Title

Prevalence and Predictors of Pre-hospital and Emergency Department Pain Assessment, Pain Severity, and Pre-hospital Analgesic Use in Military Trauma Patients in a Combat Zone

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Publication Date

2014

Peer reviewed|Thesis/dissertation

Prevalence and Predictors of Pre-hospital and Emergency Department Pain Assessment, Pain Severity, and Pre-hospital Analgesic Use in Military Trauma Patients in a Combat Zone

By

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DISSERTATION

Submitted in partial satisfaction of the requirements for the degree of

DOCTOR OF PHILOSOPHY

in

Nursing

in the

GRADUATE DIVISION

of the

UNIVERSITY OF CALIFORNIA, SAN FRANCISCO

[redacted]

Dedication

To the Navy Hospital Corpsmen who have challenged and inspired me to keep learning, growing, and teaching. I am proud to serve with you.

Acknowledgements

Many people deserve my public and personal thanks for their contributions towards this research. First and foremost, I acknowledge the unwavering and incredible support of my husband, David Blackman, and our children, Claire and Joshua. From coaching me through the doctoral program application through reading drafts of multiple papers, to managing everything else in our lives while I have been consumed by this endeavor, David has provided the strong foundation to allow me to focus on this work. Claire has provided a steady stream of pictures and encouraging notes to accompany me to the library, and she and Joshua continue to bring incredible joy and meaning to my life. Thank you to our extended family, and our friends who have become a family. Your support has made this journey possible, and punctuated hard work with laughter, delight, and wonderful experiences.

I am thankful to my dissertation committee: Dr. Kathleen Puntillo, who first welcomed me as a guest in her classroom nearly 15 years ago, then guided me through the Critical Care/Trauma master's program, and encouraged me (and the Navy) to return for the doctoral program; Dr. Kathy Lee, who guided me to a clearer understanding of research design, and whose ability to help me envision a scholarly future and the impact of my research encouraged me through this process; and especially to my chairperson, Dr. Linda Franck, who took me on as her student despite an already full schedule, the Navy's strict timeline, and numerous variables beyond our control, but to whom I am indebted for her willingness to mentor me. Thank you for helping me to distill complex concepts into clear, logical statements, and for gently and patiently guiding my transformation into a scientist.

I especially thank the following mentors: Dr. Nancy Stotts, for encouragement during the master's program to return for the doctoral program, for providing the incredible experience of

international research collaboration, and for her friendship and support; Dr. Janice Humphreys, who chaired my qualifying examination committee, challenged and encouraged me to deepen my thinking, and was supportive during a personally difficult time; and Dr. Steven Paul and Dr. Bruce Cooper, without whose mentoring on statistical analyses and the intricacies of SPSS and Stata software this work would never have been completed.

I gratefully acknowledge the encouragement of Captain Frank Butler (Medical Corps, US Navy, Ret.) to pursue this research, and his gracious introductions to others engaged in military pre-hospital trauma care research. I thank Mike Galarneau and Judy Dye, RN at the Naval Health Research Center, and Colonel Nancy Molter, PhD, RN (Nurse Corps, US Army, Ret.), Susan West, RN and Beatrice Stephens, RN at the Army Institute of Surgical Research. Each of them enthusiastically supported the importance of my research, and all were unfailingly helpful and patient in explaining the details of registry data collection and processing.

I am grateful to the many friends and colleagues who have encouraged me through the years, and particularly as I pursued this research. I have been blessed by your friendships, your thoughtful conversations about all aspects of this work, and your confidence in my abilities. Thank you.

Finally, I gratefully acknowledge the US Navy Nurse Corps for again providing full funding for my graduate education through the Duty Under Instruction program, and for a military nursing career of amazing opportunities.

Abstract

Persistent pain after traumatic injury is a significant clinical problem. Pain assessment increases likelihood of pre-hospital (PH) and emergency department (ED) analgesic administration in civilian settings. Military health systems deliver sophisticated trauma care, yet little is known about combat zone PH and ED pain care. Because combat casualty care includes different challenges than civilian emergency care, military-specific research is needed.

This dissertation explores pain physiology and how physiologic theory provides a compelling rationale for early analgesic intervention and examines PH and ED pain assessment and PH analgesic intervention practices among US military combat zone trauma patients.

Chapter 1, the Introduction, provides an overview of the problem of combat injury pain and its impact on clinical care and outcomes. Chapter 2 reviews physiologic theories of pain processing and transition from acute to persistent pain. Pain management in PH and ED is proposed as an essential trauma care component that may reduce long-term morbidity from persistent pain.

Chapters 3 and 4 describe two original retrospective, cross-sectional studies of combat zone pain care practices in US military patients from 2010-2013. Multiple logistic and linear regression analyses, as appropriate, were used to build explanatory models of PH and ED pain assessment documentation, PH analgesic administration, and PH and ED pain severity score (0-10) using demographic, clinical, and health system variables. Analyses revealed that 18.6% of records (n = 1,258) had PH pain assessments, and this increased to 37.8% if PH vital signs were also recorded. PH analgesic administration was reported in 25% of the sample (n = 1684), increasing to 51.5% if patients had pain assessment, and 82.2% if patients had a pain severity score of 4-10. ED pain assessments were found in 60.5% of records (n = 3339). Mean pain

severity was 5.5 for both the PH and ED samples. Documentation improved each year in both samples.

Chapter 5 provides a synthesis of the work and discusses implications for research and clinical practice. Pain after traumatic injury can become a chronic, persistent condition that robs survivors of quality of life and creates an economic burden. Findings from this dissertation suggest that even in the austere combat zone PH and ED environments, pain assessment and analgesic interventions are possible. More research is needed to determine how these interventions influence the patient's trajectory of pain experience.

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Chapter 1

Introduction

Trauma is the leading cause of death and disability for persons under age 65 in the United States (US)[1] and worldwide,[2] and is frequently accompanied by moderate to severe pain.[3-5] Inadequately treated pain can interfere with recovery from trauma and become chronic and debilitating.[6,7] For example, 46% − 80% of civilian trauma survivors reported persistent post-trauma pain measured 4 months to 6 years post-injury[8-11] and among military combat-related trauma survivors at polytrauma rehabilitation centers, 68%[12] to 82%[6] reported ongoing pain. In addition to the individual burden of suffering, persistent pain in the US costs over $635 billion annually.[7,13-15] However, effective treatments for chronic persistent pain are elusive, with one study finding that only 58% of patients in comprehensive pain programs report relief.[16]

Because treating persistent pain is so difficult, one line of inquiry is to determine if early intervention for patients with trauma-related pain, e.g., in the pre-hospital (PH) period and in the emergency department (ED), decreases the risk of persistent pain. Reframing acute pain treatment immediately after trauma occurs as an opportunity to avert a potentially chronic problem could impact clinical decision-making in acute care[17-19] and ultimately improve patient outcomes.

Pain assessment, with re-assessment after intervention, has long been recognized as an essential component of pain management, both to guide interventions and evaluate the effectiveness of analgesic interventions.[20,21] Pain assessment is a critical element of an early intervention PH and ED pain management approach. However, minimal high-quality evidence is available to guide PH pain assessment and analgesic intervention practice despite recommendations for such research over a decade ago.[22-24] Evidence from the ED setting is

somewhat stronger, but recent studies demonstrate that early, effective pain management in the ED often is not achieved,[25] and ED pain assessment remains suboptimal.[26-29]

Trauma patients encounter the healthcare system in the PH and ED setting, and because pain assessment is the fundamental first step in pain care, this dissertation examines pain assessment practices in both the PH and ED settings. While the external environment (PH or ED) may have little physiologic impact, the context of the health care system is dramatically different between the two settings. In the US, PH care is commonly provided to a single injured person at a time by a team of Emergency Medical Technician-Paramedic (EMT-P) and EMT-Basic (EMT-B), with limited pain management expertise or analgesic resources.[22,23,30-34] Conversely, ED care is provided by a complex team that may include specialized emergency medicine physicians, trauma surgeons, emergency nurses, respiratory therapists, technicians, social workers and chaplains. The nature of the ED environment is such that additional patients can and do arrive at all times, creating need for triage of personnel and equipment resources, and with the potential to delay care.[35-37]

These differences in environment, personnel and medication resources, capacity and expectation for definitive care between the PH and ED settings suggest that patterns and predictors of pain assessment documentation may differ between PH and ED.[38-40] Additionally, because some proportion of patients present to the ED after PH care, it is important to determine if and how PH care influences ED practice patterns and patient outcomes.

Investigators using primarily retrospective research designs found that rates of PH pain assessment in trauma patients vary widely, from 15%[4] to 71%[3]. While lacking the generalizability of rigorously conducted randomized controlled trials, these studies, many of which included thousands of patients, provide evidence that PH pain assessment is feasible.

Most PH systems in the US report using the verbal numeric rating scale (NRS), in which 0 is no pain and 10 is the worst possible pain.[34,41-45] Alternately, some systems use a mechanical visual analog scale (VAS), an unmarked 10 centimeter line anchored by no pain and worst possible pain, on which the patient slides a marker to the level of his or her pain, which is then measured by the clinician.[46] The varying rates of pain assessment documentation and findings from qualitative studies[39,40] suggest multiple barriers to PH pain assessment documentation exist.

PH analgesic interventions have primarily included opioids, most commonly morphine or fentanyl, as well as inhalational medications nitrous oxide[47,48] and methoxyflurane.[49,50] Multiple researchers have evaluated the proportion of trauma patients treated with PH analgesics, and results vary between systems from 15%[4] to 75%.[30] Studies evaluating PH analgesic effectiveness (i.e., pain relief) are less common and difficult to compare because a definition of pain relief has not been universally adopted. A 2011 systematic review[51] that defined analgesic failure as a final pain score above 30/100 (on VAS) or 3/10 (on NRS) determined that across the 21 studies evaluated, 60% to 70% of patients were analgesic failures 10 minutes after treatment, and 30% still failed to achieve pain relief 30-40 minutes after treatment. However, investigators continue to report varying definitions of pain relief: 30% reduction in pain score,[52] decrease of one,[30,53,54] two,[55-58] or three[4,59] units on the NRS, or final pain severity score no more than 3 on the NRS or 30 on the VAS.[3,60-66]

Studies from the ED, where pain assessment has been required by Joint Commission regulation since 2001,[67] demonstrated how changes to the ED documentation tools were associated with increased rates of pain assessment documentation and ED analgesic administration.[28,68,69]

As a military nurse, my population of special interest includes more than 50,000 United States (US) military personnel injured since 2002 while supporting combat operations.[70] While there is a small body of research on civilian PH pain assessment and analgesic intervention practices with trauma patients,[3,4,56,58-65,71-75] very limited evidence exists describing PH and ED pain management practices (pain assessment and analgesic intervention) from the combat setting.[66,76-79] Given that military trauma patients are typically young adults aged 18-30, their high risk for poor pain outcomes after trauma translates to 50 to 70 years of ongoing pain and suffering for each individual. Additionally, because combat casualty care entails challenges unique to the setting and environment (i.e., less predictable PH care times, variable training and resources for PH clinicians,[80,81] higher proportion of penetrating injuries[82]), findings from civilian research may not be directly applicable to the military context.

Guidelines for US military PH care providers (Tactical Combat Casualty Care) include analgesic therapy.[83-88] In 2004, the US military established the Joint Theater Trauma Registry (now called the Department of Defense Trauma Registry, DoDTR) to capture clinical data from the point of injury through return to duty, death, or discharge from a participating facility.[89,90] Previously, investigators have reported documentation rates of PH assessment[78] and analgesic administration[77] low enough to preclude useful research on patient outcomes (i.e., 20% of records had any PH vital signs,[78] 3% to 6% of records had any PH analgesics documented[77]). While verbal clinical communication about PH assessments and interventions may have occurred, registry-based research is restricted to written documentation.

Recent efforts have been dedicated to increasing documentation of PH assessments and interventions.[78,91] Preliminary data provided by DoDTR staff revealed over 700 cases with both PH and ED pain assessment documentation (S. West, RN. Personal communication. May, 2013).

Therefore, it was determined that a sample size now exists that would be adequate to study the prevalence and predictors of PH and ED pain assessment documentation, pain severity, and PH analgesic use in combat zone trauma patients. Such a study could provide insight to inform further system improvements and promote better patient outcomes.

