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# The Capability of Skin Conductance to Monitor Pain Compared to Other Physiological Pain Assessment Tools in Children and Neonates

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## Abstract

**Background:** In some European countries and the US it is mandatory to assess and treat pain. In Pubmed there are more than 240 papers when searching for "skin conductance" and "pain".

**Aims:** The aim is to review the utility of the skin conductance responses (SCR)/sec to assess pain in infants and children.

**Study design:** Two searches in Pubmed, where one includes the key words "skin conductance", "pain", and "children". Search two included "skin conductance", "pain", and "infants". The finds in these searches are discussed and compared with other physiological pain assessment tools.

**Outcome measures:** Search one; regarding children, included twelve papers, and search two, regarding infants, included 20 papers.

**Results:** All the found papers show that the SCR/sec increases during defined painful procedures. Postoperatively, at intensive care units, and at neonatal units, the SCR/sec shows high sensitivity to monitor pain, but a lower specificity. The the SCR/sec is the most accurate means to assess pain when compared to the HR and peripheral oxygen saturation.

HR is influenced from respiratory rhythm, changes in blood volume status, drugs acting on the blood circulation, environmental temperature, and emotional stress, and is therefore less specific to pain than the SCR/sec which only is influenced from emotional stress. For infants and children, variation for SCR/sec is low compared to HR and peripheral oxygen saturation when the patients are at the same pain/discomfort level.

**Conclusions:** The SCR/sec could be adjunctive warning tool for when to validate possible pain.

**Keywords:** Heart rate; Pain; Peripheral oxygen saturation; Physiological pain assessment tool; Skin Conductance responses

**Abbreviations:** HR: Heart Rate; SCR: Skin Conductance Responses; bpm: Beats Per Minute; ECG: Electro Cardio Graphi; HRV: Heart Rate Variability; JCAHO: Joint Commission on Accreditation of Healthcare Organizations; NIRS: Near Infrared Spectroscopy; NFCS: Neonatal Facial Coding System; NIDCAP: Newborn Individualized Developmental Care and Assessment Program

## Introduction

In 2001, the Joint Commission on Accreditation of Healthcare Organizations (JCAHO), US, introduced standards which require pain assessment and treatment. In addition to blood pressure, heart rate, respiration, and temperature, pain was defined as the fifth vital sign. Even though the patient's satisfaction with pain management has increased on a general level, increased incidences of opioid-associated adverse drug reactions with the potential of a fatal outcome have been reported. Similar guidelines showing the importance of monitoring and treating pain are about to be established in France, Italy, and Russia.

The definition of pain is "an unpleasant sensory and emotional experience associated with actual or potential tissue damage, or described in terms of such damage". Children below three years of age have difficulties in communicating their pain verbally. Neonates and children below three years of age are the most challenging groups in which we assess pain.

For a long time one has believed that neonates did not perceive pain due to neurological immaturity. On several occations new-borns did not receive analgesic or anaesthetic medication during pain inducing procedures, e.g. surgery. Compared to older children and adults, lower pain thresholds have been found in preterm infants. This is probably due to the absence of inhibitory descending spin thalamic fibres. The way in which the preterm infant perceives pain may be immature at birth; however, it is believed that preterm infants are able to perceive pain [1].

Treatment of pain in neonates which is not satisfactory has both short-term and long-term side effects. After exposure to noxious or painful stimuli changes in behavioural, hormonal, and metabolic parameters as well as other physiological variables are observed. These factors may possibly be linked to an increased occurrence of postoperative complications and even deaths. Deeper anaesthesia reduced severe outcomes such as sepsis and mortality after surgery. Respiratory-distressed neonates receiving pain relief during tracheal suction and routine procedures improved their oxygenation [1]. An increase in intracranial pressure after painful procedures which may result in severe intraventricular haemorrhage has been suggested in preterm infants [2]. When circumcised boys had their vaccination

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months later, they showed a stronger pain response compared to infants who were not circumcised. This is possibly due to sensitisation [3].

Infants should also be protected against non-invasive stressful routine procedures because similar side effects as the ones which are seen during painful procedures may occur [4].

Interestingly, long term side effects of children suffering acute pain after surgery do not develop into chronic pain as often observed in adults [5]. This phenomenon is possibly due to physiological as well as psychological factors. It has been suggested that the plasticity in the nervous system reduces the risk of developing chronic pain.

