



# Long-term Patency of Primary Arterial Repair and the Modified Cold Intolerance Symptom Severity Questionnaire

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**Background:** The goal of this study was to assess the long-term arterial patency of repaired arteries in the upper extremity and any morbidity resulting from the subsequent occlusion of these vessels. Concurrently, a new questionnaire, the modified Cold Intolerance Symptom Severity (mod CISS) questionnaire, was developed to allow for better assessment of cold intolerance.

**Methods:** Thirteen patients who had undergone repair of the radial (4 patients), ulnar (6 patients), brachial (1 patient), digital (1), and an undefined lower arm artery (1) were examined using questionnaires, physical examination, and high-resolution ultrasound.

**Results:** Outcome measures that were statistically significantly worse in the group of patients who presented with nerve injuries included cold intolerance symptoms, Disabilities of the Arm, Shoulder, and Hand score, Michigan Hand Questionnaire, and grip strength (middle setting on dynamometer). The results from the mod CISS correlated with high statistical significance with the results of the CISS score for the injured hand. Of note, wrist extension was significantly better with patent arteries.

**Conclusions:** Sixty-seven percent of arterial repairs remained patent at 6 years (mean) follow-up. The presence of nerve injury has a higher impact on the outcome metrics assessed in this study than arterial patency. Our modification of the CISS score enhances its utility as a survey of cold intolerance. (*Plast Reconstr Surg Glob Open* 2015;3:e551; doi: 10.1097/GOX.0000000000000522; Published online 5 November 2015.)

Vascular injuries to the upper extremities represent nearly half of all vascular injuries in civilians.<sup>1</sup> Multiple management approaches have been described in the literature as how to best treat these patients.<sup>2-5</sup> Long-term patency rates after primary repair of upper extremity arteries are difficult to assess because of the many variables

that come with these injuries. Some of these variables include patient comorbidities, mechanism of injury, concomitant use of vein graft, and size of injured vessel. Although the current literature reports long-term patency rates ranging from 46% to 84%, the consequences of repair occlusion are not well understood.<sup>2,5-17</sup>

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Received for publication May 15, 2015; accepted September 1, 2015.

The study is registered on ClinicalTrials.gov and the registration number/identifier is NCT02228057.

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DOI: 10.1097/GOX.0000000000000522

We set out to determine the proportion of our patients who maintained patency of their upper limb arterial repairs at a minimum of 6 months after repair. Using multiple questionnaires and a physical assessment, we examined strength, range of motion, pain, sensation, and cold intolerance of the injured limb. We introduce a new questionnaire, the modified Cold Intolerance Symptom Severity questionnaire (mod CISS) score, to better help document cold intolerance in our patients.

## MATERIALS AND METHODS

Approximately 190 patients were identified by searching in the pooled patient database from the Departments of Plastic and Orthopedic Surgery. Patients with repaired blood vessels in the upper extremity (CPT 35206) were sent a letter to participate in the study. Interested patients were screened telephonically to verify age (>18 years) and postoperation duration (>6 months). Approximately 30 patients could not be contacted (incorrect listed addresses). Four patients showed interest but never came to the scheduled visit. The majority never contacted the primary research coordinator.

From August 2014 to January 2015, 13 patients participated, after obtaining written consent, in this cross-sectional study. Every patient filled out 4 questionnaires: the Michigan Hand Questionnaire (MHQ),<sup>18</sup> the CISS questionnaire,<sup>19</sup> the Disabilities of the Arm, Shoulder, and Hand (DASH) questionnaire,<sup>20</sup> and the mod CISS questionnaire. The visual analogue scale was used to assess pain. Each patient underwent a physical assessment of both hands consisting of strength measurements using a dynamometer and a pinch strength meter. Range of motion of the wrist and 2-point discrimination of the thumb, index, and small finger were assessed as well. At the end of the visit, each patient underwent a high-resolution ultrasound imaging of the forearm arteries bilaterally using a commercial ultrasound scanner (Vevo 2100, VisualSonics Inc., Canada) (Fig. 1). All assessments were performed by the same blinded physician.