Therefore, this dissertation was undertaken to (1) explore current understandings of pain physiology and how physiologic theory might provide a compelling rationale for early analgesic intervention, (2) examine PH pain assessment and analgesic intervention practices, and (3) examine ED pain assessment practices among US military trauma patients injured in a combat zone. The body of this dissertation is presented in three papers prepared for journal submission.

Chapter 2 of this dissertation is a theoretical paper that argues for consideration of PH and ED pain management as an essential component of trauma care that may reduce long-term morbidity from persistent pain. The paper reviews the current physiologic theories of pain processing (transduction, transmission, perception, modulation) and transition from acute to persistent pain (peripheral sensitization, central sensitization, descending modulation). Interventions to interrupt pain processing at each step are considered for PH and ED use. Finally, recent research on PH pain assessment and analgesic practices is reviewed and synthesized. The paper concludes with specific recommendations for future PH and ED pain management research, particularly for evaluating potential relationships between PH and ED pain care and development of persistent pain.

The retrospective, cross-sectional study conducted for this dissertation research is presented in Chapters 3 and 4. The study samples were extracted from the DoDTR database and analyzed. Two samples were examined, one from the PH setting (care from point of injury to first emergency department) and one from the initial ED. The overall goals of each paper were

to: (1) identify current rates of pain assessment, analgesic administration, and pain severity and (2) determine if demographic, clinical and health system factors explained the findings. The conceptual model is presented in figure 1.

Demographic characteristics include age, gender, rank, and military branch of service. Clinical characteristics included presence or absence of vital signs, [i.e., heart rate (HR), respiratory rate (RR), and systolic blood pressure (SBP)], as well as injury characteristics [i.e., type of trauma, mechanism of injury, injury severity score (ISS)]. Health system factors were limited to year of injury and facility level of the receiving emergency department.

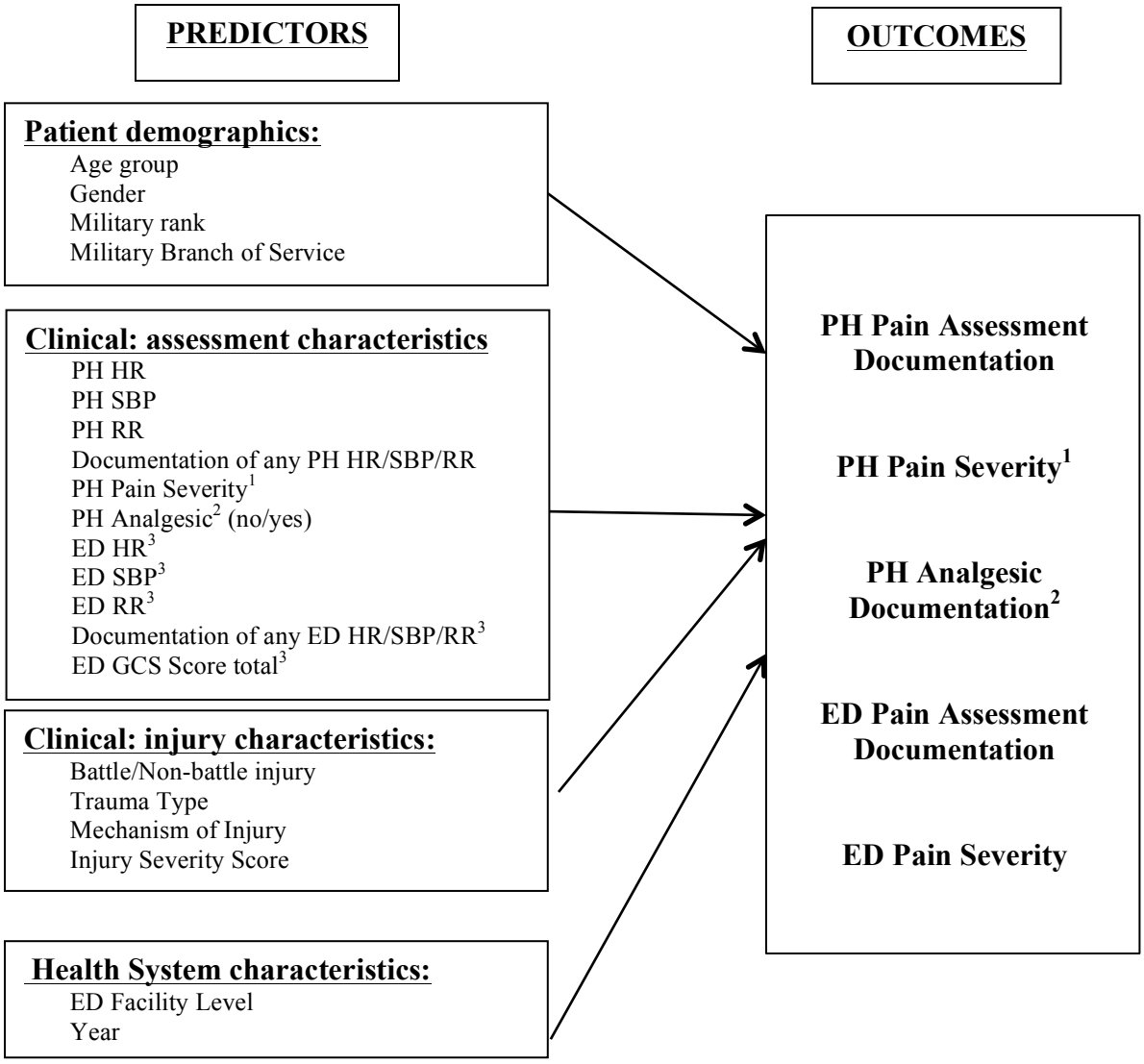
In each paper, after eliminating all records with data that suggested the patient would not be able to complete a verbal self-report (e.g., intubated, paralyzed, sedated, unconscious), the proportions of records with pain assessments (PH or ED) documented and with PH analgesics administered were determined. Pain severity scores were characterized with mean, standard deviation (SD), and median. To identify relationships between demographic, clinical and health system characteristics and pain assessment documentation, pain severity, and PH analgesic administration, univariate logistic and linear regression models were tested. Only those variables which were significant ($p < 0.05$) in univariate models were then included in a multivariable model. Backwards step-wise regression was then used in multivariate logistic and linear regression models (as appropriate) to build the most parsimonious explanatory models of pain assessment documentation, PH analgesic administration, and pain severity. The same process was repeated in the ED sample. However, because medication data are not recorded in the DoDTR, only ED pain assessment documentation and ED pain severity could be examined.

Finally, Chapter 5 discusses the key findings from the review of current theory and existing PH pain management research and the DoDTR PH and ED studies, and suggests

direction for future research and implications for clinical practice. The overarching purpose of this work is to analyze current PH pain assessment, PH pain severity, PH analgesic administration, ED pain assessment and ED pain severity in order to contribute knowledge that will inform future research, education, and practice. Ultimately, it is hoped that such knowledge will help to equip PH and ED care providers in civilian or military settings to optimally treat trauma patients' pain to optimize recovery and reduce the risk for developing persistent pain.

Chapter 1 Figure 1

Conceptual model of influences on PH and ED outcomes of pain assessment, pain severity, and PH analgesic administration from data fields recorded in the DoDTR



[1]Evaluated first as an outcome, and then as a predictor for PH Analgesic Documentation, ED Pain Assessment Documentation and ED Pain Severity.
[2]Evaluated first as an outcome, and then as a predictor for ED Pain Assessment Documentation and ED Pain Severity.
[3]Evaluated only for ED outcomes
Abbreviations: PH=Pre-hospital; ED=Emergency Department; DoDTR=Department of Defense Trauma Registry; HR=Heart Rate; SBP=Systolic Blood Pressure; RR=Respiratory Rate; GCS=Glasgow Coma Scale

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Chapter 2

Pre-hospital Analgesia: Might It Prevent Persistent Pain?

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Abstract

Purpose: The aim of this article is to reframe pre-hospital analgesic interventions for injured patients as critical steps to prevent long-term morbidity from persistent pain.

Major points: Advances in understanding the physiological processes of pain transduction, transmission, perception and modulation; transition to persistent pain; and actions of common pre-hospital analgesic interventions are reviewed. Analgesic interventions that target each step of pain processing are considered for pre-hospital use. Recent pre-hospital analgesic intervention studies are synthesized, and specific suggestions for needed research are offered.

Conclusion: Ongoing research suggests that unresolved acute pain becomes a self-propagating disease state (persistent pain) for many survivors of traumatic injury. Peripheral sensitization, central sensitization, and descending modulation may all occur, contributing to this change. Early intervention, such as pre-hospital analgesia, may reduce the risk of chronic, persistent pain, but few studies to date demonstrate successful pre-hospital pain relief. Future studies with long-term follow up are needed to test this theory.

INTRODUCTION

BACKGROUND

Traumatically injured patients experience pain.[1-4] Acute pain is an expected and protective response to injury that provides awareness of tissue damage, prompts an automatic withdrawal reflex, and, by its unpleasantness, causes a person to attend to the injury.[5] Pain was long considered an inevitable result of injury that resolves with treatment. Yet, unlike acute pain, persistent pain serves no biologic purpose and has been likened to a constant "false alarm," alerting the pain system to a "fire" that does not exist.[6] Persistent unresolved pain was often ignored, seen as a somatoform disorder, believed to be evidence of drug-seeking behavior, or thought to be an indication of a psychiatric problem.[7-9] Further, since "pain never killed anyone"[10] (p. 411) its treatment may have limited its priority for emergency care providers.[10,11]

Researchers have begun to examine persistent pain as a negative outcome of trauma and have found it to be a prevalent health problem. In this paper, persistent pain will be used to describe pain that persists after objective physiologic healing is believed to be complete, also known as chronic pain. Refer to Table 1 for definitions of concepts described in this article. Persistent pain is known to occur in 79.2% of trauma patients at four months;[12] 46-85% of polytrauma patients at least 2 years post-injury; [3] 81.5% of polytrauma patients from 3 months to five years post injury;[13] and 60% of trauma ICU survivors at 6 years post-injury.[14]

SIGNIFICANCE

Investigators report that persistent pain in the United States (US) costs over $635 billion annually.[15-18] Globally, chronic pain has become a public health crisis affecting over 20% of the population and costing billions each year.[16] Effective treatments are elusive, with some studies

finding that only 58% of patients in comprehensive pain programs report relief.[19] Given the breadth, severity, and cost of the problem in addition to unsuccessful treatments, research is turning towards prevention.

PURPOSE OF THIS PAPER

Reframing acute pain treatment as an opportunity to avert a potentially chronic problem could impact clinical decision-making in acute care.[20-22] Prompt assessment and intervention (often multi-modal analgesia) are encouraged to reduce pain, to relieve immediate suffering, and to reduce the risk for acute pain to become persistent.[23,24] However, little high-quality research exists to guide pain care in the unique clinical and environmentally challenging pre-hospital emergency setting.[25] Therefore, the purpose of this paper is to underscore the risks for trauma patients in developing persistent pain, the opportunity for pre-hospital providers to intervene, and the research needed to better guide pre-hospital emergency trauma care. To accomplish this goal, this paper will: (1) review current theories of pain physiology; (2) summarize current theories of transition from acute to chronic pain and how early intervention may be preventive; (3) examine pre-hospital pain research for feasibility and clinical effectiveness; and (4) highlight gaps in knowledge and questions to be explored in future research.

THE PAIN SYSTEM

PAIN ANATOMY

The pain system is a specialized sub-unit of the nervous system. The nervous system's general structure, with division into peripheral (PNS) and central (CNS, consisting of the spinal cord and brain) systems, was characterized over 100 years ago.[26] Research at cellular,

epigenetic, and molecular levels continues to refine our understanding of the system's complexity.

Nociceptors are specialized neural cells that detect mechanical, thermal, and chemical changes over a noxious threshold via specific receptors.[27] Like other sensory neurons, nociceptors consist of four primary functional areas: the cell body; a bifurcated single axon of varying length and diameter for transmission of impulses; a peripheral terminal (located in the skin, muscle, tendon, ligament, bone, or visceral organ of the target tissue); and a central terminal (located in the dorsal root ganglion [DRG] of the CNS).[5,27,28] Multiple ion channels and receptors on each nociceptor, while triggered by different stimuli, all determine the capacity of the cell to initiate pain processing.[29]

PAIN PROCESSING

Functionally, the experience of pain involves four steps: transduction, transmission, perception and modulation. Each step is described below, with new knowledge and analgesic targets highlighted.