Both behavioral and physiological pain assessment tools are non specific to pain [6]. Caregivers must therefore use their clinical judgment in understanding why the infant is in distress. If an ongoing stimulus occurs, the emotional stress response is very likely to be caused by this stimulus. Thus the treatment should focus on reducing the stimulus that has induced the distress, or treat the symptoms according to the origin of the stimulus. Behavioural pain assessment tools are often used in infants [6]. Physiological pain assessment tools should be used in infants exposed to hypothermia, infants exposed to a number of previous painful procedures, as well as patients who are critically ill or sedated [1,7]. These physiological pain assessment tools should also be applied regarding patients where real time pain assessment is required. In infants below 28 weeks of gestational age a physiological pain assessment tool, skin conductance responses (SCR)/sec, is to be preferred when measuring levels of pain [7]. When searching for "skin conductance" and "pain" in Pubmed there are more than 240 papers to be found.

The objective of this review is to focus on the utility of the skin conductance responses (SCR0/sec to assess pain in infants and children. Furthermore, the finds will be discussed and compared with other physiological pain assessment tools.

## Method

This review is based on two searches in Pubmed. Search one includes the key words "skin conductance", "pain", and "children". Search two includes the key words "skin conductance", "pain", and "infants". The findings in these searches are discussed and compared with other physiological pain assessment tools.

## Results

Search one, regarding children, included twelve papers of which five showed the SCR/sec during painful procedures or after observational pain scores were used [8-12]. Only one of these studies examined the SCR/sec during painful/discomfort procedures, and the SCR/sec increased and correlated with the COMFORT sedation score [10]. In the other of these studies the sensitivity and specificity of SCR/sec were calculated in the postoperative setting, with different cutoff values for the SCR/sec to discover moderate and severe pain, and different analysing windows. Cut off value of 0.13 SCR/sec to discover moderate and severe pain and 15 sec analysing window showed the best results [8], and are also recommended from the manufactor (www.med-storm.com). Among the other seven, one paper showed skin conductance activity during skin disease, another showed skin conductance activity during the emotional stress of presentation, a third paper showed skin conductance activity during Pavlovian condition reflex, and a fourth paper showed skin conductance activity in adults. The remaining three studies showed skin conductance activity during painful procedures, however, the SCR/sec to validate pain was not used [13-15]. Search two, regarding infants, included 20 results where four of the papers also were in searh one [8,10-12]. Of the remaining 16, an increase in the SCR/sec during painful procedures was found [6,16-24] (another three which were Russian), or that the SCR/sec was used for developing a pain score by testing variation between and within patients [25,26]. In one study the mean skin conductance level was used for pain assessment which is less sensitive to assess pain [27].

The sympathetic nerve activity in preterm infants appears to be developed to a final stage at about 25 weeks of gestational age [28]. The Skin Conductance Algesimeter index, SCR/sec, has been used in several studies to monitor pain. To examine the variation between and within infants, the SCR/sec was studied in infants during sleep, described as behavioral state 1. The variation was between 0.00 and 0.04, median 0.00, when 15 infants were studied six times during 48 hours [26], also confirmed in the paper from Valkenburg [25]. Interestingly, when the SCR/sec was used as a pain indicator, 0.21 SCR/sec is used as a pain threshold which is five times higher than the maximum value of the SCR/sec of the infants who were asleep (www.med-storm.com) (Table 2). When developing the Skin Conductance Algesimeter index for infants, Table 2, the SCR/sec was compared to the behavioral pain scores, HR, and Newborn Individualized Developmental Care and

| | Desaturation measured peripheral | Sympathetic muscle outflow (microcirculation/vasoconstriction) | Sympathetic skin outflow (increase in skin conductance peaks) |
|---|---|---|---|
| **Emotional stress without arousal** | | No influence | Yes |
| **Arousal stimuli such as sudden inspiration, chest compression, sudden electrical skin shock.** | Desaturation without general hypoxia but probably due to hypoperfusion | Yes, vasoconstriction | Yes |
| **Frightening situation** | Desaturation without general hypoxia but probably due to hypoperfusion | Yes, vasoconstriction | Yes |
| **Cooling** | Desaturation without general hypoxia but probably due to hypoperfusion | Yes, vasoconstriction | No influence |
| **Warming** | | Yes, inhibited outflow vasodilatation | No influence |
| **Respiratory rhythm** | | Yes, influence | No influence |
| **Apnea** | Desaturation with general hypoxia | Yes, influence | No influence |
| **Hypoxia** | Desaturation with general hypoxia | Yes, vasoconstriction | Not studied |
| **Baroreflex control** | | Yes, influence | No influence |
| **Valsalva manoeures** | | Yes, influence | No influence |
| **Carotid sinus nerve stimulation** | | Yes, inhibited outflow, vasodilatation. | No influence |

