“Eyeball test” of thermographic patterns for predicting a successful lateral infraclavicular block

L'évaluation ‘à coup d’œil’ des motifs thermographiques pour prédire la réussite d’un bloc infraclaviculaire latéral

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Abstract

Purpose Increased distal skin temperature can be used to predict the success of lateral infraclavicular (LIC) block. We hypothesized that an “eyeball test” of specific infrared thermographic patterns after LIC block could be used to determine block success.

Methods In this observational study, five observers trained in four distinct thermographic patterns independently evaluated thermographic images of the hands of 40 patients at baseline and at one-minute intervals for 30 min after a LIC block. Sensitivity, specificity, and predictive values of a positive and a negative test were estimated to evaluate the validity of specific thermographic patterns for predicting a successful block. Sensory and motor block of the musculocutaneous, radial, ulnar, and median nerves defined block success. Fleiss' kappa statistics of multiple interobserver agreements were used to evaluate reliability.

Results As a diagnostic test, the defined specific thermographic patterns of the hand predicted a successful block with increasing accuracy over the 30-min observation period. Block success was predicted with a sensitivity of 92.4% (95% confidence interval [CI], 86.8 to 96.2) and with a specificity of 84.0% (95% CI, 70.3 to 92.4) at min 30. The Fleiss' kappa for the five observers was 0.87 (95% CI, 0.77 to 0.96).

Conclusion We conclude that visual evaluation by an eyeball test of specific thermographic patterns of the blocked hands may be useful as a valid and reliable diagnostic test for predicting a successful LIC block.

Résumé

Objectif Une température accrue de la peau distale peut être utilisée pour prédire la réussite d'un bloc infraclaviculaire latéral (ICL). Nous avons émis l'hypothèse qu'un ‘test à coup d’œil’, c'est-à-dire l'observation subjective, de motifs thermographiques infrarouge spécifiques apparaissant après un bloc ICL pourrait être utilisé pour prédire la réussite du bloc.

Méthode Dans cette étude observationnelle, cinq observateurs formés pour quatre relevés thermographiques distincts ont évalué de manière indépendante les images thermographiques des mains de 40 patients avant l'intervention, puis à des intervalles d'une minute pendant 30 minutes après l'installation d'un bloc ICL. La sensibilité, la spécificité et les valeurs prédictives d'un test positif et négatif ont été estimées afin d'évaluer la validité de motifs thermographiques spécifiques pour prédire la réussite d'un bloc. Le bloc était considéré comme réussi s'il y avait bloc sensitif et moteur des nerfs musculocutané, radial, cubital et médian. La mesure statistique du Kappa de Fleiss mesurant les concordances multiples inter-observateur a été utilisée afin d'évaluer la fiabilité.

Résultats En tant que test diagnostique, les relevés thermographiques spécifiques définis de la main ont prédit la réussite du bloc avec une précision croissante au cours de la période d'observation de 30 minutes. La réussite du bloc a été prédite avec une sensibilité de 92,4 % (intervalle de confiance [IC] 95 %, 86,8 à 96,2) et une spécificité de 84,0 % (IC 95 %, 70,3 à 92,4) à la minute 30. Le Kappa de Fleiss

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était de 0,87 (IC 95 %, 0,77 à 0,96) pour les cinq observateurs.

Conclusion Nous concluons que l'évaluation subjective 'à coup d'œil' de motifs thermographiques spécifiques des mains sous un bloc peut être utile comme test diagnostique valide et fiable pour prédire la réussite d'un bloc ILC.

Brachial plexus blocks are widely used for upper limb regional anesthesia. Presently, determination of block success is predominantly based on subjective methods, e.g., testing for cold sensation, pinprick, muscle force, etc.^{1,2} These examinations can be time consuming and require an examiner with detailed anatomical knowledge as well as a cooperative patient.