Transduction

Pain processing begins with generation of an action potential at the nociceptor.[6,28] Compounds that bind to the cell membrane sensitize the peripheral terminal of the nociceptor, initiating a cascade of intracellular signals to the cell body, and onward to the central terminal.[28] Specific thresholds distinguish noxious from non-noxious stimuli.[28] Interrupting the transduction of noxious heat and mechanical stimuli is the first opportunity to reduce trauma pain.

Ice was identified as a temporary analgesic at least since the time of Hippocrates.[30] The precise mechanism by which application of cold (e.g., ice packs) reduces the pain of

musculoskeletal injuries is not entirely clear, but cold may interrupt transduction of pain impulses. Centuries of use demonstrate that short-term application of ice packs immediately after injury can offer temporary relief. However, protracted (> 20 minutes) application of ice packs can cause damage and may slow healing,[31,32] and cold pain is a well-described experimental pain model.[33] Further study to determine the mechanism of cold therapy on pain transduction, evaluate its impact on analgesic requirements, and elucidate the effect of cold therapy on ultimate healing is warranted. Meanwhile, pre-hospital care providers can consider short-term cold packs to reduce pain in traumatically injured patients.

Local anesthetics effectively halt cellular depolarization, preventing pain transduction by inhibiting the influx of sodium ions into nociceptive neurons.[34,35] Injection of a local anesthetic targeting specific nerves can provide rapid effective pain control with peripheral nerve blockade (such as a femoral block in patients with suspected femur fractures) and has been suggested as a potential pre-hospital intervention for trauma patients in pain.[36] While there is evidence of this modality's effectiveness in reducing pain, it has been reported primarily in anesthesiologist-staffed pre-hospital systems.[37-40] Feasibility and safety of pre-hospital peripheral nerve blocks were demonstrated in both registered nurse-staffed[41] and paramedic-staffed[42] EMS settings, and regional analgesia has been advocated as an emergency department competency.[43,44] Concerns about potential injury,[45] scope of practice, training requirements,[36] and how to ensure ongoing competency have yet to be resolved.

Anti-inflammatory medications such as non-steroidal anti-inflammatory drugs (NSAIDS) are thought to produce analgesia by binding to receptors for substance P (a neurotransmitter) and blocking transduction of nociceptive impulses. The potential to exacerbate bleeding through disruption of platelet aggregation contraindicates the use of most NSAIDS (such as ibuprofen)

for management of pre-hospital trauma patients. However, selected (COX-2) inhibitors such as parecoxib do not have this property and may have a role in parenteral trauma analgesia.[46] An oral selective COX-2 inhibitor (meloxicam), along with acetaminophen, is now provided to US military personnel as part of a "combat pill pack" for battlefield pain relief for moderately painful injuries.[47]

Opioids also inhibit pain transduction. Propagation of signals within the pain system is dominated by the influx or efflux from the cell of sodium, potassium, calcium and chloride.[48] Cell membrane receptors [e.g., G-protein coupled receptors (GPCRs)] that open or close channels in neural cell membranes to modulate ionic flow have been identified.[49,50] For example, transduction decreases when opioids bound to GPCRs open the channels and change sodium and calcium influx as well as potassium efflux from the cell.[51,52] A current area of research is to identify how changes to the extra- and intra-cellular chemical micro-environment change the polarization of the cell membrane and pH of the intracellular compartment. These changes may alter the frequency and amplitude of action potential transmission, which may contribute to pain severity. Opioids have been used extensively as pre-hospital analgesics for decades, in both military and civilian settings,[53,54] but concerns about safety and diversion persist.[55,56]

Another area of research focus is sex differences in opioid receptors and subsequent variation in effectiveness of morphine analgesia.[57-60] Using rodent models, researchers have determined that the distribution of mu opioid receptors in the brain (specifically, the ventrolateral periaqueductal gray and rostral ventromedial medulla) differs by sex, and males typically achieve greater anti-nociception from opioid analgesics.[58,61-63] Hormonal manipulation studies in rodents demonstrate variation in response to opioids, with poorer opioid response in castrated

males and enhanced response in ovariectomized females, further evidence that opioids may provide greater relief to males.[64,65] However, little evidence is available to answer how sex differences might affect pain processing or opioid effectiveness in acute trauma-related injury pain. Another review warns that multiple genetic, environmental and social factors all interact with these sex-based differences and individualized interventions based on patient response are advocated.[66] The few observational studies of paramedic practice that examined sex/gender differences in pre-hospital opioid administration found that men were more likely to receive opioids, but neither dose nor analgesic effectiveness were evaluated.[67-69]

Transmission

Transmission is how an action potential (see Table 1) moves from the target tissue through the PNS to the CNS. Multiple neuromodulators and neurotransmitters impact propagation frequency and speed of action potential transmission.[5,28,70] Upon stimulation by peripheral fibers, spinal neurons are activated to transmit pain messages upwards to the brain, where multiple areas are active in interpreting the signals as pain.

Centrally acting alpha-2 (α-2) agonists such as clonidine and dexmedetomidine are thought to provide analgesia by interrupting pain transmission, although precise mechanisms are still under study.[71] Dexmedetomidine has been recommended for use in wound care, burn care, and intensive care, due to its analgesic and sedative effects while reducing opioid demand.[72-75] No studies of dexmedetomidine or clonidine in the pre-hospital setting were identified. Local anesthetics (previously described) are also thought to prevent pain transmission.[76]

Perception

Occurring a mere fraction of a second after the initial impulse is generated, pain perception is the process by which the brain recognizes a sensation as painful.[29] Multiple neural

structures are involved in pain perception. Cortical structures (e.g., somatosensory cortex) are thought to provide sensory/discriminative information such as pain's location and intensity, while subcortical structures (e.g. thalamus, midbrain periaqueductal gray [PAG], pons, and medulla) process a sensory/emotional/affective response.[29]

Opioids and ketamine are analgesics most commonly used in the pre-hospital setting that change a patient's perception of pain. Ketamine blocks the N-Methyl-D-Aspartate (NMDA) receptor's action of impulse propagation.[48] Ketamine has been used both alone and combined with morphine in the pre-hospital setting.[77-80] Patients treated with ketamine report rapid decrease in pain scores[77] and required lower doses of opioids than patients treated with opioids alone.[78,81] Dysphoria, hallucination, and emergence phenomenon are known side effects of ketamine, but are thought to be less likely at low doses.[82] In pre-hospital clinical trials that combined ketamine with morphine, dysphoria or other neuropsychological side effects have been reported in 0-1%,[79,83] 6%,[78] and 36%[81] of patients treated with pre-hospital ketamine. Concommitant use of benzodiazepines may control dysphoric effects.

Modulation

Modulation is the process by which pain signals between the periphery and brain are attenuated or amplified.[5,6,29] Instead of a fixed network in which a given stimulus always produces the same response, the pain system is best conceptualized as open to modification at every point and level, from nociceptor to brain.[29] Neurotransmitters and neuromodulators (see Table 1) are highly complex pain modification substances that exist within and between neurons, many of which also play critical roles in other body systems. Together, these substances facilitate and inhibit signaling; up- and down-regulate the expression of receptors; and impact the

total life cycle of these cells. However, the mechanism by which they regulate the frequency of pain action potentials is not yet completely understood.[84,85]

Neurotransmitters and their receptors are potential targets for analgesic action. Ketamine, as previously discussed, is one medication with demonstrated safety and efficacy in pre-hospital analgesia, and is also proposed for use in the emergency department.[86,87]

Neuropeptides can also exhibit both excitatory and inhibitory capacity, but are grouped separately due to their slower mechanism of action. Excitatory neuropeptides include substance P, neurokinin A, calcitonin gene-related peptide (CGRP), and cholecystokinin (CCK).[48] As previously described, NSAIDS achieve analgesia by blocking substance P receptors and inhibiting cyclooxygenase, which then prevents formation of prostaglandins, prostacyclin, and thromboxanes.[88] Inhibitory neuropeptides bind to nociceptors and slow or prevent the transmission of pain signals, and include somatostatin, cannabinoids, and enkephalins. Despite encouraging animal evidence,[89] human studies of cannabinoids to treat acute (post-surgical) pain were unsuccessful,[90] and while research with cannabinoids for acute pain is ongoing, no immediate clinical applications are apparent.[91-93]

Enkephalins, endogenous substances that bind to opioid receptors to provide analgesia, are also research targets. Current pharmacologic research includes development of medications that would inhibit enkephalin destruction.[94,95] Current non-pharmacologic research includes use of acupressure and acupuncture,[96,97] theorized to work by stimulating enkephalin production.[98-100] Auricular acupuncture has been advocated for pre-hospital pain management,[101,102] as has acupressure.[101,103-105] While non-pharmacologic therapies hold unquestionable appeal due to perception of lower risk perception, evidence is scant and questions

remain related to adequate training, competency maintenance, proper credentialing, and scope of practice.[100]

CURRENT THEORIES OF TRANSITION FROM ACUTE TO PERSISTENT PAIN

Specific cellular and molecular processes that indicate transition from acute to persistent pain have yet to be precisely defined and timed.[106] However, the phenomenon is clinically familiar: the original injury is healed, yet the patient still reports pain for which no organic cause can be found. One challenge in acute-to-persistent pain research is that some social factors found in human observational studies that contribute to persistent pain e.g., socio-economic status, work-related injury, social role, have yet to be modeled in animals.[107-110] Despite that obstacle, much has been learned about the pathophysiological changes that occur over time.

PHENOTYPIC SWITCHING

As described by Basbaum and colleagues[5] nociceptive neurons are different from other neurons because their central and peripheral terminals are biologically equivalent, which enables transmission of impulses in either direction. However, action potentials moving "backwards," generated by an ectopic focus, are abnormal. This leads to potentially maladaptive changes: spontaneous activity, allodynia (i.e., a lowered threshold for mechanical sensitivity), and amplified responses to stimuli (i.e., hyperalgesia, an exaggerated response to a mild stimulus).[5]

The nociceptive neuron may change functional patterns after injury, a phenomenon of cellular reprogramming referred to as a "phenotypic switch."[111,112] For example, sun-burned tissue exhibits allodynia and hyperalgesia.[113] When sunburn occurs, the phenotypic switches thought to produce allodynia and hyperalgesia are: (1) a nociceptor detecting change across a

larger area of skin than prior to injury (expansion of receptive field); and, (2) a new expression of substance P by Aβ fibers (non-noxious mechanical nerve fibers).[5] The Aβ fiber begins to function as a nociceptive fiber and contributes to inflammatory hypersensitivity.[114] This change in response is functional and adaptive when it leads an injured person to prevent re-injury to damaged tissues (e.g., not walking with a broken foot). However, the change can become dysfunctional, causing hypersensitivity in the presence of a non-noxious stimulus, if it does not resolve when healing is complete. Research is needed to identify interventions that facilitate the return of nociceptors to their pre-injured state. One potential may be to reduce the intensity and duration of exposure to painful stimuli through the use of pre-hospital analgesics.

Neurochemical and anatomical signals of change from acute-to-persistent pain are the target of current research in: post-surgical patients;[115-117] patients with painful diabetic neuropathy[118] or post-herpetic neuralgia;[119] and patients with whiplash;[120,121] acute low back pain,[122,123] and other musculoskeletal disorders.[124,125] Three distinct but inter-related maladaptive neuroplastic changes are seen across populations: peripheral sensitization, central sensitization, and descending modulation. Current research and understanding of each change and its potential to be impacted by pre-hospital interventions will now be described.

PERIPHERAL SENSITIZATION

It is postulated that change in the microenvironment of peripheral nociceptive terminals is driven by tissue damage that disrupts cellular integrity. As nearby cells are lysed (through thermal, chemical, or mechanical destruction), the release of their intracellular contents causes a local acidosis. The substances released include inflammatory mediators such as cytokines, chemokines, bradykinin, histamine, prostaglandin and growth factors. These substances have the ability to propagate inflammation and further provoke pain by activation of the nociceptor

terminal itself.[119,126] Additionally, nociceptor sensitizers serve a catalytic effect, lowering the threshold of the peripheral terminal so that it becomes responsive to normally innocuous stimuli.[6,127,128] Anti-inflammatory agents (both oral and parenteral) may best target the inflammation.

