Estimating the Economic and Absolute Number of Complications Associated with Emergency Intubations Performed Outside the Operating Room; A Methodology for Estimating the Burden in the United States.

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Abstract

Background:

The national burden of complications and costs associated with emergency tracheal intubation, performed outside of the Operating Room, is unknown in the United States.

Methods:

A methodology is presented in this study to systematically link the incidence of major complications per intubation attempt, failure rates for each intubation attempt, and complication costs, that can be used to estimate and better understand the total cost burden airway management in the critically ill.

Results:

Assuming a national first-pass intubation success rate of 84.1%, we estimate the annual national burden of peri-intubation morbidity and cost to be at least 1,161,316 major complications costing at least $5,937,615,900, assuming three million emergency tracheal intubations. We estimate the portion of this burden attributable to first-pass intubation failure to be at least 167,594 major complications costing at least $890,415,900.

Conclusions:

These estimates of complications and costs associated with tracheal intubation are a significant national burden. Investments in infrastructure for tracking and benchmarking tracheal intubations can provide data needed to monitor and improve care for the critically ill, at a tactical level and refine our understanding at a strategic level.

Key Points

Question:

What is the burden of major complications and associated costs with tracheal intubation of the critically ill in the United States?

Findings:

We estimate the annual national burden of tracheal intubation morbidity and cost to be at least 1,161,316 major complications costing $5,937,615,900, assuming three million emergency intubations, and the portion of this burden attributable to first-pass intubation failure to be at least 167,594 major complications costing $890,415,900.

Meaning:

This paper provides the first estimation of the burden of first-pass intubation failure of the critically ill in terms of the number of complications and costs in the United States.

Introduction

Intubation and mechanical ventilation are critical procedures and therapy when taking care of critically ill patients. Each year in the United States, millions of critically ill patients undergo emergent and urgent tracheal intubations. These intubations mainly take place in the prehospital, Emergency Department, and Intensive Care Unit settings. Emergency intubation differs from elective intubation for several reasons; cardiopulmonary instability, full stomachs, and limited time. These differences all increase the risk of major complications in the peri-intubation period. Emergency airway management remains dangerous for patients and difficult for practitioners.

Multiple-intubation attempts in emergency intubations are associated with sharp increases in major complications such as esophageal intubation, aspiration, hypoxemia, hypotension, and cardiac arrest. Mort[1] demonstrated markedly increased major complications after two intubation attempts, while Sakles et al.[2] demonstrated markedly increased major complications after one attempt. Others have documented this same association of increasing complications with multiple-intubation attempts.[3–8] These studies also provide intubation failure rates for each intubation attempt.

Complications associated with airway management can add to the already high pathophysiologic burden in the critically ill and have been linked to sharply increased morbidity and mortality in some subsets of the critically ill.[9,10] Currently, no methodology has been proposed to estimate the national burden of complications and cost associated with intubation of the critically ill. Estimations of complications and the burden of a disease can help to inform the allocation of attention and resources at a national or even international level.

In this study, we present a methodology to systematically link the incidence of major complications per intubation attempt, failure rates for each intubation attempt, and complication costs that can be used to estimate and better understand the total cost burden of airway management in the critically ill. Furthermore, this methodology can be used to better understand a portion of the total cost attributable to first-pass intubation failure at different first-pass failure rates. Establishing this relationship between cost and first-pass intubation failure rates is especially important because first-pass success is a common benchmark that can be tracked and used to understand the impact of interventions on the overall cost burden associated with emergency intubations.[11]

We believe this study represents the first reported cost estimates of the national burden attributable to first-pass intubation failure in emergency tracheal intubations.

Methods

Calculation of the cost of the national burden of adverse events was estimated during the peri-intubation period for emergent intubations as a function of the number of intubation attempts required for the successful placement of an endotracheal tube. This study only considered endotracheal tube intubations performed outside of the operating room. The analysis was restricted to one of six possible major outcomes to simplify the calculation: esophageal intubation, hypotension, hypoxemia, macro-aspiration (resulting in pneumonitis or pneumonia), cardiac arrest, or no complication. Costs were estimated from a provider perspective, using an expected value approach factoring in the probability of first-, second-, and third-pass success, costs for each complication, and incremental increases in complication rates for each successive intubation attempt. The stopping point in our model is after a third attempt, as there is no data regarding the progression of airway management after this point. The expected value calculation was performed using TreeAge® software and represents a weighted average for cost per intubation case considering probabilities and costs for each of the six outcomes. The model assumes that patients will only experience one of the six complications or none.

