Nail Polish Does Not Significantly Affect Pulse Oximetry Measurements in Mildly Hypoxic Subjects

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BACKGROUND: The effect of nail polish on pulse oximetry measurements in non-hypoxic subjects has been studied extensively. Some studies found that nail polish decreased pulse-oximetry (S_{pO_2}) values, whereas others found no effects from nail polish. OBJECTIVE: To determine if nail polish affects S_{pO_2} measurements in mildly hypoxic subjects. METHODS: At high altitude, 5 investigators, whose mean oxygen saturation was 91.3% (mild hypoxia), and with 2 brands of pulse oximeter and oximetry probe, obtained S_{pO_2} measurements from a finger with nail polish and from the matching finger on the opposite hand without nail polish. We tested 9 different nail-polish colors and made 210 pairs of S_{pO_2} measurements. RESULTS: The mean ± SD S_{pO_2} values from the fingers with and without nail polish, respectively, were 91.4 ± 4.1% and 91.2 ± 3.5% (difference 0.2 ± 3.2%, 95% confidence interval −0.2% to 0.4%). CONCLUSIONS: With the pulse oximeters and oximetry probes we tested, nail-polish had no significant effect on S_{pO_2} in mildly hypoxic healthy subjects. *Key words: pulse oximetry, S_{pO_2}, nail polish, hypoxia, high altitude*. [Respir Care 2008;53(11):1470–1474.

Introduction

Pulse oximetry is an essential monitoring technology. Clinical decisions are often made based on pulse oximetry oxygen saturation (S_{pO_2}) measurements. Pulse oximetry works by transmitting light onto one side of a digit (or other tissue appendage) and sensing the light transmission on the opposite side of the digit. Standard pulse oximetry uses 2 light sources and 2 sensors. The red light source is visible. The infrared light source is invisible. Changes in light transmission through the digit permit the pulse oximeter to calculate oxygenation, based on the assumption that hemoglobin A is pulsing through the capillaries. The technical aspects of pulse oximetry have been summarized by others.[1,2] New developments in pulse oximetry are improving its capabilities.

Since pulse oximetry probes are most commonly applied over the fingernails, it has been a concern that nail polish impedes light transmission. Previous studies have reported conflicting results (Table 1). Earlier studies found that some nail-polish colors reduced S_{pO_2} by clinically important percentages,[4-6] but more recent studies found S_{pO_2} measurements accurate even with opaque nail-polish colors, including black, blue, and purple.[8-11] Controversy remains, because the earlier studies found S_{pO_2} decreases of 5–10%, whereas in the more recent studies the S_{pO_2} decrease was $< 2\%$. All those studies used only non-hypoxic subjects.

We studied the accuracy of S_{pO_2} measurements through nail polish in mildly hypoxic subjects. S_{pO_2} measurements use the color of the blood to measure oxygenation, so a hypoxic subject could have different light-absorption characteristics that might interact differently with certain nail-polish colors. For example, red nail polish could falsely increase S_{pO_2} readings, and blue and purple nail polish could have the opposite effect. The effect of nail polish on S_{pO_2} in non-hypoxic patients cannot necessarily be extrapolated to hypoxic patients.

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Table 1. Studies of the Effect of Nail Polish on Pulse Oximetry Measurements

First Author	Year	Pulse Oximeter	Summary
Kataria[3]	1986	Nellcor, model not specified	Nail polish (color not specified) had no effect on S_{pO_2}.
Rubin[4]	1988	Ohmeda Biox 3700	31 nail-polish colors were tested on one subject. Only the "Blue Flame" color decreased S_{pO_2}, from 97% to 87%. Two other blue colors and the other 28 colors tested did not decrease S_{pO_2}.
Coté[5]	1988	Nellcor N-100	Red nail polish had no significant effect on S_{pO_2}, but purple, black, green, and blue decreased S_{pO_2} by 1.7, 3.1, 5.2, and 5.9%, respectively, compared to controls.
White[6]	1989	Ohmeda Biox 3740 and Nellcor 200	With the probe in the anteroposterior orientation there were S_{pO_2} decreases, as described by Coté,[5] but with the probe positioned sideways on the finger, the nail polish caused no S_{pO_2} differences.
Battito[7]	1989	Not specified	Fingerprinting ink resulted in falsely low S_{pO_2} values.
Brand[8]	2002	Nellcor N-209A	Ten nail-polish colors tested. None of the colors affected S_{pO_2}, compared to the controls.
Chan[9]	2003	Ohmeda Biox 3740	Small S_{pO_2} decreases with all 10 colors tested. Only black and brown decreased S_{pO_2} by $\geq$ 2%. There were no differences when the probe was placed in the lateral (side to side) orientation.
Hinkelbein[10]	2007	Siemens SC1281, and Nellcor DS-100A probe	All 9 nail-polish colors tested caused small S_{pO_2} decreases ($<$ 2% with most colors), compared to arterial blood gas values. Black, purple, and dark blue had larger effects than the other colors.
Rodden[11]	2007	Nellcor N20 and N595	Ten nail polish colors tested. Only red, blue, and brown significantly decreased S_{pO_2}, but the decrease was $<$ 1%.