CENTRAL SENSITIZATION

Central sensitization (see Table 1) results in increased frequency of action potentials, initially triggered by ongoing input from the peripheral terminal.[129] An additional mechanism has been described as transcription-dependent: that is, transcriptional changes occur within the DRG cell such that stimuli which were originally inadequate to trigger a response (subthreshold) become capable of triggering an action potential.[130-132] Investigators examining central sensitization found that ketamine (acting on CNS receptors) was successful in reducing mechanical allodynia in rats.[133] Clinically, researchers who performed a systematic review of ketamine for prevention of persistent post-surgical pain reported that protocols were too varied, sample sizes too small and patient populations too heterogeneous to determine if ketamine offered any protective effect.[134] However, the use of ketamine, an NMDA antagonist, has been shown effective in reducing pain in the pre-hospital setting.[77,78,83] Unlike opioids, ketamine increases blood pressure and provides bronchodilation without decreasing respiratory drive, making it a safer option for patients with hypotension or for whom advanced airway interventions are high risk or unavailable.[135]

Neuroimmune interactions may also be involved in central sensitization.[112,130,136-139] Macrophages are ubiquitous in body systems as first responders to infection and cellular damage. Normally quiescent microglial cells of the CNS (particularly the spinal cord) become rapidly activated to a more macrophage-like state after nerve injury.[140] Thus, within the CNS, the

microglial cells provide an immediate immune response to cellular damage. Glia may change patterns of gene transcription within the neurons and provide cytokines and chemokines that serve to promote and maintain nociceptor sensitization.[137] The ultimate result of these sensitizing processes is that pain becomes self-propagating, generating action potentials in response to normally innocuous stimuli, or even independent of external stimuli.

DESCENDING MODULATION

The final element required for the transition from acute to persistent pain is descending modulation. In pain system studies of an organism responding to an acute nociceptive stimulus, modulation is multifaceted: both attenuation and amplification are observed. The loss of pain inhibition is one component of transition to persistent pain.[137,138] Although animal models have identified potential mechanisms of decreased descending inhibition,[141,142] these findings have not yet been translated to humans. Transcutaneous electrical nerve stimulation (TENS) is one intervention targeting pain modulation that has been tested for treatment of pre-hospital acute pain, and a recent systematic review of four pre-hospital randomized controlled trials concluded that TENS was more effective than placebo in reducing moderate to severe pain.[143] However, further research is needed to determine which patients will benefit most from pre-hospital TENS therapy, what types and locations of pain are most responsive, and how effectiveness of TENS compares with analgesics.

The concept of a dynamic pain/analgesic response suggests that the system has multiple targets for intervention.[144,145] It may be that traumatic pain treated aggressively after initial injury may interrupt the transition process and make persistent pain less likely. Prompt, effective analgesia may offer the best available defense for trauma patients against the transition to persistent pain.

PRE-HOSPITAL ANALGESIA PRACTICE AND EVIDENCE

Pain research in the pre-hospital setting is a growing field. Since 2000, and the identification of pain control as an important EMS outcome,[146] more research on pre-hospital analgesic interventions with non-cardiac patients has been published. While nitrous oxide and methoxyflurane have been advocated in the British and Australian pre-hospital health systems,[147-150] the use of inhalational analgesics has not been widely adopted in US emergency medical services (EMS) systems. Early studies using pre-hospital opioids examined only cardiac patients, because pain relief in [presumed] acute cardiac syndromes was directly associated with improved mortality.[151]

Park and colleagues used a Delphi technique among military and civilian pain specialists to identify optimal outcomes in a 2010 systematic review of pre-hospital analgesia.[152] Most clinicians agreed on the following five outcomes: pain should be reduced to mild, within 10 minutes; patients should respond to verbal stimuli, require no airway or ventilatory support, and experience no harmful adverse events. Park and colleagues then analyzed 21studies published between 1946 and 2009 (combined n=6,212), of which 11 studies reported pre-hospital opioid use. The proportion of patients achieving pain relief and rates of adverse events were evaluated. Pain relief was defined as no more than mild pain (visual analogue scale [VAS] score of 30 or less on a 100mm line, or numeric rating scale score of 3 or less on a 0-10 scale) within 10 minutes. Most (60-70%) patients did not achieve pain relief by the 10 minute goal, and 30% still did not have pain relief after 30-40 minutes. Adverse events related to respiratory or cardiovascular status were extremely rare, with no patient requiring ventilatory support and only two needing naloxone (reversal agent). Analgesic efficacy was reported by only one of the three

ketamine studies reviewed. Fascia iliac blocks were effective, but only for patients with femur fractures, a small proportion of PH trauma patients.[152]

PRE-HOSPITAL PAIN MANAGEMENT FOR TRAUMA PATIENTS

A search was conducted for studies of pre-hospital analgesic interventions that reported the number of traumatically injured patients for whom both analgesic interventions and pre- and post-analgesic pain scores were reported, published since or not included in the 2010 Park and colleagues[152] review. All included studies were published between 2007 and 2014. Excluded were 12 pre-hospital analgesic studies (combined n = 674,609) because they: did not indicate analgesic effectiveness by reporting pre- and post-intervention pain assessments;[68,153-157] only examined an exclusively geriatric population;[158] did not report findings for trauma patients separately;[55,159] or reported on intramuscular morphine[80] as there is evidence that it can be harmful in trauma patients. There were 10 retrospective cohort studies[1,2,150,160-165] (combined n = 98,194) identified, as well as 3 prospective observational cohort studies[4,166,167] (combined n = 3,459), and 6 randomized controlled trials (combined n = 539).[78,79,81,83,168,169]

Randomized controlled trials (RCTs) are widely regarded as the "gold standard" of clinical research. Compared to the millions of patients cared for each year, relatively few EMS interventions have been tested with RCTs.[170] Many EMS practices are simply adapted from the emergency department or other clinical environment without specific pre-hospital validation. While the environment (limited space, time constraints, challenges for ensuring unpressured informed consent) is daunting, and study enrollment often takes longer than anticipated (e.g., two years instead of six months)[78,79] controlled clinical pain research in the pre-hospital environment is possible. Physician-staffed EMS units conducted four of the studies, three in France[79,81,168]

and one in the United States.[169] The remaining two RCTs were conducted in paramedic-[78] and registered nurse-staffed[83] systems in Australia and Sweden, respectively.

These clinical trials compared opioids (e.g., intravenous (IV) morphine vs. IV sufentanil[168] or IV morphine vs. IV fentanyl[169]), or compared IV morphine alone to IV morphine plus IV ketamine.[78,79,81,83] Pre-and post-intervention pain assessments were reported for all patients, but different definitions of pain relief (clinical effectiveness) made comparison between studies and generalization to other populations difficult. While three investigations[78,81,83] concluded that morphine plus ketamine was more effective than morphine alone and reduced the total morphine requirement, Wiel, et al[79] reported no significant difference. Both of the opioid comparison studies found no difference in final pain score. Overall, the most striking finding was that, when evaluated against a goal of final pain score no greater than 3/10, analgesic failure (final pain score > 3/10) was reported in 30% - 50% of patients in all of the studies.

The three prospective observational cohort studies examined pre-hospital safety and effectiveness of intranasal fentanyl,[166] predictors of pain relief and adverse events,[167] and prevalence and management of pre-hospital acute pain.[4] Two studies defined pain relief as a final score of no more than 3/10, yet only 38%[167] and 51%[4] of patients, all treated with IV opioids, and most with an additional analgesic as well (e.g., paracetamol), achieved this goal. Findings for trauma patients treated with intranasal fentanyl were also dismal; 50% of patients had a final pain score of at least 5-6/10.[166] Rather than a score of 3 or less, however, authors defined clinically relevant pain reduction as a decrease of at least 2 units on the 0-10 scale. Therefore, their overall result for "analgesic success" was 79% of patients (including 70%-85% of trauma patients).

Routine pain assessment and re-assessment after analgesic intervention are essential steps in pain management. The retrospective observational studies demonstrated through audits of pre-hospital documentation that adherence to this practice varies widely, from 15%[2] to 75%.[162] Five of these studies compared pain relief between trauma and chest pain patients.[150,160-162,171] Two studies[160,161] found that chest pain patients were more likely to achieve relief. While Bakkelund, et al, reported higher opioid doses for trauma patients,[160] Siriwardena and colleagues[161] did not report dose information, but found that trauma patients were less likely than chest pain patients (39.4% compared to 25.6%) to receive opioids. Jennings and colleagues[171] and Fleischman and colleagues[162] both reported that pain relief was not significantly different between pre-hospital chest pain and trauma patients. Conversely, Middleton, et al., found that when patients with chest pain were compared to trauma patients in a multivariable logistic regression model, the patients with chest pain were 16% less likely than patients with trauma to achieve pain relief (OR = 0.84, 95% confidence interval 0.77-.09).[150] Similar to findings from the RCTs above, pain relief was defined in various ways, but was achieved by only 40%-70% of patients across all studies.

Educational interventions that focused on pain and analgesic practice with pre-hospital care providers (both paramedics[156,172] and physicians[173]) improved both assessment and intervention rates. Systems where pre-hospital pain assessment, intervention, and documentation are prioritized may achieve better pain management and pain documentation outcomes. Together, these findings demonstrate the feasibility of conducting both prospective and retrospective research in the challenging pre-hospital setting. The practice audits demonstrate the feasibility of incorporating pain assessment, safe administration of pre-hospital analgesic medications, and pain reassessment into routine care. However, these data suggest that even in

system in which pre-hospital pain care is a priority, a substantial proportion of patients do not experience pain relief. Given the concern that unrelieved acute pain may trigger the development of persistent pain, research on more effective pre-hospital interventions and their outcomes is needed.

RECOMMENDATIONS FOR FUTURE RESEARCH

Expanding research questions to include long-term outcomes in addition to pain severity ratings during the pre-hospital phase of care is important for future research. Jennings and colleagues reported pain outcomes at 6-12 months for participants in their RCT of IV morphine vs. IV morphine plus IV ketamine.[174] Despite better pre-hospital outcomes for the morphine plus ketamine group, no difference in long-term pain outcomes was detectable. An important first step in evaluating distal impact of pre-hospital practice, these findings lead to additional considerations. These include evaluating the trajectory of subsequent ED pain levels and analgesic interventions, as well as operative interventions (which each create risk for persistent pain), and evaluation of social and psychological variables.

As long-term differences are evaluated, it is important to determine if the critical factors are medication exposure, duration of intense pain, or both. For example, is there a minimum dose needed to interrupt biochemical changes and potentially prevent phenotypic switch and central sensitization? Or is there a time interval for severe pain that, if exceeded, increases a patient's risk for persistent pain? No studies were identified that evaluated if patients who reported effective pre-hospital analgesia (a decrease in patient-reported pain severity to a score of 3/10 or less) were less likely than those with prolonged severe pain to develop persistent trauma-related pain.

Existing research demonstrates that pre-hospital documentation of pain assessment and analgesic interventions are achievable goals, and that pre-hospital analgesics can be safely administered. Studies are needed to identify and determine the importance of rapid medication administration, reduction in pain, or a critical time threshold (duration) of a given pain intensity as being most essential in developing persistent pain. Pre-hospital interventions can then be tailored to reduce risk. Further research is needed to improve data capture for non-medication interventions. Such evidence is needed in order to evaluate the effectiveness of such interventions (ice-packs, splinting), many of which have theoretical support but little empirical data to guide practice.[170,175,176]

Better characterization of future research samples (e.g., age, sex, severity of injury) is needed to enhance generalizability of findings. Many studies deliberately excluded hemodynamically unstable patients, a subgroup that merits particular attention, as they are at high risk for persistent pain (e.g., patients with subsequent intensive care unit admission).[107,177-179]

CONCLUSION

This paper has summarized recent advances in pain physiology and current theories on transition from acute to persistent pain. From the evidence presented, we suggest that effective early (i.e., pre-hospital) pain control fulfills the overarching goal to reduce suffering and may mitigate risks for persistent pain. Review of existing pre-hospital pain research illustrated that pre-hospital analgesic interventions can be safely delivered. Further, current research was synthesized and specific recommendations for future research offered.