First-, second-, and third-pass success rates, as well as complication rates and the associated costs, were obtained from the medical literature. The use of expert opinion occurred when the search for cost in the medical literature yielded empty results. Sensitivity analyses were performed for model parameters. As the primary objective was to provide an estimate of cost at the national level, and considering that medical training differs between countries, we initially limited the selection of studies to include only those performed within the United States. However, first-pass success rates from a recently completed meta-analysis by Park et al.[11] utilized studies both in the United States and outside of the United States and have become widely accepted among Emergency Physicians within the United States. Thus, we used these values for our base case, as well as our scenario analyses, where the cost burden for differing first-pass success rates was calculated again. To estimate the current national burden of first-pass intubation failure, all costs were inflated to 2018 USD using the medical care component of the United States Bureau of Labor Statistics Consumer Price Index. Cost estimates obtained from our model were scaled up to a national level by assuming that approximately three million intubations will occur in the Emergency Department and Intensive Care Unit in the year 2019. This figure was obtained by utilizing values from the 2014 National Ambulatory Survey [12], a 2013 publication by Pfuntner et al.[13] and applying an annual growth rate of 6%, as suggested by Frost and Sullivan in 2003.[14]

Results

Figure 1 provides the framework utilized to perform the expected value calculation of costs associated with intubation, and Table 1 provides the values obtained from the literature utilized to parameterize our expected value calculation.

Table 2 presents the expected counts for each complication included in the model, assuming three million emergent intubations performed annually in the United States and if an intubation attempt could include up to three attempts before successful placement or intervention by an anesthesiologist. Using a base case first-pass success rate of 84.1%, our model predicted a total of 1,161,316 cases of peri-intubation complications or 120,000 instances of esophageal intubation; 720,000 cases of hypotension; 301,027 hypoxemia cases; 16,087 aspiration cases; and 4,201 cardiac arrest cases. The first-pass failures, or 167,594 of the 1,161,316 cases, account for approximately 14% of these complications. Thus, providers could avoid approximately $890 million in the aggregate if all patients experience successful first-pass intubations. Take note that the potentially avoidable cases and costs associated with esophageal intubation and hypotension are both zero. The explanation for this is rates of esophageal intubation and hypotension (4% and 24%, respectively) do not vary with several attempts in the model. However, this may not be true, but without empirical estimates of differing rates by an attempt, we made the conservative assumption that they stayed constant.

From a per-million intubation case perspective, an 84.1% first-pass success rate would yield 40,000 cases of esophageal intubation, 240,000 cases of hypotension, 100,342 cases of hypoxemia, 5,362 cases of aspiration, and 1,400 cases of cardiac arrest, for a total of 387,105 complications per 1 million intubations performed. If all patients were intubated successfully on the first attempt (100% first-pass success), the per million avoidable cases of complications would be 52,974 cases of hypoxemia per million intubations, 2,457 cases of aspiration per million intubations, and 433 cases of cardiac arrest per million intubations, for a total of 55,865 avoidable cases of per-intubation complications per million intubations.

Table 3 provides the expected cost per intubation, considering various first-pass success rates. In the reference scenario (100% first-pass success), the weighted average cost per intubation was $1,682 (or $5.05 billion per year, assuming three million intubations performed annually). For the base case (84.1% first-pass success), the weighted cost per intubation was $1,979 (or $5.94 billion per year, assuming three million intubations). For other first-pass success rates analyzed (81.8% and 82.3%), the expected costs were $2,022 and $2,013 per intubation, respectively (or $6.07 million annually and $6.04 million annually, respectively, assuming three million intubations). On a per-million intubation case scale, these values correlate to $1.98 billion per million intubations for 84.1% first-pass success, and $2.02 billion and $2.01 billion per million cases for 81.8% and 82.3% first-pass success rate, respectively. Comparing each to a 100% first-pass success rate, potentially avoidable costs are $890 million, $1.02 billion, and $991 million, respectively. For every million intubations, the avoidable costs are $297 million per one million intubations for the first-pass success of 84.1%, and $340 million, and $330 million for 81.8% and 82.3% first-pass success rates, respectively. Figure 2 summarizes the sensitivity analysis of the first-pass success rates.

