Tactile, thermal and pain sensibility in burned patients
with and without chronic pain and paresthesia problems

Annie Malenfant\textsuperscript{a,b}, Robert Forget\textsuperscript{c}, Rhonda Amsel\textsuperscript{f}, Jacques Papillon\textsuperscript{a,d}, Jean-Yves Frigon\textsuperscript{b} and Manon Choinière\textsuperscript{a,d,e,*}

\textsuperscript{a}Centre des Grands Brûlés, Centre Hospitalier de l'Université de Montréal,
Campus Hôtel-Dieu, H2W 1T8 (Canada),
Départements de \textsuperscript{b}Psychologie, \textsuperscript{c}Ecole de Réadaptation, \textsuperscript{d}Chirurgie et \textsuperscript{e}Anesthésie, Faculté de Médecine, Université de Montréal, Montréal, H3C 3J7 (Canada) and \textsuperscript{f}Department of Psychology, McGill University, Montréal, H3A 1B1 (Canada)

Abstract

Abnormal return of cutaneous sensibility is common after burn injuries and many patients complain of painful and/or paresthetic sensations in their healed wounds. However, little is known about the exact nature and severity of these problems. The present study was designed to provide a quantitative evaluation of the cutaneous sensibility in burned patients. Tactile, thermal and pain thresholds were measured in 121 patients with healed burns paired-matched to 121 control healthy subjects more than 18 months after the burns. Testing was confined to both upper limbs and was performed in a healed burned area and its contralateral burned or unburned counterpart. The tested sites were also divided into symptomatic and asymptomatic ones depending on the presence or not
of pain or paresthesia at the site. The results showed significantly higher sensory thresholds in burned patients than control subjects. Severity of the deficits on the various sensory modalities was however a function of burn depth. Deep burn injuries which had required skin grafts to heal were more seriously affected than superficial burns which had healed spontaneously. Significant sensory losses were found not only in burned sites but also in the noninjured areas suggesting changes in the central nervous system. When symptomatic and asymptomatic sites were compared, significant deficits were observed in the tactile modality (touch-pressure). Other significant predictors of chronic sensory problems were burn depth and patients' age. Pathophysiological mechanisms of diminished sensibility in burned and unburned skin as long as several years after the injury are discussed along with those implicated in pain and paresthesia problems reported by the patients.

**Key Words:** Cutaneous sensibility, quantitative sensory testing, pain, paresthesia, burns

1. **Introduction**

Few studies have documented the nature of the long-term sensory consequences of severe burn injuries. Burn victims often report cutaneous sensibility losses but the severity of these deficits is not well known. Moreover, burned patients often complain of abnormal or painful sensations in their wounds, and even though the prevalence of these problems is fairly high (Choinière et al., 1991; Malenfant et al., 1996), we still ignore whether or not they are related to precise sensory deficits.
Conclusions originating from previous studies which have investigated cutaneous sensibility in burned patients have to be considered with circumspection as they are either based on qualitative data or suffer from important methodological deficiencies (e.g. low sample size, lack of control group, numerous testing sites, inappropriate statistical analyses). In a qualitative study, Pontén (1960) observed that tactile, thermal, pain and discriminative sensibility recovered to normal in grafted areas more than one year after the burn injury, after a transitory period of pain hypersensitivity. Later studies suggested that the severity of sensory deficits may vary as a function of burn depth. Hermanson et al. (1986) found that deep burns which had required skin grafts for healing had sensibility thresholds (two-point discrimination, pressure, thermal and pain sensibility) which were significantly higher than in control areas (i.e. unburned contralateral side or homologous sites in healthy subjects). Normal sensibility was obtained in superficial burns which had healed spontaneously, except for touch threshold. Ward et al. (1989) also observed, in a qualitative study, that deep burns altered cutaneous sensibility and that sensory function in non-grafted areas was better or recovered to normal. Other studies have demonstrated a diminution of sensibility after burn injuries (Slors et al., 1984; Ward and Tuckett, 1991; Choinière et al., 1994). Data from Ward and Tuckett (1991) and Hermanson et al. (1986) studies also suggested that patients could have deficits not only in burned sites but also in unburned areas. There is a general agreement from the previous reports that burn injuries produce permanent sensibility abnormalities but this issue has to be examined more closely considering the important drawbacks previously described in these studies.

Pain and paresthesia problems constitute another common long-term effect of burn injuries. These problems are relatively frequent even several years after the burns and sufficiently intense to
interfere with patients' activities (Choinière et al., 1991; Malenfant et al., 1996). The presence of this type of problems in burned patients is not surprising when one considers the nature of injury, which damages underlying nerve structures, the kind of surgery carried out (skin grafting) and the possible problems of the scarring process. Several studies in patients with peripheral nerve pathologies have shown associations between the symptomatic condition of the patients (i.e. report of abnormal sensations or chronic pain) and objective cutaneous sensibility deficits (e.g. diabetic neuropathy: Ziegler et al., 1988; Lanting et al., 1989; post-herpetic neuralgia: Rowbotham and Fields, 1989, 1996; Nurmikko and Bowsher, 1990; other peripheral traumas: Lindblom and Verrillo, 1979; Fruhstorfer and Lindblom, 1984; Wahren, 1990). Such associations between objective deficits and subjective sensory complaints have not been addressed in the literature devoted to burn injuries.