Paramedics provide critical life-saving interventions without the full breadth and depth of knowledge possessed by the receiving Emergency Department team. Similar to the success of early defibrillation, paramedics can provide life-saving care and effective analgesia to injured

patients without comprehensive knowledge of pain neuroanatomy and physiology. Awareness of the pain system's complexity, the evidence that patients who survive traumatic injury are at risk for persistent pain, and the potential for pre-hospital intervention to reduce risk for persistent pain may help drive EMS practice changes. Ensuring that early pain relief is a priority in pre-hospital trauma care may improve pre-hospital pain management and decrease the risk for pain to become persistent.

Chapter 2, Table 1. Definitions

Persistent pain	The term used when pain persists for at least 3 months, particularly after the painful stimulus has been removed or resolved.[5,6] The International Association for the Study of Pain (IASP) includes both duration and appropriateness in the definition of persistent pain: pain without apparent biologic value that has persisted beyond the normal tissue healing time (usually taken to be three months).
Action potential	The electrical signal that transiently makes the transmembrane potential positive and carries information along the length of the axon to move through the nervous system.[27]
Neuromodulators/ neurotransmitters	Chemical substances that affect how impulses move between neurons. Neuromodulators include opioid peptides such as enkephalins, endorphins, dynorphins. Neurotransmitters, such as serotonin, acetylcholine, dopamine, GABA, glycine, and norepinephrine, are released by the presynaptic neuron and either excite or inhibit the post synaptic neuron.[26,180]
Peripheral sensitization	"Increased responsiveness and reduced threshold of nociceptive peripheral neurons to the stimulation of their receptive fields" (IASP, p. 213).
Central sensitization	"Increased responsiveness of nociceptive neurons in the CNS to their normal or subthreshold afferent input"[6] (IASP, p. 209)
Emergence phenomena	A collective term for visual or auditory hallucinations, vivid dreams, and mood changes reported by patients after treatment with ketamine. Incidence of emergence phenomena may be dose dependent, as lower rates are reported after subanesthetic doses used in pre-hospital use than after intra-operative use.

Chapter 2 References

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Chapter 3

Prevalence and Predictors of Pre-Hospital Pain Assessment, Pain Severity, and Analgesic Use in Military Trauma Patients, 2010 − 2013

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Acknowledgement:

The authors acknowledge Department of Defense Trauma Registry (DoDTR) for providing data for this study.

Abstract

Objective: We describe pre-hospital (PH) pain care practices for US military personnel injured in Iraq and Afghanistan 2010 – 2013.

Methods: We performed a retrospective, cross-sectional study using the Department of Defense Trauma Registry. We tested demographic, clinical, and health system variables for associations with three outcomes: 1) pain assessment documentation; 2) pain severity (0-10 scale); and 3) analgesic administration (yes/no). Including only variables with significant associations, we used backward stepwise regression to develop explanatory models for each outcome.

Results: Patient records (n = 3,317) were evaluated for documentation of PH pain assessment and analgesic administration. The prevalence of PH pain score documentation was 37.8% (n = 1,253). Overall, the proportion of records with PH pain scores increased over time: 7.4% (2010), 8.0% (2011), 40.4% (2012), and 42.7% (2013). Severity of pain scores ranged 0–10; mean = 5.5 (SD = 3.1); median = 6 (IQR = 3-8). Analgesics were reported for 50.8% (n = 1,684), of whom 38.3% had a pain severity score documented. The pain assessment documentation model included any documented vital signs, injury year, and mechanism of injury and explained 19.3% of the variance in documentation. The pain severity model included vital signs and injury severity score (ISS) and explained 5.0% of the variance in severity. The analgesic model included any vital signs, pain severity, trauma type, mechanism of injury, ISS and year.

Conclusion: Pain assessment and treatment documentation improved each year, but remain suboptimal. Available data yielded poor prediction of the outcomes of interest,

emphasizing the importance of individual assessment. Analgesic effectiveness could not be evaluated.

INTRODUCTION

BACKGROUND

Trauma is the leading cause of death and disability for persons under age 65 in the United States (US)[1] and worldwide,[2] and is frequently accompanied by moderate to severe pain.[3-5] Inadequately treated pain can interfere with recovery from trauma and become chronic and debilitating.[6,7] For example, 46% − 80% of civilian trauma survivors report persistent post-trauma pain measured 4 months to 6 years post-injury.[8-11] Among military combat-related trauma survivors at polytrauma rehabilitation centers, 68%[12] to 82%[6] reported ongoing pain.

IMPORTANCE

Providing early analgesic intervention, such as during pre-hospital (PH) care may improve long-term pain outcomes.[13-15] Another important element of optimal emergency care after traumatic injury is pain assessment.[16,17] Pain assessment documentation increases likelihood of PH analgesic administration in civilian PH[18,19] and emergency department (ED)[20-22] settings. However, recent published data on military PH care showed that only 4.9% of records (2002-2009) had any PH vital sign (heart rate, blood pressure, respiratory rate, pain severity score) data[23] and only 6.7% of records (2007 − 2009) reported PH analgesic administration.[24] Since then, the military has placed greater emphasis on accountability for documentation of PH care and has worked to improve PH data capture.[25-27] Understanding what influences pain assessment documentation, pain severity, and analgesic administration on the front lines of military trauma care is key to ensuring early pain control.

GOALS OF THIS INVESTIGATION

Given the importance of PH pain care and renewed emphasis on its documentation in military trauma care, this study examined PH pain management for US military personnel in Iraq and Afghanistan (2010 − 2013) to:

1. Determine the prevalence of PH pain assessment documentation
2. Determine PH pain severity
3. Determine the prevalence and type of PH analgesic administration
4. Identify associations between demographic, clinical, and health system characteristics and PH pain assessment documentation, PH pain severity, and PH analgesic administration
5. Develop explanatory models of the influence of demographic, clinical, or health system factors on PH pain assessment documentation, pain severity, and analgesic administration.

METHODS

STUDY DESIGN

This retrospective, cross-sectional study analyzed de-identified data from the US Department of Defense Trauma Registry (DoDTR). Figure 1 depicts proposed conceptual relationships between demographic, clinical, and health system characteristics and PH pain assessment, pain severity, and analgesic administration outcomes.

DATA SOURCE

The DoDTR includes over 50,000 patient trauma care and outcomes records since 2004 from point of injury through rehabilitation.[28] The DoDTR is unique among trauma registries

because it was designed to capture PH pain assessments as well as other clinical and demographic variables. Patient data are entered prospectively in the DoDTR at field medical facilities by trained trauma nurse registrars, and records are updated at subsequent facilities until discharge from participating facilities. Because the researchers had no access to personally identifiable information, the study was deemed non-human-subjects research and exempt from review by the Committee on Human Research at the University of California, San Francisco.

STUDY POPULATION AND SETTING

Inclusion criteria limited the population to DoDTR records of US military personnel receiving treatment for their first combat-zone traumatic injuries who were alive on arrival to a US military medical facility and required inpatient care from January 1, 2010 − August 31, 2013 in the military operations Operation Iraqi Freedom (OIF), Operation Enduring Freedom (OEF) and Operation New Dawn (OND). All of the patients in the sample had care documented from the PH phase of care (point of injury to first ED). Excluded were records of Iraqi or Afghan military personnel, coalition military personnel, civilians, enemy combatants, and US military personnel who received outpatient care only or were deceased upon arrival.

DEMOGRAPHIC CHARACTERISTICS

Demographic data included military service and rank, gender, and age. Mortality was recorded upon discharge from first facility and at final contact with DoDTR. Race and ethnicity are not recorded in the DoDTR.

CLINICAL CHARACTERISTICS

Relevant PH clinical data included heart rate (HR), systolic blood pressure (SBP), respiratory rate (RR), intubation (yes or no), neuromuscular blockade administered (yes or no), sedation (yes or no), and pain score using the 0-10 Numeric Rating Scale (NRS). Vital signs

were categorized as low, normal, or high according to standard values: HR < 60, 60-100, or > 100; SBP < 110, 110-130, or > 130; RR < 12, 12-16, or > 16.[29,30] Analgesic data included administration of morphine, fentanyl, and ketamine (yes or no for each medication). Because dose and route of administration were missing for the majority of patients, these data were not extracted.

Injury-related data included trauma type (blunt, penetrating, burn, or other), injury classification (battle or non-battle), primary mechanism of injury (explosion, gunshot wound [GSW], motor vehicle crash [MVC]/machinery/fall, or other), Abbreviated Injury Scores (AIS), and Injury Severity Scores (ISS). ISS was calculated by DoDTR personnel based on the highest AIS using a previously described method.[31] ISS ranges from 0-75 and is typically categorized as minor (0-15), moderate (16-25), severe (26-50), and critical (51-75).[32]

HEALTH SYSTEM CHARACTERISTICS

Health system characteristics included military operation supported (Operations Iraqi Freedom and New Dawn were in Iraq; Operation Enduring Freedom was in Afghanistan), injury month and year, and name and level of first ED. Method of PH transport (dedicated medical air or ground, "lift of opportunity" air or ground) and qualifications of PH medical personnel[33-36] were only reported for a small fraction of patients, and therefore were not extracted.

ANALYSIS

INCLUSION OF RECORDS FOR ANALYSIS

Figure 2 shows the derivation of the samples for the three analyses: PH pain assessment documentation; PH pain severity; and PH analgesic administration. All analyses were conducted with Stata/SE Release 13 (StataCorp: College Station, TX. 2013).

MANAGEMENT OF MISSING DATA

Missing clinical data is a known deficiency of the DoDTR,[23,24,37] particularly for the PH setting, and use of complete case analysis would have excluded nearly 80% of records, reducing statistical power and creating biased results.[38,39] Therefore, multiple imputation (MI) was used to maximize the data available for analyses and reduce bias in estimation.[40]

Percent of cases with non-missing data are shown in Table 1. Potential predictors for which data were missing were HR, SBP, RR and pain severity score. The distribution of observed vital sign data was highly skewed, and the imputation model with three categories failed to converge. Therefore, the low and high categories were combined to create binary variables (normal/abnormal) for HR, SBP, and RR.

MI with chained equations is an appropriate method when missing data include dichotomous, ordinal and categorical variables, as it accommodates non-normal distributions.[41-43] Therefore, MI with chained equations using logistic regression was used to impute normal/abnormal PH vital signs (HR, SBP, and RR). PH pain score was also imputed, using truncated regression (lower limit = 0, upper limit = 10). To reduce bias in the estimates, 100 imputed data sets were generated.[39-41,44-46] The imputation models included all variables with missing data predicted by all remaining variables, including the outcome variables.[40]

DESCRIPTIVE ANALYSES

Demographic, clinical, and health system characteristics of all records that met inclusion criteria and the two subsamples with adequate data for analysis (PH Assessment and Analgesics, PH Pain Severity) are presented in Table 1. Simple proportions and percentages were then computed.

REGRESSION ANALYSES

Relationships between all potential predictors and the outcomes of interest (PH pain assessment documentation, PH pain severity score, PH analgesic administration) were explored using logistic or linear regression, as appropriate.[46-50] Post-hoc pairwise comparisons for categorical predictors were carried out with the Bonferroni correction.

Finally, for each outcome, all predictors with statistically significant relationships (p <0.05) in the simple regressions were entered into a multi-variable model. Backwards step-wise regression was then used to achieve the most parsimonious model,[47,48] and post-hoc pairwise comparisons of categorical variables were completed with the Bonferroni correction.

RESULTS

DEMOGRAPHIC CHARACTERISTICS

Study inclusion criteria were met in 6,755 records of unique patients (see Figure 2). Table 1 reports demographic, clinical, and health system characteristics for the total sample of eligible records and two analysis samples: 3,317 records were evaluated for documentation of pain assessment and PH analgesic administration; 1,253 records were evaluated with respect to pain severity scores. Because the samples were very similar, characteristics for the total sample of 6,755 are presented, with differences in each analysis sample highlighted. Patients were predominantly 18 − 25 years old (mean age = 25.6 years) and held a junior enlisted rank in the Army or Marine Corps; 97% were male. Overall, 87 (1.29%) patients died; 37 (42.5%) died at the first facility in which they were treated, and battle injuries accounted for 31 of the 37 deaths. Of the pain assessment and analgesic administration sample, 38 patients (1.1%) died; 17 (44.7%) died at the first facility in which they were treated, and battle injuries accounted for 31 of the

38 deaths. Of the PH pain severity sample, 6 (0.5%) died; 2 died at the first facility in which they were treated and battle injuries accounted for 5 of the 6 deaths.