Previous studies show that brachial plexus blocks at different levels lead to increased skin temperature (Ts) in the hand and forearm.³⁻⁵ This most likely occurs when sympathetic nerve fibres within the brachial plexus are blocked causing the arteriovenous anastomoses at the fingertips to open.^{6,7}

Asghar *et al.* studied a cohort of patients who received a lateral infraclavicular (LIC) block in a standardized setting.^{8,9} The authors showed that the use of thermography or sense by touch to measure the difference in temperature between a blocked and a non-blocked hand was valid for predicting block success. In addition, they observed four distinct thermographic patterns representing block success, partial failure, or complete block failure following a LIC block. We hypothesized that an "eyeball test" of pre-defined thermographic patterns may be used to predict block success early and with high validity and reliability.

The aim of our study was twofold: 1) to evaluate whether visual evaluation with an eyeball test of the thermographic patterns after a LIC block could be used as a diagnostic test for block success and 2) to evaluate the reliability of this diagnostic test by determining the interobserver agreement of the visual evaluation of the thermographic patterns.

Methods

We conducted this observational study after receiving approval of the study protocol from the Committees on Biomedical Research Ethics of the Capital Region of Denmark (H-C-2008-047, May 2008; amendment approved December 2011). The study protocol and prospective assessments and interventions presented in this study were based on data previously described and published by Asghar *et al.*^{8,9}

After we obtained written informed consent, adult patients who were American Society of Anesthesiologists physical status I-III and scheduled for hand and/or forearm surgery were enrolled in the study. Before performing each block, both of the patient's hands were acclimatized for at least ten minutes in the recovery ward with 5°C cold packs. This was done in an attempt to standardize measurements and to augment the magnitude of a potential temperature difference between the hands once the LIC block was introduced. The patient's hands remained on the cold packs throughout the study. The attending anesthesiologist performed an ultrasound-guided single-shot LIC block with 20 mL ropivacaine 7.5 mg·mL⁻¹.

Clinical block assessment

Trained blinded nurses evaluated the block after 30 min. The block was categorized as successful when all four (musculocutaneous, radial, median, and ulnar) nerves were affected in both sensory and motor function. In contrast, the block was categorized as failed when any part of the tested sensory or motor function was still intact. The nerve block was tested as follows: Cold sensation was assessed by applying a cooled glass vial (5°C) over predefined skin areas innervated by each of the four nerves. The sensation was recorded as either cold or not cold. Motor function was tested by the ability to voluntarily 1) flex the elbow joint (musculocutaneous nerve), 2) extend the wrist (radial nerve), 3) oppose the first digit (median nerve), and 4) flex the distal interphalangeal joint of the fifth digit (ulnar nerve). Motor block of each nerve was recorded as either normal or compromised compared with the non-blocked arm.⁹

Thermography

A newly calibrated Thermovision A320 thermographic camera (FLIR Systems, Danderyd, Sweden; Emissive factor of 0.98) was used to obtain thermographic images of both hands at baseline and at one-minute intervals for 30 min after performing the block. The camera was fixed approximately 1.3 m above the patient's hands.⁸ From the data in the study by Asghar *et al.*, we established that a temperature scale adjustment to 30-37°C on the thermographic images would give good visual discrimination between failed and successful blocks.

The diagnostic test

Following a LIC block, observers used an eyeball test to evaluate block success as regards the thermographic images of the patients' hands. The thermographic evaluation was based on the following four distinct

thermographic patterns observed previously⁸: A) successful block with increase in Ts in all five fingers and the hand; B) partial block failure with only ulnar increase in Ts (fourth and fifth finger and ulnar side of the hand); C) partial block failure with only radial increase in Ts (first, second, third finger, and radial side of the hand); and D) complete block failure with no increase in Ts. The four thermographic patterns are illustrated in Fig. 1.

Five independent observers were trained to classify thermographic images in accordance with Fig. 1. Following training, they evaluated the thermographic images and classified them as representing A) successful block, B) partial failure with only ulnar increase in Ts, C) partial failure with only radial increase in Ts, or D) complete failure of the block. Before the evaluations, all images were randomized according to patient identification and time of recording. Thus, the observers were blinded to the clinical block assessment, judgement of the other evaluators, time of the recorded images, and patient identification. There were 31 thermographic images (baseline + images at one-minute intervals for 30 min) for each patient. In one patient, the images from the 19th–30th min were lost. Thus, each of the five observers evaluated and classified 1,228 thermographic images, resulting in a total of 6,140 evaluations (Fig. 2).