In order to get a better understanding of the long-term effects of burn injuries, the present study proceeded to a thorough quantitative evaluation of the cutaneous sensibility in a large sample of patients with healed burns. Tactile, thermal and pain thresholds were assessed in burned and unburned areas and compared to thresholds in normal healthy subjects. Sources of variation in post-burn sensory recovery were also investigated. Finally, the study examined if there was any association between cutaneous sensory dysfunction and subjective reports of abnormal sensations in healed burns.
2. Methods

2.1. Subjects

Participants to the present study were recruited among adult burned patients who had been hospitalized at the Centre des Grands Brûlés of the Campus Hôtel-Dieu of the Centre Hospitalier de l'Université de Montréal (CHUM) between June 1985 and December 1993. The subjects were recruited from a computerized list of consecutive admissions during this period. Patients were eligible for the study if they were aged between 18 and 70 years and had undergone second- or third-degree burns in upper limbs. Only white patients were included in the study as previous reports have suggested that black people were more susceptible to develop hypertrophic scars (Ketchum, 1977; Deitch et al., 1983). All participants were tested 18 months or more after discharge from the burn unit to insure completion of the scar process (Ketchum, 1977; Larson et al., 1977; Pruitt, 1979) and maximization of the axon regeneration and sensory cortical adaptation following the injury (Murdoch and McAllister, 1994). Excluding the patients who were deceased, had a diagnosis of psychiatric illness clearly documented in their medical file or lived outside the Montreal area (more than 100 km), the initial population included 392 patients.

Three hundred and twenty-eight of them were located but 121 of them were excluded because of 1) inability to properly understand French or English, 2) presence of a disorder susceptible to affect sensory function (e.g. neurological antecedents, cutaneous illness at upper limbs, diabetes, daily alcohol intake, consumption of street drugs, chronic pain or paresthesia not originating from burns,
HIV), 3) surgery undergone in the 6 months preceding the study, or 4) amputation at upper limbs. Eighty-six patients refused to take part in the study leaving a subsample of 121 patients.

A group of 121 healthy volunteers (recruited among the staff of the Campus Hôtel-Dieu or the patients' entourage) were paired-matched to burned patients on age (± 3 years), sex and educational level (± 3 years). Inclusion of educational level as a pairing criterion was justified by an observation made in a preliminary study at the Burn Center (Choinière et al., 1994) where more educated people were observed to be more concerned with their performance on the psychophysic tests than less educated people (unpublished data). Control subjects were selected according to the same study selection criteria than those applicable to burned patients. All subjects were paid for their participation in the study.

2.2. Procedure

The present protocol was approved by the institutional Ethics Committee. To verify their eligibility in the present study, burned patients and control subjects were contacted by phone by one of the investigators (A.M.) or the research nurse who was assigned to subject recruitment. Participants were invited to come to the Burn Centre to take part in the evaluation protocol which consisted of a structured interview and sensory tests. All participants were asked to not take any medication in the previous 24 hours.
2.3. Structured interview

After having obtained the patients’ written informed consent, the research nurse conducted a structured interview during which she administered a modified version of the questionnaire developed by Choinière et al. (1991). The first part of the questionnaire consisted of descriptive items on demographic and medical history. The second part collected information about the presence, location and characteristics of painful and/or paresthetic sensations at the sites of the burn injuries. This information was used to determine the sites for the sensory testing, which sites were classified into symptomatic (presence of abnormal sensations) or asymptomatic (absence of abnormal sensations) ones.

The testing sites (surface of 4 cm X 4 cm), which were traced by the research nurse with a black marker, were confined to both upper limbs and included a healed burn area and its contralateral homologous burned or unburned site when available (n = 79). When a patient reported post-burn neuralgia problems in more than one site, the choice was confined to the most annoying one and its contralateral area. When the latter was burned, the second most disturbing symptomatic area was chosen if its contralateral area was unburned.

For asymptomatic patients, selection of the sites was made to include a burned site and a contralateral unburned area if possible. Otherwise, bilateral burned sites were picked up based on their location giving the priority to the dorsum of the hand. In control subjects, both test sites were anatomically paired-matched to those of burned patients. Testing was always performed on glabrous skin. Skin was shaved when necessary, fifteen minutes prior to the testing.
2.4. Sensory testing

Subjects were conducted in the experimentation room where the temperature was maintained at 22°C ± 1°C. A period of 15 to 20 minutes was allowed to permit the subject to acclimatize to the temperature room. The testing was carried out by one of the investigator (A.M.) with all participants (patients and control subjects). For the group of burned patients, the experimenter did not know whether the tested sites were symptomatic or asymptomatic.