CLINICAL CHARACTERISTICS

Of records with non-missing data, over half of the patients had normal HR and RR documented, and less than 5% had low HR or RR, whereas only 34.5% of patients had normal SBP. Battle injuries (predominantly explosions, followed by gunshot wounds) comprised 70% of injuries. Non-battle injuries were most commonly the result of motor vehicle crashes, machinery or falls. The percentages of blunt (48.7%) and penetrating (49.4%) traumas were nearly equal, and few (1.7%) patients had a primary burn injury. Minor injuries (Injury Severity Score [ISS] 1-15) were predominant (82.1%) (Table 1).

HEALTH SYSTEM CHARACTERISTICS

The majority of patients (90.6%) were injured supporting operations in Afghanistan, and most (70.3%) were transported to Level III facilities. Percentage rates were higher among patients with documented pain assessment and analgesic administration (93.2% and 79.9%) and pain severity scores (94.3% and 82.1%), respectively.

PH PAIN ASSESSMENT AND ANALGESIC DOCUMENTATION AND PAIN SEVERITY-UNIVARIATE ANALYSES

After discarding 3,438 records missing all vital sign, pain assessment, and analgesic data, 3,317 records were available for analysis (Figure 1). Across records in the pain assessment and analgesic sample, the prevalence of PH pain score documentation was 37.8% (n = 1,253). Overall, the proportion of records with pain scores increased from 2010 to 2013. Pain severity scores ranged from 0 − 10, with a mean of 5.5 (SD = 3.1), and median of 6.

Analgesics were reported for 1,684 patients (50.8%), of whom 645 (38.3%) had a pain severity score documented. Morphine was the most commonly reported analgesic (1,013 patients, 60.2% of patients with documented analgesics), followed by fentanyl (670 patients, 39.8%) and ketamine (250 patients, 14.8%). Ketamine use increased from 10% of all analgesics in 2010 and 2011 to 19.5% in 2012 and 38.4% in 2013. Fentanyl use also generally increased over time: 34.9%, 32.5%, 52.4% and 46.4% of patients receiving analgesics in 2010 to 2013. Morphine use declined from 68.2% of analgesics in 2010 and 70.3% in 2011 to 44.2% in 2012 and 40.0% in 2013.

In univariate logistic regression models, likelihood of pain assessment was increased if vital signs were documented, if the mechanism of injury was anything other than explosion, gunshot, motor vehicle/machinery/fall, or if the patient was transported to a Level III ED facility rather than a Level IIa or IIb facility. Pain assessment documentation was also increasingly likely in each successive year from 2010 to 2013. Conversely, pain assessment was less likely to be documented for patients with an abnormal RR, or patients in the Marine Corps compared to Army. Test statistics and confidence intervals of the odds ratios are shown in Table 2.

Univariate linear regression demonstrated that abnormal HR, abnormal RR, and ISS category of moderate or severe compared to minor were associated with higher pain severity scores (Table 3). No differences in pain severity were found between other ISS categories.

In univariate logistic regression models, documentation of analgesic administration was more likely with: abnormal HR; abnormal RR; penetrating versus blunt injuries, gunshot or explosion compared to motor vehicle/machinery/fall and all other mechanisms of injury; battle injuries versus non-battle injuries; moderate or severe ISS compared to minor; injury in 2012

compared to 2010 or 2011, and higher pain scores (Table 4). Documentation of analgesic administration was less likely (OR=0.44) when any PH vital signs were documented.

PH PAIN ASSESSMENT AND ANALGESIC DOCUMENTATION AND PAIN SEVERITY - EXPLANATORY MODELS

All variables significant ($p < 0.05$) in single-variable analyses were included in multi-variable models for each of the three outcomes. Backwards step-wise regression was then used to achieve the most parsimonious model (See Figures 3a, 3b, 3c).

Pain Assessment Documentation

The predictors in the final model predicting percent of pain assessment documentation were 1) any vital signs, 2) mechanism of injury, 3) facility level, and 4) injury year (Table 5). Because complete data were present for each of these variables, the final model was run using non-imputed data, yielding a model that predicted 19.3% of the variance in documentation (Likelihood Ratio chi-square with 8 df = 847.04, $p < .001$).

The presence of any vital signs increased the odds of pain assessment documentation by 22.55 times. The odds of pain assessment also increased each year: 1.93 times increase between 2010 and 2011; 2.71 times between 2011 and 2012; the differences between 2012 and 2013 was non-significant. Compared to explosions, there was no difference in the odds of pain assessment documentation for patients injured by gunshot or motor vehicle/machinery/fall. Patients with "other" injuries had 1.7, 1.85, and 1.81 times the odds of pain assessment documentation, respectively, as patients injured by explosions, gunshots, or motor vehicles/machinery/falls. Odds of PH pain assessment were 2.1 times greater for patients transported to Level III facilities compared to Level IIa or IIb.

Pain Severity

All variables with significant relationships to pain severity in single-variable regressions remained significant in this multiple regression model. The model included HR, RR, and ISS. Each variable was significant, but the model explained only 5.0% of the variance in pain severity [F (5, 1239.2) = 12.57, $p < .001$].

Patients with moderate and severe injuries had significantly higher pain scores (1.04 and 1.41) than patients with minor injuries as shown in Table 6. There were no differences in pain scores between those with critical and minor injuries. Abnormal HR and abnormal RR were associated with slightly higher reported pain severity (Table 6).

Analgesic Administration

Six variables —documentation of any vital signs, pain severity, trauma type, mechanism of injury, ISS and year — made significant ($p < .05$) individual contributions in the final model [F (13, 12,508.0) = 22.90, $p < .001$] to predict analgesic administration (Table 7). Patients with penetrating trauma (compared to blunt) had 1.99 times the odds of analgesic administration. Paradoxically, documentation of any vital sign was associated with a 66% lower odds of analgesic administration (OR = 0.34). Mechanism of injury was also a significant predictor; patients injured by gunshot or explosion had 1.95 and 1.52 times greater odds of analgesic administration than "other" injuries (Table 7). There were no other significant differences between injury mechanisms. Patients with moderate injuries had 1.48 times greater odds of analgesic administration compared to minor injuries; no other differences between ISS categories were significant. Similarly, the only significant year-to-year change was between 2011 and 2012, when odds of analgesic administration increased 158%. Finally, for each unit increase in pain severity score, the odds of analgesic administration increased 126%. Of the 1,253 patients

with any pain severity score, 51.5% were treated with an analgesic, including 23 who reported pain severity = 0. Of those with a pain severity score of 4 or higher, 82.2% received analgesics.

DISCUSSION

LIMITATIONS

Missing data were substantial in the data set, so we used multiple imputation (MI) to maximize the available data for analyses and conserve statistical power to detect small effect sizes.[50,51] This technique demonstrated increased precision and reduced bias in a study examining missing PH assessment data in statewide trauma registry.[52] In our study, MI enabled evaluation of thousands of cases that would have been lost with the use of complete case analysis, providing a more robust analysis of pain assessment and analgesic use. While we believe these findings are representative of the population of US military combat zone patients, replication is necessary to verify that these relationships are not sample-specific.

We assumed that pain severity scores preceded analgesic administration. However, the data source did not provide date and time for assessments or interventions so that assumption could not be verified, nor could we explore the adequacy of pain relief after analgesic administration.

The lack of information on medication administration route precludes more detailed analyses. Time spent in PH care and levels of PH care providers were also unknown, and may have been a source of bias in the present study.[34,37]

PAIN ASSESSMENT DOCUMENTATION

To our knowledge, this is the first study to examine predictors of military PH pain assessment and analgesic administration in a combat zone. PH analgesic information was sparse

in the DoDTR for the entire period evaluated, suggesting that pain assessment and treatment were infrequent. This was confirmed in a medical record review of PH analgesic use conducted by DoDTR staff for a subset (n=1,588) of patients in the data set that found a discrepancy rate of only 4% between the DoDTR data and medical records (unpublished, B. Stephens, RN, personal communication, January 31, 2014). Our finding that 18.6% of all records had PH pain assessments, and 37.8% of records with PH vital signs also contained PH pain assessments is a major improvement over previously reported (6.7%) documentation of PH combat-zone pain care,[23,24] but clearly indicates the need for further improvement.

Multiple studies demonstrate that high rates of PH pain score documentation can be achieved in the context of military and civilian clinical trials.[53-60] Wedmore and colleagues[60] reported on 286 US military combat trauma patients treated with fentanyl lozenges and found that both pre- and post-analgesic pain assessment scores were reported for 68.9%. Civilian trauma care researchers report PH pain assessment rates from less than 20%[4] to 73.4%.[61] In a US study on PH pain assessment in trauma patients during 2005, 69% had a pain score documented[62] while 54% of records from all 2011 North Carolina EMS transports (adult trauma and non-trauma) included pain scores.[641] Another recent study of PH pain assessment reported pain severity scores for 73.4% of suspected fracture and 85% of suspected acute myocardial infarction patients.[61] As stated in our first goal, we described the degree to which pain assessment is achieved in the context of usual care in a military combat zone. Our findings suggest improvement over the time period examined, but rates are far from optimal.

Systems where PH pain assessment is the standard have achieved impressive results. Initial and final pain scores were reported for 86% of 108,853 patients treated by Ambulance Victoria in 2008.[64] In a similar EMS context, after multiple educational interventions with

paramedics over seven years, the use of validated pain scales as standard practice increased from 45% to 75%.[18,19] Future research should explore whether similar interventions would be effective for military trauma patients.

Nevertheless, the documentation rates for all PH data reported in this study were markedly improved compared to previous analyses.[23,24] The longitudinal nature of our data shows that pain assessment documentation increased significantly (OR = 1.93, 2.71) from 2010 – 2012, respectively. Although beyond the scope of this study to determine causes, possible explanations that should be explored in future studies include greater accountability for data entry in the registry, greater training emphasis, or more pain-relevant feedback to care providers.[25] Perhaps because more patients were transported directly to Level III facilities with DoDTR data entry capacity, there was less risk of data loss. Understanding these processes is essential to improvement in pain assessment and treatment.

Our finding that PH documentation of pain scores was missing more frequently than PH physiologic assessment parameters may be a sign that clinicians do not view the parameters as equally valuable,[65,66] or that there is a lack of organizational support to ensure complete documentation. Further research is needed to better understand the reasons for the observed differences and guide effective interventions to systematically improve processes of pain assessment and treatment.

We note with interest that patients injured by explosions, gunshot or motor vehicle/machinery/falls were less likely to have pain assessments documentation than patients with "other" injuries. One possible explanation is that patients with "other" injuries were more often single casualties compared to multiple casualties that are more likely with explosions, gunshot or motor vehicle/machinery/falls. Future research in both military and civilian samples

should examine the influence of patient clustering on documentation, and interventions to improve documentation during mass casualty scenarios.

PH PAIN SEVERITY

Patients in this sample reported pain severity from 0 − 10, with a mean of 5.5 and median of 6. Interestingly, these scores are somewhat lower than mean PH pain scores reported in the civilian trauma literature,[3,55,67,68] but the distribution is similar to combat zone ED patients in World War II and 2011.[31,69] Forty-two percent of patients in this sample reported severe pain (7-10), but there was not sufficient documentation of pain reassessment to determine if analgesic treatment was adequate for these patients. Patients with very similar injuries reported widely differing pain scores, as found in previous studies of both military and civilian trauma patients.[3,4,55,69,70] While we analyzed all available data, our model accounted for only 5% of the variance. There are clearly other unmeasured influences such as stress-induced analgesia,[71] survival euphoria, or unique battlefield contextual factors.

Clinically meaningful change in verbal pain severity scores among ED patients was found to be 1.3[72] and 1.4[73]; no studies from the PH setting were identified. Given this definition, no clinically meaningful relationships between vital signs and pain scores were found in our study. Our findings are similar to results from a study of adult civilian PH patients with both trauma and non-trauma complaints,[70] and confirm recent data from a pain, agitation, and delirium guidelines panel and their recommendation to avoid using vital signs as a valid and reliable indicator of pain.[74] A statistically significant relationship between RR and pain severity was identified in an large ED cohort of military trauma patients, but the difference of 18 to 19 breaths per minute was not likely to be clinically useful.[31] Pain is an individual phenomenon; therefore interventions to increase documentation of baseline pain and adoption of analgesic

protocols with specific pain reduction targets and reassessment are needed. Research with within-person analyses will be useful to characterize patients as responders and non-responders to PH analgesic interventions.

