CASE REPORT:

Two Cases of Differential Desaturation: Acrocyanosis and Multiple Epiphyseal Dysplasias as Possible Causes.

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INTRODUCTION

Clinical conditions in which the appearance of cyanosis may differ from one body part to another is known as differential cyanosis[1]. This classically occurs when right heart blood bypasses the lung and flows straight through a patent ductus-arteriosus to join the aortic-arch carrying oxygenated blood[2]. The venous blood will dilute the oxygen content of the blood distal to the ductus-arteriosus aortic-arch junction. This can be seen in patients with a patent ductus arteriosus with pulmonary hypertension, and some other types of complex congenital heart disease[3]. The left hand and the feet appear cyanotic, whilst the head and right arm may appear normal. The head and right hand is supplied by fully oxygenated blood from the more proximal aortic arch. The cyanotic left hand and the feet receive deoxygenated blood from the aortic arch distal to the junction of the ductus arterious.

Commonly, peripheral tissues such as toe and finger tips may appear to have a mottled blue color due to severe vasoconstriction when exposed to severe cold. The central tissues, such as the ears and lips, may still look pink. Pulse oximeters typically do not function on severely vasoconstricted fingers and toes[4]. Pulse oximeters require a pulsatile blood flow to determine the oxygen saturation of arterial blood. This measurement is called the SpO2. When arterial blood flow is strong enough to create a pulse, the oximeter measures a SpO2 value similar to that measured in the laboratory on the patient's arterial blood sample and it displays a regular plethysmographic waveform of the arterial pulsations. This regular sine-wave type pulsatile plethysmograph indicates the SpO2 was measured from arterial pulsations. An irregular spiky type plethysmographic wave suggests the pulsimeter is measuring artifact movement and the SpO2 measurement is false and meaningless.

A pulse oximeter determines the SpO2 by measuring the transmitted light absorbance of all of the tissues in the light path from the oximeter light source to the oximeter light sensor[5]. It then distinguishes the absorbance represented only by tissue components that pulsate and utilizes that portion only to calculate the SpO2. Lastly, the transmitted red-light frequencies used by the pulse oximeter are differentially absorbed by de-oxygenated hemoglobin and oxyhemoglobin, and the fraction of arterial blood that is oxygenated is calculated and expressed as the SpO2 percentage. The assumption is that arteries are the sole source of pulsation. Conversely, normal capillaries and venules have linear and steady blood flow.

We describe two patients that demonstrated finger SpO2 measurements that were much lower than the SpO2 values measured on their ears. We speculate on the possible explanations for our observations. We call this difference in SpO2

measurement in a central place (ear pinnae) and a peripheral place (fingers) with left and right-side similarity *differential desaturation*. That is different from *differential cyanosis*.

CASE 1:

A 57-year- old male presented for repair of a shoulder rotator-cuff tear following a fall 2-months earlier. His co-morbid diseases were non-insulin dependant diabetes mellitus and hypertension. He had a good exercise tolerance and was generally healthy. His weight was 114 kg with a BMI of 33. He had a manual job in the home construction industry. He was an active person with no known cardiac disease.

During placement of an interscalene brachial plexus catheter, prior to surgery, his SpO2 measured on the left index finger was 90% while breathing room air and 92% when breathing supplementary nasal oxygen at 3 l/min. Later, prior to induction of general anesthesia, his oxygen saturation measured 92% on the left index finger when he breathed room air. General anesthesia was induced with propofol and maintained with nitrous oxide and sevoflurane. He was ventilated via an endotracheal tube. After induction of anesthesia his left index finger SpO2 increased to 98% whilst he breathed 100% oxygen. Thereafter, his fiO2 was decreased to 45% and his finger SpO2 fell to 96% where it remained until the end of surgery. Intraoperative patient temperature was 36.6 degrees centigrade.

At the conclusion of surgery, he was repositioned from the sitting position, used for the surgery, to a supine position. His left index finger SpO2 then fell to 89%. After 100% oxygen was administered the SpO2 improved to 98%, where after he was extubated. His saturation then fell to 92% while breathing nasal oxygen at 2 l/minute flow.

