Masimo Perfusion Index Versus Doppler for Tourniquet Effectiveness Monitoring

Piper Wall, DVM, PhD[1]; Charisse Buising, PhD[2]; David Nelms, MD[3]; Lisa Grulke, BA[4]; Catherine Hackett Renner, PhD[5]*

ABSTRACT

Background: In addition to a plethysmograph, Masimo pulse oximeters display a Perfusion Index (PI) value. This study investigated the possible usefulness of PI for monitoring limb tourniquet arterial occlusion. **Methods:** Tactical Ratcheting Medical Tourniquets were applied to the thighs of 15 subjects. Tightening ended at one ratchet-tooth advance beyond Doppler-indicated occlusion. The times and pressures of Doppler and PI signal absences and returns were recorded. **Results:** Intermittent PI signal error occurred in 149 of 450 runs (PI, 33% versus Doppler, 0%; $p < .0001$). PI signal loss lagged Doppler-indicated occlusion by 19 ± 15 seconds (mean ± standard deviation, $p < .0001$). PI Signal Return lagged tourniquet release by 13 ± 7 seconds (Doppler Signal Return took 1 ± 1 seconds following tourniquet release; $p < .0001$). PI failed to detect early Doppler audible pulse return in 30 of 39 occurrences. **Conclusion:** The PI available on Masimo pulse oximeters is not appropriate for monitoring limb tourniquet effectiveness.

KEYWORDS: *tourniquet; monitoring; hemorrhage; first aid; emergency treatment*

Introduction

Limb tourniquets need to exert sufficient pressure to stop limb arterial blood flow.[1,2] Complications associated with limb tourniquets that do not stop arterial blood flow are ongoing blood loss, venous congestion and distension, rebleeding, expanding hematoma, compartment syndrome, fasciotomy, shock, and death.[1,2] Inadequately tight tourniquets occur; a US military forward surgical team reported pulses present in 54 of 65 tourniqueted limbs.[3] Monitoring the arterial occlusiveness of limb tourniquets matters because physiology happens: muscles relax,[4] tourniquet pressure decreases over time,[5] and systolic blood pressure increases when bleeding is stopped.[6] Any of these can result in resumption of limb arterial blood flow.

The noninvasive, laboratory gold standard for monitoring limb tourniquet arterial occlusion is arguably audible Doppler ultrasound. An easier, hands-off method to monitor limb arterial blood flow distal to a tourniquet is to look for the presence or absence of a pulsatile pulse oximeter waveform. Pulse oximeters are sometimes present where tactical field care is being provided[7] and are prevalent in patient transport platforms. However, the plethysmographic waveform can fail to detect weak pulsatile arterial flow that is detectable by Doppler monitoring.[8] In addition to the plethysmographic waveform, Masimo pulse oximeters (Masimo, www.masimo.com) display a variable labeled "Perfusion Index" (PI), which has been suggested to be a sensitive indicator of weak arterial flow and has been stated to provide "instant and continuous feedback as to the perfusion status of the selected monitoring site."[9,10]

The study purpose was to compare the presence of a PI value greater than zero with Doppler pulse detection distal to a limb tourniquet. The hypothesis was that the presence of a PI value greater than zero would not match Doppler pulse detection.

Methods

A main study was carried out investigating the effects of distance between paired tourniquets.[11] PI data collection for this project occurred during that main study, which already included the collection of Doppler data. The Drake University Institutional Review Board approved the prospective main study with the inclusion of this side project. Data collection took place October 2016 through November 2016. The tourniquets were requested from and donated by m2 Inc (https://www.ratchetingbuckles.com/). The Masimo Radical pulse oximeter was provided by UnityPoint Health Des Moines, Iowa Methodist Medical Center.

Tourniquets, Pressure Measurements, Appliers, and Recipients

The tourniquets, pressure measurements, appliers, recipients, and tourniquet application protocol are fully described in reference 11. Briefly, single or paired Tactical Ratcheting Medical Tourniquets (RMTs; m2 Inc) were used on the thighs of 15 healthy volunteers and were tightened one-tooth advance beyond loss of the audible Doppler pulse signal from the dorsal pedal artery on top of the foot or the posterior tibial artery at the ankle. Tactical RMTs were used because of their finer-resolution pressure control as compared with windlass tourniquets. Pressure measurements were from a No. 1 neonatal blood pressure cuff placed under each tourniquet. Tourniquets were released 125 seconds after the one-tooth advance beyond loss of the Doppler pulse signal.