ANALGESIC ADMINISTRATION

Analgesics were administered to 25% of the total sample, 51.5% of patients with a PH pain assessment, and 82.2% of patients with a pain severity score of 4-10. The increase in PH analgesic use, from a previously reported 6.7%[24] is an important finding and underscores the necessity and urgency to improve the performance of pain assessment in combat casualty care. Similar to our findings, greater PH analgesic administration for civilian trauma patients with higher pain severity scores was reported by Frakes and colleagues. Using 2005 data, they found that presence of a pain score ≥ 4 was associated with greater likelihood of analgesic use.[62]

More patients in our study received analgesics than had pain assessment documentation (1,684 vs. 1,258). Reasons for this discrepancy are not clear and warrant further investigation. Potential reasons include differential valuing of documentation by clinicians; medication administration records may be perceived as more important for patient safety and pharmacy accountability. Alternately, the documentation may have been lost (e.g., blown away by helicopter rotor wash [H. King, CRNA, personal communication. October 19, 2014]) while medications are often attached to casualties (i.e., fentanyl lozenge taped to the finger, morphine auto-injector clipped to a uniform) or documented in permanent marker on the patient's body (e.g., "M 1115" indicates morphine given at 11:15), enabling data capture without traditional documentation.[75] Interventions to overcome barriers to PH pain assessment and treatment documentation may be an important step to improving PH pain care. Albrecht and colleagues[3] evaluated 1997 – 2006 data from a physician-staffed helicopter emergency medical service and

reported 70.5% of patient records included pain assessment documentation, while 80.4% received analgesics. Importantly, this study carefully distinguished patients who received medications (analgesics) from those who achieved pain relief (analgesia). Similar research is needed in the military trauma context.

In summary, as the military medical system specifies policy, training, and equipment for PH care providers, robust systematic evaluation of clinical outcomes, such as in this study, is essential. Our findings emphasize the need for individual pain assessment, because possible correlates such as vital signs or injury characteristics did not predict PH pain scores for trauma patients. Future research should examine the impact of PH pain assessment and analgesic practices on patient, provider, and system outcomes. Such information is critical to guide policy and training for PH care providers, determine most appropriate staffing patterns, and help identify the most appropriate analgesics for PH combat casualty care.

Chapter 3 Table 1

Demographic, Clinical, and Health System Variables from Each Subsample

	Total Sample		**PH Assessment and Analgesic Subsample (YES/NO)**		**PH Pain Severity Subsample**	
Number of Patients	6,755		3,317		1,253	
Demographic Characteristics						
Age: Mean (SD)	25.6	(SD = 6.0)	25.1		25.1	
Range; Median	18-59	24 yrs				
Age by Group (% of total)						
18 – 20	1,051	(15.6%)	548	(16.5%)	207	(16.5%)
21 – 25	3,121	(46.2%)	1,600	(48.2%)	604	(48.2%)
26 – 30	1,443	(21.4%)	687	(20.7%)	276	(22.0%)
31 – 60	1,140	(16.9%)	482	(14.5%)	166	(13.3%)
Sex: % female; *n*	2.6	(*n* = 178)	1.6	(n = 53)	1.8%	(*n* = 23)
Rank by Group[1] (% of total)						
E1-E5	5,438	(80.5%)	2,714	(81.8%)	1,009	(80.5%)
E6-E9	932	(13.8%)	435	(13.1%)	172	(13.7%)
Officer	383	(5.67%)	166	(5.0%)	71	(5.7%)
Missing	2	(0.03%)	2	(0.06%)	1	(0.1%)
Military Service[2] (% of total)[2]						
Army	4,430	(65.6%)	1,919	(57.9%)	771	(61.5%)
Marine Corps	1,979	(29.3%)	1,254	(37.8%)	433	(34.6%)
Navy	178	(2.6%)	93	(2.8%)	34	(2.7%)
Air Force (AF)	165	(2.4%)	48	(1.5%)	13	(1.0%)
Coast Guard (CG)	3	(0.04%)	3	(0.1%)	2	(0.2%)
Mortality (% *n* died)	(1.3%)	(*n* = 87)	1.1%	(*n* = 38)	0.4%	(*n* = 5)
Clinical Characteristics[3]						
Pre-Hospital (PH) Assessments						
Number of records with >1 set of PH HR/SBP/RR	257	(3.8)	249	(7.5%)	79	(6.3%)
Number of records with PH intubated/paralytics/sedated = no	2,742	(40.6%)	2,736	(82.5%)	1,212	(96.7%)
PH HR[3]						
Records with non-missing data, % of total	2,590	(38.3%)	2,583	(77.9%)	1,205	(96.2%)
Mean (SD)	94	(SD = 23)	93.5	(SD =23.4)	94.2	(SD=22.3)
Range	0 - 298					
Low (0-59) =	86	(3.3%)	86	(3.3%)	35	(2.9%)
Normal (60-100) =	1,716	(66.3%)	1,713	(66.3%)	804	(66.7%)
High (> 100) =	787	(30.4%)	784	(30.4%)	366	(30.4%)
PH SBP[3]						
Records with non-missing data, % of total	2,039	(30.2%)	2,034	(61.3%)	964	(76.9%)
Mean (SD)	122	(SD = 24.5)	122.1	(SD=24.5)	122.7	(SD=23.5)

	Total Sample		PH Assessment and Analgesic Subsample (YES/NO)		PH Pain Severity Subsample	
Range[§]	0 - 205					
Low (0-110) =	532	(26.1%)	530	(26.1%)	232	(24.1%)
Normal (110-130) =	704	(34.5%)	703	(34.6%)	356	(36.9%)
High (> 130) =	803	(39.4%)	801	(39.4%)	376	(39.0%)
PH RR[3]						
Records with non-missing data, % of total	1,996	(29.5%)	1,989	(60%)	1,055	(84.2%)
Mean (SD)	17	(SD=4)	17.5	(SD=4.9)	17.3	(SD=4.2)
Range:[§]	0 – 60					
Low (0 – 11) =	38	(1.9%)	38	(1.9%)	14	(1.3%)
Normal (12 – 16) =	1,017	(51.0%	1,012	(50.9%)	535	(50.7%)
High (> 16) =	940	(47.1%)	939	(47.2%)	506	(48.0%
PH Pain Severity Score	1,258	(18.6%)	1,253	(37.8%)	1,253	(100%)
PH Analgesic	1,684	(24.9%	1,684	(50.8%)	645	(51.5%)
Injury Characteristics						
Battle	4,925	(72.9%)	2,609	(78.7%)	967	(77.2%)
Non-Battle	1,830	(27.1%)	708	(21.3%)	286	(22.8%)
Injury Type[4]						
Blunt	3,292	(48.7%)	1,427	(43.0%)	524	(41.8%)
Burn	115	(1.7%)	53	(1.6%)	17	(1.4%)
Other	11	(0.2%)	1	(0.03%)	0	
Penetrating	3,337	(49.4%)	1,836	(55.4%)	712	(56.8%)
Mechanism of Injury						
Explosives	3.935	(58.3%)	2,053	(61.9%)	772	(61.6%)
GSW/Firearm	1,096	(16.2%)	627	(18.9%	220	(17.6%)
MVC/Machinery/Fall	867	(12.8%)	350	(10.6%)	127	(10.1%)
All others[5]	857	(12.7%)	287	(8.7%)	134	(10.7%)
Injury Severity Score (ISS) % of total						
Minor (1 – 15)	5,548	(82.1%)	2,639	(79.6%)	1,004	(80.1%)
Moderate (16 – 25)	653	(9.7%)	354	(10.7%)	134	(20.5%)
Severe (26 – 50)	514	(7.6%)	298	(9.0%)	108	(8.6%)
Critical (51 – 75)	40	(0.6%)	26	(0.8%)	7	(0.6%)
Health System Characteristics						
Iraq (OIF, OND)	633	(9.4%)	225	(6.8%)	71	(5.7%)
Afghanistan (OEF)	6,122	(90.6%)	3,092	(93.2%)	1,182	(94.3%)
ED Facility level[4]						
IIa	34	(0.5%)	6	(0.2%)	1	(0.2%)
IIb	1,973	(29.2%)	661	(19.9%)	222	(17.7%)
III	4,748	(70.3%)	2,650	(79.9%)	1,029	(82.1%)
Injury Year						
2010	3,000	(44.4%)	1,116	(33.6%)	221	(17.6%)
2011	2,190	(32.4%)	1,124	(33.9%)	305	(31.5%)
2012	1,176	(17.4%)	815	(24.6%)	474	(37.8%)
2013	389	(5.8%)	262	(7.9%)	163	(13.0%)

[1]For analyses, E1-E5 vs. E-6 and up
[2]For analyses, Navy, AF, CG combined
[§]HR/SBP/RR = 0 verified by medical record review by DoDTR staff; patients undergoing CPR.
[3]For analyses, high and low HR, SBP, RR combined
[4]For analyses, Burn/Other combined
[5]Causes of "other" injuries included sports, crush injuries, blunt objects, aviation mishaps, or flying debris.
[6]For analyses, IIa/IIb vs. III
Abbreviations: PH = Pre-hospital; ED = Emergency Department; AIS = Abbreviated Injury Score GSW = Gunshot Wound; MVC = Motor Vehicle Crash;

Chapter 3 Table 2

Simple Logistic Regressions
Dependent Variable: PH Pain Assessment Documentation, $N = 3{,}317$*

Predictor**	Overall Model F Test	*P* value of overall model	Odds Ratio	Confidence Interval of Odds Ratio[1]	
				Lower Bound	Upper Bound
DECREASING FACTORS:					
PH RR <12 or >16[2]	11.67	0.0007	**0.68**	**0.54**	**0.85**
Military Service	5.59	0.0037			
Marine Corps vs. Army***			**0.79**	**0.66**	**0.94**
Navy/Air Force/Coast Guard vs. Army			0.77	0.50	1.19
Marine Corps vs. Navy/Air Force/Coast Guard			0.98	0.63	1.53
INCREASING FACTORS:					
Documentation of any PH HR/SBP/RR	198.34	< 0.0001	**30.28**	**18.84**	**48.67**
Mechanism of Injury	3.96	0.0078			
GSW vs. Explosion			0.90	0.70	1.15
MVC/Machinery/Fall vs. Explosion			0.94	0.69	1.30
GSW vs. MVC/Machinery/Fall			0.95	0.73	1.52
Other vs. Explosion***			**1.45**	**1.04**	**2.03**
Other vs. GSW***			**1.62**	**1.11**	**2.38**
Other vs. MVC/Machinery/Fall***			**1.54**	**>1.00**[3]	**2.36**
ED facility - Level III vs. IIa /IIb	6.23	0.0126	**1.26**	**1.05**	**1.50**
Year	114.05	< 0.0001			
2011 vs. 2010***			**2.19**	**1.70**	**2.84**
2012 vs. 2010***			**5.63**	**4.29**	**7.40**
2013 vs. 2010***			**6.67**	**4.51**	**9.85**
2012 vs. 2011***			**2.57**	**2.00**	**3.29**
2013 vs. 2011***			**3.04**	**2.09**	**4.42**
2013 vs. 2012			1.18	0.81	1.74

* 100 imputations
**Predictors included only if model was significant at 0.05
***Significant post-hoc pairwise comparison if 1 is not in the interval and **bold**
[1]Confidence interval = 95% for binary variables; confidence interval with Bonferroni correction for 3 categories of predictor = 98.33%; confidence interval with Bonferroni correction for 4 categories of predictor =99.17%.
[2]Proportion of imputed data=40%
[3]Lower bound of confidence interval = 1.00 due to rounding; lower bound = 1.001851, p=0.008
Documentation of PH Pain Assessment was unrelated to: Gender, Age Group, Military rank, PH HR; PH SBP, Battle vs. Non-battle Injury, Trauma Type, Injury Severity Score.
Abbreviations: PH = Pre-Hospital; HR = Heart Rate; SBP = Systolic Blood Pressure; RR = Respiratory Rate.