Supplemental Figures 1 and 2 present sensitivity analyses of costs and rates, respectively, of each complication following the first intubation attempt, while keeping all other model variables constant. Each graph shows the value utilized for the base case scenario in our model, for reference. The resultant costs shown on the y-axes for each 1-way sensitivity analyses in Supplemental Figures 1 and 2 indicate that the expected cost per case to intubate is most sensitive to changes in cost of hypotension and probability of cardiac arrest after the first attempt and least sensitive to changes in cost of cardiac arrest and probability of hypoxemia after the first attempt.

Discussion

This paper provides the first estimation of the burden of first-pass intubation failure in terms of the number of complications and costs in the United States. Many neglected diseases, injuries or therapies have been successfully advocated for and addressed using the strategy: identify the problem, characterize the cost, raise awareness of the costs, and advocate for solutions based on the economic value created in solving the problem.[15–17]

Allocation of strategic resources always involves robust and persuasive economic analysis. Consistent, reliable, comparable data detailing the impact of such a problem is a key component needed in driving and prioritizing policy decisions in any health system. The aggregate cost is key to understanding potential impacts of any allocation of resources towards a problem. Efforts are currently underway to increase awareness and address the problem at the tactical level.[2,18,19] The next step is to raise awareness of the cost of first-pass intubation failure in entities involved in the strategic allocation of resources for the entire medical system.

<u>Limitations</u>

Interestingly, there is uncertainty surrounding the total number of emergency intubations performed each year in the United States. We chose to circumvent this problem by presenting the data in an average complication cost per patient and estimated cost per million patients. The estimated cost can easily be scaled up or down as needed.

A comprehensive estimate of the total cost is not possible due to the patchwork of available data needed to link the incidence of each major complication and the cost of each complication. This patchwork of available data means that the uncertainty of our estimates increases as we move stepwise from complication incidence to cost. We acknowledge this problem of growing uncertainty and present the cost estimates at two levels, each with an increasing level of uncertainty: 1) absolute number of complications, 2) direct costs of these complications.

Reported first-pass intubation success varies widely. A recent meta-analysis found a mean first-pass rate of 84.1% when reviewing the Emergency Department literature.[11] It could be that the Intensive Care Unit rate is different from Park et al.[11], as it only included Emergency Department studies.

<u>Underestimates</u>

The total number of emergency intubations per year is likely higher than our estimate of three million per year for several reasons; the number of prehospital intubations is unknown, reported intubations in the Emergency Department and the hospital are self-reported into hospital databases, and emergency procedures are underreported.

Our estimate likely underestimates the total complication cost. This study excludes many complications resulting from multiple-intubation attempts. Sakles et al.[2] demonstrated an increase in dysrhythmias, endobronchial intubations, dental injuries, and laryngospasm with multiple-intubation attempts. These complications certainly add cost and morbidity; however, we felt the uncertainty surrounding each incidence or cost was too great for inclusion.

Major complications likely occur at a significantly higher rate than reported due to a self-reporting bias. Rates of major complications are significantly higher when gathering data via an uninvolved observer.[20] Rinderknecht et al.[20] reviewed videos of intubations and compared them to complications reported in procedure notes. They found providers consistently underreported adverse events in every category studied.

Lastly, because we used the lowest reported costs in a range of costs associated with each complication, the real cost is higher. We do not know the distribution of cost variation across medical systems. We, therefore, cannot estimate a true average cost for the complication. To be as conservative as possible, we used the lowest reported cost. True costs are undoubtedly higher.

<u>Overestimates</u>

Complex relationships exist between the major complications we studied. For example, esophageal intubation is an example of a major complication which has been shown to increase with each failed intubation attempt and, most certainly, can lead to morbidity and mortality. If recognized immediately and the endotracheal tube removed promptly, there may be no further physiologic complications to the patient and no cost incurred. Nevertheless, a second intubation attempt, alone, increases the overall risk of complications. Alternatively, esophageal intubation and ventilation of a full stomach, even if promptly recognized, can rapidly trigger a cascade of adverse events including; regurgitation and aspiration of stomach contents forced out by ventilation of the stomach. These complications can lead to a prolonged failure to deliver oxygen to the alveoli, hypotension, and in extreme cases cardiac arrest or death.

