Spatial and Temporal Assessment of Orofacial Somatosensory Sensitivity: A Methodological Study

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Aims: *To evaluate the sensitivity and reproducibility of a multimodal psychophysical technique for the assessment of both spatial and temporal changes in somatosensory function after an infraorbital nerve block.* ***Methods:*** *Sixteen healthy volunteers with a mean (± SD) age of 22.5 ± 3.4 years participated in 2 identical experimental sessions separated by 2 weeks. The subjects rated the perceived intensity of standardized nonpainful tactile, painful pinprick, warm, and cold stimuli applied to 25 points in 5 × 5 matrices in the infraorbital region of each side. The reproducibility of single points was tested, and a mean difference of 1.4 ± 0.5 was found. A 0-50-100 numerical rating scale (NRS) with 50 denoting "just barely painful" was used. A modified ice hockey mask with adjustable settings was developed as a template to allow stimulation of the same points in the 2 sessions. Assessment of somatosensory function was carried out before the injection (baseline) and after 30 and 60 minutes on both the anesthetized and contralateral (control) side. In addition, the applicability of the psychophysical techniques was tested in pilot experiments in 2 patients before maxillary osteotomy and 3 months afterward.* ***Results:*** *The overall analysis of mean NRS scores, number of points, and center-of-gravity coordinates for all stimulus modalities showed no significant main effects of session. Post-hoc tests for all stimulus modalities demonstrated significantly lower mean NRS scores and significantly more points (hyposensitivity) at 30 and 60 minutes postinjection compared to baseline values on the injection side (Tukey tests:* P *< .002). In the 2 maxillary osteotomy patients, the psychophysical techniques could successfully be applied, and bilateral hyposensitivity to all stimulus modalities was demonstrated at the 3-month follow-up.* ***Conclusion:*** *The present findings indicate that the psychophysical method is sufficiently reproducible, with no major differences between sessions in healthy subjects. All stimulus modalities demonstrated adequate sensitivity. Furthermore, measurement of points in 5 × 5 matrices allowed a spatial description of somatosensory sensitivity. This method may be valuable for studies on changes in somatosensory sensitivity following trauma or orthognathic surgery on the maxilla.* J OROFAC PAIN 2007;21:19–28

Key words: local anesthesia, orthognathic surgery, psychophysics, somatosensory sensitivity, trigeminal physiology

Orthognathic surgery is a well-established and widely used procedure in the correction of developmental or congenital anomalies of the maxillary physiognomy.[1–5] All techniques share the disadvantage that the utensils used during the different surgical steps may contact branches of the maxillary nerve

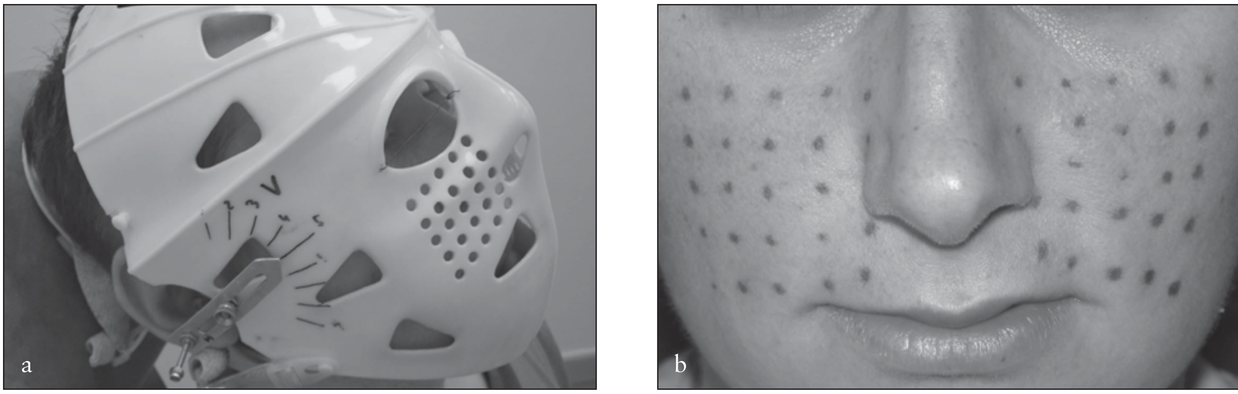

Fig 1 *(a)* Picture illustrating a test subject with the adjustable face mask. *(b)* The mask was used to identify 25 stimulation points in the infraorbital region.

and cause compression, stretching, or laceration of the nerve fibers, which may lead to both reversible and irreversible alterations in somatosensory function. Relatively few studies have, however, described and quantified the specific alterations in maxillary nerve function after orthognathic surgery.[6–11] The available studies report that between 6% and 80% of patients experience permanent changes in somatosensory function or pain after maxillary osteotomies,[6–14] which suggests a wide variation in assessment techniques and classification of somatosensory disturbances.