Our protocol was reviewed and approved by our institutes' institutional review board.

**Disclosure:** *The authors have no financial interest to declare in relation to the content of this article. The Article Processing Charge was paid for by the authors.*

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The mod CISS is a new questionnaire based on the original CISS. Because we developed this questionnaire during the course of the study, only the last 8 patients filled out the mod CISS. The new questionnaire has been included. (See Fig., Supplemental Digital Content 1, which displays the modified Cold Intolerance Symptom Severity Questionnaire, <http://links.lww.com/PRSGO/A149>.) Differences with the original CISS are underlined. Question number 1 helps researchers determine if use of the questionnaire is indicated.

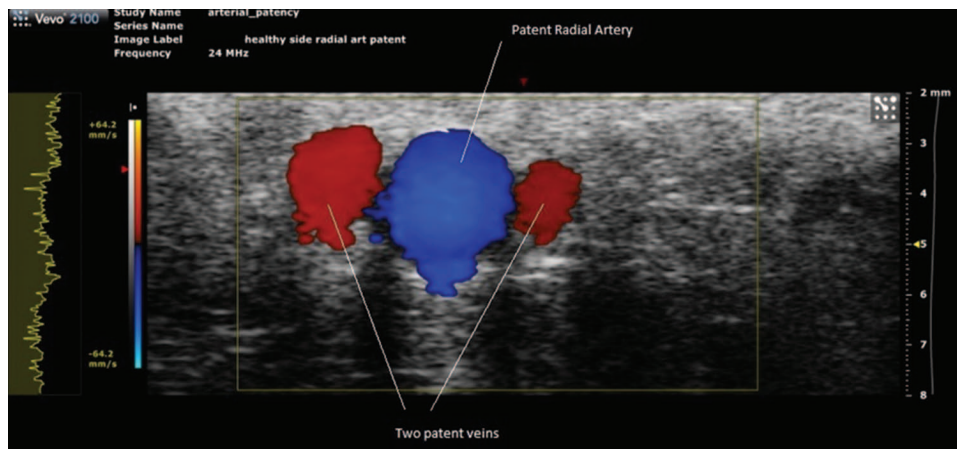
The third question was refined to increase applicability, "How often do you experience these symptoms when you are in cold weather or are directly exposed to cold items?" Some of our patients reported cold induced symptoms when holding cold items but not during cold weather.

In the original CISS questionnaire, if the answer for question number 5 was "other," a 10-point increase of the score followed. We believe this was not always warranted. For example, one patient reported that in cold weather he carries a warm drink in his hand. In our opinion, this action represents a much lower life-impact than someone who wears gloves all the time or actively avoids cold weather. We have removed the "other" response and instead match the patient's response to the closest-related response listed on the CISS survey. Because of the loss of the "other" response, the highest score obtainable from the mod CISS is 98.

For questions 6 and 7, a specific description of the meaning of extreme values was outlined. This led to a better standardization of the questions and helped the patient better understand what was being asked. Timeframes were added to the responses in question 6 to improve patient understanding of the question.

For the statistical analysis, the data gathered from a patient with crush injury were omitted, as we believe this situation varies from that of the other patients. His injury was a mid-hand amputation with damage to the digital arteries, whereas the other patients suffered simple lacerations of the brachial, ulnar, or radial arteries. The data of the patient with a brachial artery laceration were included in the analysis. Part of the MHQ was not filled out by 1 patient. Subsequently, the data for this patient, when analyzing the results of this questionnaire, were not available. The data of 1 patient who had undergone arthrodesis of the wrist, many years after the vascular injury, were not included in the analysis of range of motion of the wrist. For certain parameters described in the results section, only 12 patients are mentioned, as the latter patient failed to provide his operation report.

Complications were defined as postoperative hematoma, seroma, necrosis, infection, or anything requiring a second operation within days after the initial operation.