Statistical methods

We categorized all partially failed blocks as failed blocks. In this way, the diagnostic test was dichotomized to either successful or failed block. The diagnostic accuracy was evaluated according to the sensitivity, specificity, positive and negative predictive values, and positive and negative likelihood ratios for each minute from baseline until 30 min after the block. The estimates of the diagnostic tests were calculated in two steps. 1) Each patient was evaluated individually by the five observers. We calculated the estimates of the diagnostic tests for each observer. 2) Afterwards, we pooled the estimates from each observer into summary estimates. Likewise, standard errors and 95% confidence intervals (CIs) of pooled estimates were calculated.^{10,11} Each of the five observers evaluated 40 patients. This was a convenience sample since the data were collected prior to initiating the study and a power calculation was not conducted. Likewise, the reliability of the five different evaluators was assessed for each minute. The Fleiss' kappa coefficient was used to assess the interobserver consistency. All estimates were presented with 95% CI. *P* values < 0.05 were considered statistically significant. We used SPSS® version 22.0.0.0 (SPSS Statistics; Chicago, IL, USA) software package, and Meta-DiSc version 1.4 (Zamora J, Muriels A, Abaira V,

Fig. 1 Infrared thermographic imaging of the dorsal side of the hands following a lateral infraclavicular block. Four specific thermographic patterns are illustrated: (A) Successful block with temperature increase in all five fingers and the hand; (B) Partial block failure with ulnar temperature increase (fourth and fifth finger and ulnar side of the hand); (C) Partial block failure with radial temperature increase (first, second, third finger, and radial side of the hand); (D) Complete block failure with no increase in temperature

Fig. 2 Flowchart illustrating the retrieval of thermographic images for assessment

Table 1 The diagnostic accuracy of the five individual observers at min 30

	Diagnostic accuracy				Sensitivity	
	TP (Number of patients)	FP	FN	TN	TP/ (TP + FN)	95% Confidence Interval
Observer 1	27	2	2	8	93.1%	77.2 to 99.2
Observer 2	26	1	3	9	89.7%	72.6 to 97.8
Observer 3	28	2	1	8	96.6%	82.2 to 99.9
Observer 4	26	2	3	8	89.7%	72.6 to 97.8
Observer 5	27	1	2	9	93.1%	77.2 to 99.2
Pooled sensitivity					92.4%	86.8 to 96.2

Sensitivity of the diagnostic test performed by each of the five observers and pooled sensitivity with corresponding 95% confidence interval
 FN = false negative; FP = false positive; TN = true negative; TP = true positive

Madrid, Spain) was used for pooling estimates with corresponding 95% CIs.

Results

Forty-five patients were included for assessment⁸; however, five patients did not complete the study, as one patient had a toxic reaction, two patients were unable to keep their hands still, and two patients had poor-quality thermographic images. Thus, in the present study, we evaluated data from 40 patients. Thirty of the 40 (75%) blocks were successfully performed (95% CI, 62 to 88). With regards to the eyeball tests of the thermographic patterns of the hands, the accuracy of predicting a successful block increased over the 30-min observation period. Table 1 presents the diagnostic accuracy of the five

individual observers at min 30. Further, as an example, the sensitivity of the individual observers and the corresponding pooled sensitivity, including the pooled 95% CI, are presented. Table 2 presents all pooled estimates of diagnostic accuracy 30 min after the block. Here, the observers were able to predict block outcome with a sensitivity of 92.4% (95% CI, 86.8 to 96.2) and a specificity of 84.0% (95% CI, 70.3 to 92.4). Fig. 3 illustrates the development of diagnostic accuracy over time at each minute until min 30. *Post hoc*, it seems that the sensitivity reaches a plateau after 18 min (Table 3). At this time point, the observers were able to predict a successful block with a positive predictive value (PPV) of 95.4% (95% CI, 90 to 98), and the sensitivity was increased to 82.7% (95% CI, 75 to 88).

