Creation of an Open-Source, Web-Based, Mathematical Model of Aggregate Intubation Outcomes at Variable Levels of VL Implementation.

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Introduction

Tracheal intubation is performed tens of millions of times annually by hundreds of thousands of providers. Complications—though rare per provider—accumulate into significant levels of clinical harm and economic burden at scale.

Use of video laryngoscopy (VL) compared to direct laryngoscopy (DL) has been conclusively demonstrated to be clinically superior in both the operating room (OR) setting and the setting of the critically ill in multiple well conducted multicentered randomized controlled trails with observed outcomes, yet implementation of routine VL use based on this evidence is slow.

The frequency of complications for any one provider may be rare at a personal level which may contribute to a lack of understanding of the impact of routine video VL scaled to a national or global level. This misperception of personal impact and scaled impact may slow the pace of individual implementation.

These same RCT demonstrate that the main reason for failed first pass intubation differed for DL and VL. DL intubations failed mainly due to *failure of visualization* while VL intubations failed due to *failure of tracheal access* despite adequate visualization. This is important as most efforts of the DL era have focused on improving visualization. At some point of increased VL use, first pass failures due to *failure of tracheal access* will become

the main cause of intubation failure. Predicting this inevitable shift in failure modes can aid in anticipatory awareness and strategic planning to address the main failure mode of the VL era.

We created a mathematical model in the form of an Excell spreadsheet calculator to explore aggregate intubation outcomes and complications at a national and global scale based on the latest literature's findings for 1) VL and DL first pass rates, 2) reasons for first pass failure (*failure of visualization* or *failure of tracheal access*), for intubations in both the OR and in the critically ill. In addition, in the setting of the critically ill, the rates of 1) major complications and 2) excess deaths attributable to first pass failure can be calculated.

We used this mathematical intubation model to answer critical quantitative questions at the scale of 25,000,000 intubations in the OR and 1,000,000 in the critically ill.

Questions asked:

What would the impact of increasing VL use from 20% to 100% in a single year in terms of number of first pass failures (Simulated accelerated implementation of VL over a 1-year period.)

At what DL to VL ratio does first pass failure due to *failure of visualization* exceed first pass failure due to *failure of tracheal access*?

What is the excess mortality contributable to use of DL in the critically ill in absolute numbers at variable ratios of DL to VL?

Methods

A mathematical model capable of calculating aggregate first pass failure and cause of first pass failure, (*failure of visualization* vs *failure of tracheal* access) in both the operating room and critically ill. Additionally, the model can calculate aggregate major complications, and excess mortality attributable to first pass failure in the setting of the critically ill.

Non-variable inputs:

1) Population of 25,000,0000 intubations for OR and 1,000,000 intubations for critically ill.
2) Data from two recently published large, multi-centered, randomized controlled trials with observed outcomes comparing VL and DL in both the operating room setting and in the critically ill was used as baseline inputs for: first pass success rate of VL and DL, and the main reason for first pass failure (failure of visualization or failure of tracheal access). (Prekker 2023, Krieg 2023) See Table 1:

3) The increase in rates of major complications and mortality attributable to first pass failure in the critically ill. (Russoto 2021, Sakles 2011)

Variable Inputs:

1) Ratio of DL to VL intubations.

Outputs:

1) OR intubations, 2) Critically ill intubations:

-Total number of first pass failures.

-Total number of first pass failures due to failure of visualization.

-Total number of first pass failures due to failure of tracheal access.

Outputs in critically ill intubations:

-Total number of major complications attributable to first pass failure.

-Total number of excess deaths attributable to first pass failure.

Results

Accellerated implimnetation of VL use from 20% to 100% would reduce annual first pass failures by 2,400,000 / 25,000,000 intubations in the OR and 114,400 / 1,000,000 intubations in the critically ill (ED/ICU). (See table 1. and 2.)