Conventional psycho-physical techniques were used to determine sensibility thresholds for tactile (pressure), two-point discrimination, thermal (heat, cold) and heat pain modalities. All the tests were performed out of sight of the subject, using a screen between the experimenter and the subject. A verbal cue was given immediately before the application of the stimulus to insure adequate attention from the subject. The different sensory modalities were tested in a random order except for the heat pain test which was always performed last to avoid producing the paradoxical heat phenomenon (Greenspan et al., 1993). For control subjects, the order of the test administration was the same as the one for the patients with whom they were paired. Periods of rest of a few minutes were introduced between the tests to reduce fatigue effects. Duration of the sensory testing was about two hours.

Pressure and two-point discrimination thresholds were obtained with the method of limits performed with the staircase procedure (Engen, 1971; Wolff, 1986). After an orientation series (see below), three ascending and three descending series of stimuli were performed. Each series was carried out by alternating the limb side (right, left) to minimize sensitization of afferent fibers.
resulting from repeated stimulations to the same testing site (Price et al., 1977). Thresholds were calculated by taking the mean of the stimulus values perceived in the ascending and descending series.

For the thermal and heat pain tests, thresholds were obtained with the method of levels (Yarnitsky and Ochoa, 1990, 1991) where the temperature increases (or decreases) to a certain target level and returns to its baseline until the subject detects the presence of heat (or cold). Thermal and pain thresholds were calculated from the results obtained on three series.

2.4.1. Pressure sensibility

Semmes-Weinstein monofilaments were used to measure pressure sensibility (Semmes et al., 1960). Each of the 20 filaments vary in diameter (.06 to 1.14 mm) for which is assigned a calibration value corresponding to the log of 10 times the strength required to bend the filament in demi-circle (Corkin et al., 1970; Jones, 1989). For the orientation series, every three filaments were applied until perception of the stimulus. The filament felt constituted the orientation value. The ascending series were started three filaments below the orientation value and three filaments above for the descending series. All filaments in this range were successively applied for 1 to 1.5 second (Bell-Krotosky, 1990) until the subject reported its presence (ascending series) or absence (descending series). Time between stimulus application varied from 5 to 15 seconds to avoid temporal summation (Price, 1994). Semmes-Weinstein filaments are the most frequent way of assessing pressure sensibility (Jones, 1989) and psychometric values in terms of validity, reliability and
sensitivity of the measures have been fully documented (Semmes et al., 1960; Bell-Krotosky and Tomancik, 1987; Bell-Krotosky and Buford, 1988).

2.4.2. Two-point discrimination

Two-point discrimination thresholds were obtained with the Weinstein aesthesiometer. This instrument is provided with two blunt points and is calibrated in millimeters. The two points were applied simultaneously by the experimenter and without movement on the skin. The subject had to report whether he or she felt one or two points (Corkin et al., 1970; Jones, 1989).

The testing began with an orientation series which started with a distance of 30 mm between the two points and gradually decreased by a 3-mm step until the subject reported only one point. The ascending series were begun 3 mm below the orientation value, and 3 mm above for the descending series. The distance between the points was increased or decreased by 1 mm until the subject reported the presence of one (descending series) or two points (ascending series). The interstimuli interval was 15 seconds (Semmes et al., 1960; Corkin et al., 1970; Horch et al., 1992). The validity and reliability of the two-point discrimination test have been demonstrated by Semmes et al. (1960) and Dellon et al. (1987).

2.4.3. Thermal sensibility

Heat and cold sensibility were measured with a 1-cm² contact thermode (Medical Instrumentation Facility, Yale University School of Medicine) which generates extremely precise thermal stimulations. The apparatus is composed of a heating element and a cooling system, and operates by the Peltier principle. Increasing and decreasing linear temperature rate was kept constant at
19°C/sec throughout the experimentation. Baseline temperature was settled at subject's skin temperature i.e. at a temperature which the subject did not feel cold or heat (ranging from 26°C to 36°C, median: 30°C).

Depending on the modality tested (heat or cold) the orientation series was begun 3°C higher (or lower) the baseline temperature and increased (or decreased) by 3°C until the subject perceived the stimulus. The ascending and descending series were then achieved from 3°C below or above the orientation value with a temperature modification of 1°C at each stimulation. A minimum of 15 seconds separated two stimuli (Bushnell et al., 1984). Maximum temperature values were 0°C and 50°C to avoid tissue damage (Ziegler et al., 1988). Subjects whose thresholds were not reached at 0°C or 50°C were assigned these maximal values.

2.4.4. Heat pain sensibility

Heat pain detection thresholds were obtained with the contact thermode previously described. For each subject, the baseline temperature of the thermode was set at the value corresponding to his/her heat threshold obtained previously. The orientation series followed the same procedure than the one used for heat thermal test. A period of at least 60 seconds was allowed between stimuli to prevent suppression or sensitization of cutaneous receptors or primary nociceptive afferents (Price and Dubner, 1977; Talbot et al., 1987, 1989).

Test-retest reliability of the thermode was evaluated with eight healthy subjects (4 males/4 females; mean age: 43.9 ± 4.8 years) whose heat, cold, and heat pain thresholds were measured twice at one week interval. Intraclass correlation coefficients (ICC) calculated varied between 0.69 and 0.95.
According to Fleiss and Cohen (1973) and Landis and Koch (1977), values between 0.61 and and 0.80 represent good agreement and those above 0.81 represent excellent agreement between measures. There was no effect of laterality (p > 0.05).