S_{pO_2} = oxygen saturation measured via pulse oximetry

Methods

Hypoxia was most conveniently induced by conducting the study at high altitude. The summit of Hale'akala National Park, Maui, Hawaii, at 3,048 m, is easily accessible by car. The calculated air pressure is 523 mm Hg (compared to 760 mm Hg at sea level). At 523 mm Hg, a 0.21 fraction of inspired oxygen yields an ambient P_{O_2} of 110 mm Hg (compared to 160 mm Hg at sea level). The arterial P_{O_2} at 3,048 m is approximately 55–70 mm Hg.

The 5 study subjects (ages 50, 49, 20, 17, and 15) each applied nail polish (Table 2) to the digits of one hand. The corresponding digits on the other (control) hand had no nail polish. Two coats of nail polish were applied, and each coat was allowed to dry before applying the next coat or the pulse oximeter probe. S_{pO_2} measurements were made serially on the nail-polished digits and the non-nail-polished (control) digits (same digit on the opposite hand, not necessarily in that order). The measurements were conducted in a sheltered environment (an observation enclosure or a vehicle), because at the summit of Hale'akala the outdoor temperature is cold, which affects perfusion. Most of the measurements were made with the subjects at rest, after achieving an oxygenation steady state. We also made some measurements following a brief jog or brisk walk.

We used 2 pulse oximeter models: RDS1, Masimo, Irvine, California, and N20, Nellcor, Pleasanton, California. A disposable neonatal digit probe and a reusable adult clip digit probe were used with the Masimo RDS1. With each RDS1 measurement we also recorded the perfusion index, which is the percentage of pulsatile signal to non-pulsatile signal. With each Nellcor N20 measurement we recorded the number of perfusion "bars"; in Nellcor's perfusion-measurement system, the maximum number of "bars" is 14. The purpose of using 2 different pulse oximeter models and different probes was to study whether observed differences were consistent between the different pulse oximeters and probe types.

The pulse oximetry probes were applied in an anterior-posterior direction only (no oblique or lateral orientation measurements). The anterior-posterior alignment maximizes the effect of the nail polish. Each digit was measured with the probe's light on the nail side of the digit, then the measurement was repeated with the light on the pad (palm) side of the digit. This was done to confirm that the nail polish versus control comparisons were consistent between the different methods of applying the probe.

Pulse oximetry measurements are continuous and not always in a perfectly steady state. We observed the numeric values and the pulsation/perfusion data and recorded

Table 2. Nail Polish Brands and Colors Tested

Company	Nail Polish Trade Name	Color	Company Product Color Code
Del Laboratories Uniondale, New York	NYC New York Color Long-Wearing Nail Enamel		
		Black Lace Creme (black)	119A
		Skin Tight Denim Creme (blue)	115A
		Purple Pizzazz Frost (purple)	133A
		Big Money Frost (green)	118A
		Wing It Wine Creme (brown/maroon)	121A
		White Lights Glitter (white glitter)	101A
		Big Apple Red Creme (red)	131A
		Times Square Tangerine Creme (orange)	112A
California Colors Pacoima, California	California Colors Nail Enamel	Pink	33

the most dominant value (the most apparently correct value), as we do when reading S_{pO_2} values in the clinic.

Our measurement sampling was optimized to compare the nail-polished and non-nail-polished digits by always pairing a nail-polish measurement with a non-nail-polish measurement, with the same pulse oximeter and probe type for each pair of measurements. We did not perform similar pairing with pulse oximeter types, pulse oximeter probe types, or nail-polish colors, which made the comparisons between oximeter types, probe types, and nail-polish colors potentially subject to unintentional sampling bias.