At this point the pulse oximeter was placed onto the left ear pinna where it measured the SpO2 6% higher at 98%. His pinna was large enough to accept the same Nellcor adult reusable oximeter probe that had been used on his finger. The pulse oximeter displayed a similar regular plethysmograph at all times

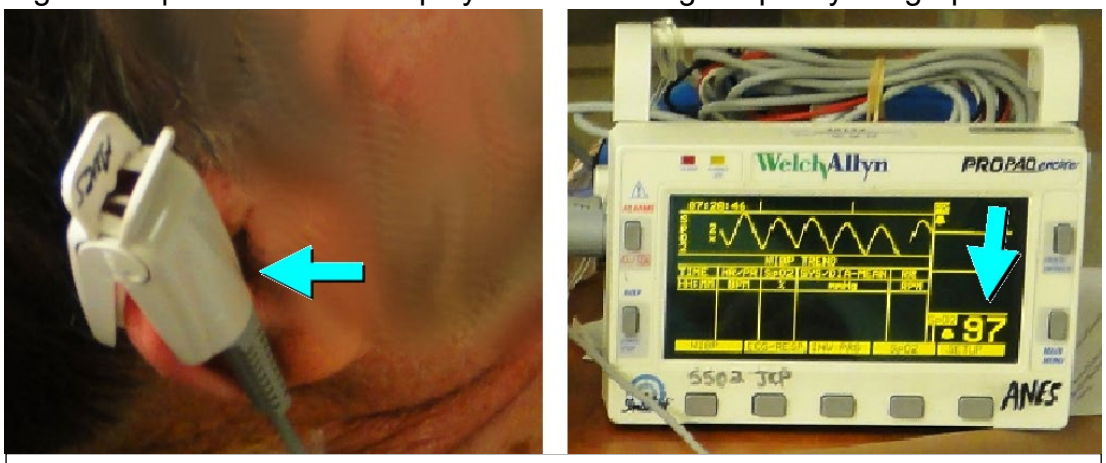

Figure 1: **Right ear** pulse oximeter saturation measurement of **97**%. The patient was breathing room air. Note the normal plethysmograph wave tracing.

whether on the ear or on the index finger. Patient temperature was 36.8 degrees centigrade at the end of surgery.

Twenty-five minutes later, in the anesthesia recovery room, the patient was re-examined. The SpO2 was 100% on each of the left and the right ears, and 8% less on each index finger. Nasal oxygen supplementation was being administered at two l-minute flow.

The patient was re-examined the following morning. The patient reported feeling well, comfortable and warm. He was hearty and pain free. Pulse-oximeter measured each left and right ear's pinna SpO2 as 97% and each index finger SpO2 was 5% less. See images 1, 2 and 3. The patient was breathing room air. There was no nail polish, skin stains, or pigments present on the fingers, toes or ears. All the toes similarly showed at SpO2 5% less than that measured on the ears.

Close examination of the hands showed a very subtle darker purple color of the finger tips on the distal phalanx palmar aspect. There was no obvious

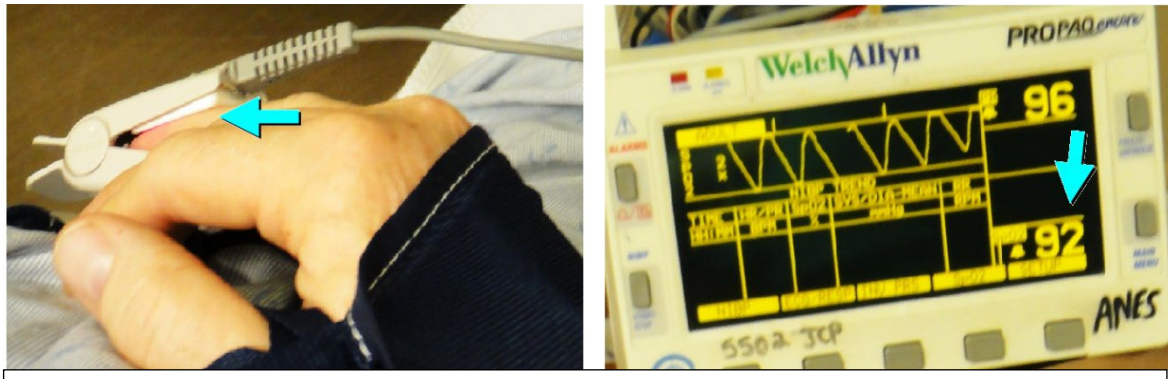

Figure 2: **Right third finger pulse** oximeter saturation measurement of **92**%. The patient was breathing room air. Note the normal plethysmograph wave tracing.