*Correspondence to piperwall@q.com

[1]**Dr Wall** is a researcher in the Surgery Education Department of UnityPoint Health Iowa Methodist Medical Center, Des Moines, IA. [2]**Dr Buising** is a professor of biology and director of the Biochemistry, Cell and Molecular Biology Program at Drake University, Des Moines, IA. [3]**Dr Nelms** is a surgery resident at UnityPoint Health Iowa Methodist Medical Center. [4]**Ms Grulke** is an emergency medical technician-paramedic and a laboratory instructor in the Biology Department, Drake University. [5]**Dr Renner** is associate vice president of Analytic Support and Institutional Research at Grinnell College, Grinnell, IA.

Doppler and Masimo PI

The Doppler monitor was an Ultrasonic Doppler Flow Detector Model 811 with 9.5MHz adult flat probe (Parks Medical Electronics; www.parksmed.com). The PI value was displayed on a Masimo Radical set to "2 second averaging" with "Fast Sat = No."

Signal Gone Definition

The Doppler signal was defined as "Signal Gone" when no distal arterial Doppler pulse signal could be heard with the ratcheting buckle in its rest position and the applier's hands off the tourniquet. The PI was defined as Signal Gone whenever a value of zero was displayed. Any PI value greater than zero was considered "Signal Present."

Signal Return Definition

The Doppler signal was defined as "Signal Return" when the distal arterial Doppler pulse signal again became audible. The PI was defined as Signal Return whenever a value greater than zero occurred after any period of PI Signal Gone.

PI Signal Monitoring

The pulse oximeter sensor was the reusable, spring-hinged style designed for use on adult fingers. The sensor was placed on the second toe of the leg receiving the tourniquets. One person with a stopwatch recorded times of PI change to or from zero for comparison with times of Doppler Signal Gone and Doppler Signal Return.

Statistical Analysis

Numeric time and pressure data were organized in Excel 2003 (Microsoft Corp; www.microsoft.com). Statistical analyses were performed with GraphPad Prism, version 7.04 for Windows (GraphPad Software Inc; www.graphpad.com). Unpaired *t* tests with Welch's correction were used to compare Doppler and PI time differences. Fisher's exact test was used to compare the number of runs with intermittent PI Signal Present (error) versus intermittent Doppler Signal Present (error). Means are shown ± standard deviation.

Results

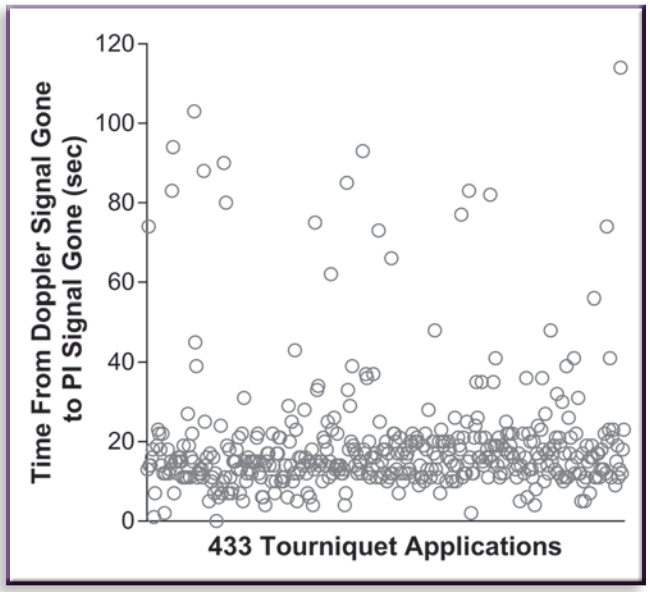
There were 450 thigh tourniquet runs. PI Signal Gone did not occur in 16 runs despite tourniquet completion pressures that were 46 ± 10mmHg higher than Doppler Signal Gone pressures (occlusion pressures). With only the two forms of monitoring for arterial flow, it was not possible to be sure the persistent PI Signal Present in those 16 runs was an error.