**Fig. 1.** Example of high-resolution ultrasound assessment of vessel patency using color Doppler.

SPSS 17.0 (SPSS Inc., Chicago, Ill.) was used for statistical analysis. Based on tests for normality (Shapiro–Wilk test) and equal variances (Levene’s test), a combination of student *t* tests, Mann–Whitney *U* tests and Kolmogorov–Smirnov tests were used to analyze the data assuring that all assumptions of each test were met. Grip strength was corrected for dominance by decreasing the result of the dominant hand by 6.6%.<sup>11</sup> The difference in grip strength, pinch strength, and the range of motion values were all normalized by subtracting the injured value from the healthy value followed by division by the healthy value. The correlation between the CISS and the mod CISS was assessed with the Pearson correlation coefficient.

Results are reported as (mean ± SD). Statistical significance was assumed when *P* value is less than or equal to 0.05. (See Fig., Supplemental Digital Content 1, which displays the modified Cold Intolerance Symptom Severity Questionnaire, <http://links.lww.com/PRSGO/A149>).

## RESULTS

Nine males and 4 females participated in the study. The mean age of the patient at the time of assessment was  $43.4 \pm 17.6$  years. The mean age of the patient at the time of the accident was  $37.5 \pm 18.1$  years. The mean time between the accident and the assessment was  $5.9 \pm 4.5$  years.

Four patients sustained damage to the radial artery, 6 injured the ulnar artery, 1 injured 2 digital arteries, 1 sustained an injury to either the radial or the ulnar artery, and 1 injured the brachial artery. All repaired radial arteries and the repaired brachial artery were patent at follow-up. Three out of 6 repaired ulnar arteries were patent (50%). The digital arteries were not assessed. The combined arterial patency rate for the limb arteries, excluding the patient with digital arteries injuries, was 67%. Eleven arteries were repaired directly. The brachial artery was repaired by

interposition of a saphenous vein graft. The details of the 13th patient’s repair were unavailable.

Seven patients reported still experiencing pain in the injured hand (53.8%), and the level of pain was not statistically significantly different between the patent and nonpatent group ( $P = 0.55$ ). Seven patients injured their dominant hand (53.8%). The injury was work related for 2 individuals (15.2%). Eleven patients had lacerations of their arteries (84.6%), 1 patient had arterial damage caused by a crush injury of the palm, and the remaining patient had a brachial artery injury because of dislocation of the elbow joint. Nine patients had their injury at the distal forearm (69.2%) (includes the patient with the digital artery injury), 3 had their injury in the middle of the forearm (23.1%), and 1 was injured at the distal upper arm (7.7%). Only the patient with the crush injury had concomitant bone fractures (7.7%). Eleven out of 12 patients had associated tendon damage, which required surgical repair (91.7%). Nine out of 12 patients had associated nerve damage requiring surgical repair (75%). Only the patient with the crush injury incurred a postsurgical complication (necrosis of skin graft) (8.3%).

Five out of 12 patients (41.7%) reported cold intolerance symptoms in the healthy hand based on the original CISS. Eleven out of 12 patients (91.7%) reported cold intolerance symptoms in the injured hand based on the original CISS. Two out of 8 patients (25.0%) reported cold intolerance symptoms in the healthy hand based on the mod CISS. Seven out of 8 patients (87.5%) reported cold intolerance symptoms in the injured hand based on the mod CISS. There was no statistically significant difference in the CISS score between the patent and nonpatent group for the injured limb ( $P = 0.91$ ). The same applies for the mod CISS ( $P = 0.48$ ).

The difference in DASH score between the patent and nonpatent group was not statistically signifi-



cant ( $P = 0.67$ ). The same applies for pinch strength ( $P = 0.09$ ); 2-point discrimination measured at the thumb ( $P = 0.08$ ), at the index ( $P = 0.17$ ), at the small finger ( $P = 0.84$ ); grip strength measured with the dynamometer at the first setting ( $P = 0.52$ ); grip strength measured at the third setting ( $P = 0.07$ ) and at the fifth setting ( $P = 0.10$ ); and the MHQ ( $P = 0.15$ ). No statistically significant differences were found between the patent and nonpatent group for wrist-flexion ( $P = 0.31$ ), radial deviation ( $P = 0.19$ ), ulnar deviation ( $P = 0.33$ ), pronation ( $P = 0.10$ ), and wrist supination ( $P = 0.10$ ). There was a statistically significant difference in wrist-extension ( $P = 0.03$ ) in favor of the patent group.