The predominate mode of failure (visualization vs tracheal access) would change after increasing VL use. First pass failure due to *failure of tracheal access* can be expected to exceed first pass failure due to *failure of visualization* at a VL use rate of 74% in the OR and a 72% use rate in the ICU (See table 1. and 2.)

Increasing VL use from 20% to 100% in the critically ill can be expected to reduce deaths attributable to first pass failure by 7,943 / 1,000,000 intubations. (See table 3.)

Discussion

Mathematical modeling can provide predictive data enabling data driven decisions at both the personal and policy levels during the transition from the DL era to the VL era.

Predictive mathematical modeling can support evidence-based policy by linking personal practice to national and global outcomes, demonstrating how broader VL adoption can save lives, reduce healthcare burden, and align personal VL implementation with strategic system-wide improvements in patient safety and resource allocation.

Simultaneously, providers may gain insight into how personal device choices affect broader outcomes. The model may bridge clinical and administrative decision-making, aligning individual practice with data-driven clinical choices, and potentially drive accelerated adaptation of routine VL use to achieve system-wide improvements in patient safety.

Conclusion

Increasing the ratio of VL to DL use is predicted to reduce first pass failures; in both the OR and critically ill. The main failure mode of DL is failure of visualization while the main failure mode of VL is *failure of tracheal access*. As VL use increases failure of tracheal access will overtake *failure of visualization* at a VL use rate of approximately 72% - 74%.

An open-source web-based mathematical model based on the latest literature concerning DL and VL use can be used to model future expected outcomes at variable DL to VL use ratios. This predictive data can be used to gain insight and drive data driven decisions at a personal, national or global level.

A link to the calculator can be found by Intubation outcomes calculator

https://docs.google.com/spreadsheets/d/1ilOID3_SC2b3MqG8wJeAsQZDHtLpYKwjuw34XX52xNs/edit?gid=391036037#gid=391036037

Tables

ED/ICU
Intubation Failures Calculator

INSTRUCTIONS

This calculator will predict the total number of first pass intubation failures for a given VL and DL usage. To use calculator, enter the total number of intubations to be analyzed. Conceptually, this may be the total number of intubations globally, nationally, institutionally etc

Enter the total number of intubations ---> **1,000,000**

Total number of intubations	VL Use	DL Use	VL First Pass Failures	DL First Pass Failures	Total First Pass Failures	Visualization Failures	Tracheal Access Failures
1,000,000	10%	90%	14,900	262,800	277,700	191,654	86,046
1,000,000	20%	80%	29,800	233,600	263,400	175,988	87,412
1,000,000	30%	70%	44,700	204,400	249,100	160,322	88,778
1,000,000	40%	60%	59,600	175,200	234,800	144,656	90,144
1,000,000	50%	50%	74,500	146,000	220,500	128,990	91,510
1,000,000	60%	40%	89,400	116,800	206,200	113,324	92,876
1,000,000	70%	30%	104,300	87,600	191,900	97,658	94,242
1,000,000	80%	20%	119,200	58,400	177,600	81,992	95,608
1,000,000	90%	10%	134,100	29,200	163,300	66,326	96,974
1,000,000	100%	0%	149,000	0	149,000	50,660	98,340

Table 1. ***First pass failures and reasons for failures in intubations of the critically ill at variable ratios of DL to VL use per 1,000,000 intubations***

- *Change in total first pass failures from 20% to 80% VL use rate.*
  - *149,000 – 263,400 = 114,000*
- *Shift in main mode of first pass intubation failure.*
  - *72%*

Operating Room
Intubation Failures Caclucator

INSTRUCTIONS

This calculator will predict the total number of first pass intubation failures for a given VL and DL usage. To use calculator, enter the total number of intubations to be analyzed. Conceptually, this may be the total number of intubations globally, nationally, institutionally etc.

