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Research Article

The value of doppler ultrasound in predicting arterial injuries of the penetrating forearm trauma

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ABSTRACT

Objective: The aim of this study was to determine the diagnostic value of Doppler ultrasound (DU) in predicting arterial injuries following the penetrating trauma of the forearm, by comparing preoperative diagnosis made by DU and that made by physical examination (PE) with the intraoperative diagnosis.

Methods: In this retrospective study, 48 patients (44 men, 3 women; mean age = 30 ± 12.5 years) who underwent surgical treatment due to a suspected arterial injury following a penetrating trauma in the forearm from 2016 to 2018 were included. The DU examination was frequently done before an orthopedic examination. In the orthopedic PE, the knowledge as to whether an arterial injury occurred or (if present) which artery was injured was noted. Preoperative diagnoses by PE and DU were first compared with each other, and then with the intraoperative diagnoses. The specificity, sensitivity, negative and positive predictive values were calculated.

Results: While the DU findings from 24 patients (50%) matched their intraoperative results, the result from the remaining 24 patients (50%) did not. Nine (18.75%) were considered false-positive and 15 (31.25%) were false-negative. Whereas the PE findings from 30 patients (62.5%) matched their intraoperative results, the remaining 18 patients (37.5%) did not. Six (12.5%) were considered false-positive and 12 (25%) were false- negative. No significant difference was found between the diagnoses of DU and PE, and there was good agreement between the DU and PE findings ($P = 0{,}065$, $\kappa = 0{,}504$). While the DU findings were significantly different from the intraoperative findings ($P = 0.004$), the PE findings were not significantly different from the intraoperative findings ($P = 0.302$). Sensitivities of DU and PE were both 75% for the diagnosis of radial artery injury as well as 63.3% and 70% for the ulnar artery injury, respectively. Specificities of DU and PE were 83.3% and 91.66% for the diagnosis of radial artery injury as well as 77.77% and 72.22% for the ulnar artery injury, respectively.

Conclusion: The PE seems more sensitive and useful than the DU in predicting arterial injuries following the penetrating trauma of the forearm.

Level of Evidence: Level IV

Introduction

Isolated extremity trauma with concomitant vascular injury has approximately a 10% mortality rate or limb loss. Arterial injury and associated blood loss causing shock are among the most serious conditions seen in the Emergency Department (ED). Accurate evaluation of a patient with an arterial injury is crucial, in terms of preserving tissue viability and limb salvage. However, the optimal approach for managing a penetrating extremity trauma is still controversial.[1]

An imaging study is usually needed if there is a suspicious arterial injury. If vascular pathology is suspected, but there is no hard signs of vascular injury; then, various imaging studies are chosen according to the infrastructure of the institution. But if there is an obvious arterial injury, immediately surgery should be performed as soon as possible.[2]

Physical Examination (PE) of the penetrating upper extremity may be difficult, and application of the Allen test to an injured area may be difficult due to pain and anxiety. The effectiveness of angiography is indisputable, and conventional angiography is considered the gold standard test for diagnosing vascular pathology.[2] However, conventional angiography has some limitations such as cost, invasive nature and 7/24 availability. Another diagnostic method, Computed Tomography Angiography (CTA) has mostly replaced the need to conventional angiography. CTA has a specificity of 98%–100% and a sensitivity of 90%–95% for the detection of arterial injuries in lower and upper extremities.[3] CTA also has the advantage of detecting concomitant bony and soft tissue injuries. But CTA has the similar drawbacks such as radiation exposure, time, cost and contrast agent. Doppler Ultrasound (DU) is a non-invasive, cost effective and less time consuming procedure. However, disadvantage of DU is the dependence of an experienced operator.

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This study aimed to investigate the correlation between the pre-operative diagnoses made by PE and DU evaluation and the intraoperative diagnosis to understand which pre-operative diagnostic method is more effective for detecting arterial injuries of the forearm.

Materials and Methods

In this retrospective study, we evaluated 90 patients who had undergone surgery due to penetrating trauma of the forearm between 2016 and 2018. The study was approved by the local ethics committee (Decision no. 1057).

The exclusion criteria were 1) age < 15 years; 2) no pre-operative DU examination; 3) patients with obvious arterial injury; 4) penetrating injury above the elbow joint or < 3 cm from the wrist; 5) any patient who did not have triphasic flow in the uninjured extremity; and 6) patients evaluated by inexperienced (minimum 3 years) radiologist or orthopaedic surgeon.

The data collected pertinent to the study were surgery reports, ED records and Picture Archiving and Communication System (PACS) records that was used to obtain demographic information, radiology reports, details of pre-operative procedures, the operation and pre-operative and intraoperative diagnoses (Mia-Med version 1.0.1.2808, Mia Technology).