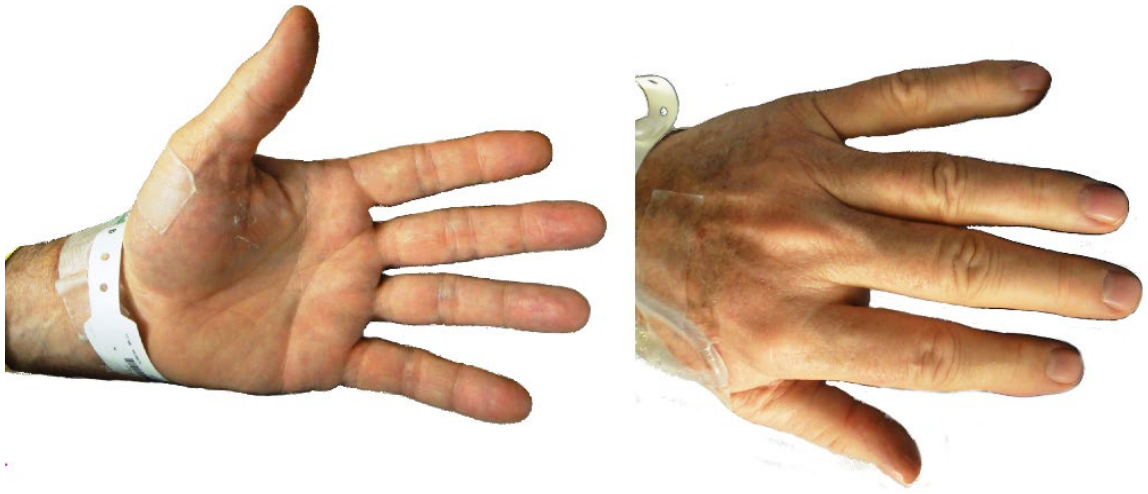

Figure 3: Patient number one's left hand dorsal and palmar views.

clubbing.

On further history taking the patient revealed he had once experienced frost bite on the distal phalanx of the left fifth finger. He also reported that he

easily got cold hands and fingers with slight pain when working outdoors in winter. He notably experienced this finger problem when his fellow construction workers working in the same winter circumstances had no such problem. He however had never had severe pain in the fingers nor sudden attacks of blueness and pain in the hands, as seen in Raynaud's disease. His symptoms were more gradual in onset. He had no other illnesses or complaints.

All SpO2 measurements were done with the same Nellcor adult reusable finger probe on the ears, fingers and toes. The very first SpO2 measurement at the time of nerve block and the second day measures used a Welch-Allen Propaq Encore portable vital sign monitor. The intraoperative and post-anesthesia care unit SpO2 measurements observations were done with Datex Ohmeda N-Sat module units. The oximeters displayed normal plethysmographic wave forms at all times.

CASE 2:

A 58-year-old male presented for a redo knee arthroplasty. He was given general anesthesia with a femoral nerve block. Anesthesia was induced with propofol, and maintained with sevoflurane. He was ventilated via an endotracheal tube.