The interobserver agreement for each minute of the test was high throughout the observational period, with an

Table 2 The overall diagnostic accuracy after 30 min

	Pooled estimates	Pooled 95% confidence intervals
Sensitivity	92.4%	(86.8 to 96.2)
Specificity	84.0%	(70.3 to 92.4)
Predictive value of a positive test	94.4%	(88.8 to 97.4)
Predictive value of a negative test	79.2%	(65.5 to 88.7)
Positive likelihood ratio	5.8	(3.1 to 10.9)
Negative likelihood ratio	0.09	(0.05 to 0.16)

Fig. 3 Change in diagnostic precision over time using visual evaluation of specific thermographic patterns after a lateral infraclavicular block

increasing tendency over time. Just a few minutes after the block, the Fleiss' kappa value showed substantial agreement 0.62 (95% CI, 0.53 to 0.73) and increased over time to 0.87 (95% CI, 0.77 to 0.96; almost perfect agreement) after 30 min (Fig. 4). All 30 successful blocks (as defined in our assessment) were “truly” successful, i.e., no need for supplementary analgesics during the operation or postoperatively. All ten patients with partially or fully failed blocks (as defined in our assessment) received a

supplemental axillary block. It was therefore not possible to test if they were “truly” failed during surgery.

Discussion

The main purpose of this study was to investigate whether an eyeball test of the thermographic pattern following a LIC block may predict block success with high validity and reliability.

After 30 min, the observers predicted a successful block with a sensitivity of 92.4% and a predictive value of a positive test of 94.4%. The Fleiss kappa value for the five observers was 0.87 after 30 min. These results indicate that the test was valid and reliable. In addition, 18 min after performing the block, the observers were able to predict a successful block with high positive predictive value and sensitivity, suggesting that the test may be clinically useful before 20 min after performing the block.

The use of temperature measurements was previously shown to be a valid predictor of block success in this group of 40 patients. Lateral infraclavicular block success has been tested by measuring Ts, by blinded observers' touch of hands, and now by simple evaluation of thermographic patterns, all with high diagnostic accuracy.^{8,9} Nevertheless, we found an even better interobserver agreement (kappa value = 0.87) in this study, suggesting that visual evaluation of the thermographic pattern may be a less laborious method to evaluate block success in everyday clinical practice.

Table 3 The overall diagnostic accuracy after 18 min

	Pooled estimates	Pooled 95% confidence intervals
Sensitivity	82.7%	(75.4 to 88.2%)
Specificity	88.0%	(75.0 to 95.0%)
Predictive value of a positive test	95.4%	(89.8 to 98.1%)
Predictive value of a negative test	62.9%	(50.4 to 73.9%)
Positive likelihood ratio	6.9	(3.2 to 14.6)
Negative likelihood ratio	0.19	(0.1 to 0.3)

Fig. 4 Fleiss' kappa values (κ) of interobserver agreement of the evaluation of thermographic patterns at each minute following a lateral infraclavicular block

In this study, each evaluator classified 1,228 randomly ordered images. Thus, the evaluator had no information on the dynamic evolvement of the thermographic pattern over time. Information on the dynamic changes may improve the test characteristics; however, this remains to be questioned.

The thermographic patterns of the patient with twelve missing images (19th–30th min) were examined afterwards. By the 18th min a clear full thermographic pattern had evolved in this patient. Therefore, in our view, the missing images did not have any significant influence on the results or the interpretation of the results.

Determination of block success is ambiguous. In this study, we defined block success by the affection of sensory and motor function of the musculocutaneous, radial, median, and ulnar nerves. This may have been too rigorous, since motor affection does not always follow a sensory LIC block. In addition, surgery can be performed with a partially failed block if it is limited to the blocked side of the hand. It is uncertain what impact this may have had on the study.