All the patients presented to the ED due to penetrating forearm injury and suspected of having arterial vascular injury were included. Of these patients who had DU performed and consulted with orthopedic surgeons and had explorative surgery were the interest of the study. In the case of hard signs such as obvious arterial bleeding, large expanding or pulsatile hematoma, palpable trill, the patient was taken directly to the operating room (Figure 1).

The DU evaluation was usually performed before an orthopedic examination. And the radiology physician was unaware of the consultation note of the orthopedic surgeon. Injury type and location, length of the wound and distance of the wound from the wrist were noted. The findings from the PE, arterial palpation and inspection of the wound were also recorded by orthopaedic surgeon experienced in hand surgery. The physician who performed the PE wrote his personal opinion about whether there was an arterial injury or not and which artery was injured: radial, ulnar or both. The physician had no knowledge about the report of the Radiology Department until the records were completed.

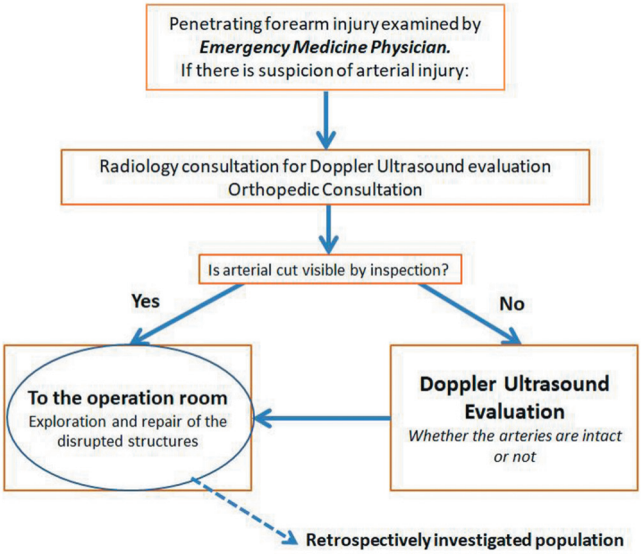

Figure 1. Evaluation algorithm of a patient with a suspected forearm arterial injury in the emergency department.

Doppler ultrasound technique

DU was performed using a high-frequency broadband linear transducer with a central frequency of 12 or 9 MHz (MyLab70XVG and MyLab Class C, Esaote, Genoa, Italy) for pre-operative evaluation of the vascular structures. Gray-scale (B-mode) ultrasound was used to evaluate the ulnar and radial arteries were evaluated first grayscale ultrasound for any anatomical disruption, thrombosis and perivascular hematoma. Next, the color mode was used to look for the presence of blood flow and its direction. Finally, a duplex mode was used for spectral analysis and to evaluate the phasicity in the proximal and distal areas of the injury. The DU diagnosis of the ulnar or radial artery was based on the combined findings of B-mode ultrasound and color duplex mode. Monophasic and biphasic flows close to the level of injury or the distal part of injury were considered abnormal. By the presence of triphasic flow especially in the distal part of the arterial injury, and the normal B-mode and color mode findings, the ulnar or radial artery was considered intact. DU was performed by an experienced radiologist with at least 3 years in the emergency radiology section of our hospital.

Evaluation of DU results

The DU results for the radial and ulnar arteries were reviewed. When the DU result did not match the intraoperative results—even one of the arteries—the entire result for the patient was considered "false."

Evaluation of PE results

The PE results for the radial and ulnar arteries were evaluated. When the PE result did not match the intraoperative findings—even one of the arteries—the entire result for that patient was considered "false."

Statistical analysis

Statistical analyses were performed using IBM Statistical Package for the Social Sciences (SPSS) Statistics 19.0 software for Windows (IBM SPSS Corp. Armonk, NY, USA). The intraoperative diagnosis was regarded as the definitive diagnosis of the arterial injury of the forearm. The preoperative PE and DU diagnoses were compared with each other and with the intraoperative diagnosis and the specificity, sensitivity, Negative Predictive Value (NPV) and Positive Predictive Value (PPV) were calculated. The differences between the diagnostic methods in the dependent groups were calculated using the McNemar test. The agreement between the preoperative diagnoses and the intraoperative diagnosis was calculated as the κ coefficient and $P < 0.05$ was considered statistically significant.

