Predictive Factors of Neurovascular and Tendon Injuries Following Dog Bites to the Upper Extremity

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Abstract

Background: Dog bite injuries to the upper extremity can result in traumatic neurovascular and musculotendinous damage. Currently, there are no clear guidelines dictating which patients may benefit from early operative exploration. The purpose of this study was to identify clinical variables that were predictive of abnormal intraoperative findings in patients who sustained an upper extremity dog bite injury. **Methods:** All patients who presented to a level I trauma center between 2007 and 2015 with an upper extremity dog bite injury who underwent subsequent surgical exploration were retrospectively screened for inclusion in our study. Patients with inadequate documentation or preexisting neurovascular or motor deficits were excluded. Abnormalities on physical exam and injuries encountered during surgical exploration were recorded for each patient. Contingency tables were constructed comparing normal and abnormal nerve, tendon, and vascular physical exam findings with intact or disrupted neurovascular and musculotendinous structures identified during surgical exploration. **Results:** Between 2007 and 2014, 117 patients sustained a dog bite injury to the upper extremity, of which 39 underwent subsequent surgical exploration and were included in our analysis. Sixty-nine percent of patients with neuropraxia on exam had intraoperative nerve damage. Seventy-seven percent of patients with an abnormal tendon exam had intraoperative musculotendinous damage. One hundred percent of patients with an abnormal vascular physical exam had intraoperative arterial injury. **Conclusions:** To date, there are no clear guidelines on what clinical criteria indicate the need for operative exploration and possible repair of neurovascular structures in upper extremity dog bite injuries. In our study, nerve, tendon, and vascular abnormalities noted on physical exam were strongly predictive of discovering neurovascular and musculotendinous damage during surgical exploration.

Keywords: dog bite, extremity, neurovascular, predictive, trauma

Introduction

More than 4.9 million animal bites occur annually in the United States, of which 750 000 require medical attention, generating more than \$850 million in annual health care costs.^{1,23} It is estimated that 1% to 2% of all emergency department visits are related to animal bites, particularly dog bites.^{9,10,29} This equates to nearly 1000 animal bite injuries requiring emergency room visits per day nationwide.²⁷ The true incidence and socioeconomic cost of dog bite injuries (DBIs) are probably higher given the absence of a national reporting system, and this incidence is likely to rise as the popularity of household pets continues to grow.^{18,23} Approximately 50% of households in the United States own a domesticated pet, and the relative lifetime risk of being bitten by a domestic animal, overwhelmingly dogs, approximates 50%.^{1,10}

The majority of these DBIs occur when picking up objects wanted by the canine, separating dog fights, or

while pushing letters through letter boxes.¹¹ These common scenarios account for nearly 70% of all DBIs involving the hand and upper extremity, resulting in a combination of penetration and crush-type forces given a canine's sharp teeth and ability to generate 2000 pounds of force per square inch.^{9,12} Victims of DBIs are at risk of both infectious and neurovascular consequences, particularly given the superficial proximity of nerves, tendons, and vessels in the hand and forearm. Two-thirds of these patients require inpatient admission and approximately one-third eventually require surgical intervention.¹ The infectious component of these

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injuries is often managed with bedside irrigation and debridement, prophylactic oral and/or intravenous antibiotics, and clinical monitoring.^{7,17,19} However, the management of the neurovascular and musculotendinous injuries in these patients remains less clear.

Up to 10% of patients with DBIs have nerve, tendon, or vessel damage.¹² To date, no consensus guidelines exist with regard to which patients with suspected neurovascular or musculotendinous damage should undergo operative exploration. Particularly with regard to nerve injury, some surgeons advocate conservative management, allowing a possible neuropraxia to resolve without intervention, whereas others recommend early surgical exploration and possible neurolysis.^{5,21} In the setting of tendon damage, some surgeons prefer to explore the tendon during initial washout and attempt primary reconstruction, whereas others prefer delayed exploration and reconstruction.¹³ Given the absence of prospective or retrospective literature regarding neurovascular and tendon damage in DBIs to the upper extremity, the decision to urgently operatively explore these injuries is largely based on clinical judgment and personal experience.

The purpose of this study was to identify consistent clinical variables that were predictive of abnormal intraoperative findings in patients who sustained an upper extremity DBI. We believe abnormalities on the physical exam can be highly predictive of abnormalities identified during surgical exploration and can help stratify which patients should and should not be operatively explored.