The thermographic patterns used to predict block success are based on a sympathetic nerve block of the arm. It is likely that opening the arteriovenous anastomoses at the fingertips plays a dominant role.⁷ Previous studies have shown that a selective block of the ulnar and median nerve leads to increased Ts, whereas a selective block of the radial and musculocutaneous nerve does not increase Ts.¹² Since the medial cord of the brachial plexus provides nerve fibres to both the median and the ulnar nerve, one may argue that a selective block of the medial cord would produce a thermographic pattern that would wrongly predict a successful LIC block, i.e., increased Ts of the whole hand. This argument also implies that the sympathetic inflow to the arm should travel only via the

medial cord. Nevertheless, it is difficult to explain the thermographic patterns of partially failed LIC and interscalene brachial plexus blocks¹³ if the sympathetic inflow is confined to the medial cord. For the LIC block, this would imply a highly reproducible partial block of the medial cord, which seems unlikely. The anatomy of the sympathetic inflow to the arm is not known in detail and is probably subject to variations at different levels. If one assumes that the sympathetic inflow stems from sympathetic nerve fibres in all three cords (or at least the lateral and medial cords), then it is easier to explain the thermographic patterns of a partially failed LIC block. This would also explain why an increase in Ts of the whole hand is predictive of a successful LIC block and not just a successful median and ulnar nerve block.

Our results differ slightly from the original assessment on the same patients.⁸ In the original assessment, only temperature differences were used as a diagnostic test, and therefore, it was a pure quantitative test. In contrast, the current eyeball test is a qualitative assessment. The differences between the two assessments also depend on the different levels and ranges of temperature scales used for the thermographic imaging. Further, the diagnostic accuracy of the temperature differences in the original assessment strongly depends on the choice of temperature cut-off used to dichotomize the continuous temperature scale.

The major limitation of our study was that it may result in circular arguments when a diagnostic test is developed and validated in the same population. Therefore, the diagnostic test has to be re-validated in future prospective assessments. Further, the lack of precision of sensitivity and specificity may be due to our use of a convenience sample for our study population rather than a sample scaled by a power calculation. Another limitation was the use of

cold packs to standardize Ts measurements. By doing so, the thermographic pattern may have been more clearly presented compared with no cooling, thereby improving the test characteristics.

There are several essential elements to consider before the thermographic eyeball test can be implemented into clinical practice. The eyeball test must be valid with a handy camera and not just with the large and bulky camera used in our study. This high-end camera was fixed at a certain distance from the patient's hands; therefore, patient movement and image blur were limiting factors in a few patients. Nevertheless, the general advancement in thermographic cameras is fast, and for a modest amount of money, the above-mentioned limiting factors may be overcome by purchasing a handheld high-quality camera with an even better thermographic resolution.

Additionally, for the eye-ball test to be valid, it must work without having to cool the patients' hands prior to performing the block.

Our results show that interpretation of thermographic images may be an equivalent alternative to the assessment of clinical block presently used as the gold standard for testing block success after 30 min. In addition, our results indicate that the thermographic images obtained after 18 min may predict clinical block success at 30 min. Our current study was not designed to assess whether the block was clinically sufficient as of 18 min. To answer this question, a different experimental setup is required where the patient's hands are examined for successful blockade simultaneously as thermographic images are taken. In clinical practice, test results would be strengthened if the eyeball test results were in accordance with the actual block success at the time the patient's hand is photographed. This would facilitate quick release of patients with successful blocks for surgery.

The negative predictive value slowly increases over time as seen in Fig. 3. Nevertheless, the external validity of our positive and negative predictive tests strongly depends on the success rate. Several studies have reported success rates ranging from 78–96%.^{14–16} Thus, based on our findings, it may be questionable to strive for early identification of patients whose block is unlikely to be successful, as it strongly depends on the success rate in the specific patient population. In our study, we used a clinical assessment as a gold standard to decide if the block was successful. Ideally, the eyeball test should assess whether the block was sufficient for surgery. In a future study, the clinical examination (gold standard) should be compared with the thermographic evaluation for predicting a successful block sufficient for surgery. Hence, even though the eyeball test is easy to perform, several relevant questions must be answered before the test can be fully adopted into clinical practice.

We conclude that a qualitative visual evaluation of thermographic patterns may be a simple diagnostic test to predict LIC block success with high reliability and validity. The test should be further evaluated in a clinical setting without cooling to determine whether it can be used as a standalone test for the assessment of LIC block success.

Conflicts of interests None declared.

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