The above variables were also assessed for the group of patients who required surgical nerve repair at the time of their injury versus those that did not. The level of cold intolerance symptoms was statistically significantly different between these groups (CISS score,  $P = 0.02$ ; mod CISS score,  $P = 0.05$ ) (Fig. 2).

The difference in result of the DASH score based on the presence or the absence of nerve damage was statistically significant in favor of the group without nerve injury ( $P = 0.05$ ). The MHQ ( $P = 0.02$ ) was statistically significantly different for the 2 groups in favor of those without nerve injury. The difference in pinch strength was not statistically significant ( $P = 0.41$ ). Two-point discriminations measured at the thumb ( $P = 0.71$ ), at the index ( $P = 0.47$ ), and at the small finger ( $P = 0.36$ ) were also not statistically significantly different. Grip strength measured with the dynamometer at the first setting did not prove to be statistically significantly different between the 2 groups ( $P = 0.07$ ). The difference in grip strength

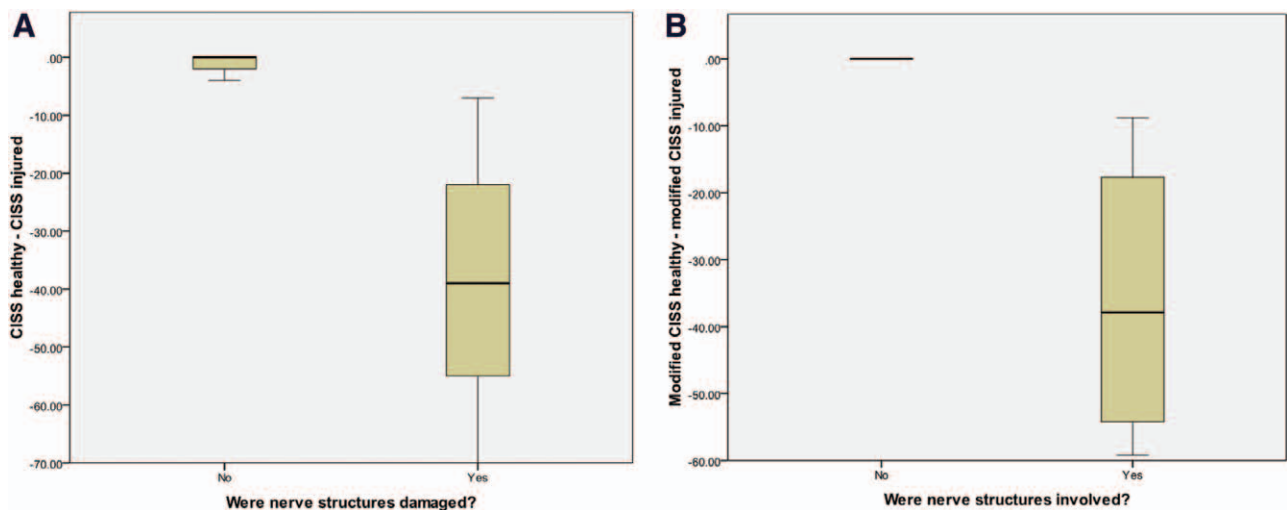
at the third setting ( $P = 0.01$ ) was highly statistically significantly different and in favor of the group without nerve damage. Grip strength, at the fifth setting, was not statistically significantly different between the 2 groups ( $P = 0.16$ ). No statistically significant differences were found between the 2 groups for wrist extension ( $P = 0.59$ ), wrist flexion ( $P = 0.82$ ), radial deviation ( $P = 0.84$ ), ulnar deviation ( $P = 0.22$ ), pronation ( $P = 0.54$ ), and wrist supination ( $P = 0.54$ ). The pain level in the injured limb was not statistically significantly different in the 2 groups ( $P = 0.15$ ).