Materials and Methods

All patients who presented to a single level I trauma center between January 2007 and May 2015 with an upper extremity DBI between the midshaft humerus and distal phalanx were retrospectively screened for inclusion in our study. Our database is limited to patients presenting after 2007 as that is when our institution implemented electronic medical records. Patients with incomplete or inadequate documentation or preexisting neurological, vascular, or motor deficits were excluded. Patients were identified by mechanism of injury.

Using our institution's electronic medical record system, we recorded the age, gender, time to presentation, and length of hospitalization for each patient included in our study. We reviewed documented physical exams to obtain the anatomic location of the dog bite(s), the number of bites, and the presence or absence of nerve palsies, tendon lacerations, or vascular abnormalities on physical exam. Nerve palsies were defined as the absence of 2-point discrimination at 6 mm, loss of sensation in an isolated nerve distribution, loss of motor function in an isolated nerve distribution, or positive special tests such as Froment sign. Tendon lacerations were defined by the presence of extensor/flexor

tendon lag on exam, inability to flex/extend digits not consistent with a particular nerve distribution, or pain with resisted flexion/extension. Vascular abnormalities were defined by nonpalpable pulses, abnormal Doppler exam, or delayed capillary refill (>2 seconds).

Finally, operative reports documenting the surgical exploration of patients with upper extremity dog bites were analyzed for the presence or absence of nerve contusions, nerve lacerations, tendon lacerations, muscle belly damage, and/or arterial damage.

Contingency tables were constructed comparing normal and abnormal nerve, tendon, and vascular physical exam findings with intact or disrupted neurovascular and musculotendinous structures identified during surgical exploration. Specificity, sensitivity, positive predictive value, and negative predictive value were calculated for each contingency table. A 2-tailed Fisher exact test was used to determine significance. Significance was set at $P \leq .05$. This study was approved by our university's institutional review board.

Results

Between July 2007 to May 2015, 117 patients with an upper extremity DBI presented to our level I trauma center's emergency department and were evaluated by an orthopedic surgeon. Of the 117 patients, 39 underwent subsequent surgical exploration and inpatient treatment. Seven patients were excluded due to inadequate documentation.

The patients in our study ranged from ages 4 to 81 years with a mean of 37 ± 18 years and presented less than 24 hours after injury (Table 1). Sixteen patients presented with a nerve palsy on physical exam, 13 patients had documented tendon dysfunction, and 4 patients had an abnormal vascular exam (Table 2). The majority of dog bites were inflicted on the forearm (69%) (Table 2). Thirty-five percent of patients had an underlying fracture, and 10% had radiographic evidence of cortical violation after the DBI (Table 2).

Forty-one percent of patients were taken to the operating room for irrigation, debridement, and exploration, whereas 20% of patients were operated on with a primary indication involving fixation of a displaced or unstable fracture (Figure 1). Only 8% of patients were taken to the operating room for isolated neurovascular and/or musculoskeletal exploration (Figure 1).

Of the 16 patients with a nerve palsy, 11 (68.9%) had documented nerve damage. Nerve palsy on physical exam was predictive of visualized nerve damage on surgical exploration with a positive predictive value of 68.8% (95% confidence interval [CI], 41.3%-89.0%). Twenty-three patients with a normal upper extremity nerve exam also underwent surgical exploration, of which 0 (0%) had documented nerve damage with a corresponding negative predictive value of 100% (95% CI, 85.2%-100%) (Table 3). No

Table 1. Patient Demographics.

Variable	
Age, y	37.3 ± 18.34
Gender	
Male	26 (66.7%)
Female	13 (33.3%)
Average time to presentation, h	<24
Length of stay, d	6.1 ± 3.44
Received antibiotics	100%

Table 2. Clinical and Radiographic Characteristics.

	No. of patients	% of patients
Location of dog bite(s)		
Finger	7	17.9
Hand	6	15.4
Wrist	0	0
Forearm	27	69.2
Arm	4	10.3
No. of bites		
1	4	10.3
2	4	10.3
3	4	10.3
4+	22	56.4
Not documented	5	12.8
Neurovascular and musculotendinous findings		
No injury	17	43.6
Palsy	16	41.0
Abnormal tendon Exam	13	33.3
Abnormal vascular exam	4	10.3
Radiographic findings		
Normal imaging	21	53.8
Cortical violation	4	10.3
Fracture	14	35.9

nerve lacerations were primarily repaired during the exploratory surgery. In 2 of the 11 damaged nerves, intraoperative nerve stimulation was used to further assess nerve function.

