Influence of nail polish on pulse oximeter readings of oxygen saturation: a systematic review

Sendoa Ballesteros-Peña1, Irrintzi Fernández-Aedo1, Artzai Picón2, Sergio Lorrio-Palomino3

Nail polish has traditionally been assumed to absorb light emitted by pulse oximeters and to interfere with the detection and measurement of oxygenated hemoglobin. In a systematic review of the literature we aimed to assess the influence of nail polish on the measurement of oxygen saturation by pulse oximetry (SpO2). A search protocol for online databases (MEDLINE, Embase, Web of Science, Scopus, Cumulative Index to Nursing and Allied Health Literature, and IBESCS [the Spanish health sciences index]) was established to find clinical trials or observational studies published between 1999 and February 2014. Twelve nonrandomized clinical trials were found. Ten were in healthy volunteers. One of the remaining 2 studies was in critical patients undergoing mechanical ventilation, and the other was in patients with stable chronic obstructive pulmonary disease. One study recreated the low oxygen level of high altitudes, while the others were done in normal atmospheric conditions. Differences between pulse oximeters and type of nail polish were found. Nail polish was associated with a statistically significant decrease in SpO2 for at least 1 color in all but 2 studies. However, the differences were within the standard error (±2.0%) of the pulse oximeters used. The authors of the studies all concluded that although nail polish might change SpO2 readings significantly, the variations are not clinically significant.

Keywords: Oximetry. Nail and cuticle products. Blood gas monitoring, transcutaneous. Diagnostic error.

Introduction

Oximeters are optical devices (spectrophotometers) that noninvasively measure the oxygen saturation (SpO2) of hemoglobin in the blood. They were developed during World War II, where they were used to monitor oxygen levels in pilots during flight1.

SpO2 quantitation by optical methods is based on application of the Beer Lambert law: if a light of known wavelength passes through a clear solution, the amount of light absorbed by this depends on the concentration of solute in the liquid, the absorption coefficient of the substance (which is dependent on the wavelength) and the distance traveled by light. In other words, there is a linear relationship between the amount of light absorbed by the substance and the concentration, so that higher concentrations involve increased light absorption.

In the case of solutions with various compounds, the absorption of light corresponds to a weighted absorption of the different compounds. The concentrations of various elements are obtained by performing
measured at different wavelengths and solving the system of equations obtained.

Oximeters developed up to the mid-1970s used this methodology. This implied knowing the absorption coefficients of each of the components present accurately, which, due to biological variability of subjects, were inaccurate measurements and optically complex devices. The development of the pulse oximeter allowed eliminating the complexity, instability and difficulty of use of traditional oximeters. The main advantage is that the pulse oximeter can detect SpO2 in arterial blood by analyzing the difference in light absorption during systole and diastole.

A generic oximeter has two types of LED emitting light at 660 nm (red) and 940 nm (infrared), and one or more sensors to collect the light intensity at these wavelengths. The pulse oximeter operating principle lies in the differences in light absorption of oxyhemoglobin and deoxyhemoglobin at different wavelengths: oxyhemoglobin has less light absorption at 660 nm than deoxyhemoglobin, while with the wavelength 940 nm the effect is the opposite. Thus, increased SpO2 means less absorption in the red and increased infrared absorption of the transmitted light intensity. To establish a correlation between the levels of perceived absorption and SpO2, pulse oximetry analyzes the absorption ratio of the signal at the two wavelengths. Furthermore, in order to correct the nonlinearity measurements, calibration between the absorption ratio obtained and a set of patients with SpO2 levels between 70 and 100% is performed. This calibration means, by design, that SpO2 values under 70% are not valid or reliable.

Today, thanks to the noninvasive nature, high reliability and availability of pulse oximeters, SpO2 is along with other vital signs (such as heart and respiratory rate, blood pressure or temperature) an essential parameter in the clinical assessment of patients.