2.5. Review of medical charts

Upon completion of the study, the patients' medical charts were reviewed to get information about the type and size of the burns (expressed in total body surface area burned), the presence or not of skin grafts at the testing sites (deep versus superficial burns) and the time elapsed between the burn injury, skin graft application and sensory testing.

2.6. Data analysis

Parametric and non-parametric statistics (t-test, $\chi^2$) were used to compare the demographic and medical characteristics of the burned patients who participated in the study and those who did not (patients not located, excluded and those who refused). For the sensory testing results, the sites were subdivided into two groups depending on burn depth (i.e. whether the site had healed spontaneously (n = 58) or required skin grafting (n = 63)). Control values were obtained from the groups of healthy volunteers. Results obtained on the five sensory tests for the burned and control sites were analysed with a two-way (group and burn depth) MANOVA (which take into account the problematic of test multiplicity) followed by ANOVAs and simple effects analysis when required (significant interaction). The same type of analysis (but one-way - group only) was performed to compare the sensibility thresholds of unburned sites in patients with those of control subjects.
Patients with bilateral burns were excluded from the latter analysis, leaving a subsample of 79 patients. As patients whose thresholds were not reached at 0°C (cold) or 50°C (heat, pain) were assigned these maximal values, additional group comparisons were made using non parametric statistics (Mann-Whitney test). These analyses are not presented, the conclusions being the same as those obtained with the parametric statistics.

As mentioned earlier, burned sites were further subdivided into symptomatic and asymptomatic ones depending on whether or not the patient were complaining of pain or paresthetic sensations in the area. Multiple logistic regression analyses were performed to identify significant predictors of the symptomatic condition of the burned sites. Relevant demographic and medical variables were included in the analyses along with the threshold values obtained on each sensory test. Continuous variables were divided into tertiles. All variables were entered into the model using a backward selection procedure, and only those with a p < 0.15 were kept for the final analysis. This procedure was done to obtain the most parsimonious model and to eliminate non-contributing variables which overloaded the analysis. In the final analysis, the values of the prognostic variables were assessed using a hierarchical stepwise selection procedure.

Finally, multiple linear regression analyses (backward selection) were carried out to identify the relationships between patients' sensibility thresholds and some demographic (age, sex) and medical variables (burn extent, burn depth, time elapsed since injury, skin graft application and sensory testing). All analyses were computed using the SPSS/PC program (version 4.0) and a p value less than 0.05 was considered for statistical significance.
3. Results

3.1. Patients' characteristics

Sample representativity was assessed by comparing the demographic and medical characteristics of the burned participants (n = 121) and non-participants (n = 271). These data are presented in Table 1. Statistical analyses showed no significant differences between the two groups with respect to sex, age, burn extent, type of burns, and the interval between the burn injury and study time.

- Insert Table 1 about here -

3.2. Cutaneous sensibility in healed burns

Figures 1-5 shows the mean thresholds (+ S.E.M.) obtained in the burn and control groups for the five sensory tests. The results are presented separately for the superficially and deeply burned sites. The statistical analyses revealed a significant group X burn depth interaction (p < 0.0001). Burned patients exhibited significant decreased sensibility when compared to control subjects but the severity of the deficit on the various modalities was a function of burn depth. Deep burned sites which had required skin grafts showed significantly higher thresholds than control sites in healthy subjects, and this was true for all sensory tests (p < 0.0001). In contrast, patients with superficial burns showed sensory thresholds which were comparable to those of controls, except for the touch pressure (p < 0.0001) and heat (p < 0.013) modalities where patients' thresholds were more elevated
than control values. Deep burns had significantly higher thresholds than superficial burns for the five sensory modalities ($p < 0.0001$).

Differences between the superficial and deep burned sites were further investigated by examining the proportion of patients who had a sensory deficit considered as severe. A severe deficit was arbitrarily defined as a threshold value exceeding 2 standard deviations (SD) away from the mean of the control group (healthy subjects). The results are displayed in Table II. Depending on the sensory modality, 21 to 52% of the patients with deep injury sites showed a loss of sensibility protection while 5% to 22% of the patients with superficial burns presented a severe deficit. The two most affected modalities were pressure and cold sensibility in either group.

3.3. Cutaneous sensibility in uninjured skin

Data on cutaneous sensibility in uninjured sites of burned patients were available for 79 subjects with unilateral burns. Mean thresholds on the five sensory tests are presented in Table III along with the control values obtained in the group of healthy subjects. It can be seen that on all sensory modalities, the burned patients showed elevated thresholds in uninjured areas and the differences reached level of statistical significance on pressure and cold modalities.
The proportion of patients with a severe sensory deficit (see above definition) in the unburned site varied from 2 to 13 percent (pressure: 8.9%, two-point discrimination: 2.5%, heat: 12.7%, cold: 8.9%, heat pain: 5.1%). Although small, these percentages are impressive in view of the fact that they were derived from unburned areas.

3.4. Cutaneous sensibility in symptomatic and asymptomatic burned sites

Seventy-nine patients complained of pain and paresthesia at the testing site while 42 were asymptomatic. In the former group, the frequency of the symptoms was classified as "continous" (more than one day a week) for 33 sites (42%) and "intermittent" (less than one day a week or as a function of the temperature) for 46 sites (58%).

