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Research Article

Preventative Measures to Reduce Incidence of Handcuff Neuropathy

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ABSTRACT

Neuropathy due to prolonged restraint in handcuffs remains a significant concern because handcuffs can be inadvertently over tightened, placing excess pressure on the superficial radial nerve. Recent modifications in handcuff design have begun to address this issue and warrant further investigation. It was hypothesized that a new handcuff design, which prevented over tightening of handcuffs, would prevent the pressure applied to the superficial radial nerve from exceeding nerve injury risk thresholds. To test this hypothesis we used a physical model of the wrist and superficial radial nerve which allowed measurement of the pressure applied by tightened and artificially loaded handcuffs. Three handcuff designs were tested, one of which was designed to prevent over tightening. Recorded pressure was compared to pressure thresholds for loss of function of the rat tibial nerve, a nerve which is similar in diameter to the human superficial radial nerve.

The results indicate that relatively low levels of force applied by tightened handcuffs produced pressures in the surrogate nerve which exceeded nerve injury risk thresholds in two of the handcuffs but not with the handcuff designed to prevent over tightening. The pressure produced by a given load depended on whether the single strand or the double strand of the handcuff was oriented over the surrogate nerve. The results suggest that handcuff designs which include features to prevent over tightening can significantly reduce the risk of injury to the superficial radial nerve even when handcuff restraints are applied for several hours. However, the results also suggest that struggling in the handcuffs can potentially lead to injury even when the handcuffs are not overly tight.

Keywords: Handcuffs; Superficial radial nerve; Neuropathy

INTRODUCTION

Neuropathy of the superficial radial nerve has been reported in a number of studies and frequently attributed to prolonged handcuff pressure [1-9]. Studies which have examined the neuropathic effects of prolonged pressure or force applied to a peripheral nerve in animal models can serve to establish thresholds for the risk of loss of superficial radial nerve function. For example, rat tibial nerve has a diameter of approximately 1 mm [10]. Which is similar to that of the human superficial radial nerve and would, therefore, be expected to undergo similar changes in function in response to externally applied pressure. Szabo and Sharkey applied pressure to the rat tibial nerve and found that constant pressures of 60 or 90 mmHg resulted in a 50% reduction in nerve function if applied for 1 h and complete loss of nerve function if applied for 2.5 h. Constant pressure as low as 30 mmHg reduced nerve function by 50% if applied for 3.25 h [11,12].

There have been few notable changes in handcuff design over the past century. The basic design comprises a double and a single semicircular strand which interlocks and tightens by engaging a ratchet mechanism. Once interlocked, the ratchet can be advanced to tighten the strands. Because the ratchet cannot be reversed, the strands cannot loosen unless the strands are unlocked with a key. Once tightened, the strands are normally locked by setting a pin, referred to as a double lock, to prevent further tightening. If the double lock is not set, the ratchet can slip with the risk of additional tightening. Thus, the amount of pressure on the superficial radial nerve depends on the initial tightening of the strands but can increase if the double lock is not engaged and the ratchet slips. GTD Scientific recently investigated the effect of over tightening in two handcuff designs and found that the pressure induced in a surrogate nerve readily exceeded the thresholds for nerve injury if maintained for prolonged periods [13].

A recent development in handcuff design, aimed at preventing over tightening, motivated the current study. It was hypothesized that the new design would prevent the pressure from exceeding nerve injury thresholds, unlike the handcuff designs which were previously tested. This hypothesis was tested using a model of the wrist with a surrogate nerve created by filling a flexible tube with mineral oil and positioning it at the approximate anatomical

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location of the superficial radial nerve. The surrogate nerve allowed measurement of the internal pressure when the handcuff was tightened or when loaded with a weight.

MATERIALS AND METHODS

Apparatus

The wrist model consisted of two wooden dowels joined with a bolt, to simulate the radius and ulna (Figure 1). In addition to stabilizing the dowels, the bolt permitted adjustment of the separation distance. Dowels of 2.54 cm diameter, separated to create a width of 5.5 cm, were used to model the wrist. A silicone tube with an inside diameter of 1 mm and outside diameter of 2 mm, taped along the side of one of the dowels, served as a surrogate for the superficial radial nerve. A sheet of SynDaver 8N SynTissue, which simulates skin and underlying subcutaneous fat, was wrapped around the dowels to serve as surrogate skin overlying the superficial radial nerve. The tube was filled with mineral oil and connected to a pressure sensor (Focket 30 PSI, China). The mineral oil was pressurized by means of a syringe attached to a valve connected to the tube prior to testing, such that all measurements were made as increases in pressure relative to the baseline of the pressurized tube.