Results

Among the 90 patients who were evaluated, 48 (53%) were included in the study (44 men and 4 women). Their mean age was 30 ± 12.5 years. The demographic data and preoperative and intraoperative findings are listed in Table 1. Of the 48 patients, 35 were injured in the right forearm and 13 were injured in the left forearm. The mean length of the open wound was 4.88 cm (range = 1–11 cm, Standard Deviation (SD) = 2.59), the average distance from the wrist joint was 5.11 cm (range = 3.5–12 cm, SD = 2.36), and all open wounds were located on the volar side in zone 5 of the forearm.

In this study; three patients younger than 15 years old, four patients who received the DU by an inexperienced radiologist, 22 patients who had inappropriate injury location for DU examination, nine patients

Table 1. Demographic Data, Preoperative and Intraoperative Findings

Parameters		Count	%
Gender	Male	44	91.7
	Female	4	8.3
Side	Right	35	72.9
	Left	13	27.1
PE of radial artery	Intact	36	75.0
	Injured	12	25.0
PE of ulnar artery	Intact	23	47.9
	Injured	25	52.1
DU result of radial artery	Triphasic	33	64.6
	Not-triphasic	15	35.4
DU result of ulnar artery	Triphasic	24	50
	Not-triphasic	24	50
Intraoperative examination of radial artery	Intact	36	75.0
	Injured	12	25.0
Intraoperative examination of ulnar artery	Intact	18	37.5
	Injured	30	62.5
Both radial and ulnar arteries	Both intact	8	16.7
	Both injured	2	4.2
	One of them injured	38	79.1

PE, Physical Examination; DU, Doppler Ultrasound.

who were directly taken to the operation room without DU evaluation due to visible arterial cut or excessive bleeding, three patients who were not available for DU evaluation due to their disorientation and one patient who had different values on the other forearm were excluded. Injury types of 48 patients who were included in the study were as follows: 18 patients injured by glass, 16 patients were injured by a knife, 12 patients were injured by a sharp working machine and 2 patients were injured by a sharp home object.

Evaluation of DU results

The DU results of 24 (50%) patients matched the intraoperative results and those of the other 24 (50%) patients did not. Nine (18.75%) patients were considered false positive and 15 (31.25%) were false negative.

Evaluation of PE results

The PE results of 30 (62.5%) patients matched the intraoperative results and those of the other 18 (37.5%) did not. Six (12.5%) patients were considered false positive and 12 (25%) were false negative. The results of other parameters for each artery are listed in Table 1.

Table 2. Comparison Between DU and Intraoperative Results

	Intraoperative Results		
	Intact	Injured	Total
DU injured	2	26	28
DU intact	6	14	20
Total	8	40	48

DU, Doppler Ultrasound.

Table 3. Comparison Between PE and Intraoperative Results

	Intraoperative Results		
	Intact	Injured	Total
PE injured	5	30	35
PE intact	3	10	13
Total	8	40	48

PE, Physical Examination.

Table 4. Sensitivity, Specificity, PPV, and NPV of the Preoperative Diagnosing Methods

	Sensitivity	Specificity	PPV	NPV
Doppler ultrasound	65% (26/40)	75% (6/8)	92.9% (26/28)	30% (6/20)
Physical examination	75% (30/40)	37.5% (3/8)	85.7% (30/35)	23.1% (3/13)

PPV, Positive Predictive Value; NPV, Negative Predictive Value.

The results of the preoperative diagnostic methods DU and PE compared with the intraoperative results are listed in Tables 2 and 3. Sensitivity, specificity, PPV and NPV are listed in Table 4.

There was no statistically significant difference between the DU results and the PE results; hence, there was good agreement between the DU and PE results ($P = 0.065$, $\kappa = 0.504$).

The DU results were significantly statistically different from the intraoperative results ($P = 0.004$), but an agreement between them was observed (Kappa Test $P = 0.036$) ($\kappa = 0.250$).

The PE results were not statistically significantly different from the intraoperative results ($P = 0.302$) and no agreement between them was observed with Kappa Test ($P = 0.468$).

The sensitivity rates of DU and PE were both 75% for the radial artery injury evaluation, and 63.3% and 70% for the ulnar artery injury evaluation, respectively. The specificity rates of DU and PE were 83.33% and 91.66% for the radial artery injury evaluation, respectively, and 77.77% and 72.22% for the ulnar artery injury evaluation, respectively.

Discussion

This study showed that PE is more sensitive than the DU in the evaluation of forearm arterial injury.

During the primary survey of Advanced Trauma Life Support, life threatening bleeding should be controlled with direct pressure or in the operation room. According to Western Trauma Association (WTA) position paper,[4] in the presence of soft signs such as a history of arterial bleeding at the scene or ambulance, proximity of the wound to the artery or non-pulsatile hematoma over an artery, a comprehensive physical examination of the vascular structures and arterial pressure index measurement is suggested. But there is no method, such as the arterial pressure index, for detecting the arterial injuries of the forearm at this level. The PE is limited to inspection of the wound and the palpation of the arteries. The lack of cooperation of the patient due to anxiety diminishes the effectiveness of the PE.