Enter the total number of intubations ---> **25,000,000**

Total number of intubations	VL Use	DL Use	VL First Pass Failure Rate (Kreige et al.)	DL First Pass Failure Rate (Kreige et al.)	VL First Pass Failures	DL First Pass Failures	Total First Pass Failures	Visualization Failures	Tracheal Access Failures
25,000,000	10%	90%	6%	18%	150,000	4,050,000	4,200,000	3,423,000	777,000
25,000,000	20%	80%	6%	18%	300,000	3,600,000	3,900,000	3,066,000	834,000
25,000,000	30%	70%	6%	18%	450,000	3,150,000	3,600,000	2,709,000	891,000
25,000,000	40%	60%	6%	18%	600,000	2,700,000	3,300,000	2,352,000	948,000
25,000,000	50%	50%	6%	18%	750,000	2,250,000	3,000,000	1,995,000	1,005,000
25,000,000	60%	40%	6%	18%	900,000	1,800,000	2,700,000	1,638,000	1,062,000
25,000,000	70%	30%	6%	18%	1,050,000	1,350,000	2,400,000	1,281,000	1,119,000
25,000,000	80%	20%	6%	18%	1,200,000	900,000	2,100,000	924,000	1,176,000
25,000,000	90%	10%	6%	18%	1,350,000	450,000	1,800,000	567,000	1,233,000
25,000,000	100%	0%	6%	18%	1,500,000	0	1,500,000	210,000	1,290,000

Table 2. First pass failures and reasons for failures in intubations of the critically ill at variable ratios of DL to VL use.

- *Change in total first pass failures from 20% to 80% VL use rate.*
  - *1,500,000 – 3,900,000 = 2,400,000*
- *Shift in main mode of first pass intubation failure.*
  - *74%*

-	Total First Pass Failures	Major Adverse Events for 2+ Intubation Attempts (VL + DL)	Deaths within 28 Days among patients who had a Major Adverse Event	Visualization Failures	Tracheal Access Failures
20% VL + 80% DL	263,400	139,602	18,288	175,988	87,412
100% VL + 0% DL	149,000	78,970	10,345	50,660	98,340
Difference	**114,400**	**60,632**	**7,943**	**125,328**	**-10,928**
Note	The above total in the row labeled "Difference" is the number of **first pass failures** that would be avoided by adopting 100% VL compared to current global level of 20% VL and 80% DL.	The above total in the row labeled "Difference" is the number of **major adverse events** that would be avoided by adopting 100% VL compared to current global level of 20% VL and 80% DL.	The above total in the row labeled "Difference" is the number of **deaths** that would be avoided by adopting 100% VL compared to current global level of 20% VL and 80% DL.	The above total in the row labeled "Difference" is the number of **visualization failures** that would be avoided by adopting 100% VL compared to current global level of 20% VL and 80% DL.	The above total in the row labeled "Difference" is the number of **visualization failures** that would be avoided by adopting 100% VL compared to current global level of 20% VL and 80% DL. **Due to the overall increase in VL use, tracheal access failures would *increase* become the predominate mode of failure. However, due to the major reduction in visulaization failures, overalll first pass failures will decrease.**

Table 3. Expected number of adverse events and attributable deaths with full implementation of VL for intubations of the critically ill.

-	Total First Pass Failures	Visualization Failures	Tracheal Access Failures
20% VL + 80% DL	3,900,000	3,423,000	834,000
100% VL + 0% DL	1,500,000	210,000	1,290,000
Difference	**2,400,000**	**3,213,000**	**-456,000**
Note	The above total in the row labeled "Difference" is the number of **first pass failures** that would be avoided by adopting 100% VL compared to current global level of 20% VL and 80% DL.	The above total in the row labeled "Difference" is the number of **visualization failures** that would be avoided by adopting 100% VL compared to current global level of 20% VL and 80% DL.	The above total in the row labeled "Difference" is the number of **visualization failures** that would be avoided by adopting 100% VL compared to current global level of 20% VL and 80% DL. **Due to the overall increase in VL use, tracheal access failures would *increase* become the predominate mode of failure. However, due to the major reduction in visulaization failures, overalll first pass failures will decrease.**