Three handcuff designs were compared. One design was a standard design used by the majority of manufacturers. The model which was tested was the Smith and Wesson M-100 (Figure 2A). The second design involves a modification to the strand shape, creating a more oval contour and a smoother edge. The model which was tested was the ASP Ultra Plus (Figure 2B). The third design incorporates an automatic double lock which prevents further tightening, once engaged. The model which was tested was the Spider Cuff Model 40 (Figure 2C).

Protocol

Tests were performed to determine the tube pressure created by either loading or tightening the handcuff. One test involved loading the handcuff with a series of weights. In this test the dowels were clamped in a vise so that the tube could be loaded vertically through the gravitational force applied by the weights (Figure 1A). The handcuff strands were engaged but loose enough such that pressure was applied to the tube only by adding weight rather than by tightening the handcuff. A cable was passed through a handcuff link and weights were attached to the cable such that the handcuff applied pressure to the tube. The weights produced forces of 5 lb, 10 lb and 15 lb. Tube pressure was measured continuously over a 5 s interval, from before the weight was attached to the cable until the weight was hanging in a steady state.

The other test involved increasing the handcuff tightness by single increments. Measurements began before the handcuff was tightened and continued as the strand tightness was incremented by one ratchet tooth at a time until the tightness limit was reached, i.e. until it was not possible to move the strand. During this test, the dowels were clamped to a countertop using C-clamps (Figure 1B). Tube pressure was measured continuously over a 25 s interval, beginning when the handcuff was loose and ending after the strand had been advanced to the maximum tightness.

Data acquisition

Tube pressure was acquired at a sample rate of 1000 Hz. All pressures are reported in mmHg to allow for comparison with the animal studies on isolated nerves. Each test was repeated 5 times. Prior to analysis, the pressure signal was digitally low-pass filtered using a fifth-order Butterworth filter with a cutoff frequency of 10 Hz, implemented in Matlab.

Analysis

Baseline tube pressure was computed as the average pressure during a 100 ms interval prior to tightening or loading the handcuff. Final steady state tube pressure after loading was computed as the average tube pressure during the final 0.5 s of the sampling period (Figure 3). Pressure after tightening the cuff was taken as the pressure immediately after the transient increase in pressure as the strand was tightened to the next ratchet tooth (Figure 4). The mean and standard deviation of the change in tube pressure relative to baseline of the 5 trials for each condition were then computed.

RESULTS

The mean pressure for the 5 trials with a load of 5 lb applied to the surrogate nerve, ranged from 108 mmHg for the Spider Cuff to 177 mmHg for the ASP handcuff as shown in (Figure 5). The mean pressure increased with the size of the load and ranged from 219 mmHg for the Spider Cuff to 248 mmHg for the Smith and Wesson handcuff with a load of 15 lb.

Handcuff design dictates that the single strand would normally be the component pushing against the anatomical location of the superficial radial nerve. However, rotation of the wrist or ill-fitting handcuffs might cause the double strand to push against the nerve. Because the plates of the double strand are thinner than the plate of the single strand, the double strand could impose higher pressure. A single test, consisting of 3 trials under each condition, was conducted with the Spider Cuff using a 10 lb load to compare the pressure applied by the double strand with the pressure applied by the single strand. On average, the pressure was found to be approximately 65 mmHg higher with the double strand placed over the surrogate nerve than with the single strand.

The effect of tightening the handcuff is shown in (Figure 6). At minimum tightness, the mean pressure was 4.79 mmHg for the ASP handcuff, 5.75 mmHg for the Spider Cuff and 6.39 mmHg for the Smith and Wesson handcuff, indicating that the pressure on the nerve was comparable for all handcuff models and well below the threshold for risk of nerve injury. However, at maximum tightness, the mean pressure only increased to 30.3 mmHg for the Spider Cuff, whereas it reached 175mmHg for the Smith and Wesson handcuff and 178 mmHg for the ASP handcuff. This difference between the Spider Cuff and the other two handcuff models is attributed to the automatic double lock on the Spider Cuff which limited the amount by which it could be tightened. Whereas the strands of the Smith and Wesson and ASP handcuffs could be tightened by 6 ratchet teeth, the Spider Cuff strand could only be tightened by 3 ratchet teeth from the tightness at which pressure first began to increase above the baseline level.