In order to provide a comprehensive description of changes in somatosensory function, eg, following orthognathic surgery, a battery of sensitive and reproducible psychophysical techniques is needed. Mechanoreceptive, thermoreceptive, and nociceptive function all must be considered in the assessment.[15–18] Furthermore, it has been proposed that the development of sensitive and reproducible methods for the assessment of spatial and temporal changes in somatosensory function would be valuable.[19,20] So far, few studies have attempted to systematically assess spatial aspects of somatosensory sensitivity, eg, by testing multiple sites across the border of impaired sensitivity in the affected region.[16]

The aim of this study was therefore to apply a new multimodal psychophysical technique for the assessment of spatial and temporal patterns of changes in somatosensory function in the midface. A local anesthetic block of the infraorbital nerve was used to test the sensitivity of the techniques, and the experiment was repeated in 2 sessions to assess the reproducibility. In addition, the applicability of the psychophysical techniques was tested in 2 patients scheduled for maxillary osteotomy.

Materials and Methods

Subjects

Sixteen volunteers were recruited from students at the University of Aarhus, Denmark. All subjects were healthy with no reports or signs of disturbances in facial somatosensory function and no complaints of orofacial pain or temporomandibular disorders. Six men and 10 women with a mean (± SD) age of 22.5 ± 3.4 years were randomly selected, and all participants gave their informed consent in accordance with the Helsinki declaration. The study was approved by the local ethics committee. The study was not designed or powered to examine potential sex differences in somatosensory sensitivity, and the women were not tested in a specific phase of the menstrual cycle.

Study Design

A modified ice-hockey face mask was used as a template to identify the test region in the midface. The mask was adjusted individually with reference to the pupillary line and outer ear (tragus). The mask had 25 holes (5-mm diameters) on both sides in 5 × 5 matrices according to the innervation territories of the infraorbital nerves (Fig 1a). The 25 points were marked on the skin on both sides with a pen (Fig 1b). Then the mask was removed, and somatosensory sensitivity to 4 stimulus modalities was assessed at each point on both sides as a baseline measure. This was followed by an infraorbital nerve block with 0.5 mL mepivacaine hydrochloride (30 mg/mL Scandonest) on the right side in accordance with standard guidelines.[21] The left side served as a control side. Assessment of somatosensory function was repeated on both sides after 30 and 60 minutes. To test the reproducibility of the assessments, the exact same procedure was repeated after 14 days in the same 16 subjects.

Furthermore, the reproducibility of the marking procedure of the points was tested. The ice-hockey face mask was mounted on 10 new volunteers (4 men and 6 women; ages 18 to 54 years; mean age ± SD, 32.2 ± 15.11 years), and 1 point was marked with fluorescent ink. The mask was removed and remounted after 10 minutes, and the same point was marked again with black ink. Fluorescent light was used to identify the first point, and the distance between the 2 points was measured in millimeters.

Assessment of Somatosensory Function

Four different stimulus modalities were used to assess mechanoreceptive, thermoreceptive, and nociceptive function. A response-dependent psychophysical technique[22,23] was used, ie, the subjects used a numerical rating scale (NRS) to assess the perceived intensity of the stimuli applied to skin for about 1 second. The subjects were carefully instructed in the use of the NRS, where 0 was defined as "no sensation at all," 50 was defined as "just barely painful," and 100 defined as "most pain imaginable."[24] Thus, scores < 50 characterized nonpainful sensations, and scores ≥ 50 denoted painful sensations. This NRS was chosen to encompass both nonpainful and painful sensations in 1 scale. All subjects attested that they understood the construct of this scale.

Mechanoreceptive Function. Light touch stimuli were applied with a von Frey nylon fiber corresponding to a bending force of 0.445 g (Stoelting). All 25 points on both sides were stimulated for about 1 second, and stimulation was repeated 3 times in a randomized order. The average of the 3 NRS scores was used for further analysis. About 1.5 seconds were allowed between repeated stimuli, which allowed the subject to rate the stimulus on the NRS and the investigator to write down the score.

Nociceptive Function. Pin-prick stimuli were applied with a von Frey nylon fiber corresponding to 46.54 g bending force (Stoelting), but otherwise the methodology was identical to that described for light touch stimuli.

Thermoreceptive Function. For warmth stimulation, 2 custom-made aluminum cylinders (15 mm diameter, 90 mm height) with a tapered circular end (stimulus diameter 5 mm) were used. These thermal test bodies were fitted into insulation containers to minimize the loss of temperature. A temperature-regulated water bath set at 40°C was used to standardize the temperature of the 2 test bodies. The thermal test body was taken from the water bath, inserted into the insulation container, and used for stimulation of 10 points in randomized order (about 10 seconds) before being returned to the water bath. Another thermal test body was then selected for the next stimulation. Laboratory assessment of the temperature loss had shown that the thermal test bodies kept their temperatures within 1°C for about 50 seconds. In a similar way, 2 aluminum thermal test bodies were cooled down to 5°C in a refrigerator and used for cold stimulation. The methodology was otherwise identical to that described for light touch and pinprick stimulation.