Next Steps

The next logical area of investigation in this vein should be to focus on the mortality associated with failed-intubation attempts. The relationship between multiple-intubation attempts and an increasing number of major complications is known. The relationship between complications and mortality is less well defined. For example, the literature describes the increasing incidence of hypoxemia, hypotension, and esophageal intubation with each attempt, however little was identified on their impacts on mortality in the general population of critically ill patients.

The methodology presented in this paper can be combined with the data from Spaite et al.[10] to understand the impact of first-pass intubation failure on mortality in the setting of closed head injuries. A recent retrospective study of prehospital hypoxia and hypotension in closed head injury demonstrated a mortality increase from 5.6% to 28.1% if hypoxia alone was present during prehospital care[21]. Recent research by Spaite (2019)[22] demonstrates a clear 'dose-response' relationship with outcomes in the setting of closed head injuries. The increasing magnitude of hypotension and hypoxia can lead to an increase in poor outcomes.

While our estimates contain uncertainty, the magnitude of this burden justifies the strategic allocation of resources and attention. Reducing the rate of first-pass intubation failure seems a reasonable target as is a measurable surrogate for associated complications and costs. Areas of focus might include; development of improved intubation equipment, improved availability of advanced airway equipment, increase in the availability of airway training, and simulation of providers performing emergency intubations. Also, investment in better infrastructure for tracking and benchmarking intubation can provide the data needed to monitor and improve care at a tactical level as well as refine our understanding of the problem at a strategic level.

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Figure Legends

Figure 1. Framework for calculating the expected value of peri-intubation adverse events as a function of the number of attempts.

Figure 2. Variations in weighted cost per tracheal intubation according to the first-pass success rate. Values highlighted are the base case scenario used in our model and additional values published in Park et al.[11] meta-analysis.

Supplemental Figure 1. How cost per case varies with cost of complication. Note that axes scales vary between graphs.

Supplemental Figure 2. How cost per case varies with probability of complication after the first attempt. Note that axes scales vary between graphs.

Table 1. Base case model parameters and ranges analyzed to construct an estimate of the national burden.

Parameter	Value Used In Base Case	Range Analyzed *Lower*	*Upper*	Literature Reference
Probability of Success				
On 1st Attempt	0.841	0	1	Park et al. (2017)[11]
On 2nd Attempt	0.852	0	1	Diggs et al. (2014)[23]
Probability of Aspiration				
On 1st Attempt	0.003	0	1	Mort (2004)[1]; Sakles et al. (2013)[2]
On 2nd Attempt	0.023	0	1	Mort (2004)[1]; Sakles et al. (2013)[2]
On 3rd Attempt	0.130	-	-	Mort (2004)[1]; Sakles et al. (2013)[2]
Probability of Hypoxemia				
On 1st Attempt	0.048	0	1	Mort (2004)[1]; Sakles et al. (2013)[2]
On 2nd Attempt	0.331	0	1	Mort (2004)[1]; Sakles et al. (2013)[2]
On 3rd Attempt	0.700	-	-	Mort (2004)[1]; Sakles et al. (2013)[2]
Probability of Cardiac Arrest				
On 1st Attempt	0.001	0	1	Mort (2004)[1]; Sakles et al. (2013)[2]
On 2nd Attempt	0.004	0	1	Mort (2004)[1]; Sakles et al. (2013)[2]
On 3rd Attempt	0.110	-	-	Mort (2004)[1]; Sakles et al. (2013)[2]
Probability of Hypotension				
On 1st Attempt	0.24	0	1	Bernhard et al. (2019)[24]; Taboada et al. (2018)[25]
On 2nd Attempt	0.24	0	1	Bernhard et al. (2019)[24]; Taboada et al. (2018)[25]
On 3rd Attempt	0.24	-	-	Bernhard et al. (2019)[24]; Taboada et al. (2018)[25]
Probability of Esophageal Intubation				
On 1st Attempt	0.04	0	1	Casey et al. (2019)[26]; Bernhard et al. (2019)[24]; De Jong et al. (2018)[27]
On 2nd Attempt	0.04	0	1	Casey et al. (2019)[26]; Bernhard et al. (2019)[24]; De Jong et al. (2018)[27]
On 3rd Attempt	0.04	-	-	Casey et al. (2019)[26]; Bernhard et al. (2019)[24]; De Jong et al. (2018)[27]