**Table 1:** This table includes an overview of the neurophysiological papers where the activity of the sympathetic nervous system when acting on the microcirculation and skin is decribed. The sympathetic nervous system acts differently through the microcirculation compared to when it acts through the skin inducing changes in palmar or plantar skin conductance. The activation depends on which stimulus that occurs. Furthermore, this table describes how the different situations will influence the peripheral oxygen saturation.

| | |
|---|---|
| WHITE: 0.00-0.07 SCRs per sec | The patient is calm |
| LIGHT YELLOW: 0.14 SCRs per sec | The patient is calm and moves a little |
| YELLOW: 0.21-0.027 SCRs per sec | The patient is active, observe the patient, pain/discomfort threshold is reached |
| ORANGE: 0.33 SCRs per sec | The patient is probably in pain/discomfort, evaluate the situation |
| RED: 0.40 SCRs per sec or more | The patient is in increasing pain/discomfort |

**Table 2:** The Skin Conductance Algesimeter index shows how the skin conductance responses per sec increase during painful procedures (www.med-storm.com).

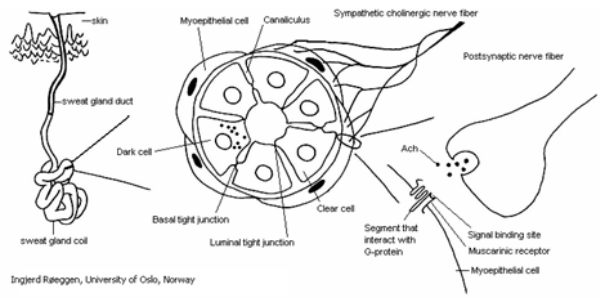


**Figure 1:** The changes in skin conductance is influenced from burst in the skin sympathetic nerves activating the muscarinic receptors and then sweat is released from the sweat glands to the upper part of the skin before the sweat again is reabsorbed.

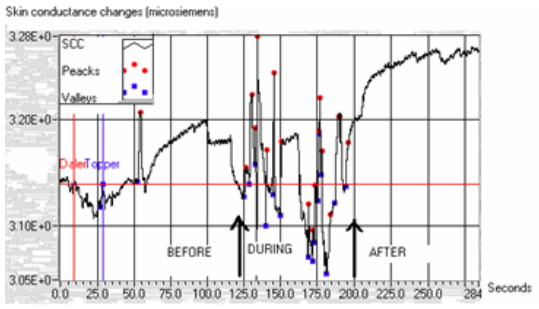


**Figure 2:** The skin conductance responses monitored before, during, and after heel stick for blood sampling in infants from 25 weeks of gestational age. During painful procedures, the skin conductance responses/sec increases statistical significant.

Assessment Program (NIDCAP) nurses behavioral rating score. The COMFORT sedation score and the infants' crying time before, during and after painful procedures were also applied while developing the Skin Conductance Algesimeter index. Approximately 400 infants and children participated in these studies [6,8,10-12,16-31]. These studies show that the SCR/sec and observational pain scores increase during defined painful procedures in infants when tested. In one study concerning infants younger than 28 weeks of gestational age, it was only the SCR/sec that increased during heel stick, not the NPASS observational pain score [6]. A correlation between the observational pain score, the Neonatal Infant Pain Score (NIPS), and the Skin Conductance Algesimeter index, SCR/sec, was found in infants during the process of heel stick for blood gas analyses (R=0.554, p=0.008) [21]. Several studies show that the SCR/sec is not influenced by gestational and postnatal age during painful procedures [6,20-22,26], and also that it is possible to use from 25 weeks of gestational age [6,22] (Figure 2). When a cut off value of 0.571 SCR/sec was used, the sensitivity was 54.5% and the specificity was 79.4 when pain was measured by the Neonatal Facial Coding System (NFCS) [12], the analysing window for the SCR/sec was defined to be only 5 sec. The recommended cut off value is 0.13 SCR/sec to discover moderate and severe pain, and the recommended analysing window is defined to be 15 sec (www.med-storm.com). In premature infants, neuromuscular blockers should be used with caution [32], probably because of immature development of the muscarinic-nicotine receptor.