Since pulse oximeter probes are placed more often on fingertips, it has been argued that nail polish can absorb light emitted by the equipment and interfere with the detection and measurement of oxygenated hemoglobin. And so, during the clinical examination of the patient in the area of accident and emergency, nail polish is removed routinely for assessing SpO2. This process requires the availability of suitable solvents and some seconds of time. Furthermore, it may be necessary to obtain prior consent from the patient, and this could be a possible reason for confrontation with patients who refuse to remove the polish.

The objective of this review was to assess the influence of nail polish in SpO2 values in patients undergoing pulse oximetry.

**Method**

We performed a literature search of Medline (PubMed), Web of Science (WOS), Scopus, EMBASE (through OVIDSP), CINAHL (via EBSCO Publishing) and Spanish Bibliographic Index performed in Health Sciences (IBECS).

Search strategies tailored to various databases were designed, combining controlled vocabulary and free text terms (Table 1). The period between January 1999 and February 2014 was established as the search period, given that the validity, accuracy and reliability of current pulse oximeters could differ from older ones. As a secondary strategy, bibliographical references were located in articles to identify possible relevant studies retrieved from the electronic databases and they were reviewed.

We selected clinical trials or observational studies with access to full texts on the influence of nail polish on the SpO2 measurements in capillary blood using pulse oximetry. Also, we excluded systematic reviews, meta-analyses and opinion pieces, and those published in languages other than Spanish, French, English, German, Italian and Portuguese works.

Two reviewers independently selected potentially relevant articles by reading the title and abstract. Subsequently the full texts of all references were evaluated to check they met the selection criteria. Disagreements were resolved by consensus between the two, and the opinion of a third reviewer was sought in doubtful cases.

After the search and selection of studies, a data extraction template was used to record each item, designed according to the PICO structure. The extraction was carried out by one reviewer and checked by the second. The level of scientific evidence and methodological quality of the selected studies was classified based on the criteria proposed by the Catalan Agency for Health Technology Assessment in Catalonia.

**Results**

The search in the six electronic databases of biomedical literature resulted in the identification of 56 references, which were reduced to 24 on eliminating duplicate entries. Of these, 10 were excluded after reading their titles or abstracts, for lack of relation to the rese-
arch question. By expanding the search using the reference list of publications, two new abstracts were located. After critical reading of the full text of all selected articles we excluded 4 papers: 2 because they were opinion letters and 2 literature reviews (Figure 1).

Finally, the present study included 12 articles, all randomized clinical trials, with sample sizes ranging from 5 to 80 participants and cataloged with a level of evidence V (average quality). The main characteristics of the articles included are shown in Table 2.

**Description of the studies included**

The study methodology was based on the examination of the differences in the values of SpO\(_2\) obtained by pulse oximetry before and after nail polish application to fingernails with several different colors or comparing measurements of SpO\(_2\) captured in fingernails painted with one or more nails unpainted as a control. As a general rule, two layers of nail polish were applied, although one trial added a third and in another a single application. In two studies this aspect was not contemplated in the methodology.

In five experiments several models of pulse oximeter were used to assess the accuracy and reliability of the models, and in three trials the difference in values obtained was compared depending on whether the sensor of the oximeter was placed in the traditional way (perpendicular to the nail) or lateral position (after a 90\(^\circ\) rotation of the sensor). The tests were performed on healthy volunteers except in two studies: Hinkelbein et al. performed measurements on critically ill patients undergoing mechanical ventilation and Shimoya Bittencourt et al. used patients with stable chronic obstructive pulmonary disease (COPD). In addition, except Yamamoto et al. who recreated mild hypoxia under conditions at altitude, other authors performed measurements under normoxic conditions in people with baseline values above 95\% SpO\(_2\). In addition to measurements at rest, Yamamoto et al. and Shimoya Bittencourt et al. also performed measurements after a moderate physical effort.