In the other 434 runs, Doppler Signal Gone occurred before any PI Signal Gone in 433 with an average delay for PI Signal Gone of 19 ± 15 seconds (versus Doppler Signal Gone, $p < .0001$; Figure 1). In the single instance of PI Signal Gone before Doppler Signal Gone, the PI signal was gone for 6 seconds during tourniquet tightening and then returned for the remaining 29 seconds of tourniquet tightening to reach Doppler Signal Gone. The returned PI signal then took 6 seconds after Doppler Signal Gone to reach zero.

In 411 runs, the Doppler signal did not return until tourniquet release. In those runs, the delay from tourniquet release to Doppler Signal Return was 1 ± 1 second (Figure 2). In 416 runs, the PI signal did not permanently return until tourniquet release. In those runs, the delay for PI Signal Return was 13 ± 7 seconds (versus Doppler Signal Return, p < .0001; Figure 2).

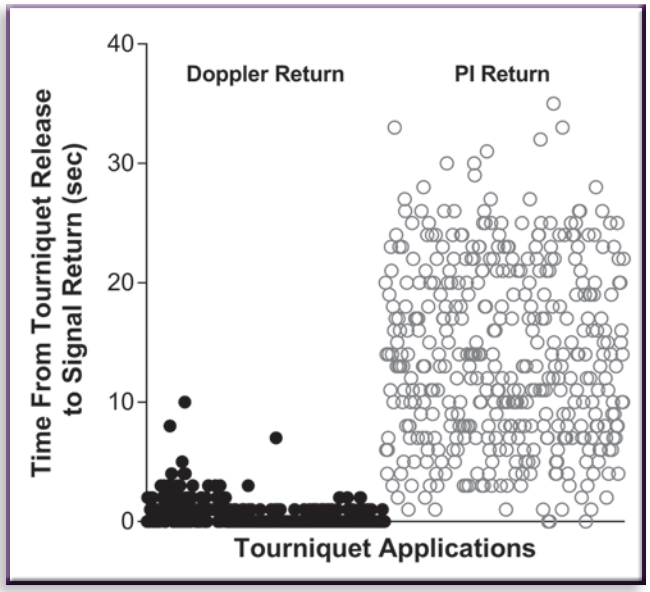
In 149 runs (33% of runs), the PI signal was incorrectly present for a total of 1,611 seconds (this time excludes PI delay

FIGURE 1 *Times from Doppler Signal Gone to PI Signal Gone.*



The graph shows the times in seconds from Doppler Signal Gone at time 0 until PI Signal Gone for each of the 433 tourniquet runs that had PI Signal Gone after Doppler Signal Gone (for the time difference between PI Signal Gone and Doppler Signal Gone, $p < .0001$). A time is not shown for the tourniquet run with a PI value that was transiently gone before Doppler Signal Gone. Also not shown are any times for the 16 tourniquet runs that did not have a PI Signal Gone. Each open gray circle represents the time to PI Signal Gone from a single run. PI, Perfusion Index; sec, seconds.

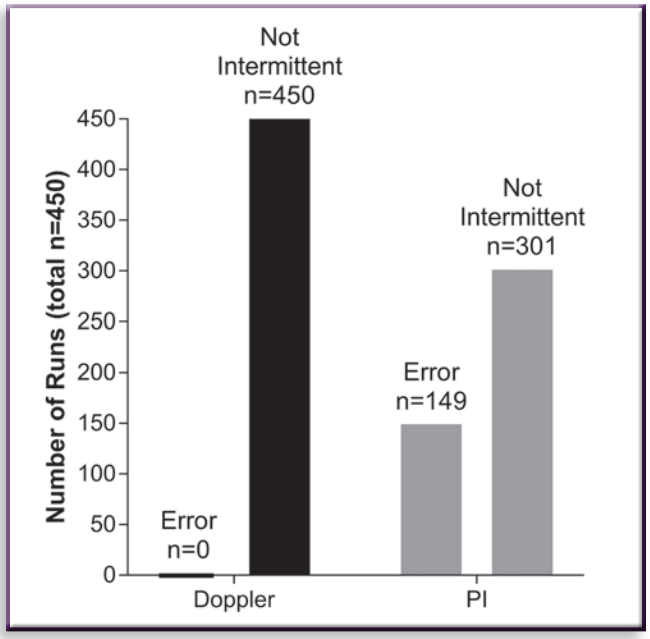
FIGURE 2 *Times from tourniquet release to Doppler Signal Return and to PI Signal Return.*



