations of numerous case studies have resulted in a comprehensive briefing on the current state of choking treatment.

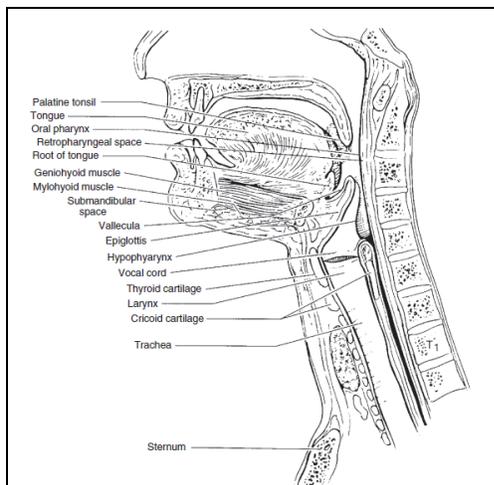


Figure 1. Adapted from Aboussouan L, Stoller JK. Diagnosis and management of upper airway obstruction. *Clin Chest Med.* 1994; 15:35-53.

Choking Statistics:

Choking continues to demand attention as one of the leading causes of accidental death in the United States and the European Union.¹⁻² In fact, choking is the 4th leading cause of accidental death in the U.S. (~5,000 cases per year) following poisonings, motor vehicle crashes, and falls.¹ A danger at all ages, choking deaths are most common in the elderly; between 2007 - 2010, there were more than 2,200 deaths (550 cases per year) among people aged 65 or older in the U.S.³ The incidence of choking is also trending upwards, with the latest findings reporting a 4% increase from 2009 – 2010.¹ Considering the above and with a rapidly growing age segment of 65 years and over in the US and global populations, choking death rates are likely to rise in the both the near term and for decades to come.

Causes of Choking:

Airway obstruction due to food is the most common cause of choking in the elderly, and problems are often compounded due to dentures and difficulty swallowing. The main causes for coughing emergencies in children are toys, coins, and household items. *Figure 1* shows the upper airway and the major anatomical landmarks. Upper airway foreign body obstructions (also called café coronary) were examined in 78 forensic autopsies, and in a large number of cases, the occluding bolus was non-masticated meat or meat product.⁴ The study reports that the foreign body could not bypass the narrowing of the hypopharynx, occluded the entry to the larynx, and was often lodged in the arytenoid cartilages (which form part of the larynx). Time to therapy is critical especially during “penetration syndrome”, when a sudden onset of choking and intractable cough with or without vomiting occurs.⁵ Hypoxia (lack of oxygen) of only four to six minutes duration may result in irreversible brain damage.

A History of Choking Treatment:

It has been over 160 years since Dr. Samuel Gross published the first significant medical review on airway obstruction⁶ and just over 50 years since renowned otolaryngologist Chevalier Jackson passed away, with Chevalier having his collection of over 2,300 inhaled or swallowed foreign objects placed on display at the Mutter Museum, Philadelphia, PA.⁷ Early choking interventions of this era consisted primarily of back blows, and then in 1975, Dr. Henry Heimlich published the paper “A Life-Saving Maneuver to Prevent Food-Choking” in the *Journal of the American Medical Association*.⁸ The Heimlich maneuver was then created, a method that Dr. Heimlich invented after noticing that people were dying in restaurants not from heart attacks as suspected, but due to foreign body

airway obstructions as revealed by subsequent autopsies. Using a dog from his research clinic, he was able to expel a small piece of meat from the dog's trachea by using his classic sub-diaphragmatic compressions.⁹ In 1985, Surgeon General C. Everett Koop stated that while many Americans had been taught to treat choking by giving back blows, they must now learn that the best rescue technique in any choking situation is the Heimlich maneuver.¹⁰ There has been some controversy between Dr. Heimlich and the American Red Cross (ARC) regarding back blows, with some believing these should be performed before the Heimlich maneuver and others stating that this intervention may actually drive a foreign object deeper down the throat.¹¹ This has resulted in the term "abdominal thrusts" being used in some protocols to describe the Heimlich maneuver. As of the date of this manuscript, the ARC does not use the term Heimlich maneuver, while the American Heart Association (AHA) continues to do so.¹² Dr. Heimlich did create a degree of controversy when he made remarks concerning malaria therapy and a few other topics. After reviewing the research, this author fully acknowledges the contributions Dr. Heimlich has made in advancing this field of treatment.