Quantitative evaluation of cutaneous sensibility in the symptomatic sites revealed a quite high proportion of patients with a sensory deficit defined as severe (see above definition). The majority of the patients who got very abnormal thresholds reported painful or paresthetic sensations in the site (pressure: 77.1%; two-point discrimination: 83.3%; heat: 63.3%; cold: 70.7%; heat pain: 57.8%).

Significant predictors of the presence of pain or paresthesia at the burned site are displayed in Table IV. Symptomatic patients were more likely to have high touch-pressure thresholds than patients without sensory complaints. Results obtained on the other sensory tests (two-point discrimination,
heat, cold, heat pain) were not consistent predictors. The odds of reporting abnormal sensations were higher in deep burn injuries which had required skin grafts than in superficial burns which had healed spontaneously. Patients aged more than 45 years were less susceptible to report pain or paresthesia problems (p < 0.02). Patients' sex did not bring a significant contribution to the prediction of the symptomatic condition. The same was true for the size of the burns or the length of time elapsed between the injury and sensory testing.

The same type of analysis was conducted but in considering the frequency of symptoms (continuous vs intermittent, see above definition). Consistent with the above results, high pressure thresholds (p < 0.01) were associated with an increased probability of complaining of abnormal sensations whether they were continuous (p < 0.007) or intermittent (p < 0.01). Burn depth, still a significant predictor in patients with symptoms present more than one day a week (p < 0.02), was not significant in patients with intermittent symptoms (p = 0.13).

- Insert Table IV about here -

3.5. Sources of variation in cutaneous sensibility of burned patients

Patients' age or sex and medical variables such as burn extent or time elapsed since the injury did not explain a significant proportion of the variation in the sensibility thresholds. Burn depth was the only significant predictor of the values on all sensory tests, explaining more than one-third of the observed variability ($R^2$: cold: 0.46; pressure: 0.40; two-point discrimination: 0.38; heat pain: 0.37; heat: 0.35). In order to assess whether the timing of skin grafting has a significant influence on the
quality of sensory recovery, an additional multiple regression analysis was performed on a subset of
data. Only the tested sites which had been grafted were entered into the analysis and the time
interval between the burn injury and skin graft application was included among the predictors. No
significant relationship was found between skin graft timing (mean = 13.4 ± 8.2 days; range: 1-48)
and the threshold values observed on the five sensory tests.

4. Discussion

The results of the present study provide insight into the cutaneous sensibility status of burned
patients using an adequate control group design. Patients who underwent deep burn injuries
presented permanent sensibility deficits in the pressure, discriminative, thermal and pain modalities
when compared to control subjects. Patients who had superficial burns showed a sensibility which
recovered to normal except for the touch-pressure and heat thermal tests. The proportion of patients
with a deficit defined as severe was at least twice higher in patients who required skin grafts for
deep burns than patients whose burns have healed spontaneously.

These findings, from a large sample of patients, confirmed previous observations made by
Hermanson et al. (1986), Ward et al. (1989) and Ward and Tuckett (1991). While increased
sensibility (hyperalgesia) can be observed in burned patients from minutes to months following the
injury (Pontén, 1960, Dahl et al., 1993; Lundell et al., 1996), many patients exhibit decreased
sensibility once the wounds are completely healed and up to several years after the injury.
Interestingly, significant sensibility abnormalities were also found in the contralateral homologous unburned areas. The differences were not of a large magnitude but they were consistently observed on all sensory modalities and reached statistical significance on two of them. Such findings of sensory impairment in the contralateral uninjured side have been also demonstrated in patients with peripheral pathologies of other etiologies (Wilson et al., 1962; Wahren, 1990; Wahren et al., 1991; Wahren and Torebjörk, 1992; Bowsher et al., 1997).

Diminished sensibility (i.e. hypoesthesia) in burned areas is easily understood considering the peripheral mechanisms involved (tissue injury destructing nerve endings, fiber loss in the injured site, incomplete fiber regeneration). Our results of increased thresholds in all sensory modalities in deep burns indicate that both large-diameter afferents in mechanical-mediated function (touch-pressure) and small myelinated and C-fibers in thermal and noxious modalities can be affected.

In peripheral nerve lesions, sensory recovery can be correlated with the functional connections of the afferent fibers with their target structures. Thus, in deep burn injuries where all nerve elements have been destroyed and subjected to abnormal re-innervation following skin graft, it is not surprising to find deficits in all sensory modalities. In contrast, in burns which have healed spontaneously, some modalities (touch and heat) were altered while others were spared. The reduced sensibility in touch-pressure modality may be explained by the lack of collateralization from adjacent tactile fibers in the re-innervation process (Adams and Victor, 1993) and possibly by the absence (after regeneration) of rapidly adapting pacinian afferents implicated in the tactile sensibility (Mackel et al., 1983; Mackel, 1985). With respect to heat detection, Van Boven and Johnson (1994) as well as Healy et al. (1996) found similar deficit more than one year after
peripheral nerve injuries. Compared to other functions, the rate of recovery was the slowest or the sensory deficit was the largest for heat detection. No significant evidence of functional collateral sprouting from the heat conducting afferences was found (Healy et al., 1996). These authors also argued that spatial summation was insufficient to provide the adequate neural signal for heat perception considering the inappropriate number of afferent fibers (Hensel, 1982; Van Boven and Johnson, 1994).