The graph shows the times in seconds from tourniquet release to Doppler Signal Return ($n = 411$; solid black circles) and to PI Signal Return ($n = 416$; open gray circles) for each of the tourniquet runs that did not have a signal already present at the time of tourniquet release (for the time difference between Doppler Signal Return and PI Signal Return after tourniquet release, $p < .0001$). PI, Perfusion Index; sec, seconds; Doppler Return, Doppler Signal Return; PI Return, PI Signal Return.

until Signal Gone). In these runs, the PI signal returned and then left while the tourniquets were still in place and during which time the under-tourniquet pressures were decreasing in the same fashion as detailed in a previous study.[5] This means that each of the within-run PI Signal Gones after the within-run PI Signal Returns occurred at lower tourniquet pressures than the within-run PI Signal Returns. With no reason for subject blood pressures to be declining, this is clearly PI signal error (versus Doppler, $p < .0001$; Figure 3).

FIGURE 3 *Tourniquet runs with or without an intermittent signal before tourniquet release.*



For the Doppler signal (black) and the PI signal (gray), the graph shows the number of tourniquet runs with an intermittent signal before tourniquet release (Error), which is an error with the declining tourniquet pressures that were present. The graph also shows the number of tourniquet runs without an intermittent signal before tourniquet release (Not Intermittent). Doppler significantly different from PI, $p < .0001$. Doppler, Doppler Signal; PI, Perfusion Index Signal.

In 39 runs, the Doppler signal returned before tourniquet release. In four of those early Doppler return runs, the PI signal remained continuously present. In five of those early Doppler return runs, the PI signal also returned before tourniquet release. In 30 of those early Doppler return runs, the PI signal did not return until after tourniquet release, which is a clear PI signal failure.

Discussion

The key finding of this study is that Masimo PI is not a suitable indicator of limb tourniquet effectiveness. In fact, the PI appears to be an even less appropriate indicator of limb tourniquet effectiveness than the previously examined plethysmographic waveform.[8]

This study was a side project occurring within a main study designed specifically to look at the effect of distance between paired thigh tourniquets. As such, the PI study was not designed to maximize the occurrence of Signal Gone and Signal Return events by having tourniquet tightening stop at occlusion pressure and resume in response to Signal Returns that occurred before tourniquet release. As expected, all single and paired tourniquet applications achieved arterial occlusion as assessed by Doppler,[8,12,13] all tourniquet pressures declined during the 125 seconds from the final ratchet advance to tourniquet release,[5,8,12,13] and a small fraction of single Tactical RMT applications (n = 12 of 300) and a larger fraction of paired Tactical RMT applications (n = 27 of 150) had Doppler Signal Returns before tourniquet release.[11–13] The within-run Doppler Signal Returns offered opportunities for PI Signal Return detection of weak arterial flow before the full arterial flow return associated with tourniquet release.

During tourniquet application and tourniquet release, PI values were delayed relative to Doppler signals for indicating either arterial occlusion or the resumption of arterial flow after tourniquet release. This may not be completely surprising because some of the calculation choices made inside pulse oximeters give weight to signal stability regarding what to display. Signal stability would be at its least with the sudden resumption of full arterial flow that accompanies tourniquet release, and some abrupt changes in signal stability would also be present during the incremental tourniquet tightening leading to arterial occlusion. However, we would expect limited signal instability to be present after tourniquet tightening has been completed but before tourniquet release. This is also the time of high clinical monitoring interest as it would correspond to the time between initial tourniquet application and definitive care of the injured limb. In 33% of the runs, this interval between tourniquet tightening and tourniquet release had PI values that provided incorrect information (Figure 3). This is also the interval during which PI values failed to indicate the return of arterial flow before tourniquet release in 30 of 39 runs with early return of the Doppler signal.