Testing of the 4 stimulus modalities lasted 25 minutes, and the entire session lasted about 2 hours. The sequence of the 4 stimulus modalities was always the same: light touch, pin-prick, warmth, and cold stimulation.

The NRS scores were analyzed in 3 steps. First, mean NRS scores from the 25 points on both sides were calculated as an overall assessment of somatosensory sensitivity. Then, the 95% confidence interval (CI) was determined, and the number of points with NRS scores below the CI (ie, hyposensitivity) was counted. The number of points above the CI (ie, hypersensitivity) was not considered in the present study. Finally, a new center-of-gravity (COG) calculation technique was used, based on the principles related to assessment of cortical mappings of motor-evoked potentials.[25] The COG coordinates (x = medial–lateral direction, y = superior–inferior direction) were defined as $\Sigma x_i * gridvalue_i / \Sigma gridvalue_i$; $\Sigma y_i * gridvalue_i / \Sigma gridvalue_i$. Instead of the amplitude of motor-evoked potentials obtained in a predefined grid (x and y coordinates),[25] the NRS scores were used as the "grid value." The weighting of the NRS scores in this way enabled the creation of a representational map of the "center" of NRS scores in quantitative terms, ie, each map in each subject generated an X and Y coordinate for each of the stimulus modalities.

Statistical Analysis

Three-way analysis of variance (ANOVA) was used to test differences in mean NRS scores, number of points, and COG coordinates with the following factors: session (2 levels), side (2 levels: local anes-

Table 1 Results of 3-way ANOVA with Session, Side, and Time as Factors

	Light touch		Pin-prick		Warmth		Cold	
	F	*P*	F	*P*	F	*P*	F	*P*
Mean NRS scores								
Session	0.11	.741	3.19	.094	4.31	.056	0.26	.617
Side	8.41	.011	188.49	<.001	33.22	<.001	33.48	<.001
Time	21.12	<.001	75.80	<.001	20.67	<.001	29.72	<.001
Side × time	6.93	<.003	114.69	<.001	36.17	<.001	25.52	<.001
No. of points								
Session	0.92	.357	0.51	.487	1.64	.219	0.08	.776
Side	10.77	.007	43.39	<.001	96.17	<.001	36.49	<.001
Time	24.23	.001	5.95	.007	27.12	<.001	46.89	<.001
Side × time	26.83	.001	16.57	<.001	45.28	<.001	26.52	<.001
COG coordinates								
Session	0.89	.361	0.41	.531	1.16	.299	1.82	.197
Side	0.84	.374	2.13	.165	2.01	.177	12.89	.002
Time	4.43	.021	3.96	.029	2.95	.067	6.35	.005
Side × time	3.23	.053	5.25	.011	1.68	.201	5.97	.006

thetic and control side), and time (3 levels: baseline, 30 minutes, 60 minutes). Tukey post-hoc tests were used to adjust for multiple comparisons. Additional ANOVA tests with sex as a between-group factor were run on the NRS scores. For all tests the significance level was set at $P < .05$. Mean (± SEM) values are reported in the text and figures.

Results

Effect of Session and Side

The overall analysis of mean NRS scores, number of points, and COG coordinates for all stimulus modalities showed no significant main effects of session (Table 1). There were significant main effects of side and side × time interactions for mean NRS scores and number of points for all stimulus modalities (Table 1). The main effect of side was due to the significant time effects (effect of local anesthesia), since all post-hoc tests with comparisons between sides at baseline revealed no significant differences for any stimulus modality for either mean NRS scores or number of points (Tukey tests; $P > .532$). The COG coordinates demonstrated significant main effect of side for cold stimulation and significant side × time interactions for pin-prick and cold stimulation (Table 1). Post-hoc comparisons of COG coordinates at baseline between sides, however, did not indicate any significant differences for any of the stimulus modalities (Tukey tests; $P > .998$).

The reproducibility of the procedure to mark the points was tested in 10 additional subjects using the modified ice-hockey mask. This trial showed that a single point could be identified with a mean difference of 1.4 ± 0.5 mm (range, 0 to 4 mm).

In summary, the mean NRS scores, number of points and COG coordinates were remarkably consistent between 2 sessions, with no side-to-side differences at baseline. The additional ANOVA tests did not indicate significant sex-related differences in NRS scores for any of the 4 modalities (ANOVAs: $F < .791$; $P > .389$).

Effect of Local Anesthesia

Injections of local anesthetics in the infraorbital region were consistently associated with significant main effects of time for all 4 stimulus modalities (Table 1).

Mean NRS Scores. Post-hoc tests for all stimulus modalities demonstrated significantly lower mean NRS scores (hyposensitivity) at 30 minutes and 60 minutes postinjection compared to baseline values on the injection side (Tukey tests: $P < .002$) (Figs 2a to 2d). On the control side, there were no significant time effects for light touch, pin-prick, or warmth stimuli (Tukey tests: $P > .397$), but mean NRS scores for cold stimulation were significantly lower at 60 minutes compared to baseline values (Tukey test: $P = .042$) (Fig 2d).