Sensory disturbance noticed in the uninjured skin of burned patients suggest modifications in the central nervous system. It seems that peripheral lesion involving afferent fibers may alter central processing which may contribute to modify sensory function (Davar and Maciewicz, 1989; Gracely et al., 1992). Spinal, subcortical and cortical re-organization after the peripheral damage could also modify the sensory integration (Kaas et al., 1983; Devor, 1984; Pons et al., 1991; Woolf et al., 1992). The central mechanisms involved cannot be identified since the changes could occur at any of those three CNS levels. Testing unburned sites other than the contralateral homologous ones could indicate if the CNS modifications are limited to the same spinal segmental levels or generalized to other levels. However, testing other sites would not help to identify if the changes involve spinal (i.e. through propriospinal interneurones) or supraspinal integrating mechanisms.

The presence of elevated sensory thresholds in healed burned areas indicates that patients do not feel weak stimuli that normally provoke a sensation. In the present study, an important proportion of patients with highly elevated thresholds (up to 50% depending on the sensory modality) have potentially lost their protection sensibility and this is especially true for patients who had undergone deep burn injuries. For touch-pressure test, based on the data of Bell-Krotoski (1990), patients who
had thresholds above 4.56 are considered clinically as having lost their protection sensibility. For heat pain modality, patients who obtained thresholds above $50^\circ C$ are probably in danger to burn themselves. For cold thresholds, it is less clear that the observed average difference of $6^\circ C$ between patients with superficial burns and control subjects is clinically significant. In contrast, patients with deep burns had an average cold threshold which was $16^\circ C$ higher than control subjects.

The clinical significance of this hyposensitivity to cold may be difficult to understand in view of the fact that burned patients often experience difficulty in returning to outdoor work because of intolerance to cold temperatures (Ward et al., 1989; Choinière et al., 1991; Malenfant et al., 1996). However, the two phenomena - elevated threshold and increased reaction to suprathreshold stimuli - are not incompatible and can be present in the same patient (Lindblom, 1990). This is known as ‘hyperpathia’ and has been observed in neuropathic pain patients (Lindblom and Verrillo, 1979; Verdugo and Ochoa, 1992). The mechanisms are not clear however. Spatial summation may be involved. In the present study, the thermal stimuli were applied on a small surface ($1 \text{ cm}^2$). Perhaps a larger stimulation would have led to different results. In a recent study, Defrin and Urca (1996) used contact areas of different sizes and found that heat pain thresholds undergo marked spatial summation. It would be interesting to test if the same is true for the cold modality in burned patients. In their study, Ward and Tuckett (1991) made some qualitative suprathreshold sensory testing (pressure, light brush) in burned patients and their results are suggestive of impaired ability to detect suprathreshold, at least in some patients. However, these authors did not assess the thermal and pain modalities, and burned patients perhaps exhibit hyperpathia with these modalities. We are currently preparing a quantitative psychophysics study which will examine, more closely,
suprathreshold intensity function in burned patients and the influence of ongoing paresthesia or pain problems on the perceived intensity of these stimuli.

In the present study, tactile sensibility deficits (touch-pressure) were significantly associated with the presence of painful or paresthetic sensations in the sites. Another predictor of the patients' symptomatology was burn depth: the deeper the burns, the more likely were the patients to complain of paresthesia or chronic pain in the sites. Choinière et al. (1991) and Malenfant et al. (1996) also observed a relationship between burn depth and the prevalence of neuralgia problems.

None of the studies which have explored the relationships between subjective complaints of abnormal or painful sensations and objective sensory sequelae in burned or unburned patients have looked at possible differences between continuous vs intermittent symptoms. This aspect was examined in the present study and the results showed that burn depth was a significant predictor of neuralgia problems when these problems were present relatively continuous (more than one day a week) but not when they were more intermittent. These results suggest that burn depth may influence not only the prevalence but also the severity of the neuralgia problems in terms of frequency of the symptoms.

