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ORIGINAL STUDY

Digital tourniquets : A comparative analysis of pressures and pain perception

Soulat NAIM, Makaram S. SRINIVASAN

From Blackburn Royal Infirmary, Blackburn, United Kingdom

Digital tourniquets have been condemned because of the reported occurrence of neurovascular complications. This study compares the pressures and pain perception between three different tourniquets, namely the rubber glove finger stall, Foley's urinary catheter and the commercial band tourniquet. The subjects involved were 20 volunteers with 80 fingers studied in total. A direct pressure measuring technique was used. The pressures recorded were highest and most variable with the catheter tourniquet, whereas the rubber glove tourniquet recorded the lowest pressures. Correspondingly, visual analogue scale in relation to patient discomfort showed high scores with the catheter tourniquet and low scores with the rubber glove tourniquet. We conclude that catheter tourniquet use should be avoided as it generates extreme and variable pressures, whereas rubber glove finger stall tourniquets appear as a better alternative.

Keywords : tourniquets ; digital.

INTRODUCTION

Digital tourniquets are frequently used in hand surgery to provide a bloodless field during an operation on a single digit. They have been condemned because of the reported occurrence of intimal damage, vascular thrombosis, neurapraxia (*2*) and necrosis of fingers (*12*) due, in large part, to the high pressures generated directly beneath the tourniquet (*1,5,7,9*).

Changes in peripheral nerves secondary to prolonged or excessive pressure beneath and distal to the site of compression have been documented in experimental animals at cuff pressures between 500 and 1000 mm of Hg (*9,12*).

Although, in general, the digital tourniquets are relatively safe, it has been suggested that the complication rate is higher than the reported incidence in the literature (*11,12*).

Comparative pressure measurements between different types of digital tourniquets have been done : a) in cadaver hands using saline pumps (*11*), b) in patients, using stress strain correlation graphs and mathematical assumptions (*8*), and c) in volunteers using strain gauges (*3*).

The methodological shortcomings in the previous studies include the use of indirect pressure measuring techniques (*3,8*) and small (*3,8,11*) and unrepresentative samples (*11*).

■ Soulat Naim, MS (Orth), MCh (Orth), Registrar in Orthopaedics.

■ Makaram S. Srinivasan, MS (Orth), FRCS (Orth), Consultant Orthopaedic Surgeon.

Department of Orthopaedics, Blackburn Royal Infirmary, Blackburn, United Kingdom.

Correspondence : Soulat Naim, 17 Bluebell Hollow, Walton on the Hill, Staffordshire, ST17 0JP, United Kingdom.
E-mail : soulat_naim@hotmail.com

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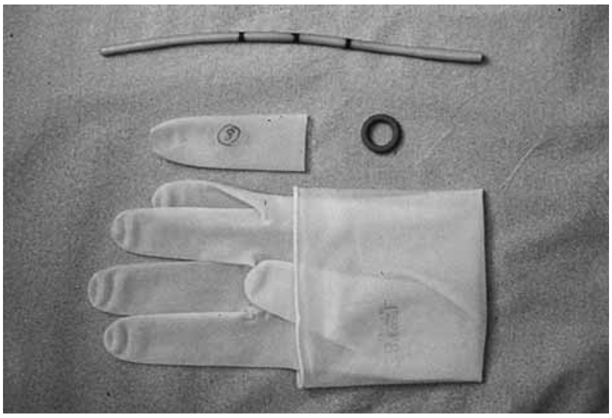

Fig. 1. — The three types of digital tourniquets.

The aim of our study was to compare the pressures beneath the three different types of digital tourniquet namely : a) rolled rubber glove, b) commercial rubber finger tourniquet band and c) urinary catheter (fig 1), in volunteers using a standardised device.

MATERIALS AND METHODS

The subjects involved were 20 healthy volunteers with eighty fingers (4 long fingers in one hand) in total, in the age range from 23 to 50 years and with equal sex distribution. The volunteers were blinded for the type of tourniquet and the hand was randomly selected. All four fingers were randomly tested with all the three types of tourniquet and the minimum time between each application was 5 minutes.

The subjects were asked to rate the pain after each application, on a visual analogue scale 0 to 10 (0 = no pain and 10 = maximum pain).