Number of Points. The number of points indicating hyposensitivity increased significantly for all stimulus modalities at 30 minutes and 60 minutes postinjection compared to baseline values on the injection side (Tukey tests: $P < .001$) (Figs 3a to 3d). On the control side, the number of points was significantly higher 60 minutes postinjection com-

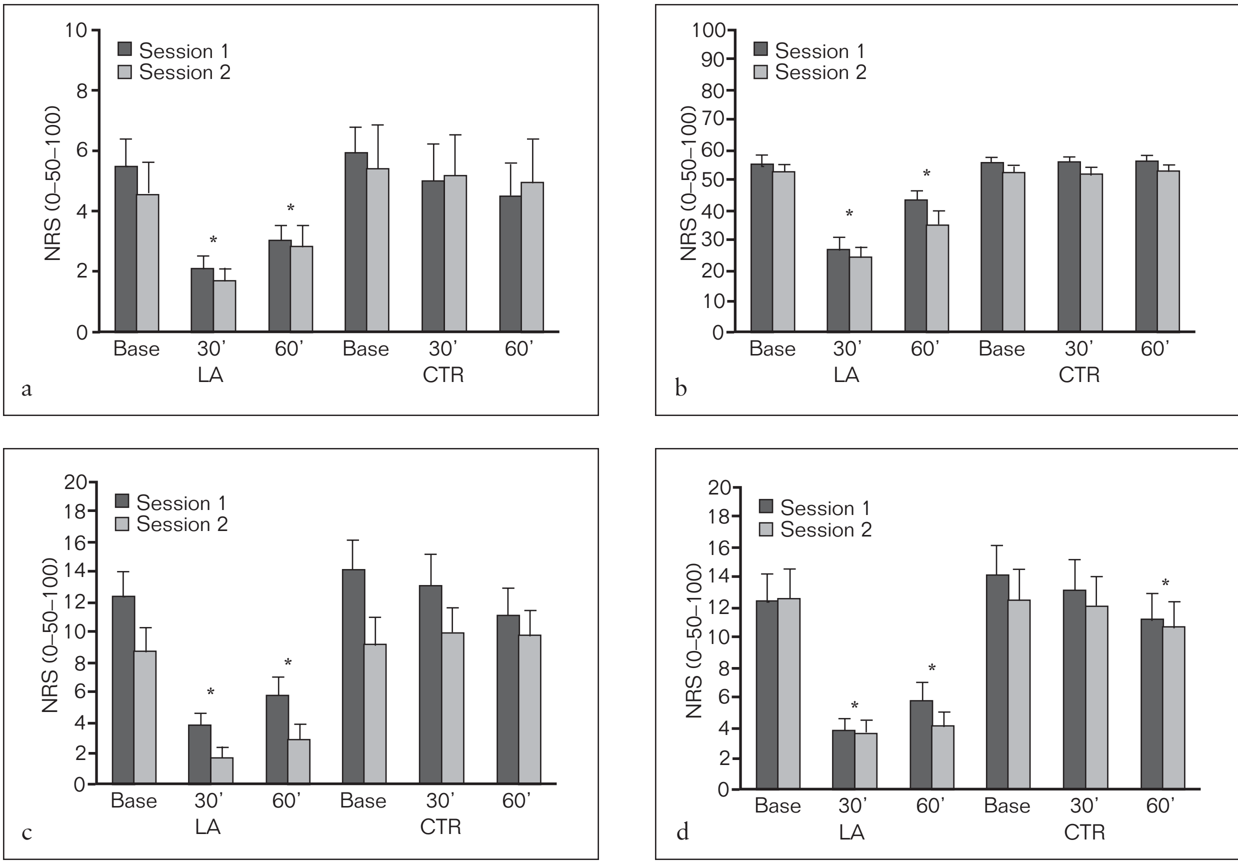

Fig 2 Mean NRS scores for *(a)* light touch, *(b)* pin-prick, *(c)* warmth, and *(d)* cold stimulation at baseline (base), 30 minutes, and 60 minutes postinjection on the local anesthetic (LA) and control (CTR) sides. Mean value ± SEM (n = 16). *Indicates significantly different from baseline values (Tukey post-hoc tests: $P < .05$).

pared to baseline values for light touch stimulation (Tukey: $P < .001$) and for cold stimulation (Tukey: $P = .047$; Figs 3a and 3d).

COG Coordinates. Post-hoc analysis of the COG coordinates also indicated subtle but significant shifts for all stimulation modalities at 30 minutes postinjection compared to baseline (Tukey tests: $P < .001$) and for warmth and cold stimulation also at 60 minutes postinjection (Tukey tests: $P < .011$; Fig 4). There were no significant time effects on the control side for the COG coordinates related to the 4 stimulation modalities (Tukey tests: $P > .997$) (data not shown).

In summary, the local anesthetic block was associated with significant decreases in mean NRS scores and significant increases in the number of grids at 30 and 60 minutes postinjection only on the injection side. On the control side, measures of somotosensory sensitivity were stable within the sessions, except that cold stimulation at 60 minutes postinjection was associated with significant changes in mean NRS scores and number of points and that light touch stimulation at 60 minutes also was associated with a significant decrease in mean NRS scores on the control side.