The association between unpleasant or painful sensations and sensibility impairment has been observed in several studies (Lindblom and Verrillo, 1979; Fruhstorfer and Lindblom, 1984; Ziegler et al., 1988; Lanting et al., 1989; Rowbotham and Fields, 1989; Nurmikko and Bowsher, 1990; Wahren, 1990; Rowbotham and Fields, 1996). In a study involving 33 patients with complete nerve transection, Ochs et al. (1989) found that poor recovery in mechanical and thermal sensibility was
mostly associated with presence of dysesthetic symptoms. Of the paresthetic patients, 25% had marked sensory losses. The co-occurrence of abnormal sensations including pain and sensibility disturbances may suggest overlapping pathophysiology (Lindblom, 1979) in view of the fact that dysesthesias have been associated with loss of peripheral afferents (Thomas, 1984; Levitt, 1990). Although both peripheral and central changes may be implicated (Ochs et al., 1989; Smith et al., 1991), the exact pathophysiological mechanisms remain unknown and more research is needed to verify some hypothesis. Anomalies in regenerated nerve endings (axon-receptor mismatch, neuroma formation, abnormal impulses discharge) or deficient re-innervation in scarred tissues may give rise to abnormal inputs which may in turn alter sensory perception (Terzis, 1976; Wall, 1979; Mackel, 1985; Levitt, 1990; Devor, 1991; Devor, 1994). Abnormal ectopic activity in damaged fibers, regenerating axons, neuromas or dorsal root ganglia is also possible (Asbury and Fields, 1984; Nordin et al., 1984; Devor, 1991; Devor, 1994; Adams and Victor, 1993). Neuroanatomical changes with possible reduced sensory inhibition in dorsal horn may occur (Levitt, 1990). Central hyperexcitability and structural changes in the central primary afferent neurons could be involved (Devor, 1984; Woolf et al., 1992; Coderre et al., 1993).

Like any other studies, the present one had its limitations. Although precaution was taken to exclude patients with disorders susceptible to affect sensory functions (e.g. diabetic neuropathy), the sample may have included patients with burn-associated neuropathy. As participants did not undergo nerve conduction and electromyographic evaluations to detect such peripheral neuropathy, the proportion is unknown. In the literature, the incidence of burn-related neuropathy vary from 2 to 52% with a majority of studies obtaining incidence rate below 30% (Henderson et al., 1971; Helm
et al., 1977; Helm et al., 1985; Dagum et al., 1993; Marquez et al., 1993; Margherita et al., 1995; Khedr et al., 1997).

Another limitation of the present study was the impossibility of determining the influence of an adjacent region on the sensibility observed in the testing site. It is conceivable that the sensibility measured in a superficially burned area, located near a deeply injured site, may have been more altered by the presence of that neighbouring zone of diminished sensibility. Therefore, deficits found in the superficial sites may have been overestimated. However, there is no experimental evidence to support this hypothesis to our knowledge. A vast literature exists on impaired sensibility beyond the site of injury (e.g. secondary hyperalgesia) but these studies were done in acute conditions i.e. in the hours following the injury. The possibility of chronic sensibility modification beyond the zone of injury deserves further investigation.

Despite the study limitations, the present results can have important clinical implications. Burned patients and physicians often have difficulties when the time comes to have chronic sensory problems (pain and paresthesia) acknowledged by compensations agencies. As an objective non-invasive assessment of functional recovery can be undertaken (with a battery of sensory tests such as the ones used in this study, with pressure test being highly sensitive), clinicians could measure sensibility deficits associated with burn injuries and attribute a percentage of incapacity corresponding to the sensory loss. Rather than considering only esthetic prejudices and motor dysfunction, guidelines for impairment evaluation could be modified so as to include disability scales specific to burn trauma and corresponding to different levels of sensibility deficits. Moreover, the presence of pain and paresthesia problems being highly associated with a poorer
sensibility could be another criterion for determination of the gravity of the sensory sequelae resulting from burn injuries.

Acknowledgements

We would like to thank all the study participants (patients and volunteers) for their collaboration. Special thanks are also addressed to Mrs Hélène Lanctôt for her precious help in the patients' recruitment, her active part in the structured interview and the revision of the medical files. Thanks are also due to Dr Parviz Ghadirian for his helpful comments when writing the research proposal and to Mr Marc Dumont for his statistical advice at the times of data analysis. This research was supported by a grant (6605-3897-60A) from Health and Welfare Canada (National Health Research and Development Program) to Dr M. Choinière and her collaborators. Annie Malenfant was supported by postgraduate scholarships from Health and Welfare Canada and from the Fondation des Grands Brûlés du Québec.
Table I
Patients' characteristics

<table>
<thead>
<tr>
<th>Table I</th>
<th>Participants (N = 121)</th>
<th>Non-participants (N = 271)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Demographic variables</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sex (% male/female)</td>
<td>80%/20%</td>
<td>78%/22%</td>
</tr>
<tr>
<td>Mean age ± SD</td>
<td>39.8 ± 11.2</td>
<td>41.1 ± 12.8</td>
</tr>
<tr>
<td>Range (years)</td>
<td>(18-69)</td>
<td>(18-70)</td>
</tr>
<tr>
<td><strong>Medical variables</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean burn extent ± SD</td>
<td>19.1 ± 15.9</td>
<td>18.5 ± 16.5</td>
</tr>
<tr>
<td>Range (%)</td>
<td>(1-75)</td>
<td>(1-80)</td>
</tr>
<tr>
<td>Mean time since injury ± SD</td>
<td>60.0 ± 28.8</td>
<td>57.6 ± 27.1</td>
</tr>
<tr>
<td>Range (months)</td>
<td>(18-121)</td>
<td>(13-114)</td>
</tr>
<tr>
<td><strong>Burn etiology, n (%)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermal</td>
<td>94 (78)</td>
<td>202 (75)</td>
</tr>
<tr>
<td>Electrical</td>
<td>15 (12)</td>
<td>48 (18)</td>
</tr>
<tr>
<td>Chemical</td>
<td>6 (5)</td>
<td>9 (3)</td>
</tr>
<tr>
<td>Combinaison</td>
<td>6 (5)</td>
<td>12 (4)</td>
</tr>
</tbody>
</table>
Table II
Percentage of burned patients who showed a severe sensory deficit as a function of the burn depth