**Description of study results**

Except for two trials, nail polish produced a statistically significant reduction in SpO\(_2\) with at least one color in patients at rest. However, with few exceptions in specific measurements, the differences detected were always below 2\%, i.e. within the margin of error of pulse oximeters employed and, according to the study authors, with no relevance for clinical practice.
### Table 2. Main characteristics of included studies

<table>
<thead>
<tr>
<th>First author. Year, country [type of study]</th>
<th>City/instrument</th>
<th>Intervention/Comparison</th>
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<tr>
<td>Brand et al. 2002, USA [ECnA]</td>
<td>12 healthy volunteers, at sea level (age 28-47 years, 1 black, 2 smokers). Pulse Oximeter Model: Nellcor NZ09A</td>
<td>3 colors of nail polish were analyzed: blue, green and lime-green. The 2nd, 3rd and 4th fingernails of one hand was varnished and SpO2 readings obtained were compared with those of the unvarnished nails of the opposite hand.</td>
<td>No differences were found (p = 0.67).</td>
<td>Nail polish does not affect the accuracy of pulse oximetry values.</td>
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<td>Chan et al. 2003, Italy [ECnA]</td>
<td>7 healthy volunteers. Pulse Oximeter Model: Ohmeda BIOX 3740</td>
<td>Red, yellow, dark blue, light blue, white, fuchsia, purple, brown, black, red and green: these 10 colors of nail polish were analyzed. SpO2 values taken in fingers with painted nails (each with 1 color) were compared with those of the other hand's unpolished fingernails. Readings were obtained by perpendicular and lateral placement if the oximeter sensor.</td>
<td>A decrease of approximately 2% in SpO2 appeared in fingernails painted brown or black with the sensor in the perpendicular position. However, when the sensor is placed in the lateral position, no significant differences between the painted and unpainted nails were observed.</td>
<td>Brown and black nail polish produced a small decrease in SpO2 measurement. Interference of nail polish on the measurement of SpO2 was avoided by placing the sensor in a lateral position.</td>
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<td>Miyake et al. 2003, Brazil [ECnA]</td>
<td>61 healthy volunteers (age: 18-32). Pulse Oximeter Model: DS-2405 Dixtal</td>
<td>Base, red, pink and bright light pink were analyzed. 4 nails of her left hand (one with each color) were painted, and SpO2 readings obtained with the 2nd finger were compared with those of the unvarnished hand.</td>
<td>SpO2 measurements on fingernails painted with base, light pink and bright pink showed no significant differences from control fingernails. Significant differences (p observed &lt;0.001) when the tests were performed on red nails, but only in 3 tests was the error &gt;2%.</td>
<td>Except in red nail polish, pulse oximeter readings were not significantly affected by nail polish.</td>
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<td>Hinkelbein et al. 2007, Germany [ECnA]</td>
<td>50 mechanically ventilated critically ill patients (age &gt; 18; Caucasian; carboxiHb and metalHb &lt; 4%; SBP &gt; 80 mmHg). Oximeter model: Siemens SC1281 and Nellcor DS-100A</td>