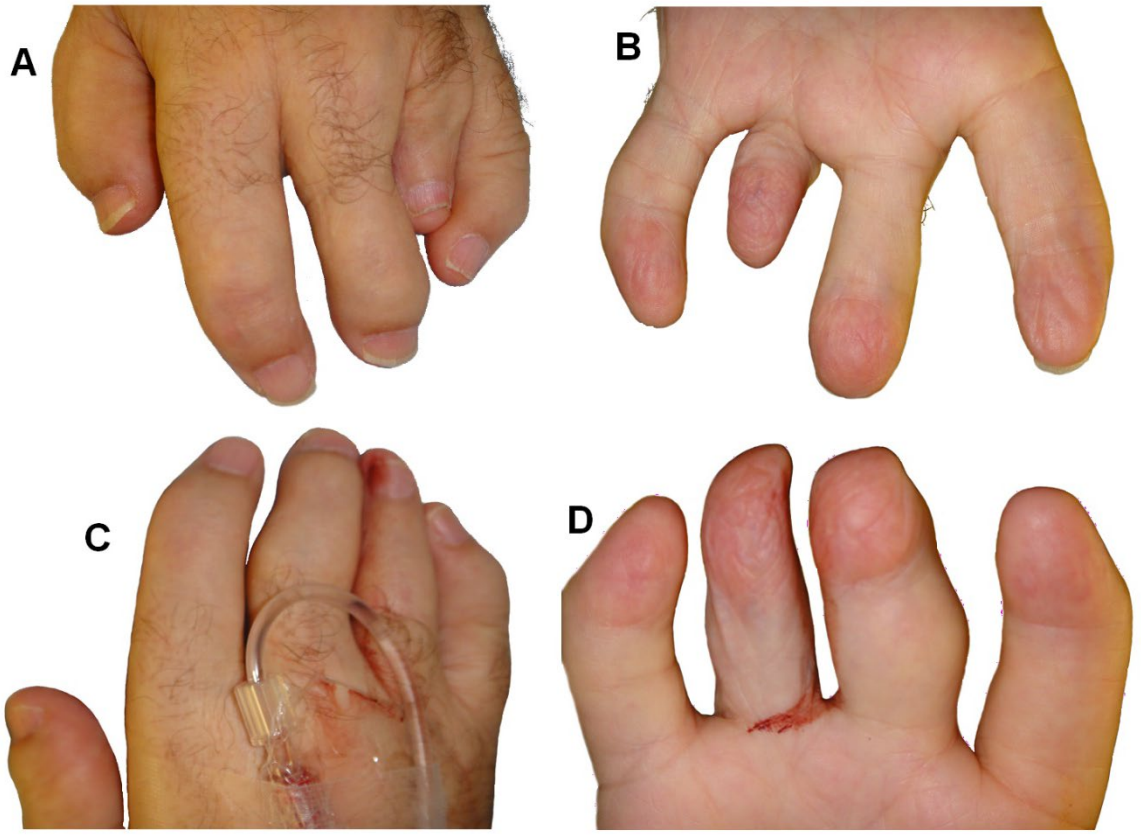

Figure 4: Case number two's fingers. A is left dorsal view, B is left palmar view, C is right dorsal view, and d is right left palmar view.

He suffered from non-specific dwarfism with a height of 144 cm. His weight was 60 kg. He suffered from multiple epiphyseal dysplasias, for which he

previously had had both knee and hip joints replaced. He was an active person with no known cardiac disease.

At the commencement of general anesthesia his left finger SpO2 was 88% but it improved to 97% when he breathed 100% oxygen. Over the course of the anesthetic his inspired oxygen was reduced to 57% and his SpO2 fell to 93%. Chest auscultation, bronchoscopy, and other clinical checks did not reveal obvious explanation for this desaturation. The oximeter probe was then moved to the ear and immediately measured 100% oxygen saturation. The oximeter displayed a normal plethysmographic wave at all times. A re-useable Nellcor adult finger probe was used for the finger. As his ear was too small to accept the reusable finger oximeter probe, an adhesive single use Nellcor adult probe was used for the ear. The pulse oximeter was a Datex Ohmeda N-Sat module. Patient temperature was 36.7 degrees centigrade.

These observations were replicated the next day at the bed side using one same adhesive single use Nellcor adult size oximeter probe on the ears, fingers and toes and a Welch-Allen Propaq Encore portable vital sign monitor unit. The patient was comfortable and warm. He was breathing nasal oxygen at two l/min flow. The SpO2 measured on his ears were 99% (both left and right). The SpO2 measured was 8% less on both his left and right index fingers. The SpO2 was also measured on all the other fingers and the toes, and those SpO2 values had a range of 91% to 93%.

He reported that his hands were generally warm and the he did not ever suffer from cold hands or blue finger color changes. On examination his finger tips on the palmar side were slightly swollen and had a dusky blue-purple color (see figure 4).

DISCUSSION

Although differential cyanosis is well known and has well described mechanisms of how it occurs, these two patients' type of differential desaturation seems to not have previously been described. These two patients were different from patients with differential cyanosis in that the left and right hand SpO2 values were identical for each patient. This makes their condition different to that of differential cyanosis with congenital cardiovascular disease. There is no known, and no conceivable congential cardiac disease that could explain these patients' differential de-saturation where the ears produced 5 - 8% higher SpO2 values than those measured off the fingers.