For the rubber tourniquet, the rubber glove size was measured by doubling the midpalmar length in inches (*8*). The fingerstall was cut just proximal to the apex where the margins are parallel and at the base. Precaution was taken not to cut the glove at the apex, as tight initial turns would cause high pressures. The finger stall was rolled completely till the base of the finger with no sleeve remaining, to prevent fall in pressure. The band tourniquet tested was one commercially available and the technique of application was as recommended by the manufacturer. As the Penrose drains (used in a study by Lubahn *et al* (*8*) were not found to be commonly used as digital tourniquets in present times, instead the common use of Foley's catheter as a digital tourniquet prompted us to use it in our study. As there are no defined formulas or methods for the use and application of Foley's catheter as digital tourniquet, we decided to apply it as described by Lubahn *et al* (*8*) and determine the pressure readings underneath. A urinary catheter (Foley size no : 12) was used as the elastic tube tourniquet and two marks were made on the tube, 26 mm apart in the unstretched state. This was wrapped around the finger until the marks touched and the tube was clamped.

The pressures were measured with a specially designed apparatus manufactured for this study by the engineering division in our city college.

It consisted of a peristaltic air compressor, which is a positive displacement pump with a volumetric delivery of 11 litres per minute. This is connected to a tube with a pressure sensor that measures the pressure in 'Bars', which can easily be converted to mm of mercury. At the end of the tube is a silicone tubing made of high strength silicone rubber with a 2 mm bore, 0.5 mm wall thickness and hardness of 50 degrees shore 'A'. The elastic properties of the tube were such that it offered minimum resistance, and the tension in the wall was just adequate to keep the lumen patent at the atmospheric pressure (fig 2).

The neurovascular structures on the finger were first marked and the silicone tube was placed on the neurovascular marking (fig 3), as the nerve is most susceptible to mechanical pressure injury (*6*).

The tourniquet was rolled over the silicone tube and the air compressor was started. As the pump gradually increases the pressure in the silicone tubing, air escapes beneath the tourniquet when the air pressure in the silicone tube becomes greater than the clamping pressure. At a stage when air escapes beneath the tourniquet the pressure reading reaches a plateau and this was taken as the tourniquet pressure. Repeated bench testing of the equipment produced identical values.

RESULTS

The rubber glove tourniquet achieved the lowest mean pressure of 561 mm of Hg. This was lower than that of the commercial band (636 mm of Hg) and the rubber tube (834 mm of Hg) (table I).

The visual analogue scale of ten (0 as no pain and 10 as severe pain), showed a high average value of 7.95 for the rubber tube and a low average

Fig. 2. — Pressure measurement apparatus.

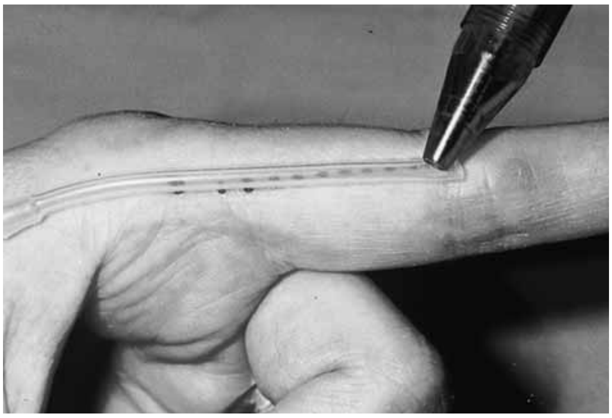

Fig. 3. — Surface marking over neurovascular bundle for pressure measurements.

Table I. — Pressures recorded with the three types of digital tourniquets tested

Tourniquet	Range of pressure (mm Hg)	Mean pressure (mm Hg)	Standard deviation (mm Hg)
Rubber Glove	225-860	561	138
Band	375-975	636	128
Urinary catheter	520-1500	834	232

value of 3.65 for the rolled rubber glove. This correlates with the pressures generated.

Data were examined using the statistical program R (*5*). The analysis was performed using ANOVA.

Analysis of pressure between fingers for the same tourniquet showed no statistical variation between fingers (F = 1.87 ; df = 3.234 ; p ~ 0.13).

Analysis of pressures measured between the three different tourniquet groups showed a statistically significant difference among the three with rubber glove tourniquet pressure being the lowest and urinary catheter tourniquet pressure being the highest (F = 53.59 ; df = 2.237 ; $p < 2 \times 10^{-16}$).