The above tests were repeated for the group with tendon injuries versus the group without tendon injuries. Only the grip strength on the third setting was statistically significantly higher in the noninjured group ( $P = 0.02$ ).

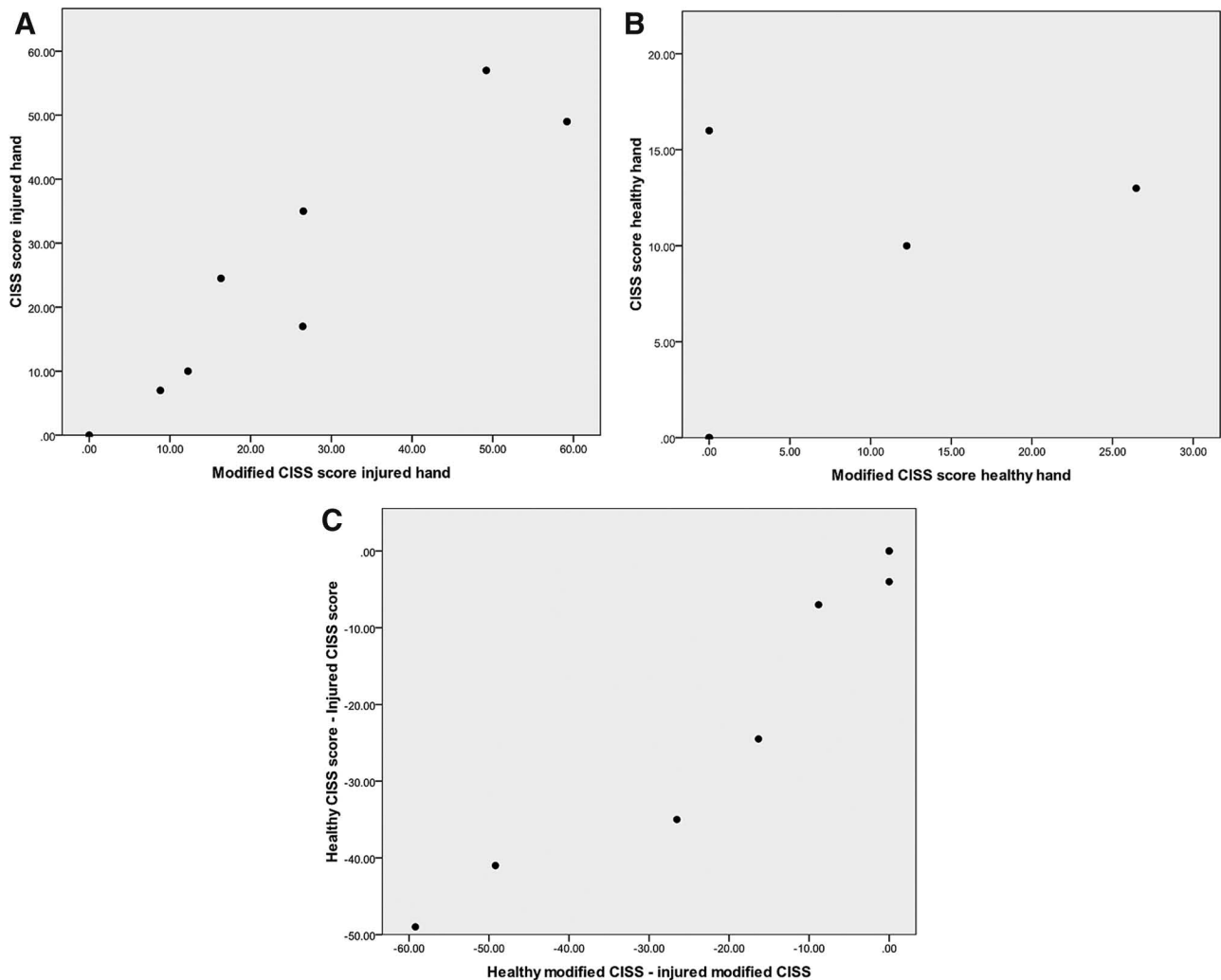
The results from the mod CISS were very highly statistically significantly correlated with the results of the CISS score for the injured hand ( $P = 0.001$ ) and for the differences between the injured and healthy hand ( $P < 0.001$ ). The correlation for the healthy hand between the CISS and modified CISS scores was not statistically significantly ( $P = 0.12$ ) (Fig. 3).