<td>Yellow, dark blue, light blue, black, purple, dark green, light green, red and transparent (9 colors) were analyzed. Each participant has 8 nails painted on one hand and SpO2 readings obtained were compared with those of the unpainted nails of the other hand, with oximeter sensor placed in the perpendicular and lateral positions.</td>
<td>Except for the light green color, a significant decrease (p&lt;0.05) was observed in SpO2 values, especially in dark blue, black and purple painted nails. The average error in the measurement of SpO2 for all colors was within the range of ± 2% determined by the manufacturer of the oximeter.</td>
<td>Nail polish in mechanically ventilated patients produced significant changes in SpO2 values, but not clinically significant. The lateral positioning of the sensor did not eliminate measurement errors.</td>
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<td>Rodden et al. 2007, USA [ECnA]</td>
<td>27 healthy volunteers (age: 27-57; 24 Caucasians, one smoker). Pulse Oximeter Model: Nellcor N20 and NS95</td>
<td>Yellow, blue, white, brown, orange, black, purple, red, pink and green (10 colors of nail polish) were analyzed. For each participant, SpO2 measurements were taken with two oximeters on each finger before and after being painted, placing the oximeter sensor in both the perpendicular and lateral position.</td>
<td>Statistically significant differences (p&lt;0.05) in the readings on blue and brown enamel were obtained, but they were not clinically relevant (differences &lt;1%). In red enamel, the lateral position sensor N20 showed a significant alteration of the SpO2 value (p = 0.016) but this was clinically irrelevant (&lt;1%).</td>
<td>Nail polish color or the lateral position of the pulse oximeter sensor caused alterations in SpO2 values, but they were not clinically significant.</td>
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<td>Yamamoto et al. 2008, USA [ECnA]</td>
<td>5 healthy volunteers (age 15-50) under mild hypoxia altitude (3048 m). Oximeter models: Massimo RDS1 and Nellcor N20 (adult and pediatric and probes).</td>
<td>Blue, white, brown, orange, black, purple, red, pink and green (9 colors of nail polish) were analyzed. SpO2 values taken in painted nails (each with a different color) were compared with those taken in unpainted nails. The measurements were performed at rest and after moderate effort.</td>
<td>210 paired SpO2 measures were taken. The overall mean of SpO2 obtained with painted nails was 91.4 ± 4.1% versus 91.2 ± 3.5% with unpainted nails (p = 0.35). No significant differences between controls and any nail color were found, but between the measurements at rest versus after effort with the oximeter Massimo (p = 0.001).</td>
<td>Nail polish produced no significant changes in SpO2 values in healthy subjects with mild hypoxia, both at rest and after exercise. There were no differences due to the instrument used.</td>
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(Continúa)
While a general trend for dark colors (black, brown, blue and purple) to distort the $\text{SpO}_2$ value was observed, no statistically significant differences between colors or layers of nail polish were observed. Moreover, differences in the readings were noted according to the model of pulse oximeter used\(^9,9,11,12,14\): the simplest or older devices more frequently presented significant differences between measurements made on fingernails without versus with polish. However, these differences were always well below 2%.