Effect of Maxillary Osteotomy

Two male patients (23 and 26 years old) were scheduled for orthognathic surgery that included a maxillary osteotomy.[1,2] Both were examined at baseline and showed normal and uniform sensitivity to all 4 stimulus modalities in the 5×5 grid in the infraorbital region with no differences between sides (data only shown for right side, Tables 2a and 2b, Fig 5). Three months following the maxillary osteotomies, the psychophysical examination was repeated. The second examination showed marked disturbances in perception of light touch, pin-prick, and warmth stimuli for both patients and in perception of cold stimuli as well for patient A (Tables 2a and 2b). The NRS scores and number of points consistently indicated hypoesthesia to the test stimuli on both sides of the midface (data only shown for right side). The COG measures did not at this time point indicate major changes in the involved

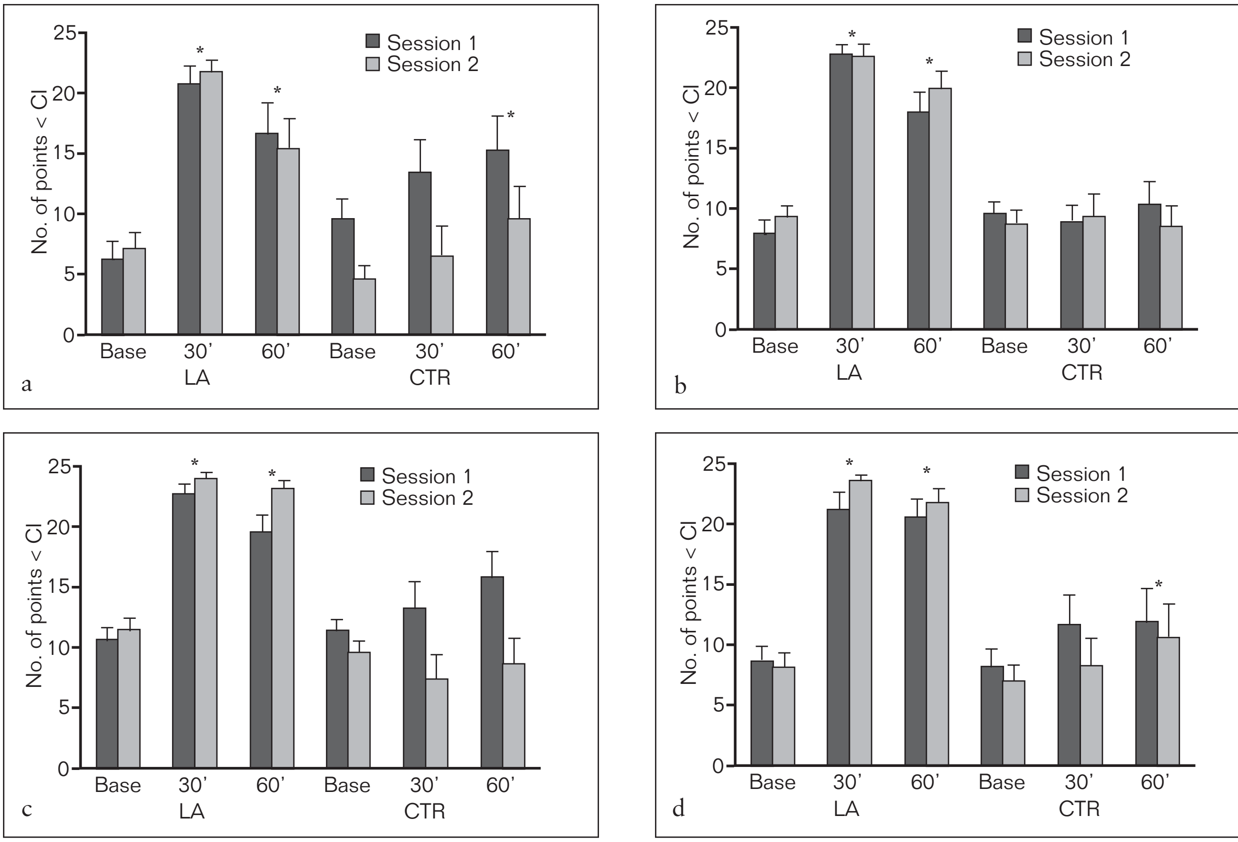

Fig 3 *(above)* Number of points indicating hyposensitivity (below 95% confidence interval) for *(a)* light touch, *(b)* pin-prick, *(c)* warmth, and *(d)* cold stimulation at baseline (base), 30 minutes, and 60 minutes postinjection on the local anesthetics (LA) side and control (CTR) sides. Mean value ± SEM (n = 16). *Indicates significantly different from baseline values (Tukey post-hoc tests: $P < .05$).