The Physics of Current Choking Treatment:

In 1652, Blaise Pascal stated that pressure applied to a confined incompressible fluid is equally transmitted in all directions such that the pressure variations are the same,¹³ as evidenced in Pascal's landmark barrel experiment (*Figure 2*). This model carries over well to the closed system that is created when a foreign body blocks the trachea. If the pressure supplied to the system via a compression or thrust is greater than the friction holding the obstruction, the object is pushed out to relieve the choking. Importantly, the force applied affects all areas of the closed system.

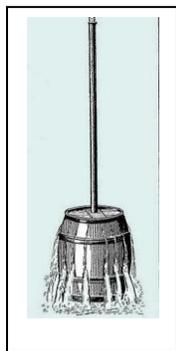


Figure 2.
Pascal's barrel.

The propulsion potential of expiratory air flow can be extremely forceful, with healthy young men able to generate peak flows of 7 L/sec during volitional coughing, 157m/hr. considering the 1cm² area of the glottis.¹⁴ When examining this force in a similar fashion by caregivers assisting quadriplegic patients ("Quad Coughing"), and therefore in the absence of any active muscle contraction, peak cough velocities are only half as forceful.¹⁵ It is also important to note that the air available for expiration during the Heimlich maneuver is only the residual volume in the lungs. For someone who has a decompensated pulmonary system, this amount could be quite low, limiting the effectiveness of compression treatment. It has been reported that Quad Coughing must be performed forcefully, as success hinges on how suddenly the lungs can be compressed.¹⁶ One study reports that back blows, which generate high initial pressures, may act to first dislodge an object and then abdominal thrusts can further move the object out of the larynx due to the more sustained increases in intrathoracic pressures.¹⁷ Another perspective is that with the diaphragm generating 80% of the respiratory force and the intercostal muscles providing 20%,¹⁸ it follows that the intrathoracic pressures generated during chest thrusts may

actually be lessened due to accommodation by the diaphragm.¹⁹

The efficacy of abdominal compressions versus chest compressions has also been a topic of debate and the literature cites conflicting research. A randomized crossover study was conducted in which emergency room physicians performed both chest compressions and the Heimlich maneuver on cadavers with simulated complete airway obstructions.²⁰ The results showed that the peak airway pressure was significantly lower with the abdominal thrusts compared to chest compressions (26.4 +/- 19.8 cmH₂O versus 40.8 +/- 16.4 cmH₂O; p=0.005), with the conclusion that for the unconscious patient, chest compressions have the potential of being more effective. Another clinical trial demonstrated the superiority in air volume and peak air flow rates of low and midchest compressions versus abdominal thrusts.²¹ However, a study examining anesthetized pigs situated with an obstructed airway compared compressions of the anterior chest, lateral chest, and abdominal region to measure chest/abdominal thrust, expiratory air flows, airway pressures and interpleural pressures.²² These results showed significantly greater airway and pleural pressures from lateral chest and abdominal compressions versus the anterior thrust technique and after autopsy, there were no rib, intra-abdominal, or intra-thoracic injury present. Another study reports that in dog models, a possible neural response to the compression of the thorax is also a contributing factor in the success of the Heimlich maneuver.²³ Lastly, a clinical investigation determined that an efficacious cough peak flow threshold of 160 L/min was established for wheelchair-dependent muscular dystrophy patients performing different cough-assisting techniques, including manual table thrusts.²⁴

Current Non-Invasive Treatments for Choking:

The U.S. National Safety Council, AHA, American College of Emergency Physicians (ACEP), Johns Hopkins University, and multiple institutions all specifically outline the repetition of the Heimlich maneuver as the key course of treatment until an obstruction is cleared.^{1, 4, 12, 18, 25-28} The ARC, Mayo Clinic and other institutions^{29, 30} advocate a “5 and 5” approach, instructing a cycle of 5 back blows and 5 abdominal thrusts until the foreign object is removed. In Dr. Heimlich’s hometown of Cincinnati, Ohio, the local hospital system Deaconess has a robust “Heimlich Hero’s” program that teaches children the fundamentals of the Heimlich maneuver and case reports abound, with children saving teachers and children saving each other.³¹ Regarding children 1 year of age or older, the Heimlich maneuver is recommended.³²⁻³⁴ Another report recommends that when the Heimlich maneuver is not effective, the “table maneuver” should be used. This technique instructs that the person choking is laid down on a table in the prone position, head facing downwards, arms hanging over the table, and sharp blows are delivered between the scapulae with the heel of the hand.³⁵ Also, if a foreign body has progressed further into the lower respiratory tract, a laryngoscope and Magill forceps are recommended.³⁶ For individuals who are alone, performing the Heimlich maneuver on yourself or using the corner of a chair/stair railing have been reported to be successful.³⁷

Vulnerable Choking Populations:

Elderly people with dementia (i.e. Alzheimer’s disease), Parkinson’s disease, and pneumonitis are most strongly associated with deaths from choking on food.³ One study examined the clinical background and scenarios surrounding 75 patients who survived a near-fatal choking episode. Sixty had choked on a solid bolus of food, almost half of them had neurologic disease and while 25 of them choked at home, most incidents happened elsewhere: 18 in nursing homes, 14 in hospitals, nine in restaurants, and nine in drinking establishments.³⁸ This study speaks to a growing awareness that choking emergencies in a portion of the elderly population is partially due to deglutition (swallowing) issues, with nearly 40% of Americans over the age of 60 experiencing dysphagia (difficulty, discomfort swallowing).³⁹

When it comes to life-threatening obesity, Prader-Willi syndrome (PWS) is cited as the most common cause and choking has been observed as key contributing factor. A survey of the families of deceased PWS patients reported that 1 in 3 had a history of choking and almost 1 in 10 listed choking as the cause of death.⁴⁰ Causes of increased choking hazards among this population included poor oral/motor coordination, poor gag reflex, hypotonia (low muscle tone), hyperphagia (excessive desire for food), decreased mastication (chewing), and voracious eating habits. It is important to note that while these symptoms were reported for PWS patients, caregivers should identify these symptoms in other populations and recognize an increased choking risk. Also in the morbidly obese, a “Knees-to-Abdomen Heimlich Maneuver” has been recommended due to physical limitations.⁴¹ Another study reports that motorized wheelchair-dependent patients with muscular dystrophy increased their unassisted cough peak flows when they combined a mastered maximal-depth glossopharyngeal breathing technique with a self-induced thoracic table thrust, simulating a Heimlich maneuver.²⁴

Clinical Choking Reviews:

An examination of the current body of research knowledge by this author and previous researchers does not reveal a definitively controlled clinical trial in which different modalities of choking intervention therapies (Heimlich maneuver, back blows, suction, etc.) have been statistically compared for efficacy.^{17,42} This is not surprising, given the immediate life threatening situation that choking causes, and the slim likelihood of an U.S. Institutional Review Board approving such a study. Therefore, it is necessary to review the documentaries, case studies, and available testing models (cadavers, animals) to extrapolate what measures can save lives, all the while remaining grounded in what can be viewed as either general guidance or specific instruction. One such review in a prehospital setting examined 513 cases of foreign body airway obstruction in adults over a 17- month period in San Diego County.⁴³ Seventeen people out of the 513 cases died (3.3%) and it is noteworthy that they had a mean age of 65 years, with the factor of increasing age correlating with a worse outcome. The Heimlich maneuver was the most common intervention used and it provided assistance in 86.5% of patients, with Magill forceps being needed in three

Heimlich refractory cases. Another study examined 182 patients less than 5 years of age, with 99 of them (55%) being less than 1 year old.³³ Liquid obstructions were predominant in the youngest children, and solids (including food) were the issue in children over 1 year of age. Before paramedics arrived, 59% of these cases were resolved. Interventions by parents included bulb suction, finger sweeps, Heimlich maneuver, and back blows. Paramedics used advanced life support in only 3 cases and 47% of parents refused transport against medical advice.

Trauma from Current Choking Treatments:

During an emergency situation, the timely resolution of the most life-threatening cause is paramount and choking is certainly one of those instances. Hence, use of aggressive and forceful compressions, thrusts, back blows, etc. appear warranted as the collateral injury or damage from such interventions can be considered irrelevant if the person dies. While thousands of lives have been saved due to the Heimlich maneuver since its inception in 1975, one thing that becomes apparent during a review of the literature review is the amount of injuries and trauma caused by choking emergency treatment. The purpose of this manuscript is not to draw out this aspect of choking treatment and will only discuss injuries that are documented via publication. Properly performing the Heimlich maneuver has a direct effect on the incidence and severity of collateral trauma.

Multiple research groups have done a sound job of reviewing the topic of post-Heimlich trauma⁴⁴⁻⁴⁶ and this author agrees that those who have had the Heimlich maneuver or any choking emergency treatment performed on them needs to seek further medical evaluation immediately to ensure that there are no collateral trauma or injuries. This applies especially to those over age 65, as the LA Med Center review pointed out that most injuries occurred in this population.⁴⁴ Further, the removal of a foreign body that is sharp should ideally be done with a laryngoscope if at all possible, and if the Heimlich maneuver or other forceful therapy was used to remove the sharp foreign object, the patient should immediately seek medical attention afterwards.⁴⁷

Radiologic evaluation has shown that a variety of deglutition (swallowing) abnormalities can be identified after a near-fatal choking episode.⁴⁸ One case study highlighted POPE (postobstructive pulmonary edema), also referred to as negative pressure pulmonary edema, which occurs with deep inspiration against an obstructed airway.⁴⁹ This paper is worth mentioning since the patient, upon high altitude air travel, became hypoxic with an altered mental status, typical indicators of a pulmonary embolus. It was only after obtaining a detailed history that the root cause was found to be the Heimlich maneuver performed days before.