The urinary catheter tourniquet showed higher variability of measured pressures when compared with other two groups (F = 97.1 ; df = 1.238 ; $p < 2 \times 10^{-16}$).

Comparison of pain scores showed a highest score with urinary catheter tourniquet and lowest with rubber glove tourniquet which was statistically significant (F = 157.1 ; df = 2.237 ; $p < 2 \times 10^{-16}$).

DISCUSSION

The pressures generated beneath the different types of digital tourniquets have been measured in various studies using different methods.

Hixson *et al* (*3*) reported a comparative study of pressures using a miniature pressure transducer (strain gauge) placed on the dorsum of the finger and not on the neurovascular marking. The transducer measures the deflection and not the actual pressure. Deflections could vary when applied on different parts of a finger.

Lubahn *et al* (*8*) compared the pressures between the rolled rubber glove and the elastic tube. The pressures were derived from a stress strain correlation graph, that used mathematical assumptions to derive at the pressure and hence the actual pressures were not measured. We found that the variations in strain are more over uneven surfaces like the finger base and hence may not be reliable. Our study showed results contradictory to the study of Lubahn *et al* (*8*), where an elastic tube marked

26 mm apart generated low and uniform pressures. This could be due to a) The different techniques and method used in measuring the pressures in these two studies, and b) The elastic properties of the urinary catheter are different from those of the Penrose drain. The Foley catheter was used in our study as the elastic tube instead of the Penrose drain due to the common use of it by orthopaedic surgeons and the reduced availability of Penrose drains in orthopaedic theatres in present times.

Shaw *et al* (*11*) reported a study done on cadaver hands where the pressures were measured directly using the Harvard pump, when the saline passed beneath the tourniquet through a saphenous vein graft placed alongside the neurovascular bundle. Their results showed lower pressure for rubber glove tourniquet than for the Penrose drain. The major disqualification of this study we feel is of over estimation of pressures due to the post mortem changes.

In our present study we corrected the methodological shortcomings of previous studies by measuring pressures directly using a special device on human volunteers. Pressures measured by our technique may not give the accurate estimate of the tissue pressure in view of the difference in elastic property of a synthetic silastic tube used in our study as compared to a digital artery. The thickness of the wall, the stiffness of the silastic tube and its contents matter too. Under the experimental circumstances this difference is probably small, and similar conditions were compared.

The pressure will vary with depth and location of the silastic tube. Although, in this study the silastic tube was placed in line with the surface marking of the neurovascular bundle, it was placed on the skin and this may not have estimated true pressures.

The pressure data of the urinary catheter revealed that a wide range of pressures were recorded. In our view this was due to multiple factors. First, we found it impossible to stretch and clamp at the same spot each time. A few millimeter differences in stretch can make a large difference in the pressure (*11*). Secondly, we used a standard length of 26 mm as recommended by Lubahn *et al* (*8*), irrespective of the finger diameter.

Similarly many variables can influence the pressures that are generated with rolled glove tourniquet. Firstly, error in the determination of glove sizes and secondly, the glove thickness and the material properties. This was minimised using the same material glove by the same manufacturer. Thirdly, the diameter of the glove decreases at the tip and tight initial turns can increase the pressure. This was minimised by not removing the narrowed tip of the fingerstall.

The rolled rubber glove showed the lowest mean and range of pressures with the added advantage of low discomfort on visual analogue scale, automatic exsanguination at the time of application, low cost, easy availability and simplicity of technique. The reported disadvantage is that the rubber glove ring can be overlooked at the end of the procedure and mistakenly left in place (*4*).

CONCLUSION

The mean and range of pressures were highest and most variable with the catheter tourniquet whereas the pressures of the band tourniquet came between the rubber glove fingerstall and the catheter. Correspondingly, the visual analogue scale showed high scores with the catheter tourniquet and low scores with the rubber glove tourniquet.

We conclude that rubber glove fingerstall digital tourniquet when compared with the other two tourniquets, generates the lowest pressures with less variability and lowest pain score in a visual analogue scale, thereby reducing the potential risk of neurovascular complications. We feel that the use of the catheter tourniquet method as proposed by Lubahn *et al* (*8*) on the finger should be avoided in view of the extreme and variable pressures generated.

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