Mechanical Analysis of Endotracheal Tube Kinking

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Introduction

Endotracheal tubes (ETT) deliver anesthesia and/or oxygen to a patient during a medical procedure (**Figure 1**).

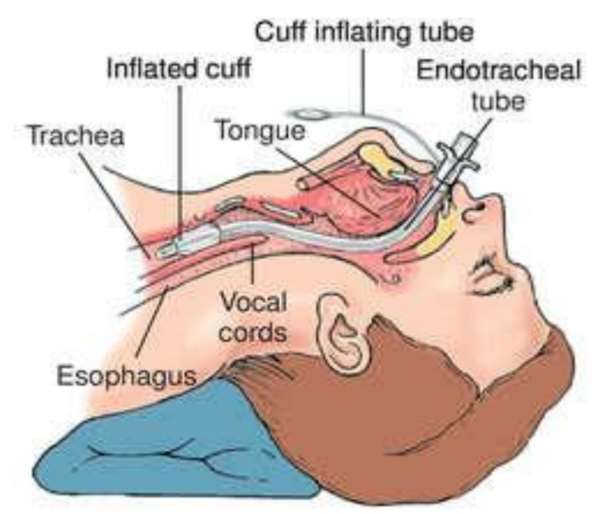

Figure 1: Endotracheal Tube (ETT) intubation. https://medical-dictionary.thefreedictionary.com/endotracheal+tube

The Problem:
Clinical practice suggests ETT Model #2 is more susceptible to **kinking** during procedures, compared to Model #1 (**Figure 2**) This can lead to:

- **procedural complications**
- **physical injury to the patient**
- **patient death.**

Previous Research Studies:
Manual kinking of ETT tubes during *in vitro* experiments were performed to determine:

- angle at which a kink occurs
- location of the kink on the ETT
- effects of a kink on ventilation

Figure 2: A) ETT Model #1 (Mallinckrodt, now Shiley) and **B)** Model #2 (Halyard). Medtronic.com; products.halyardhealth.com.

Experimental protocols are lacking for mechanically testing ETTs in an objective and reproducible manner.

Purpose

To develop a reliable protocol for testing and comparing the mechanical properties of ETTs under common clinical conditions.

References

Hubler M. Anesth Analg 2006;103:1601-2.
Deepti BS et al. AANA J 2017;85:178-80.

Methods

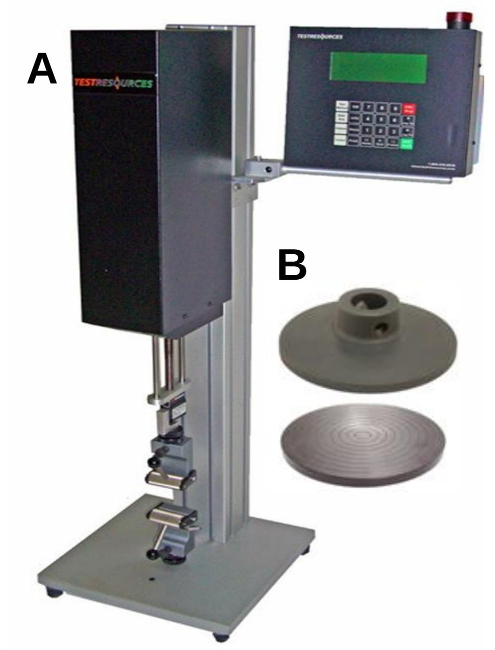

Figure 3: A) Universal Test Frame and **B)** 4-inch compression platens. testresources.net.