While complications are typically low, gastric (stomach) rupture has been cited as one of the more common injuries sustained after the Heimlich procedure and it has a high mortality rate.^{45, 50, 51} Contributing factors include individuals being over 65 years of age, and the ingestion of large amounts of food and possibly alcohol. A case study of two individuals experiencing gastric rupture stressed that the improper application and over application of the Heimlich maneuver was a significant factor.⁵⁰ Traumatic dissection and rupture of the abdominal aorta has been reported after a forcefully applied Heimlich maneuver,⁵² and a fatal splenic rupture following the application of a properly performed Heimlich maneuver has also been reported.⁴⁶

A lacerated liver and a large subscapular hematoma draining into the pelvis was the result of multiple Heimlich maneuvers which failed to dislodge a large piece of steak obstructing the airway.⁵³ Aside from those injuries specifically cited in this manuscript, other instances of trauma such as pneumomediastinum, aortic valve cusp rupture, diaphragmatic herniation, jejunum perforation, hepatic rupture, or mesenteric laceration have all been documented.⁴⁶ Another case study found that the first responder must also show care when performing the Heimlich maneuver as one emergency caregiver reported a rotator cuff tear while rendering aid.⁵⁴ Additionally, chest thrusts were examined in 323 children who died after receiving CPR (80% performed in the hospital) and 44% had rib fractures (21% bilateral), which were determined to be a significant factor in the clinical course.^{55, 56}

Airway Obstruction Treatment with Suction:

The lead focus of this literature review thus far has been the use of a compression force to propel a foreign object out of the trachea. Now, research will be presented that is intended to provide a solid foundation for an intuitive and simpler way for a first responder or emergency caregiver to remove a foreign body - by suction.

Suction catheters and systems are a mainstay in emergency rooms, hospitals, and emergency vehicles. The familiar large canisters (often with a blue lid) are connected to wall mounts and to a facility's main vacuum system to provide on-demand suction support, while battery powered portable units can assist the Advanced Responder in emergency situations (Figure 3). Typically, these units are used to keep an airway free of mucous or fluid buildup in chronically ill patients, but are often used in emergency situations to quickly and effectively remove airway obstructions of all types.

Distinct policies and procedures from the National Institutes of Health⁵⁷ along with numerous reports from healthcare personnel using suction to remove an obstruction of the airway can be found in the literature.⁵⁸⁻⁶⁴ One such group, Comprehensive Advanced Life Support (CALS) is worth highlighting here. This is an educational program specifically designed for the emergency medical training needs of rural healthcare teams. With an affiliate chapter in Minnesota, CALS has worked with The Minnesota Academy of Family Physicians, The Minnesota American College of Emergency Physicians, The University of Minnesota School of Medicine and other leading groups to develop emergency medicine initiatives.⁶³ With regards to "Airway Skills 12: Tracheal Foreign Body Removal", an intriguing and innovative method has been published in the CALS manual (Figure 4) which uses an improvised suction device (created by a syringe) for clearing the airway.⁶³ It is important to note that wall suction is first recommended, but for the rural emergency responder, this will not always be available. A portable, manual, preassembled yet powerful device that satisfies the requirements of therapeutic suction force could be invaluable in a choking emergency.



Figure 3. The Rico Model RS-4X (top) and SSCOR VX-2 Portable Suction.



Figure 4. CALS Program – Persistent Tracheal Foreign Body Removal.

dechoker anti-choking device:

In 2009, Alan Carver was attending Sea School to gain his 200-Ton Captain's License. During the medical training portion, it was advised that if initial non-invasive techniques (Heimlich maneuver, etc.) failed to remedy a choking emergency, a tracheotomy must be performed. Mr. Carver felt there had to be another way and after working with device engineers, health care professionals, and FDA consultants, the dechoker device was created. In 2015 this device gained FDA medical device registration⁶⁵ and the company is currently working with emergency personnel, restaurants, assisted living facilities, and organizations that want to provide an additional method of treatment for a choking emergency. Critical to the success of a suction device is its ability to generate enough vacuum pressure such that it is able to provide equivalent or superior force to the other noninvasive techniques outlined in this manuscript.