A linear model of the change in pressure with each increment in tightness was used to predict the pressure if it had it been possible to increase the tightness of the Spider Cuff by an additional ratchet tooth. As illustrated in (Figure 7). The predicted pressure would still have been below the 60 mmHg threshold for risk of injury with prolonged pressure.

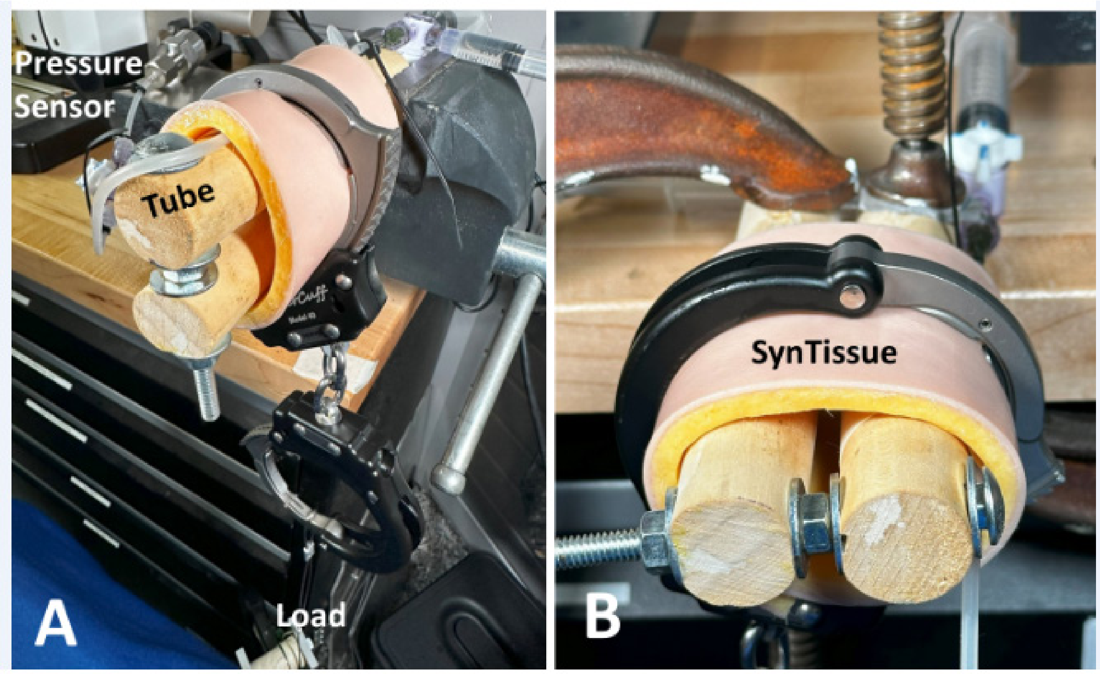

Figure 1: (A) Experimental setup for measuring pressure when loading the handcuff. Weights are suspended from a cable looped through the loose manacle; (B) Experimental setup for measuring pressure when tightening the handcuff.

Figure 2: (A). Smith and Wesson M-100 handcuff; (B) ASP Ultra Plus handcuff; (C) Spider Cuff Model 40 indicating location of the Automatic Double Lock (ADL).

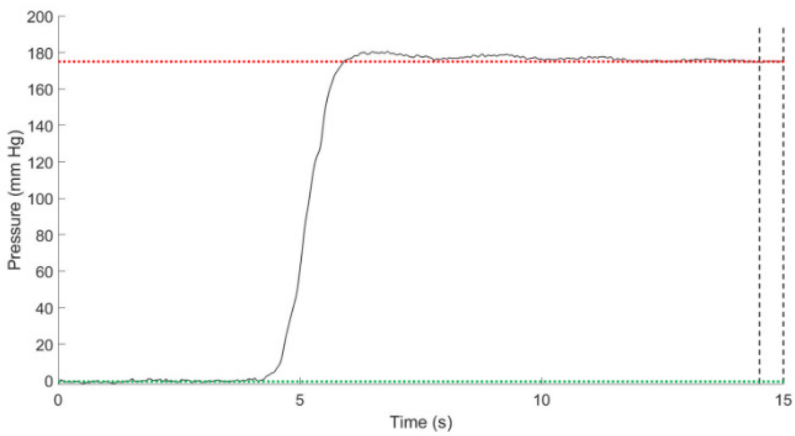

Figure 3: Pressure measurement from a trial with a 5 lb load suspended from the ASP handcuff. Horizontal green dotted line indicates baseline pressure and vertical dashed black lines indicate 0.5 s time interval for calculating average pressure. Pressure due to the load is the difference between the red and green dotted lines.