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**Table 2. Main characteristics of included studies (Continuation)**

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<td>Diccinì et al.(^10), 2011, Brazil [CnA]</td>
<td>80 healthy volunteers (age: 17-30). Pulse Oximeter Model: 2405 DX Dixtal.</td>
<td>Coffee, latte, chocolate, red and metallic (5 colors of nail polish) were analyzed. $\text{SpO}_2$ values taken in fingers with painted nails (each with a different color) were compared with those obtained in unpainted fingers of the opposite hand.</td>
<td>Brown and red nails showed significantly lower $\text{SpO}_2$ values with respect to controls (mean difference: 0.22 ± 0.09%, $P = 0.024$ and 0.19 ± 0.09%, $P = 0.047$ respectively). The remaining colors produced no significant changes in $\text{SpO}_2$ readings.</td>
<td>Brown and red colors caused a reduction in the measurement of $\text{SpO}_2$, but without clinical relevance, since they remained within the normal range of accuracy.</td>
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<td>Sütcü Çiček et al.(^11), 2011, Turkey [CnA]</td>
<td>33 healthy volunteers (mean age: 19 ± 1). Oximeter models: Fast Portable; Petas KMA 275 and 515 Novametrix</td>
<td>Yellow, dark blue, light blue, beige, white, brown, black, purple, pink, red, green, light green and transparent (13 colors of nail polish) were analyzed. Each participant had 12 painted nails (initially some measurements were made with certain colors and then with other colors after removing the varnish) and $\text{SpO}_2$ readings were compared with those obtained with unpainted nails.</td>
<td>$\text{SpO}_2$ readings obtained with the dark blue, beige, white and purple were significantly lower than those in the control (mean differences &lt;2%). The Readings obtained with Petas KMA 275 pulse oximeter were significantly higher than those obtained with the other two (mean differences &lt;2%) in all the colors.</td>
<td>Blue, white, beige and purple nail polish produced incorrect readings of $\text{SpO}_2$. There was variability according to the pulse oximeter used.</td>
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<td>Jakpor(^12), 2011, USA [CnA]</td>
<td>23 volunteers. Model oximeter: Nellcor and Nonin Onyx N395</td>
<td>Blue, white, red, red wine, pink and green (6 colors of nail polish) were analyzed. Each participant had six nails painted. $\text{SpO}_2$ readings were compared with those obtained with unpainted nails.</td>
<td>The readings obtained with Nonin pulse oximeter were lower ($p &lt; 0.05$) in nails painted blue, white and pink (mean differences &lt;2%) than controls. No differences were observed when the Nellcor model was used.</td>
<td>Blue, white and pink nail polish produced slight alterations in $\text{SpO}_2$ readings in the simplest model of pulse oximeter (Nonin), but these changes did not have clinical significance.</td>
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<tr>
<td>Shimoya-Bittencourt et al.(^13), 2012, Brazil [CnA]</td>
<td>42 patients with stable COPD, not current smokers (mean age 62.9 ± 8.7). Model oximeter: MicroCo meter-Micro Medical Ltd</td>
<td>Base, brown, red and light pink (4 colors of nail polish) were analyzed. $\text{SpO}_2$ values taken in fingers with painted nails (each with a different color) of one hand were compared with those of unpainted fingernails of the other hand. The measurements were performed at rest and after moderate exercise.</td>
<td>The colors base, light pink and red did not affect $\text{SpO}_2$ readings. Brown showed a decrease in $\text{SpO}_2$ reading at rest (93.8 ± 2.3% vs 95.0 ± 1.8%) and during exercise (92.5 ± 3.8% vs 95.0 ± 1.8%; $p &lt; 0.001$) and red only after exercise (93.5 ± 3.3% vs 95.0 ± 1.8%; $p = 0.047$).</td>
<td>Red and brown colors caused significant alterations in $\text{SpO}_2$ values in patients with COPD, but lacked clinical significance.</td>
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<tr>
<td>Sompradeekul et al.(^14), 2013, Thailand [CnA]</td>
<td>60 healthy volunteers. Oximeter models: Oxyswatch; Mini-Torr Plus and Mindray PM7000 / Masimo</td>
<td>Yellow, blue, white, brown, orange, black, silver, purple, red, pink and green (11 colors of nail polish) were analyzed. $\text{SpO}_2$ measurements on each finger were taken before and after being painted.</td>
<td>Except in orange, red and pink nails, a significant decrease in $\text{SpO}_2$ was observed when Oxyswatch and Mini-Torr Plus models were used.</td>
<td>The most common nail polishes (pink, orange and red) did not affect $\text{SpO}_2$ values. Some models of pulse oximeter were affected by nail polish.</td>
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<tr>
<td>Hakverdio lu et al.(^15), 2014, Turkey [CnA]</td>
<td>40 healthy volunteers (mean age 19.1 ± 0.9). Model oximeter: MD300C1</td>
<td>Yellow, dark blue, white, silver, purple, brown, black, red, pink and green (10 colors of nail polish) were analyzed. $\text{SpO}_2$ measurements on each finger were taken before and after being painted.</td>
<td>Except in red painted nails ($p=0.163$), a significant decrease (average approx. 1%) in $\text{SpO}_2$ values was observed.</td>
<td>Some nail polishes cause significant alterations in $\text{SpO}_2$ values in healthy people.</td>
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Hb: hemoglobin; Max: maximum; SBP: systolic blood pressure; $\text{SpO}_2$: oxygen saturation; COPD: chronic obstructive pulmonary disease.
Lateral rotation of the pulse oximeter sensor as a strategy to eliminate the artifact produced by nail polish did not offer consistent results: while in one trial the alterations caused by polish were even eliminated, in another no differences were observed with respect to the standard position and in the third, the authors managed to eliminate measurement errors when certain colors were used, but significant variations below 1% were observed in red fingernails when an older model oximeter was used.