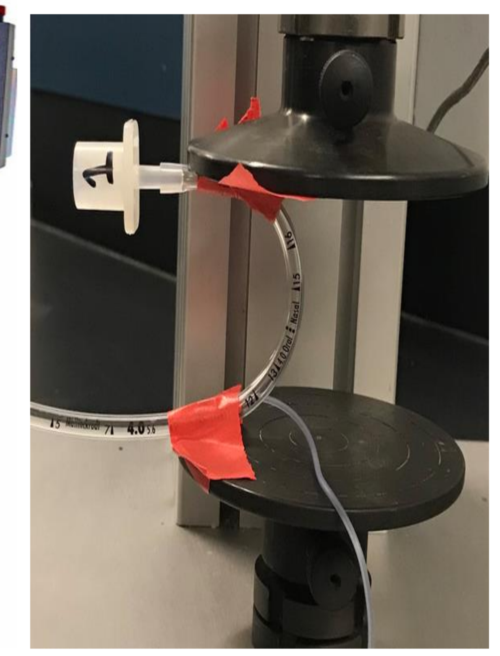

Figure 4: ETT secured to compression platens with surgical tape.

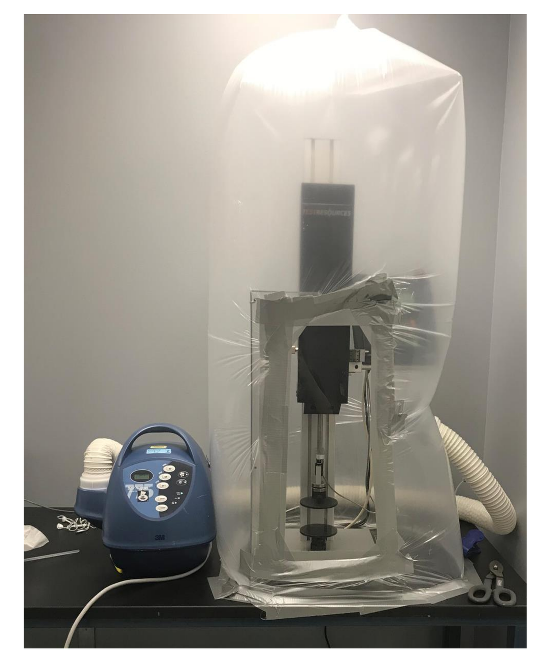

Figure 5: Tented Bair-Hugger set-up for 36°C temperature controlled compression experiments.

ETT Models:
Size 4.0 (inner diameter) oral/nasal ETTs (**Figure 2**)

- Model 1: Mallinckrodt (now Shiley) Cuffed Basic – Medtronic
- Model 2: Halyard Microcuff Pediatric – Halyard Health

Mechanical Testing Equipment:
Universal Test Frame -Test Resources, model: 100Q250-6 (**Figure 3A**)

- 1000N (250 lb) load cell
- four inch compression platens (**Figure 3B**)

Experimental Set-Up:
ETTs were secured with surgical tape to the compression platens, simulating a patient supine position (**Figure 4**).

- Initial vertical platen distance, x = 60 mm
- Compression applied at r = 60 mm/min
- Three ETTs of each model were tested at room temperature (25C)
- A tented set-up and Bair Hugger were used to repeat testing on three additional ETTs per model at 36C (**Figure 5**).

Data Collection and Analysis
Smoothed data from experiments were plotted using MATLAB

- Load (N) on the ETT was plotted vs. change in platen distance, Δx
- Second derivative of the load (N'') was calculated (right-axis) to identify a change in compression resistance (N''=0); this signifies a kink in the ETT.