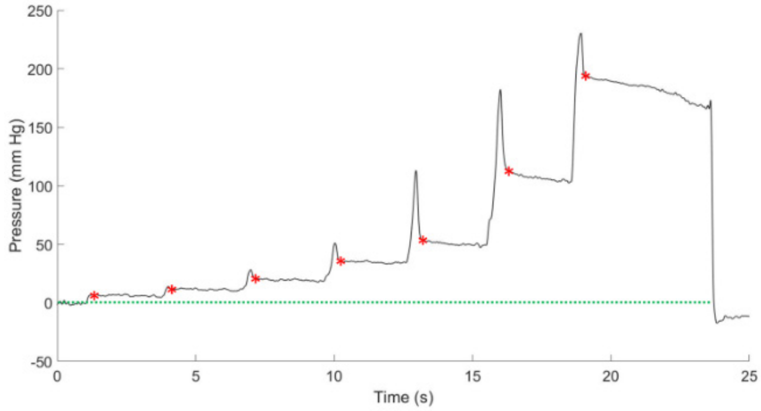

Figure 4: Pressure measurement from a trial in which the ASP handcuff was incrementally tightened. Horizontal green dotted line indicates baseline pressure and red asterisks indicate the pressure, immediately after the transient increase pressure as the strand was tightened by one ratchet tooth. Pressure due to tightening is the difference between the pressure at the red asterisk and the green dotted line.

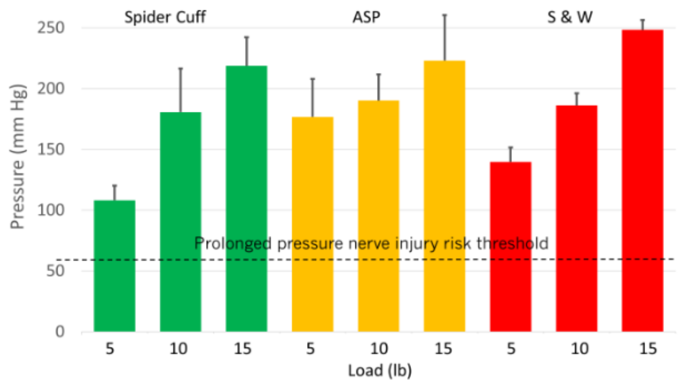

Figure 5: Mean pressure for 5 trials, displayed with the standard deviation, for each load for the Spider Cuff ( ) ASP handcuff ( ) and Smith and Wesson handcuff ( ). The dashed horizontal line indicates the threshold for risk of nerve injury when constant pressure is maintained for at least 1 h.

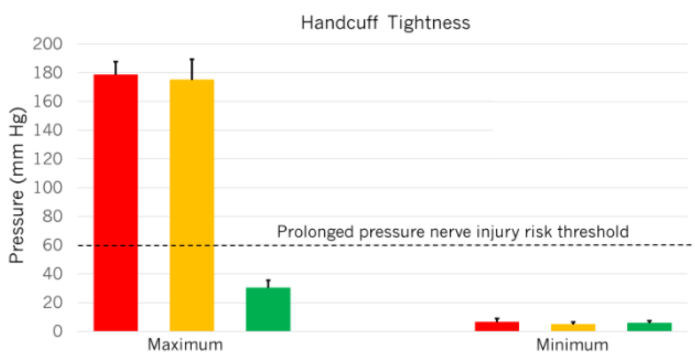

Figure 6: Mean pressure for 5 trials, displayed with the standard deviation, for the minimum tightness at which pressure first began to increase above the baseline level (right) and for the maximum tightness that could be achieved (left) for the three handcuffs.