**Discussion**

Nail polish has traditionally been considered one of the main factors that can affect the reading of SpO2 of patients undergoing pulse oximetry. However, this has been questioned by many researchers for three decades with little consensus: while some studies concluded that the presence of nail polish decreased SpO2 values, others found no such differences.

Subsequent replicated experiments yielded divergent results, in part perhaps because of methodological differences between trials, hindering comparison between them. The low sample size used, the non-random method of selection of participants in the studies, the limited number of types and colors of nail polish and, especially, the various models of pulse oximeters employed represent significant constraints that hinder the external validity of the results obtained.

Technological evolution of pulse oximeters could reasonably influence the disparity in results, a situation that has been observed in some of the trials in which measurements were performed simultaneously with different pulse oximeters and in which differences between the models were found. Advances in LED technology and sensor technology have improved the validity and reliability of the measurements from the oldest models with lower light intensity and detection capability.

Unlike older oximeters, and only in order to measure the absorption of light by arterial blood, the pulse oximeter analyzes the signal of light absorption throughout the entire cardiac cycle. Thus, in diastole, the absorption is due to the stationary tissues, capillary and venous and arterial blood, while in systole, arterial blood shows increased relative volume which increases the absorption rate. Or, put another way, the perceived absorbance by the pulse oximeter has a continuous component due to the absorption of static tissues, venous and capillary blood and part of the arterial blood, while there is an alternating component (representing only 5% of the signal intensity) that is due to pulsatile arterial blood. Removal of this alternating component by the pulse oximeter using suitable digital filters allows a signal in which the absorption depends on the composition of pulsing arterial blood alone.

Knowing the theoretical performance of current pulse oximeters, it is easy to analyze the behavior that a pulse oximeter should present to various phenomena, such as nail polish. Assuming nail polish has an absorption coefficient determined at different wavelengths, the signal perceived by the sensor should be diminished in proportion to this coefficient. Thus, in theoretical terms, use of nail varnish does not affect the absorption rate used to calculate the degree of SpO2 oxyhemoglobin.

However, it should be noted that the absorption coefficient of the enamel, especially in dark colors, can decrease the intensity of the signal by several orders of magnitude and affect pulse oximeter performance. This fact, coupled with the fact that the alternating component of the signal normally represents only 5% of the signal, means that the alternating signal components present values near zero and high noise that can affect the mathematical calculation which uses algorithms. For the same reason, it is reasonable to suppose that the greater the number of layers of applied (thereby increasing the opacity) the greater the risk of erroneous pulse oximeter readings.

Thus, despite the small differences obtained in the studies analyzed in this work, there is some consensus that discrete alterations of the measurements due to nail polish, although statistically significant, are not sufficiently large to be considered clinically relevant. In fact, the range of variation with respect to the controls remained within ± 2% maximum error of precision offered by most of the pulse oximeters employed.

Other studies that explore the influence of false nails on SpO2 measurements by pulse oximetry have also arrived at similar conclusions. However, there are reports of significant changes in SpO2 measurements before and after the administration of some contrasts or intravenous pigments such as methylene blue, with an absorption maximum at 680 nm and able to alter the color of arterial blood.

The most obvious limitation of this study, derived from the methodology, is the possibility of selection bias in the choice of reference material, the search strategy and the exclusion of works published in languages other than those selected. This possible bias was reduced using the 6 most important databases in Health Sciences, applying a non-restrictive search strategy and considering the studies published in the 6 main languages of scientific dissemination.

Finally, and in light of the results of the studies reviewed, one might conclude that there is variability in the effects of nail polish on the reading of the SpO2 pulse oximeter depending on the model used and the characteristics of polish used. However, even though the nail polish and the device used can produce a subtle alteration of SpO2 values, these variations are not clinically relevant and fall within the range of standard error of accuracy in current pulse oximeters.

**Conflict of interests**

The authors declare no conflict of interest related to this article.
References