Table 2a Application of the Psychophysical Techniques to 2 Patients at Baseline and 3-Month Follow-up After Maxillary Osteotomy—NRS and Number of Points

	Patient A		Patient B	
	Baseline	Postoperative	Baseline	Postoperative
Mean NRS scores				
Light-touch	0.8	0.4	2.4	1.9
Pin-prick	50.8	39.0	52.8	42.3
Warmth	34.8	24.0	24.3	20.6
Cold	23.4	15.4	17.1	17.0
No. of points				
Light-touch	10	12	11	12
Pin-prick	11	23	5	17
Warmth	11	24	3	20
Cold	14	25	12	12

Note that the measures indicate hyposensitivity (decreased NRS scores, increased number of points).

Table 2b Application of the Psychophysical Techniques on 2 Patients at Baseline and 3-Month Follow-up After Maxillary Osteotomy—COG

	Patient A				Patient B			
	Baseline		Postoperative		Baseline		Postoperative	
	X	Y	X	Y	X	Y	X	Y
Light-touch	2.8	2.1	3.1	2.1	3.4	2.4	2.6	2.3
Pin-prick	3.0	2.8	2.9	2.9	3.0	2.8	3.0	2.8
Warmth	3.0	3.0	3.0	2.8	3.0	3.0	3.0	3.0
Cold	3.1	2.9	3.1	2.9	2.9	2.9	3.1	2.9

Note that little change in COG measures was observed.

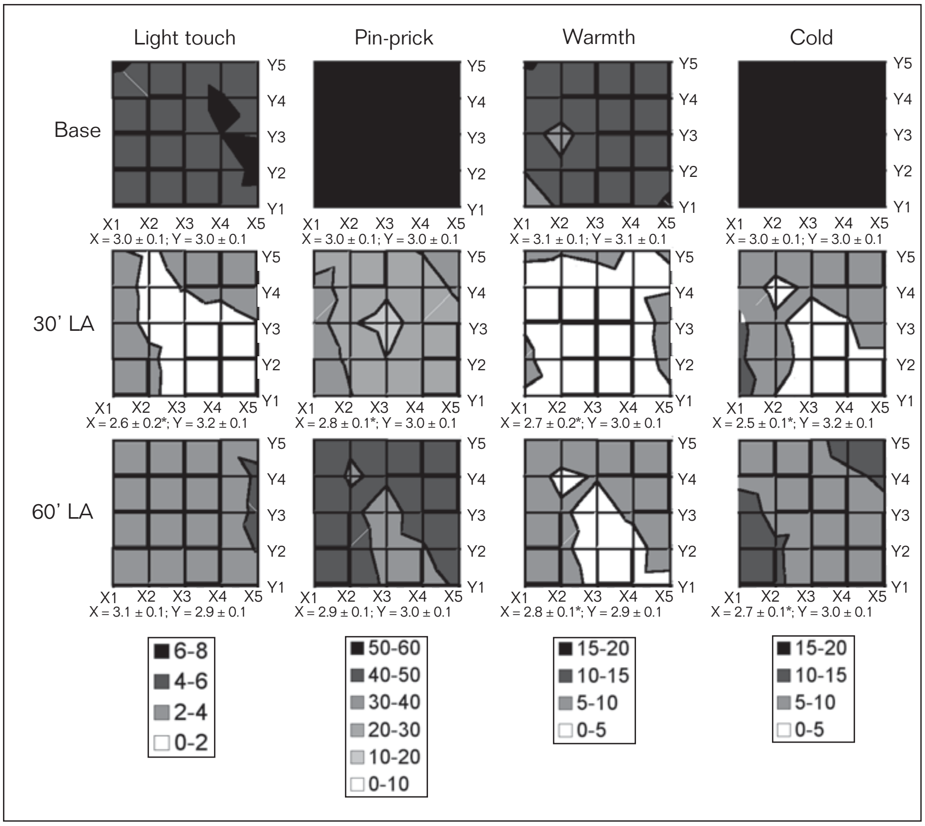

Fig 4 Gray scale 2-dimensional illustration of mean NRS scores at 25 points in the infraorbital region on the local anesthetic (LA) side at baseline (Base), 30 minutes, and 60 minutes postinjection. The COG coordinates (x, y) are shown. Mean value ± SEM (n = 16). *Indicates significantly different from baseline (Tukey post-hoc tests: $P < .05$). Data not shown from control side. Note that the spatial effect of LA is clearly demonstrated at 30 minutes, with a gradual recovery toward baseline at 60 minutes.

areas most likely because the sensitivity in the entire 5 × 5 grid was disturbed.

Discussion

Several studies have documented somatosensory changes following orthognathic surgery, but most studies have focused on the function of the inferior alveolar nerve. In the present study a new multimodal examination technique was applied which allows tracking of spatial and temporal changes in somatosensory function in the midface. The results suggested this technique provides sufficient sensitivity and reproducibility under laboratory settings and may be a useful tool in the assessment of nerve damage to the infraorbital nerve in relation to trauma or orthognathic surgery on the maxilla. Pilot experiments in 2 patients substantiated this suggestion, but further studies are required to test formally the applicability of the psychophysical techniques in clinical settings.