Testing performed by Next Medical Design (Raleigh, NC, USA) on the dechoker device analyzed numerous parameters including the ideal diameter of the barrel, required length of the plunger, force needed to pull the plunger, vacuum mask pressure achieved, barrel lubricant needed, plunger O-ring specifications, valve configurations, and overall performance of the device to resist leaking and maintain suction pressures. The ideal design for the dechoker was to fashion a plunger / barrel length of 4.5 inches with a diameter of 2 inches, creating a device 13 inches long. Lubrication amounts, O-ring machining, and the correct adhesive to bind the face mask to the plunger assembly were established. Through the combination of these elements, the dechoker device requires only 20 lbs. of pull force to generate 35 kPa of vacuum pressure as validated by numerous controlled trials.⁶⁶⁻⁷¹ Importantly, the pressure valve prevents any movement of air back into the patient and allows for repeated plunger pulls to generate additional vacuum pressure if needed. When considering this force of vacuum pressure and how it relates to the forces created during the abdominal thrusts of the Heimlich maneuver and varying chest compressions, there are several clinical studies already covered in this review that can be highlighted and used as a logical comparison.

Langhelle et al.²⁰ used human cadavers and Lipmann et al.²² used anaesthetized pigs, with both measuring critical forces relevant to the success of an abdominal or chest compression to remove a foreign body from an obstructed airway. The cmH₂O measurements in these papers were converted to kilopascals (kPa) using the conversion:

$$1 \text{ cmH}_2\text{O} = 0.098 \text{ kilopascal}$$

Of note, while Langhelle focused only on peak airway pressure, Lipmann measured peak airway pressure, thrust pressures, and intrapleural pressures. Importantly, in all cases where Langhelle and Lipmann expressed results with a mean and standard deviation, the highest possible values recorded were used in this comparison (*Table 1*).

Table 1. Comparison of Lung Pressures Associated with Simulated Choking Treatments

Model	Peak Expiratory Pressure (kPa)			Peak Thrust Pressures (kPa)			Peak Intrapleural Pressures (kPa)		
	Anterior	Lateral	Abdominal	Anterior	Lateral	Abdominal	Anterior	Lateral	Abdominal
Langhelle ²⁰	5.6	-	4.1	-	-	-	-	-	-
Lipmann ²²	0.9	2.3	2.0	12.9	15.2	16.6	0.8	1.9	1.8

It is a matter of perspective which of these three pressures would be the most relevant to the 35 kPa of vacuum force generated by the dechoker. However, it is noteworthy that the 35kPa of vacuum force generated by the dechoker is superior to all categories. It is also important to consider the current recommendations for suction devices in hospitals with regards to vacuum pressures used to remove foreign bodies or mucous. A setting of 12-16 kPa is typically advised,⁷² with pressures of 10.6 – 13.3 kPa for those under 1 year of age and 13.3 – 20 kPa for adults being recommended.⁷³ In emergency departments and other advanced treatment facilities, suction pressures from wall mounts typically reach 26.6 kPa, and if full wall suction is needed in extreme cases, pressures as high as 84 kPa can be generated.⁷⁴ *Figure 5* shows a picture of the dechoker device.



Figure 5. dechoker airway suction device.

Discussion:

A thorough review of the current treatments for choking showed that while the Heimlich maneuver has likely saved many lives, there is a missing link between the initial intervention of the abdominal thrusts and the subsequent arrival and application of advanced care. Similar to how the automated external defibrillator (AED) now provides an immediate option for advanced therapy for heart attacks, the dechoker device could also provide an added layer of care in a choking emergency. The literature establishes that injuries sustained from the Heimlich maneuver or chest compressions are likely due to their repeated application after initial attempts have failed. The incorporation of a simple suction device into the choking emergency action plan could possibly alleviate injuries in these cases.

Furthermore, as obesity continues to become a problem in the U.S. and worldwide, the ability for a first responder to wrap their arms around a person in distress may be limited and the effectiveness of compressions on an obese person while lying down is also diminished. Safety of the first responder must also be taken into consideration as a simple suction device allows for a more manageable amount of physical exertion required.

The effectiveness and the immediate time to therapy component of a properly performed Heimlich maneuver are important. Emergency action plans should continue to promote this integral first response. However, when this intervention is not effective, and before a tracheotomy is performed, the use of an effective suction apparatus appears to be a logical next step. Special populations aside from the obese (pregnant women, the extremely frail, those that have dysphagia, are bedridden, have back problems, etc.) can also benefit. As the field of choking treatment moves forward, first responders and health care professionals should consider the incorporation of a simple, manual suction device into their emergency action plans.

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