According to WTA position paper, if a patient has diminished pulses or arterial brachial index < 0.9 in the injured extremity, they suggest an imaging study according to the local expertise of the institution.[4] Despite the high specificity and sensitivity of CTA and conventional angiography in detecting an arterial injury, DU is one of the most widely amiable tool for the diagnoses of the arterial injury in the ED.[5] The artifacts such as bullet fragments or metal objects may limit the diagnostic quality and contrast agent use may limit the use of CTA or conventional angiography due to underlying renal failure. DU is portable and easy to perform. The disadvantage of DU is that it is dependent to the operator and the procedure may be painful if the injured area is near the artery.[6,7] In the literature, the sensitivity and specificity of Duplex Ultrasonography (DXU) are reported to range between 50% and 100%.[4,6–9]

In our study, the correlation between DU and intraoperative results was 50% which means 50% of the DU examinations did not match the

intraoperative results. The sensitivity and specificity of DU in our study were 65% and 75%, respectively. DU also had PPV of 92.9% (26/28). These results might be related to the emotional state of the patient while in the ED. It is difficult to get a patient in pain and suffering from anxiety to cooperate. Despite the low correlation rate between DU and intraoperative results, there was a much higher correlation rate (62.5%) between the preoperative PE and intraoperative results. The sensitivity and specificity for PE were found to be 75% and 37.5%, respectively.

Duplex ultrasound combines DU flow analysis and high-resolution B-mode ultrasound for use at a site-specific vascular injury.[10] The advantages of DXU are that it is noninvasive, portable, can be performed bedside, and is easy to perform on treated vessels for follow-up. Ordog et al. declared that if DXU is used for inpatient and outpatient follow-up, millions of dollars could be saved.[11] In contrast, there are some challenges with the use of DU or DXU for evaluating trauma patients. One is its dependence on the operator and another is the technical problem of applying the procedure to other parts of the human body such as the chest and abdomen. In our study, DU and DXU procedures were performed by a radiologist with a minimum of 3 years of experience. The low rate of correlation between the preoperative DU results and the intraoperative findings may be the result of the low degree of experience of the radiologist who performed the DU procedure. Another cause for the low rate could have been the technical difficulty of applying the procedure to patients because of the location of the injury (bleeding or open wounds) or body habitus of the patient.

Both the sensitivity and the specificity rates of the ulnar artery evaluation by DU and PE were lower than those of the radial artery. This could be related to the peripheral anatomical structures of the ulnar artery. It is easy to palpate the radial artery around the wrist because of its proximity to the skin.

There is a lack of evidence in the literature about the efficiency of DU in evaluating the vascular structures of the forearm with concomitant open wound injuries. Some studies have focused on the effectiveness of CTA and DU, but in many of those studies, the methods were applied to a lower extremity. In studies where CTA and DU were applied to an upper extremity, it was mostly above the elbow.[9,12,13] In the current study, we reported the correlation of preoperative findings with intraoperative findings of surgically treated penetrating injuries to the forearm. One challenging problem of our study was the difference in experience among the orthopedic physician who had examined the patients. Thus, we excluded the patients who had been examined by an orthopedic surgeon with <3 years of experience. Another point is that as DU is dependent to performers the technique should be improved for more accurate results. DU and PE may be performed together by the same person (Of course the physician who will perform the operation—Orthopaedic surgeon/Hand surgeon) to get more efficient outcomes.

This study has some limitations. It was a retrospective study that used data collected from a PACS system. The number of patients included in the study was small. The reliability tests of the physicians who performed the PEs and the DU procedures should have been undertaken before the study. We just compared the two methods retrospectively. The diagnostic tests were not performed to randomized selected normal population to define the real accuracy. Despite these limitations, to the best of our knowledge, this is the first study to compare the DU and PE findings of penetrating injuries of the forearm with intraoperative findings for vascular injuries. More detailed studies that include more patients are needed.

In conclusion, PE would be particularly more useful than DU for a vascular evaluation of the forearm with an open wound injury. PE of the forearm is more sensitive than a DU evaluation in those cases. The loss of time and labor in the Emergency Department is minimized with just performing PE for the patients with penetrating arterial injuries of the forearm.

Ethics Committee Approval: Ethics committee approval was received for this study from the Local Ethics Committee of Akdeniz University, School of Medicine (Decision No, 1057).

Informed Consent: N/A.

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