The differences in pulsimeter oxygen saturations that these patients manifested were also too small to be detected clinically. Clinical detection of significant desaturation or cyanosis is not consistently recognized until arterial hemoglobin saturation is 75% or less[6]. Pulse oximeter measurements were needed to detect these patients' differences, and each discovery was serendipitous. Another notable fact was that each low finger SpO2 was accompanied with a good plethysmographic wave form.

It is known that some pulse oximeter devices individually may have inherent inaccuracies up to 4% as measured against blood gas measurements[7]. If an inherently inaccurate pulse oximeter unit and probe was used, it would not explain our observed differences seen from finger to ear on one patient using the same oximeter for all measurements. Regardless of any possible probe-based

technical inaccuracy, each patient was later re-tested using the unit and the same probe on both their ears and fingers.

The effect of local temperature on pulse oximeter readings has been studied[8]. Warming the hand decreases the SpO2 by 1%, and cooling the hand increases the SpO2 by 1%. Other studies have also shown whole patient cooling leads to digital pulse oximetry readings increasing without a change in arterial blood sample oxygen saturation[9]. Mild hypothermia of the hand alone has been studied and when a normal plethysmographic wave is still present, the SpO2 measurement increases by 1%[10]. Vasodilation of the hand induced by dexmedetomidine has no effect on SpO2 measured in that hand, but vasodilation induced by axillary block reduced the Spo2 measured in that hand by 2.5% mean[11]. The ear pinna has been shown to be a good site to measure SpO2 due to being relatively immune to vasoconstrictor hormones and drugs[12]. Our two patients were normothermic and finger or body temperature factors seem unlikely explanations for our observations.

Large central venous pulsations have been shown to falsely decrease measured SpO2 in the finger[13]. It is likely those central venous pulsations were transmitted retrograde back to the finger post capillary venules under the pulse oximeter sensor. A dialysis fistula on the same limb as the finger pulse oximeter may sometimes cause a false low SpO2, also via transmission of retrograde pulsations back to post capillary venules[14]. In one case the SpO2 was 72% on the index finger of the dialysis arm, and 97% on the normal arm index finger. It seems this was probably uniquely due to the use of the side-to-side type of artery to vein graft used in this particular patient. In that same dialysis patient study, eleven other dialysis AV fistula patients who had vein end to artery side type fistulae were examined and they did not manifest differential cyanosis. It seems the pulsatile arterial blood flow to the cephalic vein via a side-to-side graft allowed a retrograde venous pulsation to occur in the finger, which created a false low SpO2 reading in the index finger distal to the AV fistula. In summary, pulsation in the finger post-capillary venules of any cause reduces the measured SpO2 in that finger making the value inaccurate.

It is not uncommon for pulse oximeters to fail to produce an oxygen saturation measurement on a finger when that finger has intense vasoconstriction due to use of vasoconstrictor drugs, hemodynamic shock, or coldness[15]. The oximeter may attempt to auto-amplify any artifact motion detectable from the finger and may produce a numerical value lower than the measured oxygen saturation of an arterial blood sample. That SpO2 value is typically accompanied by an erratic irregular plethysmographic wave signal indicating the SpO2 is inaccurate. A SpO2 value is only considered accurate if the accompanying plethysmographic wave has a regular sine-wave pulsatile waveform pattern congruous with a regular heart beat[15]. The two described patients in the case report had normal finger or ear oximeter plethysmographic wave forms at all times. See the wave forms in figures 1 and 2 of case number one.

With these two case report patients the low finger SpO2 values were finally considered false and the higher ear SpO2 values were considered accurate. No special respiratory therapy was provided. It is likely each patient had some functional blood flow abnormality affecting their digits.

The major known functional blood flow abnormalities of the fingers are[16];

1. Raynaud's disease.

2. Acrocyanosis
3. Erythromelalgia

Raynaud's disease is foremost characterized by attacks of sudden onset of blue-white-red discoloration of the digit tips or blue-white discoloration of the digit tips, and finger tip pain. Precipitating factors include exposure to cold, emotional distress, but sometimes no factor can be identified. The primary vascular change is vasospasm. Raynaud's disease can be secondary to, amongst other, scleroderma, polymyositis, and use of beta-blockers.

Erythromelalgia is a very rare disease characterized by attacks of burning sensations, warm hands, and intense redness of the hands and feet triggered by exposure to warmth.