When studying pain in 20 infants and children at the intensive care unit results of this study have revealed that calm patients without stimuli have an SCR/sec of maximum 0.03 [10], in accordance with the Skin Conductance Algesimeter index, Table 2. In children, an SCR/sec cut off value of 0.13 was found to distinguish between no or mild pain versus moderate or severe pain with a sensitivity of 90% and a specificity of 64% (positive predictive value 35%, negative predictive value 97%) [8]. Interestingely, when studying postoperative pain in children, the SCR/sec was not influenced by anxiety [8,9]. Furthermore, analgesia given to children affected by pain decreased the reported pain and the SCR/sec [8]. When studying infants and children between the ages 0 to 11 years at the Intensive Care Unit, the SCR/sec and the moderated Comfort sedation score increased during suction from trachea. The differences between the status prior to as well as during suction from trachea correlated significantly between the two methods, R=0.78, p<0.0005 [10]. In the postoperative settings, when pain was studied in general, no correlation between the Skin Conductance Algesimeter index and the Numeric Rating Score was found [9]. The SCR/sec is not influenced by the children's age [8,29].

## Discussion

Search one included twelve papers where five showed results from painful procedures where the SCR/sec was used as pain assessment. Search two included 20 results of which 19 showed results from painful or non-painful procedures where the SCR/sec was used for pain validation. All finds showed that the SCR/sec increased during defined painful procedures. Postoperatively, at intensive care units, as well as at neonatal units, the SCR/sec shows a high sensitivity to monitor pain, but lower specificity. A cut off value of 0.13 SCR/sec to discover moderate and severe pain, and an analysing window of 15 sec are recommended.

Vital fundaments for acute physiological pain assessment scores in infants and children who are unable to communicate verbally are the examination of heart rate (HR), heart rate variability (HRV), respiratory rate, blood pressure, oxygen saturation, near infrared spectroscopy (NIRS), and palmar sweating (SCR/sec).

Physiological variables like HR, HRV, blood pressure, NIRS, and peripheral oxygen saturation may be misleading for validating pain because these factors vary in response to changes in the blood circulation which occurs during illness. The HR is influenced by the respiratory rhythm [including apnoea and hypoxia, the use of mechanical ventilation, and the respiratory distress syndrome) [33], as well as changes in the blood volume status [34]. This also applies to drugs acting on the blood circulation such as beta blockers and epinephrines, environmental temperature [35], as well as emotional stressors e.g. fright evoking or unexpected situations [36], (Table 1). Interestingly, the SCR/sec measured palmary and plantary (mirroring bursts in the skin sympathetic nervous system), is not influenced by hemodynamic changes, environmental temperature, or respiratory rhythm [33-35]. However, it is influenced by emotional stressors e.g. fright evoking or unexpected situations [35] and the performance of intellectual tasks [9]. This is because the SCR is activated by acetylcholine acting on muscarinic receptors (Table 1 and Figure 1). It is important to use SCR/sec when monitoring pain. One should avoid using the skin

conductance level (microsiemens), which is less accurate to monitor pain and which also possibly correlates with skin temperature [25]. Both, the HR and the SCR/ sec react rapidly, within 1-2 sec, and are measured in real time.

The HR is influenced by both sympathetic and parasympathetic nerve activity. As opposed to the sympathetic nervous system, the parasympathetic nervous system matures and becomes more dominant with increasing age [28]. In one study an increased HR response was shown to develop with increasing gestational age in preterm infants [1]. Furthermore, the HR during painful procedures increased more in preterm infants born < 28 weeks of gestational age at a postnatal age of 4 weeks, when compared to newborn infants at 32 weeks of gestational age. These results indicate that the maturation of cardiac autonomous control may be related to gestational age, postnatal age, and the level of neurologic maturity. The HR was studied in fifteen infants six times during 48 hours of sleep (behavioural state 1). It ranged from 110 to165 beats per minute (bpm), with a mean of 137 bpm [26]. It is therefore a high variation of the HR between different infants and also within the same infant when they are calm or asleep. Therefore it is difficult to apply the HR as a standard score that is valid for all infants, in which a specific number of beats defines the pain level. These facts may question the utility of the HR as a pain assessment tool when the aim is to develop a pain index valid for all infants independent of age. In the Intensive Care and Neonatal Units, when studying infants and children between the ages 0 to 11 years, the heart rate and pain scores increased during suction from trachea and heel stick [10,17]. However, the difference between the measured values prior to and during suction from trachea did not correlate significantly between the two methods [19].