Data were entered into a spreadsheet (Excel, Microsoft, Redmond, Washington) and analyzed with statistics software (SPSS, SPSS, Chicago, Illinois). Paired results were analyzed with a paired *t* test. Unpaired independent samples were analyzed with analysis of variance.

This study was approved by the institutional review board of Hawaii Pacific Health.

Results

We took 210 paired S_{pO_2} measurements with 5 investigators. The mean nail-polish and non-nail-polish S_{pO_2} values, respectively, were 91.4 ± 4.1% and 91.2 ± 3.5% (mean difference 0.2 ± 3.2%, 95% confidence interval −0.2% to 0.4%). One hundred forty-four measurements were made at rest, and 66 were made following a brief jog or a brisk walk (Tables 3 and 4). Although the different nail-polish colors had different mean S_{pO_2} values, the non-nail-polish values were obtained contemporaneously on a matching digit on the opposite hand. None of the nail polishes significantly affected S_{pO_2} or the Masimo perfusion index or Nellcor perfusion "bars."

Table 3. S_{pO_2} With and Without Nail Polish

	Measurements (*n*)	S_{pO_2} (mean ± SD) With Nail Polish	S_{pO_2} (mean ± SD) Without Nail Polish	*P*
All measurements	210	91.4 ± 4.1	91.2 ± 3.5	.35
At rest	144	92.7 ± 2.4	92.4 ± 2.0	.27
After exertion	66	88.8 ± 5.6	88.6 ± 4.5	.75
Brand				
Masimo	114	91.1 ± 4.6	90.7 ± 4.1	.24
Nellcor	96	91.8 ± 3.4	91.9 ± 2.6	.90
Probe type				
Neonatal	124	92.0 ± 3.3	92.1 ± 2.6	.63
Adult	86	90.7 ± 5.0	90.1 ± 4.2	.12
Light applied to				
Nail	105	91.0 ± 4.9	90.8 ± 4.1	.45
Pad	105	91.8 ± 3.1	91.7 ± 2.8	.59
Nail polish color				
Black	18	93.6 ± 1.6	93.0 ± 2.1	.24
Brown/maroon	20	92.2 ± 1.9	91.5 ± 2.4	.24
Blue	26	90.7 ± 6.7	90.8 ± 3.6	.83
Purple	22	91.2 ± 4.6	91.2 ± 5.2	.99
Green	26	89.5 ± 4.8	90.0 ± 4.0	.59
Clear/glitter	28	91.5 ± 2.9	91.4 ± 3.0	.79
Pink	10	90.9 ± 3.6	90.7 ± 2.7	.78
Red	34	91.7 ± 3.5	91.2 ± 4.0	.44
Orange	26	92.2 ± 3.5	91.6 ± 2.6	.34

S_{pO_2} = oxygen saturation measured via pulse oximetry

Discussion

S_{pO_2} did not significantly differ between the nail-polished digits and the matched non-nail-polished control dig-

Table 4. Perfusion Indices, With and Without Nail Polish

Perfusion-Measurement System	Measurements (*n*)	Perfusion Value (mean ± SD)		*P*
		With Nail Polish	Without Nail Polish	
Masimo Perfusion Index*	114	2.8 ± 2.0	3.0 ± 2.3	.02
At rest	86	2.5 ± 2.0	2.5 ± 1.8	.85
After exertion	28	3.6 ± 1.8	4.8 ± 2.7	.001
Probe type				
Neonatal	28	1.7 ± 1.2	2.0 ± 1.3	.12
Adult	86	3.1 ± 2.1	3.4 ± 2.5	.07
Light applied to				
Nail	57	2.5 ± 1.9	2.8 ± 2.2	.09
Pad	57	3.0 ± 2.1	3.3 ± 2.4	.12
Nellcor Perfusion Bars†	96	8.1 ± 2.3	7.9 ± 2.3	.55
At rest	58	7.4 ± 1.9	7.3 ± 2.0	.87
After exertion	38	9.2 ± 2.5	8.9 ± 2.4	.48
Light applied to				
Nail	48	7.8 ± 2.0	7.5 ± 1.8	.27
Pad	48	8.4 ± 2.5	8.4 ± 2.5	.96

* The Masimo perfusion index is the percentage of pulsatile signal to non-pulsatile signal.
† In the Nellcor perfusion bars system, the maximum number of bars is 14.

its on the opposite hand, regardless of nail-polish color, pulse oximeter model, or probe type.