Methodological Considerations

A mepivacaine hydrochloride solution was used in this study to anesthetize the infraorbital nerve under the presumption that high concentrations of local anesthetics can effectively block the conduction of action potentials in different somatosensory afferent nerve fibers. An in vitro study by Huang et al concluded that there is no monotonic dependence of sensitivity to local anesthetic on afferent nerve fiber diameter but suggested that the mean susceptibility to nerve block by lidocaine may differ for fibers according to function.[26] Thus, high concentrations of local anesthesia were used to make sure that all fibers in the infraorbital nerve were blocked equally. In animal studies by Staiman and Seeman,[27] it was found that the fastest-conducting nerve fibers (45 m/s; about 18 μm diameter) required about 4 times higher blocking concentrations than the slowest nerve fibers (8 m/s; about 3 μm diameter) that they monitored. This indicates that small-diameter nerve fibers are more susceptible to local anesthetics than

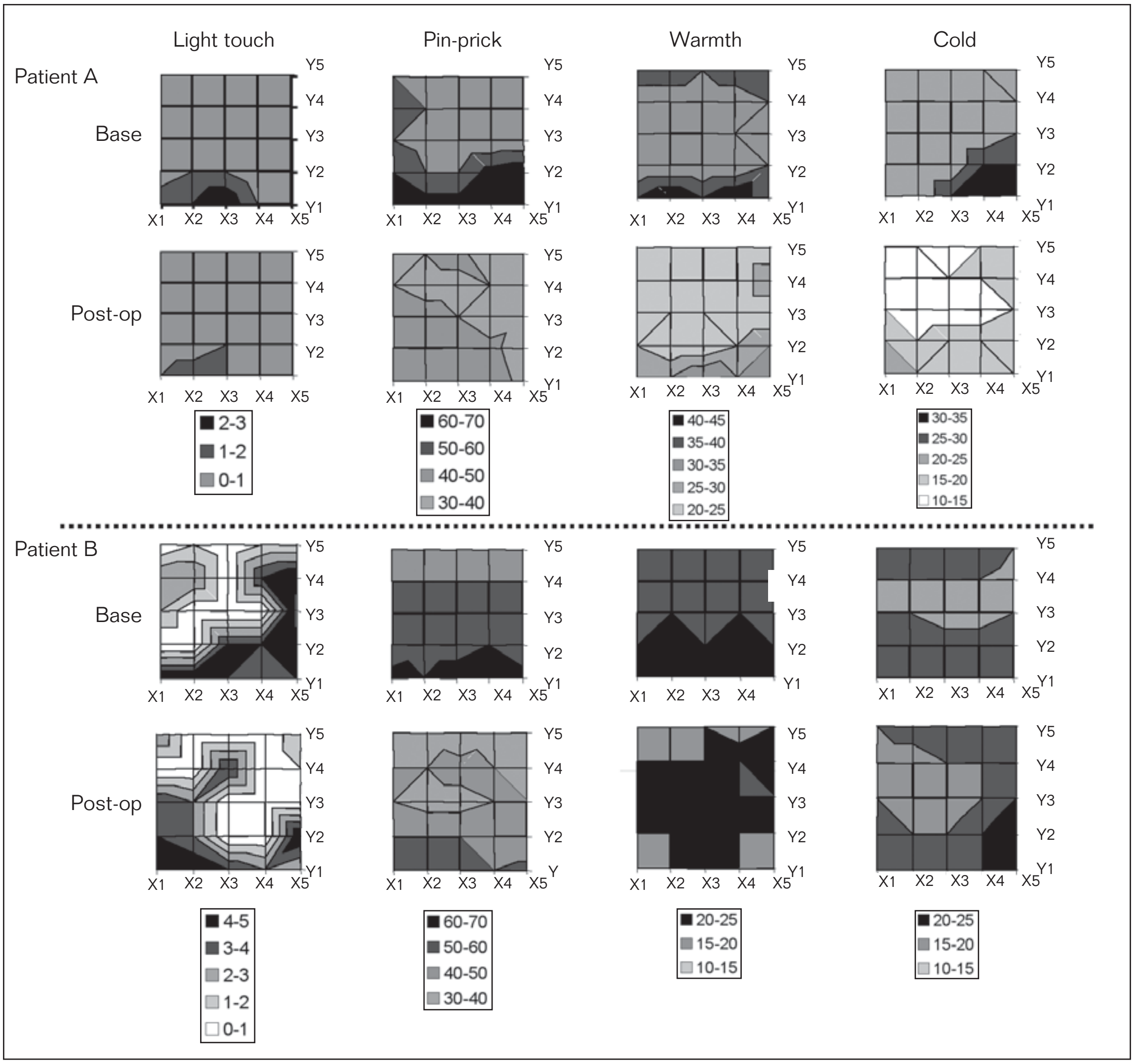

Fig 5 Gray scale 2-dimensional illustration of mean NRS scores at 25 points in the infraorbital region on the right side (left side data not shown) in 2 patients at baseline and at 3-month follow-up after maxillary osteotomies. Note the distinct hyposensitivity (lower NRS scores) in most of the points.

large-diameter fibers. This could manifest itself as a prolonged effect of local anesthetics on the level of perceived tactile and thermal stimuli caused by small residual concentrations of lidocaine remaining in the tissue. Therefore, in the present study, 3% mepivacaine concentration was used to block both high- and low-susceptibility myelinated afferent nerve fibers. This is clearly reflected in the psychophysical results that showed reduced NRS ratings for all of the 4 test modalities (Figs 2a to 2d).

