Title : TRACHEAL WALL PRESSURE CAUSED BY ENDOTRACHEAL TUBE TIP

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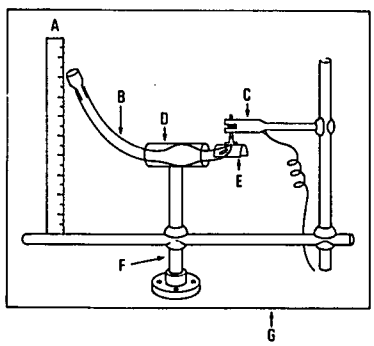
Introduction. Following a period of endotracheal (ET) intubation, anterior tracheal mucosal ulcerations have been noted. Since the natural curvature of an ET tube is concave anteriorly, a possible mechanism of injury could be mucosal ischemia caused by pressure from the tip of the ET tube. Accordingly, we measured, in a mechanical model, the force exerted by the tip of an ET tube on the anterior surface of the model as a function of ET tube: a) degree of curvature, b) wall rigidity and c) size.

Methods. The figure shows our mechanical model of an endotracheal tube inside a cylindrical plexiglass trachea of diameter 20mm. All ET tubes cuffs were inflated to visual just seal volume. Attached to the half plexiglass cylinder was a force transducer which had been calibrated with known weights and zeroed so as to eliminate the weight of the half cylinder. Thus, if the




A. METER STICK
B. ENDOTRACHEAL TUBE
C. FORCE TRANSDUCER
D. PLEXIGLAS CYLINDER - 2cm ID
E. ½ PLEXIGLAS CYLINDER - 2cm ID
F. ½ INCH ALUMINUM ROD SUPPORT APPARATUS
G. PEDIATRIC INCUBATOR AT 37°C

ET tube tip touched the cylinder, it would displace the sensor of the force transducer and generate an output in grams. The surface area of contact was measured by an imprint technique. Constant environmental temperature at 37°C was provided by a pediatric incubator. The experimental sequence consisted of placing five ET tubes of various manufacture (Rusch, Harris-Lake, American, Portex, Forreger) and size (7,8 and 9mm) into the plexiglass trachea and randomly changing the ET tube curvature by deflection and inflection of the adapter end over the range of 1-10cm markings on the meter stick. The results are the forces generated at 1,5 and 10cm marks and are reported as mean ±SE analyzed by student's paired t test ($p<0.05$=significance).

Results. The results are shown in Table 1. We found that the stiff rubber Rusch ET tube caused much more force at comparable ET tube size and degree of deflection than the other softer plastic ET tubes. All 7mm plastic ET tubes and all sized Forreger ET tubes failed to make contact with the half cylinder. Increasing the degree of deflection of the adapter end of the ET tube greatly increased the force on the half cylinder except for Forreger ET tubes. For all ET tubes that did make contact with the half cylinder increasing ET tube size always increased the force on the half cylinder. The surface area of contact at 10cm of deflection for all ET tubes was $4mm^2$.

Table 1: Force (grams) exerted on plexiglass half cylinder by tip of ET tube.

| ET Tube Make | mm | cm of ET Tube Deflection 1 | 5 | 10 |
|---|---|---|---|---|
| Rusch | 7 | 31±5 | 68±7* | 83±7* |
| | 8 | 75±4† | 137±5*† | 174±12*† |
| | 9 | 78±9 | 216±14*† | 300±10*† |
| Harris-Lake | 7 | 0 | 0 | 0 |
| | 8 | 6±2 | 59±3*† | 82±4*† |
| | 9 | 25±2 | 70±5*† | 92±6*† |
| American | 7 | 0 | 0 | 0 |
| | 8 | 24±5† | 25±6† | 29±5*† |
| | 9 | 30±2† | 53±2*† | 60±3*† |
| Portex | 7 | 0 | 0 | 0 |
| | 8 | 4±2† | 23±2*† | 24±3*† |
| | 9 | 6±3 | 25±6* | 32±3*† |
| Forreger | 7 | 0 | 0 | 0 |
| | 8 | 0 | 0 | 0 |
| | 9 | 0 | 0 | 0 |

* Significant increase with deflection
† Significant increase due to larger ET tube

Discussion. The clinical implications of these findings are multiple. First, assuming a uniform force distribution over the contact area conversion of force (in grams) to average pressure (in torr) per $mm^2$ is accomplished as follows:
760 torr=10333kg/$m^2$=10333x$10^3$gms/$10^6mm^2$=
760 torr=10333x$10^{-3}$gms/$mm^2$=10.33gm/$mm^2$
Since our surface area was $4mm^2$, the 9mm Rusch ET tube at 10cm of deflection caused a ((300/4)/10.33)760=5510 torr pressure against the half cylinder wall. The softer plastic 9mm tubes exerted a smaller calculated pressure which ranged 581-1691 torr. However, all of these pressures far exceed the pressure exerted by an ET tube cuff inflated to a just seal volume. Second, these findings indicated that in order to minimize anterior tracheal wall injury, small (7mm) plastic ET tubes should be used. Third, if a large ET tube is necessary, the Forreger brand is indicated because it has a short blunt tip distal to the cuff which prevented the tip from reaching the anterior wall of our mechanical model. Lastly, as indicated by our ET tube deflection data, head extension of intubated patients should be avoided.