Acrocyanosis is a rare illness of persistent painless blue discoloration of the hands and feet. Color changes may vary from blue-red to deep cyanosis. The color changes intensify with exposure to coldness. Acrocyanosis may occur with Raynaud's disease, but not necessarily so. Histology of acrocynotic finger tips show dilated capillaries and post capillary venules[16]. With cold exposure, blood flow may become so slow in the capillaries and venules that blood sludging may occur. This can be associated with finger swelling and hemorrhage. Primary acrocyanosis has no known cause. Secondary Acrocyanosis may be associated with cardiovascular disease, cold agglutinin disease, polyglobulia, thrombocythaemia, occlusion of acral arteries, AV shunts, neurogenic damage (poliomyelitis, paraplegia, multiple sclerosis, and stroke induced paresis), antiphospholipid antibody syndrome, anorexia, bulimia, and malignancy[16].

We suggest the first patient had acrocyanosis because of his features of mild blueness to the digit tips, absence of history of attacks of color changes or pain, but a positive history of propensity for unusually blue swollen fingers when working in the cold, and one incidence of frost bite in a finger. If he has this condition and his post capillary venules are as dilated as those seen on histology of other acrocyanosis patients, that could perhaps allow persistence of the arteriolar pulsatile blood flow to the post capillary venules which could explain a "pulse oximeter SpO2 diluting effect" lowering the measured SpO2 of the fingers compared to the SpO2 of the ears. The diagnosis of acrocyanosis is made purely clinically.

The second patient had known multiple epiphyseal dysplasias. This illness can affect the fingers as well[17]. The phalanges typically may have epiphyses that are small and rounded. It is possible there could be associated vascular anomalies in such fingers that could explain the observation of differential desaturation. This individual had fingers and toes that looked unusual, and some were notably shortened. The palmar aspects of the individual's distal phalanx of the index fingers had a subtle purple tinge to them (see figure 4). No detailed scientific descriptions of the fingers' vascularity in individuals with multiple epiphyseal dysplasias have ever been published. Possibly the second patient had widened capillaries and post capillary venules with transmission of arteriolar pulsations to reach the micro-venous circulation, thus reducing SpO2 values measured on the finger tips.

Possible vascular anomalies that could cause simultaneous different SpO2 measurements in different body parts could be classified as follows:

1. **Differential Cyanosis:** The oxygenated arterial blood supply of some body parts is selectively mixed with venous de-oxygenated blood, while other body parts receive pure oxygenated arterial blood. This typically causes differential cyanosis in opposite hands. The SpO2 measurement would be correct but only for the arterial blood oxygen content of that body part on which the SpO2 measurement was done. This can occur with complex congenital cardiovascular disease.

2. **Differential Desaturation:** The pulse oximeter simultaneously detects a pulsatile venous wave together with the arterial pulse wave, and produces a false SpO2 measurement. The correct SpO2 may be measured in a different body part resulting in a differential desaturation in the patient.

   i. The venous pulsation is transmitted <u>retrograde</u> from a source of pulsation closer to the heart.
      1. From an intra-aortic balloon-pumps. This would likely cause <u>all</u> sites for SpO2 measurements to yield false values lower than laboratory measurements of arterial blood sample hemoglobin oxygen saturation[13].
      2. From a side-to-side dialysis AV fistula. The abnormality will be seen only in the affected arm[14].
      3. From spontaneous opening of micro-AV fistulae in fingers[8].

   ii. The venous pulsation is transmitted <u>prograde</u> through unusually wide dilated capillaries and onto post capillary venules. This would cause a false low SpO2 reading of an affected finger. This is our speculated cause possibly explaining the observations in our two patients. Such vascular abnormalities have previously been described in some pathologies, but have never before been associated with false low SpO2 determinations[16].

We hope this report will stimulate new, and better, reports of patients with differential desaturation and their associated illnesses. It is our hope that other patients with established diagnoses of acrocyanosis could be investigated by having their pulse oximeter measurements determined on both fingers and ears. Also, that the information is reported to validate or refute our limited observations.

Lastly, we suggest whenever clinicians observe a significantly low SpO2 measurement taken from a finger; they also consider measuring the ear pinna SpO2 to exclude the possibility that the finger reading is a false low. Alternatively, an arterial blood sample could be tested to determine the true hemoglobin saturation. Discovery of differential desaturation may also suggest an additional diagnosis of acrocyanosis, or multiple epiphyseal dysplasias to be considered.

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