Results

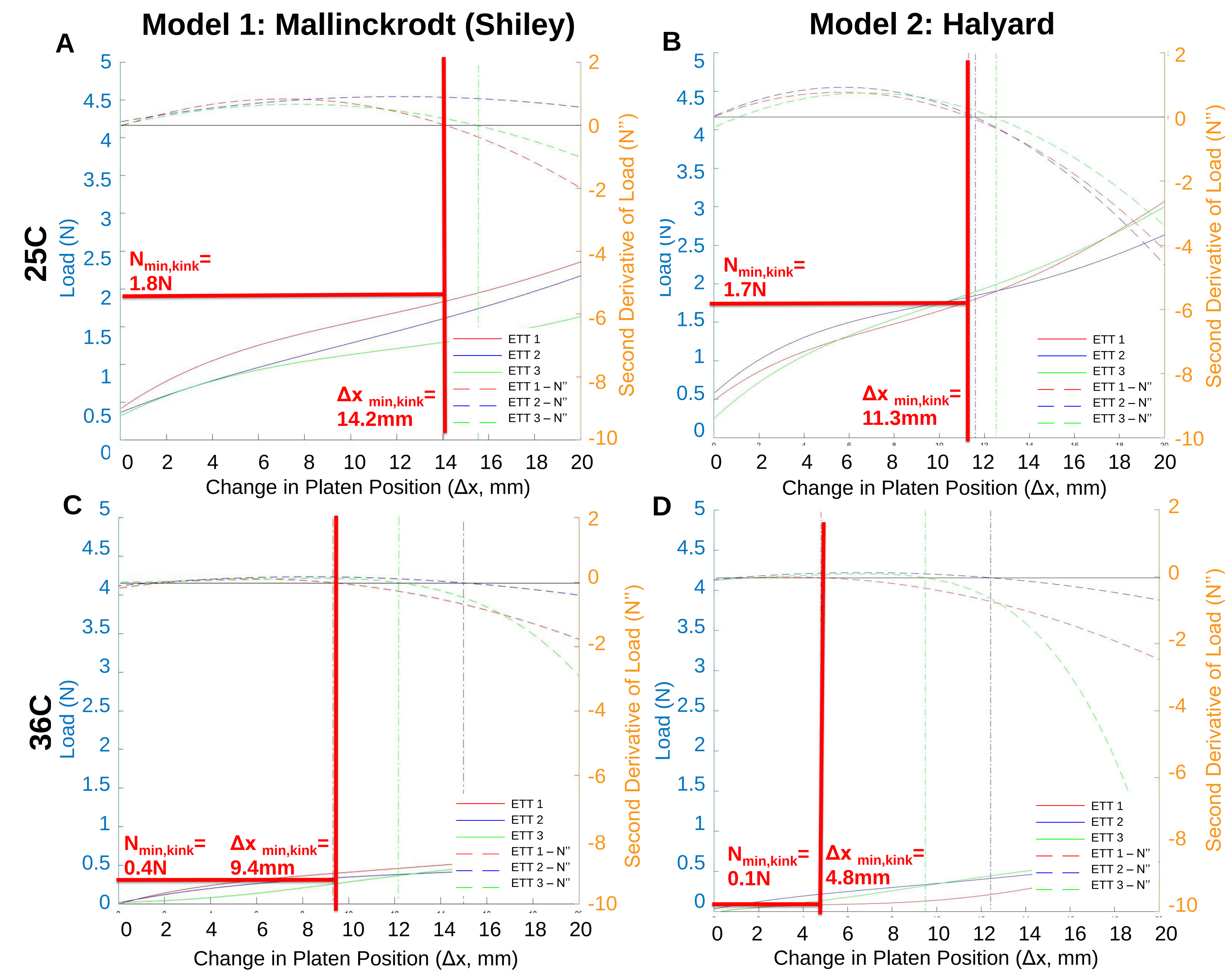

Figure 6: Load (N, left axis) and second derivative of load (N'', right axis, dotted lines) vs change in platen position from ETT compression tests: **A)** Mallinckrodt/Shiley Model at 25C; **B)** Halyard Model at 25C; **C)** Mallinckrodt/Shiley Model at 36C; **D)** Halyard Model at 36C. Kinks occur when N''=0. Minimum load ($N_{mim,kink}$) and minimum change in position ($\Delta x_{min,kink}$) at which a kink occurs is indicated with solid red lines.

Conclusions and Future Work

The Halyard ETT model kinks at applied forces as low as 0.1N, when tested at 36°C.

We have established an experimental method for objectively testing the mechanical integrity of ETTs.

Future work includes:

- Creep testing at 36°C: constant loads applied over 3 hours, to simulate prolonged surgery.
- Mechanical testing with concurrent monitoring of airflow through ETTs, to determine conditions at which airflow becomes obstructed.