<table>
<thead>
<tr>
<th></th>
<th>Superficial burns (n = 58)</th>
<th>Deep burns (n = 63)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N (%)</td>
<td>N (%)</td>
<td></td>
</tr>
<tr>
<td>Pressure</td>
<td>13 (22)</td>
<td>33 (52)</td>
<td>0.0007</td>
</tr>
<tr>
<td>Two-point discrimination</td>
<td>3 (5)</td>
<td>13 (21)</td>
<td>0.001</td>
</tr>
<tr>
<td>Heat</td>
<td>8 (14)</td>
<td>17 (27)</td>
<td>0.007</td>
</tr>
<tr>
<td>Cold</td>
<td>10 (17)</td>
<td>32 (51)</td>
<td>0.0001</td>
</tr>
<tr>
<td>Heat pain</td>
<td>6 (10)</td>
<td>17 (27)</td>
<td>0.002</td>
</tr>
</tbody>
</table>

*a more than 2 SD from the mean of the control subjects
Table III
Mean sensibility thresholds (± SD) obtained in the contralateral uninjured sites of burned patients (n = 79) compared with those of control subjects

<table>
<thead>
<tr>
<th>Sensory tests</th>
<th>Burned patients</th>
<th>Control subjects</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure</td>
<td>3.37 ± 0.42</td>
<td>3.21 ± 0.38</td>
<td>0.009</td>
</tr>
<tr>
<td>Two-point discrimination</td>
<td>2.67 ± 1.32</td>
<td>2.65 ± 1.39</td>
<td>0.79</td>
</tr>
<tr>
<td>Heat</td>
<td>38.01 ± 4.01</td>
<td>36.98 ± 3.38</td>
<td>0.09</td>
</tr>
<tr>
<td>Cold</td>
<td>27.92 ± 2.28</td>
<td>28.64 ± 1.77</td>
<td>0.04</td>
</tr>
<tr>
<td>Heat pain</td>
<td>46.27 ± 2.41(^a)</td>
<td>45.69 ± 2.36</td>
<td>0.13</td>
</tr>
</tbody>
</table>

\(^a\)Four patients were assigned a conservative value of 50\(^o\)C as their pain threshold was not reached at this temperature.
Table IV
Significant predictors of the symptomatic condition of the burned sites

<table>
<thead>
<tr>
<th>Variable</th>
<th>Patients in category (%)</th>
<th>Symptomatic patients (%)</th>
<th>Odds ratio</th>
<th>95% confidence interval</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td></td>
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<tr>
<td>&lt; 34</td>
<td>38</td>
<td>44</td>
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<tr>
<td>35-44</td>
<td>30</td>
<td>31</td>
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<td></td>
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<tr>
<td>&gt; 45</td>
<td>32</td>
<td>25</td>
<td>0.25</td>
<td>0.08-0.84</td>
<td>0.02</td>
</tr>
<tr>
<td>Burn depth</td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Grafted</td>
<td>52</td>
<td>59</td>
<td>3.99</td>
<td>1.2-12.9</td>
<td>0.02</td>
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<tr>
<td>Non-grafted</td>
<td>48</td>
<td>41</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Pressure test (threshold)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 3.52</td>
<td>33</td>
<td>27</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.53-4.01</td>
<td>31</td>
<td>28</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.02-6.0</td>
<td>36</td>
<td>45</td>
<td>12.11</td>
<td>2.4-61.9</td>
<td>0.002</td>
</tr>
<tr>
<td>Heat pain (threshold)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 46.1</td>
<td>30</td>
<td>33</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>46.2-48.68</td>
<td>38</td>
<td>32</td>
<td>0.16</td>
<td>0.04-0.71</td>
<td>0.01</td>
</tr>
<tr>
<td>48.69-50.0</td>
<td>32</td>
<td>35</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Fig. 1. Touch-pressure thresholds. ** P < 0.0001.
Fig. 2. Two-point discrimination thresholds. **P < 0.0001.
Fig. 3. Heat thresholds. Three patients with deep burns (5% of the group) whose heat threshold was not reached at 50°C were assigned a conservative value of 50°C. * P < 0.01, ** P < 0.0001.
Fig. 4. Cold thresholds. Nine patients with deep burns (14% of the group) whose cold threshold was not reached at 0°C were assigned a conservative value of 0°C.

** P < 0.0001.
Fig. 5. Heat pain thresholds. Seventeen patients with deep burns (27% of the group) whose pain threshold was not reached at 50°C were assigned a conservative value of 50°C. The same was true for six patients with superficial burns (10% of the group). ** P < 0.0001.
References


Talbot, J.D., Duncan, G.H. and Bushnell, M.C., Effects of diffuse noxious inhibitory controls (DNICs) on the sensory-discriminative dimension of pain perception, Pain, 36 (1989) 231-238.