Note: S & W ASP Spider Cuff

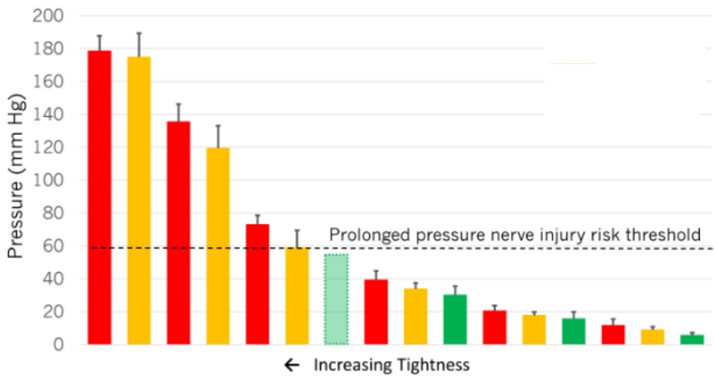

Figure 7: Mean pressure for 5 trials as tightness was incrementally increased, displayed with standard deviation, for the three handcuffs. The pale green bar outlined with dotted lines indicates the predicted pressure for the Spider Cuff had it been possible to tighten the strand by an additional increment.

Note: S & W ASP Spider Cuff

DISCUSSION

The objectives of the present study were to determine the risk of injury to the superficial radial nerve posed by pressure applied to the nerve when handcuffs are fastened and manipulated and whether handcuff design can affect the risk. A wrist model with a pressurized tube of similar diameter to the superficial radial nerve and overlying synthetic skin was used to measure the pressure when loads were applied to handcuffs or the handcuffs were incrementally tightened. It was assumed that the threshold for risk of superficial radial nerve injury would be similar to that of the rat tibial nerve, which is similar in size. From the results of a scientific study in which prolonged pressure was applied to the rat tibial nerve [12], it was determined that a pressure of 60 mmHg could lead to 50% loss of rat tibial nerve function after 1 h. It was assumed that spending an hour detained in handcuffs would not be unusual, given the amount of time that would normally elapse in processing a detainee. Therefore, a pressure of 60 mmHg was adopted as the threshold for risk of superficial radial nerve injury. The results of the present study indicate that relatively low handcuff forces produce pressures which exceed thresholds for risk of neuropathy if applied for prolonged periods.

The results of the tightness testing indicate that, regardless of the type of handcuff, the risk of injury to the superficial radial nerve can be avoided if the handcuff is kept sufficiently loose. In particular, the first three increments in tightness, from right to left in Figure 7, result in pressures below the injury risk threshold for all three handcuffs. However, only the Spider Cuff has a built in mechanism, the automatic double lock, which prevents the handcuff from being tightened beyond the injury risk threshold. Comparing the data of Figure 5 to the data of Figure 7 suggest that the force being applied by the Smith and Wesson handcuff and ASP handcuff at maximum tightness is approximately equivalent to a 10 lb load on the nerve whereas at maximum tightness, the Spider Cuff applies less than 5 lb. Previous tests conducted by GTD Scientific [13] suggest that handcuff tightness below the equivalent of a 2.5 lb load, prevents pressure on the nerve from exceeding the injury risk threshold.

In addition to using loads to estimate the force applied to the nerve by tightening the cuff, the pressure generated by the loads provides an indication of the risk of nerve injury associated with struggling in handcuffs. For example, 5 lb is a relatively small percentage of the maximum force that a detainee could apply to the handcuffs if twisting the wrists or attempting to pull the arms apart. Yet it produces pressure in the surrogate nerve which exceeds the threshold for risk of nerve injury. Even if the handcuffs are sufficiently loose, struggling in the cuffs could easily produce more force than necessary for pressure on the nerve to exceed 60 mmHg. Although forces applied to the handcuffs during struggling are not likely to be sustained, they could produce intermittent pressure in excess of 200 mmHg [10]. As animal studies have found, the greater the pressure, the shorter the time interval for risk of injury [14]. Therefore, even intermittent high pressure could lead to nerve injury as the cumulative effect of a struggle during which a detainee applied large forces to the handcuffs

CONCLUSION

Risk of injury to the superficial radial nerve can be significantly reduced with a handcuff design that prevents over tightening, such as the automatic double lock implemented in the Spider Cuff. Although over tightened handcuffs can produce pressure which exceeds the threshold for risk of superficial radial nerve injury, manipulation of the handcuffs by a detainee also poses a risk for nerve injury. It is important to ensure that the individual responsible for fastening the handcuffs is trained to appropriately limit the tightness of the handcuffs and that the detainee is made aware of the risk of nerve injury posed by struggling after handcuffs have been fastened around the wrists.

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