The analyses of the data suggested that there was a slower recovery of cold and warm thermoreceptive function than mechanoreceptive (light touch) and nociceptive (pin-prick) function (Figs 3 and 4). This finding is consistent with results by Van Boven and Johnson,[15] which demonstrated that the temporal restitution of heat sensitivity is slower than pin-prick pain for up to 1 year after bilateral sagittal split surgery that produced injury to branches of the trigeminal nerve[15] although the recovery function may not be similar for temporary nerve blocks with local anesthetics and trauma-induced neuropathies. Our pilot experiment indicated that in some patients (eg, patient B) either no changes or a rapid (< 3 months) normalization of cold sensitivity can occur, but further studies are needed to follow the time course of sensory disturbances in the midface.

The application of an adjustable mask as a template to identify the stimulation points might have contributed to the fact that the analyses showed a good reproducibility of the 4 test modalities. The short-term reproducibility of the marked points themselves was also tested in the present study, and the findings showed that the points also were reproducible within 1 to 2 mm. Moreover, it may have been important that the distance and relationship between the 25 points was the same in the 2 experimental sessions. In several studies, authors have relied on anatomic landmarks and used a pen to define the area of investigation.[15,20,28] However, it is the opinion of the current authors that the use of a drawn area of investigation does not provide optimal precision for the definition of the spatial and temporal changes within an area of altered somatosensory function because it is difficult to reproduce the same area of investigation and to use the same points with small-diameter instruments. This method is likely to result in imprecise conclusions about temporal and spatial restitution after somatosensory alterations.

It also needs to be mentioned that there may be bias in the use of NRS, although the reproducibility of the VAS instrument has been confirmed.[29,30] It could be speculated that use of a modulus, ie, a reference value to which all subsequent stimuli were rated, may have further improved the reproducibility. There appear to be no studies available to determine which psychophysical technique is associated with the best reproducibility, but the present study clearly indicated good reproducibility and no major differences between the 2 experimental sessions. However, some unexpected significant changes were observed on the control side. Cold stimulation at 60 minutes postinjection was associated with significant changes in mean NRS scores and number of points, and light touch stimulation at 60 minutes was associated with a significant decrease in number of points on the control side. These findings could suggest a certain amount of learning and adaptation to expected temporal and spatial changes. Some authors suggest that a learning effect is 1 of the limitations of psychophysics, but the present finding clearly indicates the importance of a reference or control site. Furthermore, the present study did not indicate major sex-related differences in the sensitivity to light touch, pinprick, warmth or cold stimuli in the infraorbital region, but further studies are needed to test this because the present study used a paired design, with the subjects as their own controls, and was therefore not powered specifically to examine between-group differences.

Finally, the analyses of the 60-minute postinjection values indicated that the effect of the local anesthetic block had not completely disappeared, although the typical clinical effect is reported to be 20 to 40 minutes after onset (4 to 8 minutes). The number of postinjection assessments could have been increased to investigate time-course relationships in detail; however, this was not the primary aim in the present study, which simply aimed to document changes over time (temporal aspects).

Sensitivity of Psychophysical Assessment

In the present study, 4 different stimulus modalities were used to ensure activation of different somatosensory afferent nerve fibers. The tactile nonpainful stimulus evokes action potentials in Aβ fibers, and the painful pin-prick stimulus evokes activity in high-threshold mechanoreceptive Aδ fibers.[14,16,31] For evaluation of trigeminal small nerve fiber function after the nerve block (Aδ and C), thermal heat and cold aluminum bodies were used.[18]

Although local anesthesia is not directly comparable to different levels of nerve injuries, and the present study did not address the issue of hypersensitivity, it seems reasonable to suggest that the applied method had a sufficient sensitivity to detect changes in somatosensory function following a well-characterized intervention with local anesthesia. The pilot experiments in 2 patients following maxillary osteotomies also clearly indicated hyposensitivity of the midface and demonstrated the feasibility of the present psychophysical techniques. Further studies in larger patient groups are needed to describe the time course and spatial recovery of somatosensory function in maxillary osteotomy patients.

In conclusion, it is suggested that the present multimodal psychophysical technique will be of value in prospective, longitudinal studies of patients with alteration in somatosensory function following trauma or maxillofacial surgery in the midface. This is based on the finding of good sensitivity and reproducibility for the 4 test modalities in healthy subjects as well as promising results from pilot experiments in patients who had undergone maxillary osteotomies.

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