Thirteen patients presented with an abnormal tendon exam, of which 10 (76.9%) had documented musculotendinous damage. An abnormal tendon exam was found to be predictive of visualized intraoperative musculotendinous damage with a positive predictive value of 76.9% (95% CI, 46.2%-95.0%). Twenty-six patients with a normal tendon physical exam underwent surgical exploration, of which 3 (11.5%) had documented musculotendinous damage with a corresponding negative predictive value of 88.5% (95% CI, 69.9%-97.6%) (Table 3). Of these 3 patients with normal muscle/tendon physical exams, 2 had concurrent nerve injury and 1 was immediately rushed to the operating room for an arterial injury. The types of musculotendinous

Figure 1. Indications for operation.

damage discovered intraoperatively were diverse and included tendon subluxation, muscle belly damage, complete and partial tendon lacerations, and avulsions at the musculotendinous junction.

Finally, 4 patients had an abnormal vascular exam, of whom 3 (75%) had documented arterial damage. Abnormal vascular physical exam findings were found to be predictive of visualized arterial damage during surgical exploration with a positive predictive value of 75% (95% CI, 19.4%-99.3%). Thirty-five patients with a normal vascular exam had documented arterial exploration, of whom 0 (0%) were found to have arterial damage with a corresponding negative predictive value of 100% (95% CI, 90%-100%) (Table 3). Of the 3 patients with visualized arterial damage, 2 had thrombi within the brachial artery and 1 had a complete brachial artery transection that was repaired.

Across all 39 patients included in our study who underwent surgical exploration, 22 patients had abnormalities noted on nerve, tendon, and/or vascular physical examination. Of these 22 patients, 20 (90.9%) were noted to have neurovascular or musculotendinous damage during surgical exploration (Table 3). Any combination of a nerve, tendon, or vascular physical exam abnormality was found to be predictive of discovering neurovascular or musculotendinous damage during surgical exploration with a positive predictive value of 90.9% (95% CI, 70.8%-98.9%). Of the 17 patients who underwent surgical exploration with normal physical exam findings, 0 (0%) had documented neurovascular and/or musculotendinous damage intraoperatively with a corresponding negative predictive value of 100% (95% CI, 80.5%-100%) (Table 3).

Discussion

Approximately 4 million DBIs in the United States have occurred in the past 10 years, and the annual incidence may continue to rise as the domestication of canines remains popular.⁴ DBIs were found to affect a wide range of patients in our study, causing substantial morbidity requiring on

Table 3. Physical Exam Abnormalities as Predictors of Intraoperative Neurovascular or Musculotendinous Damage.

Abnormal neurological exam	Intraoperative nerve contusion or laceration	
	No	Yes
No	23	0
Yes	5	11
$P < .0001$	Sensitivity 100%	Specificity 82.1%
Abnormal tendon exam	Intraoperative musculotendinous damage	
	No	Yes
No	23	3
Yes	3	10
$P < .0001$	Sensitivity 76.9%	Specificity 88.5%
Abnormal vascular exam	Intraoperative vascular damage	
	No	Yes
No	35	0
Yes	1	3
$P = .0004$	Sensitivity 100%	Specificity 97.2%
Nerve, tendon, or vascular physical exam abnormality	Intraoperative nerve, musculotendinous, or vascular injury	
	No	Yes
No	17	0
Yes	2	20
$P < .0001$	Sensitivity 100%	Specificity 89.5%

average 6.1 days of inpatient treatment. Thirty-nine percent of hospitalized patients required surgery, most commonly for irrigation and debridement. Our inpatient length of stay and operative rate are consistent with previously published reports on upper extremity DBIs.^{1,8,20,27}

In a subset of upper extremity DBIs, nerve, tendon, and vascular abnormalities are noted on physical exam, and there is a paucity of published literature documenting the surgical exploration of these structures.^{5,6,16,20,28} In our study, nerve palsy on physical exam was highly predictive of discovering nerve damage during surgical exploration, which ranged from minor contusions to complete lacerations. Of equal importance, the absence of a documented nerve palsy was highly predictive of no intraoperative nerve damage. Furthermore, subgroup analysis demonstrated that 81.8% of patients with a true positive on physical exam had documented motor palsy, whereas 80% of patients with a false positive on exam had only a sensory palsy, thus indicating that the motor component of the nerve exam may be a more reliable predictor of intraoperative nerve damage.

