Q&A

Question

The formula you are using is interesting. Kragh in 2011 (2011:176(10):1144) and Piper Wall in 2015 (JSOM, 2015:15(4):28) both reference a formula to determine arterial occlusion pressure: (limb circumference/TQ width) x 16.76 + 67. Have you looked at the comparison of your formula to theirs which has been the basis of several TQ studies?

Answer

The equation "(limb circumference/TQ width) x 16.67 + 67" was not developed to determine arterial occlusion pressure. The equation was put forth by Kragh et al.[1] as the linear version of the best fit equation developed by Graham et al.[2] to mathematically describe the arterial occlusion pressure data points collected by Graham et al.[2] using **pneumatic** tourniquets. The best fit equation in the Graham et al.[2] paper was $P_{occ} = (((P_{sys} - P_{dia})(\text{limb circumference}))/(3(\text{cuff width}))) + P_{dia}$. The pneumatic tourniquets used by Graham et al.[2] had widths of 4.5cm through 18cm on upper limbs and 4.5cm through 80cm on lower limbs, and the subjects were 34 normotensive volunteers with "no evidence or history of vascular disease." The Graham et al.[2] publication provided no goodness of fit information for the equation and had no separate provision of systolic blood pressure data, limb circumference data, or pressure at occlusion for any of the tourniquets. Furthermore, the reported arterial occlusion pressures for the different width pneumatic tourniquets were all taken during deflating after pneumatic tourniquet inflation to approximately 100mmHg over the observed systolic blood pressure. This is a similar protocol to obtaining systolic blood pressure, but the protocol for emergency-use limb tourniquet application does not involve tightening to 100mmHg past arterial occlusion and then loosening to the last arterially occlusive pressure; instead, emergency-use limb tourniquet application involves tightening to the arterial occlusion pressure and then securing the application at or above that pressure. And finally, the Graham et al.[2] work has no data concerning the duration of occlusion maintenance.

Kragh et al.[1] used the linear version of the equation from Graham et al.'s[2] work to guestimate what might be the upper necessary pressures for arterial occlusion with the 2.5cm wide SOFTT, the 3.8cm wide CAT, and the 8.8cm wide EMT, if each were used on a 71.46cm circumference proximal thigh. At the time of that Kragh et al.[1] publication, the literature did not have any sets of pressure data for 3.8cm-wide non-pneumatic, nonelastic tourniquets at arterial occlusion on any reported circumference limbs of any people with reported blood pressures.

At the time of the 2011 Kragh et al.[1] paper, tourniquet researchers knew that pressure profiles differed under pneumatic and non-pneumatic tourniquets and under elastic and nonelastic tourniquets, but the only "published prior to 2011, 3.8cm wide non-pneumatic,

nonelastic tourniquet pressure at arterial occlusion data" of which I am aware was the report by McEwen and Casey[3] regarding a new pressure transducer. McEwen and Casey[3] reported CAT-applied pressure on the lower limb to achieve arterial occlusion to be 450 to 700mmHg (700mmHg over the middle portion of the width and 450mmHg over the outer portions of the width). The McEwen and Casey[3] report says the CAT was "applied to a normal lower limb to stop arterial bloodflow," so it appears the pressure data comes from only one person's limb. No circumference data nor systolic blood pressure data is present in the report; how arterial occlusion was determined (palpation, audible Doppler loss, visual Doppler loss, etc.) is not present in the report; whether the pressures reported were those present with the windlass rod held at the location first achieving arterial occlusion or with the windlass rod placed in the securing bracket at the next rotational location after achieving arterial occlusion is also not present in the report, and how long arterial occlusion was maintained is not present in the report.

Three papers published by the Wall and Buising group[4-6] have shown that the equation "(limb circumference/TQ width) x 16.67 + 67"[1] does not provide good estimates of the pressure at which a non-pneumatic tourniquet will achieve arterial occlusion during the tightening process. Figures 1 and 2 of the 2013 paper by Wall et al.[4] showed that the predicted arm and thigh occlusion pressures obtained with use of the linear version[1] of the Graham-origin[2] equation were considerably lower than the actual occlusion pressures for the non-pneumatic, nonelastic, 3.8cm-wide CAT and the non-pneumatic, elastic, 10.4cm-wide SWATT. In the subjects in that study,[4] the values from the linear version[1] of the Graham-origin[2] equation were also considerably lower than the actual occlusion pressures for the 14.5cm-wide and 13.3cm-wide pneumatic tourniquets (standard and long blood pressure cuffs). Panel B of Figure 3 of the 2014 paper by Wall et al.[5] shows most of the occlusion pressures for 3.8cm-wide RMTs placed on arms and on thighs being substantially higher than the line that results from use of the linear version[1] of the Graham-origin[2] equation. The 2014 Wall et al. paper[5] also reports the slopes, intercepts, and r^2 values resulting from use of linear regression to derive the best fit lines for the data obtained in that study[5] and with the CAT in the 2013 Wall et al. paper.[4] Figure 4 of the 2015 paper by Wall et al.[6] shows best fit linear regression lines and forearm and calf actual arterial occlusion pressures for the non-pneumatic, nonelastic, 3.8cm-wide CAT; the non-pneumatic, nonelastic, 3.8cm-wide SOFTTW; the non-pneumatic, nonelastic, 3.8cm-wide Pediatric RMT; and the non-pneumatic, elastic, 10.4cm-wide SWATT. The best fit linear regression lines' slopes, intercepts, and r^2 values are provided with Figure 4.[6] The actual occlusion pressure values have considerable visible scatter;[6] the r^2 values are low,[6] which corresponds with high scatter and indicates how inadequately the ratio of limb circumference to tourniquet width explains variation in tourniquet arterial occlusion pressure; and the best fit line for the 3.8cm-wide RMT is considerably different than the best fit lines for either the 3.8cm-wide CAT or the 3.8cm-wide SOFTTW (also indicating how inadequate the ratio of limb circumference to tourniquet width is for explaining variation in tourniquet arterial occlusion pressure).[6]