Pulse oximetry monitors are optimized toward providing accurate arterial oxygen saturation information, which requires good arterial blood flow, the antithesis of arterial occlusion. This makes it not surprising that the absence of a pulsatile plethysmographic waveform is not as sensitive an indicator of limb tourniquet effectiveness as distal artery audible Doppler monitoring in a quiet room.[8] The data from this study indicates that the presence or absence of a Masimo pulse oximeter PI value greater than zero is not only not a sensitive indicator of limb tourniquet effectiveness, but can also often be an incorrect indicator of limb tourniquet effectiveness.

Conclusion

The PI available on Masimo pulse oximeters is not appropriate for monitoring limb tourniquet effectiveness.

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The authors have indicated they have no financial relationships relevant to this article to disclose.

Author Contributions

PW, CB, DN, and LG contributed to conception and design of the study and data acquisition. PW, CB, and CHR contributed to the analysis and interpretation of data. All authors contributed to drafting or revising the article, and all authors had final approval of the manuscript.

References

1. **Kragh JF Jr, Walters TJ, Baer DG, et al.** Practical use of emergency tourniquets to stop bleeding in major limb trauma. *J Trauma.* 2008;64:S38–S50.

2. **Kragh JF Jr, O'Neill ML, Walters TJ, et al.** Minor morbidity with emergency tourniquet use to stop bleeding in severe limb trauma: research, history, and reconciling advocates and abolitionists. *Mil Med*. 2011;176:817–823.
3. **King DR, van der Wilden G, Kragh JF Jr, et al.** Forward assessment of 79 prehospital battlefield tourniquets used in the current war. *J Spec Oper Med*. 2012;12(4):33–38.
4. **Wall PL, Duevel DC, Hassan MB, et al.** Tourniquets and occlusion: the pressure of design. *Mil Med*. 2013;178:578–587.
5. **Rometti MRP, Wall PL, Gildemaster YL, et al.** Significant pressure loss occurs under tourniquets within minutes of application. *J Spec Oper Med*. 2016;16(4):15–26.
6. **Schroll R, Smith A, McSwain NE, et al.** A multi-institutional analysis of prehospital tourniquet use. *J Trauma Acure Care Surg*. 2015; 79:10–14.
7. **Committee on Tactical Combat Casualty Care.** *TCCC Guidelines for Medical Personnel. 1 August 2018*. https://www.jsomonline.org/TCCC/TCCC-MP%20Curriculum%201708/00%20TCCC-MP%20Guidelines%20180801/TCCC%20Guidelines%20for%20Medical%20%20Personnel%20180801.pdf. Accessed December 4, 2018.
8. **Wall P, Buising C, Grulke L, et al.** Effectiveness of pulse oximetry versus Doppler for tourniquet monitoring. *J Spec Oper Med*. 2017; 17(1):36–44.
9. **Masimo Corp.** Perfusion Index Whitepater. Perfusion Index (PI). Masimo website. https://infiniti.se/wp-content/uploads/Beskrivning_PIWhite-paper.pdf. Accessed November 23, 2018.
10. **Masimo Corp.** Perfusion Index. Summary Clinical Applications of Perfusion Index. Masimo website. http://www.masimo.co.uk/siteassets/uk/documents/pdf/clinical-evidence/whitepapers/lab3410f_whitepapers_perfusion_index.pdf. Accessed November 23, 2018.
11. **Wall P, Buising C, Nelms D, et al.** Effects of distance between paired tourniquets. *J Spec Oper Med*. 2017;17(4):37–44.
12. **Wall PL, Coughlin O, Rometti M, et al.** Tourniquet pressures: strap width and tensioning system widths. *J Spec Oper Med*. 2014; 14(4):19–29.
13. **Wall PL, Weasel J, Rometti M, et al.** Pressures under 3.8cm, 5.1cm, and side-by-side 3.8cm-wide tourniquets. *J Spec Oper Med*. 2016;16(2):28–35.

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