Costs (2017 USD)				
Aspiration Event	$10,000	$10,000	$90,000	Boyce et al. (1991)[28]
				Siddique et al. (2000)[29]
				Warren et al. (2003)[30]
				Katzan et al. (2007)[31]
				Tong et al. (2018)[32]
				Olasupo et al. (2018)[33]
Hypoxemia	$5,000	$5,000	$20,000	(Expert Opinion)
Cardiac Arrest	$17,000	$17,000	$50,000	Kolte et al. (2015)[34]
				Dolmatava et al. (2016)[35]
				Geri et al. (2017)[36]
				Eid et al. (2017)[37]
Hypotension	$5,000	$5,000	$20,000	(Expert Opinion)
Esophageal Intubations	$5,000	$5,000	$20,000	(Expert Opinion)

Table 2. Avoidable cases and costs.

	Complications		**Costs (2018 USD)**			**National Cost Estimate**		
	Type	*Estimated No. of Cases*	*Cost Per Case*	*Range Analyzed*		*Point Estimate*	*Lower Estimate*	*Upper Estimate*
First-Pass Success Rate = 100%	Esophageal Intubation	120,000	$5,000	$2,000	$10,000	$600,000,000	$240,000,000	$1,200,000,000
	Hypotension	720,000	$5,000	$2,000	$10,000	$3,600,000,000	$1,440,000,000	$7,200,000,000
	Hypoxemia	142,105	$5,000	$2,000	$10,000	$710,526,316	$284,210,526	$1,421,052,632
	Aspiration	8,716	$10,000	-	-	$87,156,140	-	-
	Cardiac Arrest	2,901	$17,000	-	-	$49,323,132	-	-
	Total w/ Complications	993,722	-	-	-	$5,047,005,588	-	-
	Total w/o Complications	2,006,278	-	-	-	-	-	-
First-Pass Success Rate = 84.1%	Esophageal Intubation	120,000	$5,000	$2,000	$10,000	$600,000,000	$240,000,000	$1,200,000,000
	Hypotension	720,000	$5,000	$2,000	$10,000	$3,600,000,000	$1,440,000,000	$7,200,000,000
	Hypoxemia	301,027	$5,000	$2,000	$10,000	$1,505,136,138	$602,054,455	$3,010,272,276
	Aspiration	16,087	$10,000	-	-	$160,874,665	-	-
	Cardiac Arrest	4,201	$17,000	-	-	$71,425,028	-	-
	Total w/ Complications	1,161,316	-	-	-	$5,937,435,831	$2,514,354,148	$11,642,571,969
	Total w/o Complications	1,838,684	-	-	-	-	-	-

Avoidable Cases and Costs	Esophageal Intubation	0*	$5,000	$2,000	$10,000	$0*	$0*	$0*
	Hypotension	0*	$5,000	$2,000	$10,000	$0*	$0*	$0*
	Hypoxemia	158,922	$5,000	$2,000	$10,000	$794,609,822	$317,843,929	$1,589,219,645
	Aspiration	7,372	$10,000	-	-	$73,718,525	-	-
	Cardiac Arrest	1,300	$17,000	-	-	$22,101,896	-	-
	Total Avoidable Complications	167,594	-	-	-	$890,430,243	$413,664,350	$1,685,040,066

Assuming three million emergent intubations performed per year in the United States

Avoidable Complications and Avoidable Costs calculated with 100% first-pass success rate as the reference

**The model assumed rates of esophageal intubation and hypotension (4% and 24%, respectively) did not vary by the number of attempts.*

Table 3. The weighted costs per intubation case associated with several first-pass success rates.

First-Pass Success Rate	**Point Estimate**	**Weighted Cost Per Intubation Case**	**National Burden***	**Avoidable Costs**
One-hundred percent	100%	$1,682	$5,047,200,000	REFERENCE
Park et al. (2017)[11] Meta-Analysis Values				
ED**	84.1%	$1,979	$5,937,615,900	$890,415,900
Trauma	81.8%	$2,022	$6,066,418,200	$1,019,218,200
N. America	82.3%	$2,013	$6,038,417,700	$991,217,700

**Assuming three million intubations performed annually*

***Base Case used in our model*

Note: Avoidable costs for the base case shown in this table ($890,415,900) will vary slightly from the estimate shown in Table 2 ($890,430,243) due to rounding. This true for the estimated national burden shown in Table 2 versus Table 3, as well.