I would not consider the linear version[1] of the Graham-origin[2] equation to have been the basis of any emergency-use limb tourniquet studies of which I am aware, but linear regression has been used as one method of looking at obtained pressure data in various tourniquet studies.

Looking at the presented slide, I don't know precisely what was said regarding the bulleted points. Beyond what was said, there is also what listeners heard while they were processing the presented information. I note that the bullet point "Average pressure increase during transportation" does not include the words "systolic blood" between "average" and "pressure." Depending on what was said and what was heard, an audience person could easily, albeit mistakenly, think that the 25mmHg pressure increase during transportation was a tourniquet pressure increase rather than an increase in the patient's systolic blood pressure. The information and sources of the pressures used for the recommendations are present in the attachment "nonelastic strap tourniquet surface pressure recommendations v1.docx" which I pulled from my folder for the June 27, 2018, ASTM tourniquet group meeting.

The 505mmHg value is what I recommended as the **minimum** or threshold maintainable pressure for certification of a 3.8cm-wide emergency-use nonelastic strap limb tourniquet. The pressure measurement system and the responses of the underlying substance both matter,[7,8] and that 505mmHg would be the minimum pressure value when using the measurement system used by my research group[7] and when using the limbs of healthy live humans and when desiring to be able to reach and maintain arterial occlusion on 95% of normotensive, healthy adult humans. As discussed in ASTM meetings, the 505mmHg pressure value is also specific for a 3.8cm-wide nonelastic, nonpneumatic strap limb tourniquet. Because the 3.8cm-wide CAT appears to require higher pressures to reach arterial occlusion than does the 3.8cm-wide Tactical RMT,[9] achieving 505mmHg might not be sufficient to obtain and maintain arterial occlusion on 95% of normotensive, healthy adult humans when using a CAT, but we don't have anywhere near as much pressure data for the CAT as we do for 3.8cm-wide RMTs.

Concerning the 505mmHg pressure value and tourniquet certification, a testing device needs to be developed that can determine the total circumferential pressure applied by the tourniquet to the device. Based on the current data we have, the device needs to be calibrated so that its threshold total circumferential inward pressure is the total circumferential inward pressure created by the strap portion of a 3.8cm-wide RMT when applied to a healthy live human thigh at 505mmHg as measured with the pressure measuring system my group uses.

References

1. Kragh JF Jr, et al. The military emergency tourniquet program's lessons learned with devices and designs. Mil Med 2011;176:1144-1152.

2. Graham B, et al. Occlusion of arterial flow in the extremities at subsystolic pressures through the use of wide tourniquet cuffs. Clin Orthop Relat Res 1993;286:257-261.

3. McEwen JA, Casey V. Measurement of hazardous pressure levels and gradients produced on human limbs by non-pneumatic tourniquets. CMBECS Proc. 2009,32. https://proceedings.cmbes.ca/index.php/proceedings/article/view/291/286 Accesse d May 3, 2022.

4. Wall PL, et al. Tourniquets and occlusion: the pressure of design. Mil Med 2013;178(5):578-587.

5. Wall PL, et al. Tourniquet pressures: strap width and tensioning system widths. J Spec Oper Med 2014;14(4):19-29.

6. Wall PL, et al. Different width and tightening system emergency tourniquets on distal limb segments. J Spec Oper Med 2015;15(4):28-38.

7. Hingtgen E, et al. Characterizing a system for measuring limb tourniquet pressures. J Spec Oper Med 2020;20(1):47-54.

8. Wall P, et al. Pressure responses of tourniquet practice models to calibrated force applications. J Spec Oper Med 2021;21(2):11-17.

9. Wall P, et al. Pressure responses of tourniquet practice models to calibrated force applications. J Spec Oper Med 2021;21(2):11-17.

-Dr. Piper Wall