## DISCUSSION

The goal of this study was to assess the long-term patency of repaired arteries in the upper extremity and the consequences of thrombosis of these vessels. Our limited data do not allow us to clearly answer this question, and we thus believe that the strength of this publication lies in the introduction of valuable modifications to the original CISS score.



**Fig. 2.** A, The difference in Cold Intolerance Symptom Severity (CISS) score between the healthy and injured hand based on the presence of initial nerve damage. Note the negative Y axis. B, The difference in modified CISS score between the healthy and injured hand based on the presence of initial nerve damage.



**Fig. 3.** A, The scatter plot shows the relation between the Cold Intolerance Symptom Severity (CISS) score of the injured hand and the modified CISS (mod CISS) score. B, The scatter plot shows the relationship between the CISS score of the healthy hand and the mod CISS score. C, The scatter plot shows the relationship between the difference in CISS score and the mod CISS score.

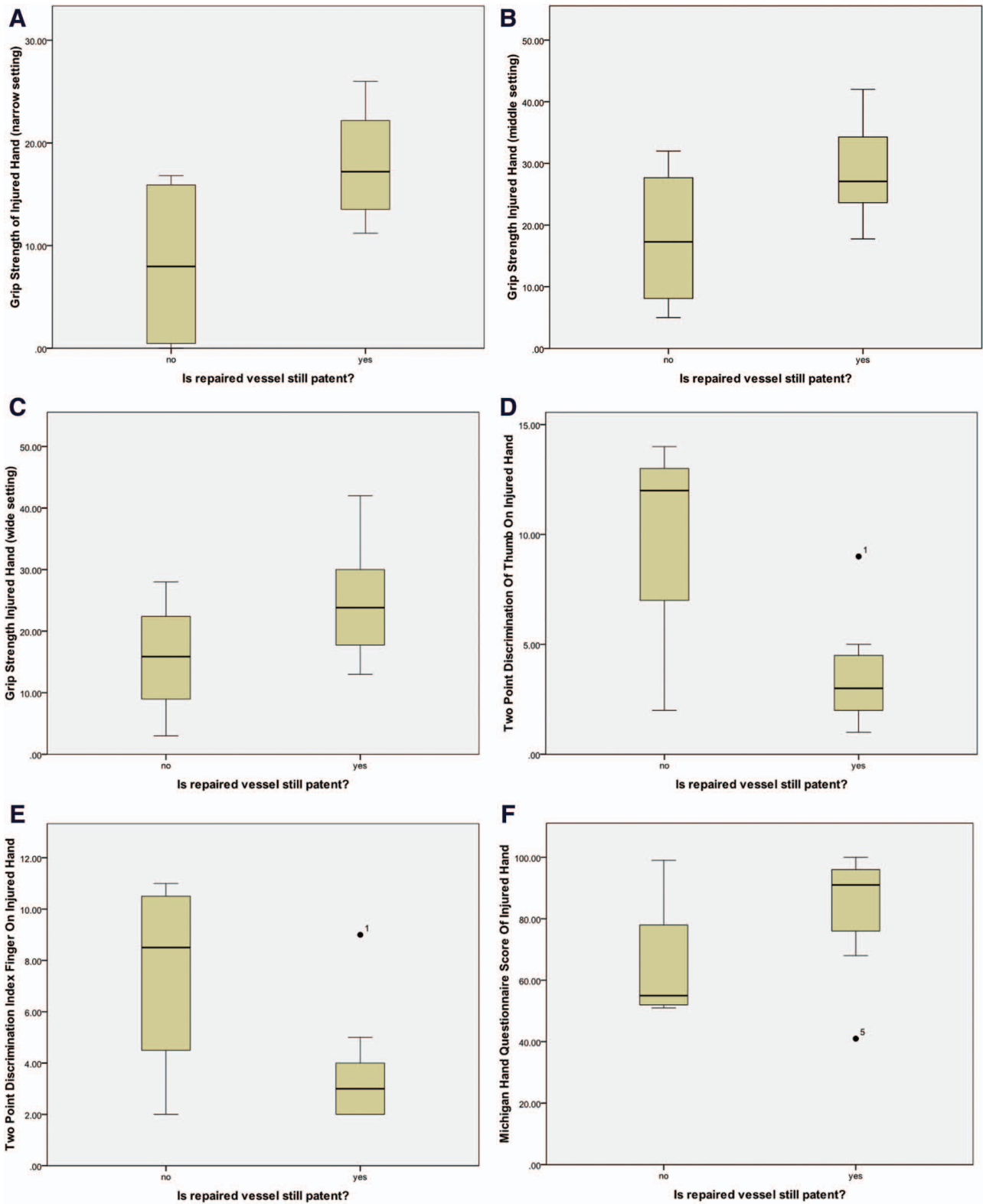
The arterial patency in our sample group of 67% is similar to the patency reported in other studies.<sup>2,6–9,11,12,21–23</sup>