Pulse oximetry measurements are less accurate when the patient is very hypoxic, but nearly all of our measurements were conducted with modest hypoxia, within the range of demonstrated accuracy.[1]

Our sampling method was not optimized to compare colors, pulse oximeters, probes, or measurements made at rest versus after exercise, so differences between those groups could be due to sampling bias. However, none of the nail-polish colors significantly affected S_{pO_2}.

We did not measure oxygen saturation by other methods such as arterial blood gas analysis or CO-oximetry, so the S_{pO_2} values were not confirmed by a standard.

The mean S_{pO_2} value indicated mild hypoxia, consistent with the high altitude. Our results are consistent with studies with non-hypoxic subjects that found no effect from nail polish on S_{pO_2}, which confirms that finding in mildly hypoxic healthy subjects.

The divergent results of previous studies might be explained by differences in light-transmission between thin and thick coats of nail polish and/or to different nail-polish colors.

Coté et al described different spectrophotometric absorption at the 660 nm and 940 nm wavelengths used by conventional pulse oximeters as a possible reason that purple, black, green, and blue nail polish decreased S_{pO_2} values by 1.7%, 3.1%, 5.2%, and 5.9%, respectively, whereas red nail polish did not affect S_{pO_2}.[5]

Rubin described similar spectrophotometric data for one blue nail polish that decreased S_{pO_2} 10%, but the other 30 colors (including 2 other blue colors) did not decrease S_{pO_2}, and the spectrophotometric data were not presented for those 30 colors.[4]

Brand et al found that 3 of the colors they studied (blue, green, and lime) had significant differences in spectrophotometric absorption at 660 nm and 940 nm, but none of the 10 colors they tested significantly affected S_{pO_2}.[8]

Hinkelbein et al published spectrophotometric curves for 9 nail-polish colors, but only the dark green color had a significant absorption difference between 660 nm and 920–940 nm, and all the nail polishes they tested caused a $< 2\%$ S_{pO_2} decrease.[10]

Rodden et al studied spectrophotometric absorption at 660 nm and 940 nm, and found the greatest absorption differences in the blue, pink, and white nail polish they studied; intermediate absorption differences in the orange, yellow, purple, black, and brown nail polish; and small absorption differences in the red and green nail polish. Significant differences were found with the red, blue, and brown nail polishes, but the S_{pO_2} decrease was $< 1\%$ and thus not clinically important.[11]

There is some consistency in the spectrophotometric data in those studies, but there are also important discrepancies, which could be attributed to the transparency (different light-transmission through a thin vs thick layer of nail polish) and the specific light-absorption characteristics of the various nail polish preparations and colors. Although the human eye perceives a particular color to be, for instance, blue, this is due to a summation of the various absorption values within the visible range of light. Color perception does not necessarily correlate with light absorption at 660 nm (the visible red light). The 940-nm infrared light is invisible, and blue nail polish would not necessarily have the same light-absorption differences at 660 nm and 940 nm. This could explain why a white nail polish could have a significant absorption difference between 660 nm and 940 nm.

The transparency of nail polish partly depends on the thickness of the nail polish coat, which we did not measure. With a thin layer of nail polish a spectrophotometer will yield an absorption curve, but a very thick layer could yield a flat spectrophotometric curve (no light transmission at any wavelength). Thus, the spectrophotometric data obtained with a thin coat of nail polish do not necessarily indicate the light transmission characteristics of a thick coat of nail polish. Coté et al made their spectrophotometric measurements through a single coat of nail polish, but applied 3 coats of nail polish to the nails of their study subjects.[5] Hinkelbein et al applied 2 coats of nail polish in their spectrophotometric measurements and on the nails of their study subjects.[10] Brand et al applied 3 coats of nail polish in their spectrophotometric measurements and on

the nails of their study subjects.[8] Rodden et al applied 1 coat of nail polish in their spectrophotometric measurements, but 2 coats on the nails of their study subjects.[11] Rubin applied 2 coats of nail polish on the nails of the study subject, but did not specify the number of coats used in the spectrophotometric measurements.[4]