The HRV (and heart rate) has also been used to assess pain in infants during heel stick for blood sampling [36]. The infant's heart rate variability (HRV) increases with age in preterm born infants. Regarding preterm infants it is, however, still low and immature at term when compared to term-born infants [28]. During anaesthesia, the HRV was compared to the skin conductance level (microsiemens) during tetanic stimuli and the HRV obtained statistical significant values differing from the skin conductance level (microsiemens) [13]. When using skin conductance to assess pain, it is crucial to use SCR/sec and not a mean skin conductance level [10,16,20,25]. Furthermore, during anaesthesia the SCR/sec was analysed with a threshold of 0.05 microsiemens, which is 10 times higher than the recommended threshold of 0.005 microsiemens for patients undergoing anaesthesia [13] (www.med-storm.com).

The NIRS has been used successfully for pain discomfort assessment in neonates [37]. However, when NIRS was compared to the SCR/sec during an eye examination in preterm born infants the NIRS did not increase differently from the SCR/sec which increased during eye examination [31].

During painful stimuli that cause arousal as well as situations associated with fear [possible tissue hypoxia due to vasoconstriction) peripheral desaturation may be observed [35]. This may also occur in cases of general tissue hypoxia due to other causes (Table 1). Thus peripheral oxygen saturation is not valid as a pain indicator because it lacks specificity [33,35]. In infants during behavioral state 1, peripheral oxygen saturation was studied, and it ranged from 91% to100% with a median of 98% when measured six times in 15 infants during a time span of 48 hours [26].

According to Berde's criteria [38] for an ideal physiological pain assessment tool, the properties should be: low cost, portability, reliability, easy to use, low risk, equipment with high sensitivity and specificity to pain within the range from no pain at all to severe pain. Because extra electrodes for pain measurement have to be fastened to the patient the SCR/sec does not satisfy the low cost critrion. However, the SCR/sec performs most accurately. The reason why the SCR/sec performs better than the HR is that it is not influenced by the variables suggested by Berde such as anxiety, exposure to cold, increased body temperature, anemia, hypovolemia, shock, congestive heart failure and medications with adrenergic agonist or adrenergic receptor blocking effects, Table 1 [8,9]. The SCR/sec and the HR may be influenced by autonomous neuropathies. The measuring SCR electrode should not be associated to the extremity with regional anesthesia or paraplegia. Interestingly, due to a low variation between and within patients when they are at the same stress/discomfort level the SCR/sec [26] may develop into an index formula valid for all patients, as opposed to HR and peripheral oxygen saturation. The sensitivity to monitor pain and the negative predictive value are high for the SCR/sec in contrast to the specificity and the positive predictive value. The SCR/sec has a stronger correlation with the self-report pain scales in articulating children than heart rate during postoperative periods [8]. In adults, however, it is only the SCR/sec which decreases when analgesia is given to reduce pain, not the HR [39]. The SCR/sec reacts fast to pain in real time and is not influenced by age. Thus it is valid for all infants and children [6,8,20,21,26,27,29]. Peripheral desaturation and an increase in the HR may be caused by both general hypoxia and pain/discomfort. Hence in infants the SCR/sec may differ between these two situations because it will probably only react during stages of pain/discomfort in infants, and may therefore possibly give a correct diagnosis leading to an appropriate treatment (Table 1).

To conclude, the Skin Conductance Algesimeter index, SCR/sec, seems to be more reliable than heart rate, NIRS, and oxygen saturation to warn and indicate when pain stimuli may occur, and should be chosen as an adjunctive pain assessment tool in infants and children.

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**Conflict of Interest:** Hanne Storm is co-owner and CEO of Med-Storm Innovation, Gimle Terrasse 4, Oslo, Norway. This company has the right of the Skin Conductance Algesimeter to monitor pain for commercial sale.

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