Lack of statistical significance with some of the variables assessed is most likely because of a lack of power. Figure 4 illustrates clear trends in favor of the patent group for grip strength, 2-point discrimination (thumb and index finger), and the MHQ.

Our data show that the effect of nerve damage on grip strength, cold intolerance, and the parameters measured with the MHQ has such an impact that even a small sample size leads to statistically significant difference. Lack of a statistically significant difference for the grip strength, using the first and fifth setting on the dynamometer, is most likely because of a lack of power, as the 3 grip strength box-plots (first, third, and fifth setting on the dynamometer)

show a very similar relationship of the measurements between these 2 groups (data not shown). For the statistical analysis of the data gathered from grip strength on the first setting, we used the Kolmogorov–Smirnov test. Data for this variable were statistically significantly different from the normal distribution, and the variances in both groups were also statistically significantly different from one another. The Kolmogorov–Smirnov test has much less power than the Student *t* test, which was used for the other 2 groups. The latter explanation also applies to the difference in statistical values of grip strength difference, related to vessel occlusion, between the first setting ( $P = 0.52$ ) and the third and fifth settings ( $P = 0.07$  and  $P = 0.10$ ).

Our data indicate, as they relate to the DASH score, that arterial patency has a lower impact on



**Fig. 4.** Box-plot showing grip strength on the first setting (A) third setting (B), and fifth setting (C) based on arterial patency. Box-plot showing 2-point discrimination of the thumb (D) and the index (E) on the injured hand based on arterial patency. F, Box-plot showing Michigan Hand Questionnaire score of injured hand.

hand function when compared with nerve damage. This relationship has also been shown in the literature.<sup>13,15</sup>

We believe the finding of statistical significant difference in wrist extension based on arterial patency to be less clinically relevant and probably because of the large number of variables studied. Basic statistical theory predicts that when *P* value less than or equal to 0.05 is used as cut off for statistical significance, by definition, 1 of 20 (random) variables studied will seem to be statistically significant.

The correlation between the CISS and mod CISS was not statistically significant for the healthy hand. The upper right scatter plot (Fig. 3) shows that 1 point stands out. We believe that if more patients were to be assessed, a statistically significant correlation would also be found for the healthy hand when evaluated by the CISS and the mod CISS.

Literature documenting the significance of upper limb arterial patency after surgical repair is limited because of the difficulty in finding a large population with isolated arterial injuries. Similar to the majority of the literature that we reviewed, our sample had significant traumatic comorbidities.<sup>1,11,13,15,16,22</sup> The combination of these injuries masks the impact of a single variable such as the presence or absence of arterial patency.