To date, no prospective studies exist addressing the appropriate setting for early surgical exploration of these peripheral nerve palsies. Retrospective studies have recommended against early nerve exploration given the high rate

of spontaneous recovery with conservative management; however, the majority of these studies were conducted in the setting of upper extremity fracture or projectile injury, not DBIs.^{2,3,22,24,25} Neuropraxia after a DBI to the upper extremity can serve as an indication for surgical exploration, particularly in settings where operative irrigation and debridement is already warranted. Early exploration provides the opportunity for early primary repair, which may result in superior long-term outcomes, avoiding the need for nerve grafting and resultant donor site morbidity.^{14,26} In settings of neuropraxia secondary to nerve contusion, early exploration allows for early neurolysis and a thorough examination of a nerve's anatomic integrity. Finally, the use of intraoperative nerve stimulation during early neuropraxia exploration can aid in determining the likelihood for spontaneous recovery, as was seen in 2 patients from our study.¹⁵ Although there may be clinical benefits of early nerve exploration and neurolysis in settings of neuropraxia, further studies are needed formally evaluating the benefit of early neurolysis.

Tendon abnormalities noted on physical exam were also highly predictive of intraoperative muscle belly and tendon damage. In the 13 patients with physical exam abnormalities, 10 were found to have abnormal intraoperative

musculotendinous structures, whereas only 3 of 26 patients with a normal physical exam had an abnormal exploration. Of the 3 patients with documented normal physical exams found to have musculotendinous damage on exploration, 2 patients had documented nerve damage, likely masking the diagnosis of an isolated muscle/tendon injury on physical exam and the third was emergently taken to the operating room for an arterial injury, preventing a thorough physical exam. In patients with confirmed musculotendinous damage, early exploration may allow for primary repair. If primary repair is achieved, the morbidity associated with delayed reconstruction, possibly requiring tendon grafting or tendon transfer can be avoided; however, surgeons may be reluctant to perform early primary repair in the setting of possible soft tissue infection.

In settings of vascular physical exam abnormalities, 75% of patients were found to have intraoperative arterial damage requiring surgical intervention. In the 1 patient with a false positive, a positive Allen test was noted on preoperative exam, but intraoperatively the radial artery was not visualized, and this abnormality was likely congenital. The complete absence of pulses in the setting of a cold or pale hand raises the concern for emergent vascular exploration. In patients undergoing vascular exploration, consideration should be given to explore surrounding nerve and musculotendinous structures as well, particularly if findings of neuropraxia or tendon dysfunction are present on physical exam.

When combining all nerve, tendon, and vascular abnormalities noted on physical exam, 90.9% of patients had intraoperative neurovascular and musculotendinous damage. No patient with a normal physical exam had an abnormal surgical exploration. This combined analysis provides further evidence supporting the exploration of patients with abnormal physical exam findings while pursuing initial conservative management in those with normal physical exam findings.

Our study has noteworthy strengths. It describes predictive factors of neurovascular and musculotendinous injuries following dog bites to the upper extremity. Second, it uses documented operative reports, as opposed to imaging and other diagnostic modalities, to confirm neurovascular and musculotendinous damage. Finally, the wide demographic range of the patients included in our study and the involvement of a diverse group of treating physicians improve the generalizability of our results. However, there are certainly weaknesses of our study including the retrospective design, which limits the strength of our conclusions. In addition, the patients in our study had poor follow-up documentation; thus, we are unable to draw conclusions about the long-term risks and benefits of early operative exploration. Finally, there were no clear operative indications or standardized protocols for the surgical exploration of nerves, tendons, or vessels, limiting the reproducibility of our results. The majority of patients in our study went to the operating room

with a primary operative indication of formal irrigation and debridement and/or fracture fixation. Only 8% of patients were taken to the operating room with a primary indication of neurovascular or musculotendinous exploration.

Currently, early operative exploration versus conservative management in upper extremity DBIs is highly physician dependent. We believe our descriptive study from a major level I trauma center provides evidence supporting the early exploration of patients with upper extremity DBIs who present with an abnormal physical exam, particularly in those patients already going to the operating room for irrigation and debridement, and/or fracture fixation, as these physical exam findings are highly predictive of actual neurovascular and musculotendinous damage. In patients with normal physical exam findings, early isolated surgical exploration may not be warranted in the absence of other operative indications.

In conclusion, this study attempts to isolate clinical factors predicting neurovascular and musculotendinous injury and provides evidence for and against early surgical exploration. Further studies are needed that assess the long-term risks, benefits, and changes in functional outcome after early surgical exploration in patients with abnormal physical exams after upper extremity DBIs.

Ethical Approval

This study was approved by our institutional review board.

Statement of Human and Animal Rights

This study was approved by the institutional review board.

Statement of Informed Consent

Informed consent was obtained when necessary.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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