Of interest is whether the pulse oximeter light is going through or around the nail. If the light is going around the nail, then the nail polish should have no effect on S_{pO_2}. We applied the black nail polish to the entire distal phalanx circumferentially (skin and nail), including the tip of the finger, so all the pulse-oximeter light was forced to go through nail polish. After 2 coats of black nail polish the Masimo RDS1 gave the same S_{pO_2} value, even though the finger appeared to be opaque, but after 4 coats of black nail polish the Masimo RDS1 could not measure an S_{pO_2} value. This suggests that even the darkest nail-polish colors have some degree of light transmission sufficient to yield a pulse oximeter signal, but if enough nail polish coats are added, the nail becomes opaque, and the light would have to go around the nail to create an S_{pO_2} reading. This could explain the S_{pO_2} discrepancies between the studies. The sensor probably receives the sum of the light transmitted through the nail and around the nail. For nail-polish colors that transmit/absorb light differentially at 660 nm and 940 nm, the S_{pO_2} reading might decline significantly only if the through-the-nail transmission component dominates the around-the-nail component.

The more recent studies tend to show no significant S_{pO_2} decrease from nail polish, whereas the older studies found significant decreases. The red, 660-nm light-emitting diode (LED) in the Masimo probe is so bright, the entire fingertip glows. LED technology has improved substantially since the original pulse oximeters, and LEDs can now be so bright that they are used as flashlights. A brighter LED probably has a larger around-the-nail component than would a less-bright LED, especially if some of the light is impeded by nail polish.

Although the more recent studies found no significant S_{pO_2} decrease from nail polish, those studies were done under ideal circumstances, in which the subject was stable. Although our study subjects were mildly hypoxic, they were healthy and had good perfusion. In a critically ill patient with more severe hypoxia, poor perfusion, or acute deterioration during critical care interventions, general anesthesia, procedural sedation, or surgery, S_{pO_2} measurement artifact could be more important. No study has studied that aspect well. Although the available studies do not suggest that nail polish significantly affects S_{pO_2}, it might be prudent and require only a minor effort to remove the nail polish (or artificial nail cover) on the digit used for oximetry if the patient has a medical condition or will undergo a procedure that requires pulse oximetry. Clinicians might encounter more patient resistance to this request if the patient has elaborate or custom nail decorations or nail-polish patterns, because they are much more expensive to apply. Studies on those types of nail decorations have not been published. Such nail decorations might be more opaque and have reflecting metallic elements and jewels as well.

Conclusions

With the pulse oximeters and probes we used, the nail polishes we tested did not affect S_{pO_2} measurements in mildly hypoxic healthy subjects.

REFERENCES

1. McMorrow RC, Mythen MG. Pulse oximetry. Curr Opin Crit Care 2006;12(3):269-271.
2. Aoyagi T, Miyasaka K. The theory and applications of pulse spectrophotometry. Anesth Analg 2002;94(1 Suppl):S93-S95.
3. Kataria BK, Lampkins R. Nail polish does not affect pulse oximeter saturation (letter). Anesth Analg 1986;65(7):824.
4. Rubin AS. Nail polish color can affect pulse oximeter saturation (letter). Anesthesiology 1988;68(5):825.
5. Coté CJ, Goldstein A, Fuchsman WH, Hoaglin DC. The effect of nail polish on pulse oximetry. Anesth Analg 1988;67(7):683-686.
6. White PF, Boyle WA. Nail polish and oximetry (letter). Anesth Analg 1989;68(4):546-547.
7. Battito MF. The effect of fingerprinting ink on pulse oximetry (letter). Anesth Analg 1989;69(2):265.
8. Brand TM, Brand ME, Jay GD. Enamel nail polish does not interfere with pulse oximetry among normoxic volunteers. J Clin Monit Comput 2002;17(2):93-96.
9. Chan MM, Chan MM, Chan ED. What is the effect of fingernail polish on pulse oximetry? (letter). Chest 2003;123(6):2163.
10. Hinkelbein J, Genzwuerker HV, Sogl R, Fiedler F. Effect of nail polish on oxygen saturation determined by pulse oximetry in critically ill patients. Resuscitation 2007;72(1):82-91.
11. Rodden AM, Spicer L, Diaz VA, Steyer TE. Does fingernail polish affect pulse oximeter readings? Intensive Critical Care Nurs 2007; 23(1):51-55.