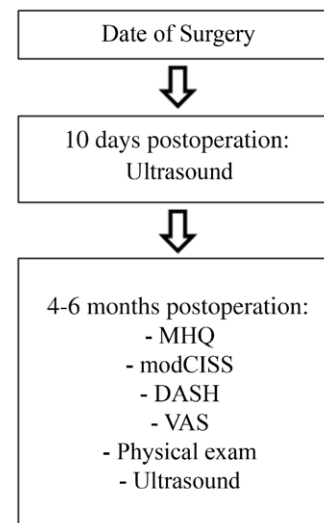
An alternative approach to assess the importance of specific blood vessels is by selectively removing those vessels and studying the comorbidity of the donor site. Budillon et al<sup>24</sup> examined the complications after harvesting the radial artery for coronary bypass grafting. Only 3.7% of their study population of 271 patients reported issues (cutaneous paresthesias). Kleinman et al<sup>25</sup> had similar results when examining the hand vasculature after the elevation of a radial forearm flap. In the latter study, only 2 of 12 patients experienced transient mild cold intolerance as a possible consequence of the loss of the radial artery. These results are in contrast with the findings of Dick et al<sup>26</sup> who also followed up on the donor site morbidity after radial artery harvesting for coronary artery bypass graft. They report persistent sensory discomfort, after a mean postoperative period of  $2.5 \pm 0.9$  years, in 57% of examined patients (70 of 123 patients). These sensory symptoms were described as numbness in the majority of cases. Pain was reported by 5% of the patients, and paresthesia and/or dysesthesia was present in 13.8%.<sup>26</sup>

A study by Antony et al<sup>27</sup> used a similar setup for the ulnar artery. They assessed the literature for hand morbidity after ulnar flap elevation. They reported impaired wrist/finger mobility in 5% of patients (18 of 358 cases) and grip strength loss in 0.8% of patients (3 of 358 cases).<sup>27</sup>

Coleman et al<sup>28</sup> showed that the superficial palmar arch is incomplete in 21.5% (140 of 650 specimens) of patients, and the deep palmar arch is incomplete in 3% of patients. The dominance of either the radial or ulnar artery in the forearm has also been variable. Kleinert et al<sup>29</sup> found the radial artery to be dominant in 3 or more fingers in 57% of their study sample (114 of 200 hands), whereas the ulnar artery was dominant in 3 or more fingers in 21.5% (43 of 200 hands). No dominant vessel was present in 21.5% of cases (43 of 200 hands). This variability may in part explain the different results reported in the literature as to the importance of vessel patency. Another factor that we believe to be important is the heterogeneous character of this population. For example, depending on the outcome variable, researchers should be careful when combining crush injuries and vessel lacerations.

We are glad to see that some authors are expanding the outcome variables of interest for this population. An interesting study by Bassetto et al<sup>11</sup> showed that bone mineral density is impacted by the long-term arterial patency. We found this interesting and believe this to be an argument for repairing the arteries in the forearm when damaged.

An important shortcoming of our study is the small sample size. As only 13 people of approximately 160 patients were followed up, a significant selection bias may well be present, compromising the external validity of our findings. Consequently, we believe that our findings do not allow us to argue for, nor against, the repair of arteries in the upper extremity



**Fig. 5.** Suggested prospective protocol to help clearly answer the initial questions set forth in this study. MHQ, Michigan Hand Questionnaire; CISS, Cold Intolerance Symptom Severity; VAS, visual analogue scale; DASH, Disabilities of the Arm, Shoulder, and Hand.

after trauma. The combination of the typical follow-up of these patients and the protocol presented in Figure 5 may well prove to give a clear answer to the initial questions raised in this study. The early ultrasound may further aid in the understanding of the etymology of vessel occlusion after repair.

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## ACKNOWLEDGMENT

High frequency ultrasound imaging scanner—Vevo2100 was supported with an NIH shared instrument grant (1S10RR027383).

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