Chapter 3 Table 3

Simple Linear Regressions
Dependent Variable: PH Pain Severity Score, *N* = 1,253*

Predictor**	Overall Model F Test	*P* value of overall Model	Coefficient of Predictor	Confidence Interval of Coefficient[1]		R^2
				Lower Bound	Upper Bound	
PH heart rate < 60 or > 100[2]	15.64	0.0001	**0.75**	**0.38**	**1.13**	1.29%
PH respiratory rate < 12 or > 16[3]	19.91	< 0.0001	**0.84**	**0.47**	**1.21**	1.80%
Injury Severity Score	14.40	< 0.0001				3.34%
16-25 moderate vs. <16 minor***			**1.23**	**0.47**	**1.98**	
26-50 severe vs. < 16 minor***			**1.68**	**0.85**	**2.51**	
51-75 critical vs. < 16 minor			-0.20	-3.30	2.89	
26-50 severe vs. 16-25 moderate			0.45	-0.60	1.51	
51-75 critical vs. 16-25 moderate			-1.43	-4.59	1.74	
51-75 critical vs. 26-50 severe		< 0.0001	-1.88	-5.06	1.30	

Note: PH Pain Severity score was unrelated to: age group; female gender; military rank; military branch of service; PH SBP, documentation of any PH vital signs; battle injury; trauma type; major injury cause; ED facility level; year.
* 100 imputations
**Predictors included only if model was significant at 0.05
***Significant post-hoc pairwise comparison if **bold**
[1] Confidence interval with Bonferroni correction for 4 categories of predictor =99.17%; not significant if 0 is in the interval
[2] Proportion of imputed data = 3.8%
[3] Proportion of imputed data = 15.8%
Abbreviations: PH = Pre-hospital; ISS = Injury Severity Score.

Chapter 3 Table 4

Simple Logistic Regressions
Dependent Variable: PH Analgesic Documentation, *N* = 3,317*

Predictor**	Overall Model F Test	*P* value of Overall Model	Odds Ratio	Confidence Interval of Odds Ratio***	
				Lower Bound	Upper Bound
DECREASING FACTORS					
Documentation of any PH HR/SBP/RR	81.79	< 0.0001	**0.44**	**0.36**	**0.52**
INCREASING FACTORS					
PH heart rate < 60 or > 100[1]	13.07	0.0003	**1.35**	**1.15**	**1.58**
PH respiratory rate < 12 or > 16[2]	23.46	< 0.0001	**1.54**	**1.29**	**1.83**
PH Pain Severity Score[3]	43.93	< 0.0001	**1.23**	**1.15**	**1.30**
Injury Type	70.57	< 0.0001			
Penetrating vs. Blunt***			**2.36**	**1.98**	**2.80**
Burn/Other vs. Blunt			1.57	0.81	3.05
Penetrating vs. Burn/Other			0.67	0.78	2.91
Mechanism of Injury	25.04	< 0.0001			
GSW vs. Explosion***			**1.63**	**1.27**	**2.08**
MVC/Machinery/Fall vs. Explosion***			**0.63**	**0.46**	**0.87**
GSW vs. MVC/Machinery/Fall***			**2.57**	**1.79**	**3.69**
Other vs. Explosion***			**0.56**	**0.39**	**0.78**
Other vs. GSW***			**0.34**	**0.23**	**0.50**
Other vs. MVC/Machinery/Fall			0.88	0.57	1.35
Battle vs. Non-battle Injury	32.36	< 0.0001	**1.63**	**1.38**	**1.93**
Injury Severity Score	17.15	< 0.0001			
16-25 moderate vs. < 16 minor***			**2.06**	**1.51**	**2.82**
26-50 severe vs. < 16 minor***			**1.72**	**1.23**	**2.40**
51-75 critical vs. < 16 minor			1.10	0.39	3.11
26-50 severe vs. 16-25 moderate			0.84	0.54	1.28
51-75 critical vs. 16-25 moderate			0.53	0.18	1.56
51-75 critical vs. 26-50 severe			0.64	0.22	1.88
Year	5.96	< 0.0001			
2011 vs. 2010			0.98	.078	1.22
2012 vs. 2010***			**1.38**	**1.08**	**1.77**
2013 vs. 2010			0.95	0.66	1.36
2012 vs. 2011***			**1.42**	**1.11**	**1.81**
2013 vs. 2011			0.97	0.67	1.39
2013 vs. 2012***			**0.68**	**0.47**	**1.00**[4]

Note: PH analgesic documentation was unrelated to age group, gender, military rank or service, PH SBP, ED facility level.
*100 imputations
**Predictors included only if model was significant at 0.05
***CI=95% if binary predictor, 98.33% with Bonferroni correction for post-hoc pairwise comparisons with 3-category predictor; 99.17% with Bonferroni correction for post-hoc pairwise comparisons with 4-category predictor. Significant if 1 is not in the interval and **bold**.
[1]Proportion of imputed data = 22.1%
[2]Proportion of imputed data = 40.0%
[3]Proportion of imputed data = 62.2%
[4]Upper bound of confidence interval = 1.00 due to rounding; upper bound =0.9954145, p=0.008
Abbreviations: PH = Pre-hospital; HR = Heart Rate; SBP = Systolic Blood Pressure; RR = Respiratory Rate; GSW = Gunshot wound, MVC = Motor Vehicle Crash.

Chapter 3 Table 5

Multiple Logistic Regression
Dependent Variable: PH Pain Assessment Documentation, *N* = 3,317

Overall Model Likelihood ratio Chi-square =847.04, *P*-value of overall model < 0.0001; Pseudo R^2 = 19.26%			
Predictor	**Odds Ratio**	**Confidence Interval of Odds Ratio***	
		Lower Bound	**Upper Bound**
Documentation of any PH HR/SBP/RR	**22.55**	**13.96**	**36.43**
Mechanism of Injury			
GSW vs. Explosion	0.91	0.69	1.22
MVC/Machinery/Fall vs. Explosion	0.94	0.66	1.33
GSW vs. MVC/Machinery/Fall	0.98	0.65	1.48
Other vs. Explosion*	**1.69**	**1.15**	**2.50**
Other vs. GSW*	**1.85**	**1.19**	**2.88**
Other vs. MVC/Machinery/Fall*	**1.81**	**1.11**	**2.94**
ED facility level: Level III vs. IIa /IIb	**2.05**	**1.66**	**2.54**
Year			
2011 vs. 2010*	**1.93**	**1.46**	**2.55**
2012 vs. 2010*	**5.23**	**3.86**	**7.09**
2013 vs. 2010*	**6.57**	**4.25**	**10.15**
2012 vs. 2011*	**2.71**	**2.06**	**3.55**
2013 vs. 2011*	**3.40**	**2.26**	**5.11**
2013 vs. 2012	1.26	0.83	1.90
Constant	0.01	0.01	0.02

*CI=95% if binary predictor, 99.17% with Bonferroni correction for post-hoc pairwise comparisons with 4-category predictor. Significant if 1 is not in the interval and **bold**.
Abbreviations: PH = Pre-Hospital; HR = Heart Rate; SBP = Systolic Blood Pressure; RR = Respiratory Rate; GSW = Gunshot wound; MVC = Motor Vehicle Crash; ED = Emergency Department.

Chapter 3 Table 6

Multiple Linear Regression
Dependent Variable: PH Pain Severity Score, *N* = 1,253*

Overall Model F (5, 1,239.2) = 12.57; *P*-value of overall model < 0.0001			
Overall R^2 = 5.01%			
Predictor**	Coefficient	Confidence Interval (CI) of Coefficient***	
		Lower Bound	Upper Bound
PH Heart Rate < 60 or > 100[1]	**0.41**	**0.02**	**0.80**
PH Respiratory Rate < 12 or > 16[2]	**0.68**	**0.31**	**1.05**
Injury Severity Score			
16-25 moderate vs. < 16 minor*	**1.04**	**0.29**	**1.80**
26-50 severe vs. < 16 minor	**1.41**	**0.57**	**2.26**
51-75 critical vs. < 16 minor	-0.59	-3.68	2.49
26-50 severe vs. 16-25 moderate	0.37	-0.68	1.42
51-75 critical vs. 16-25 moderate	-1.64	-4.78	1.51
51-75 critical vs. 26-50 severe	-2.01	-5.17	1.15
Constant	4.76	4.48	5.02

*100 imputations
**Predictors included only if single-variable model was significant at 0.05
***CI=95% if binary predictor, 99.17% with Bonferroni correction for post-hoc pairwise comparisons with 4-category predictor.
Significant if 0 is not in the interval and **bold**
[1]Proportion of imputed data = 3.8%
[2]Proportion of imputed data = 15.8%
Abbreviation: ISS = Injury Severity Score.

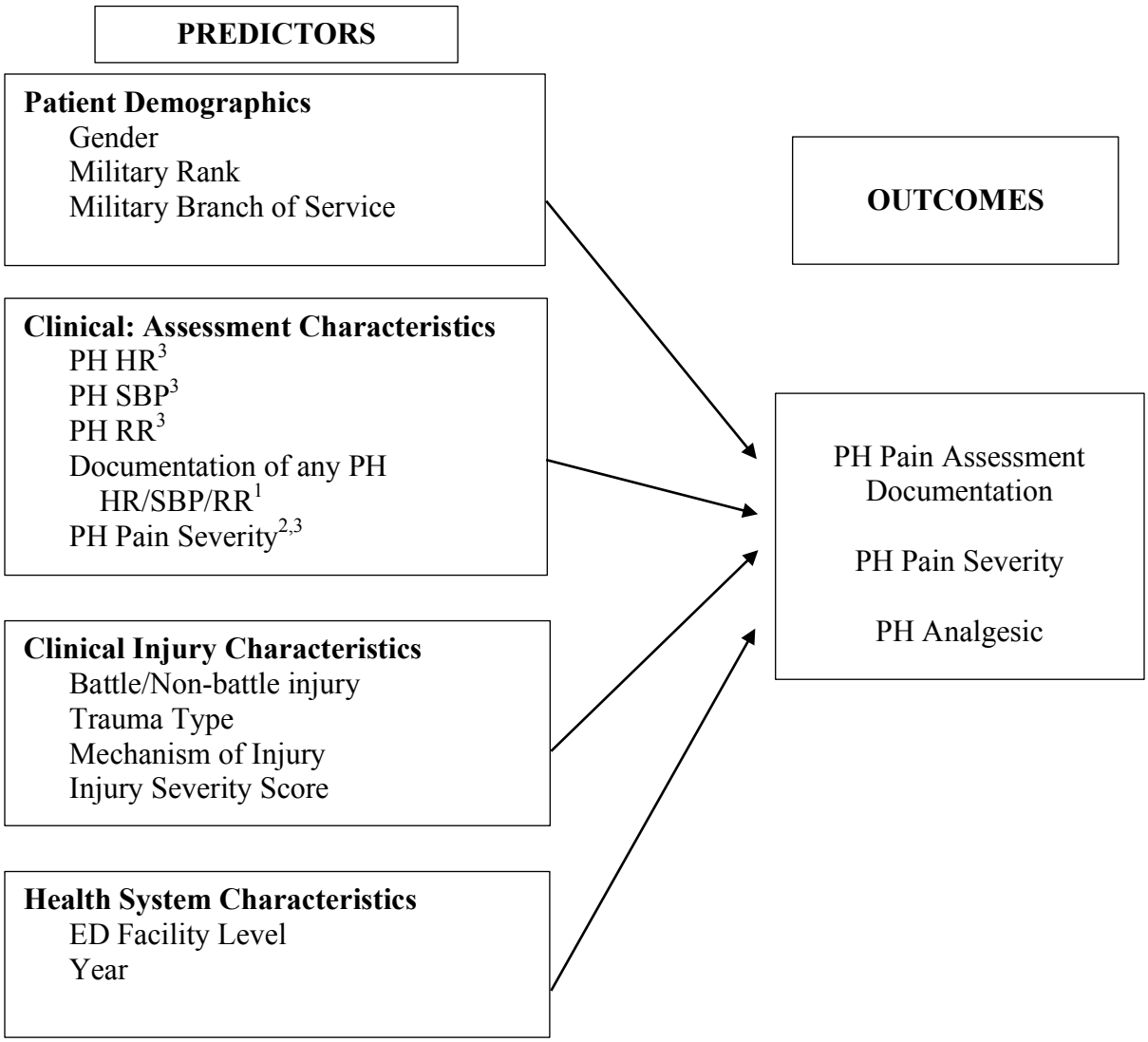
Chapter 3 Table 7

Multiple Logistic Regression
Dependent Variable: PH Analgesic Documentation, N=3,317*

Overall Model F (13, 12508.0) = 22.90; *P*-value of overall model < 0.0001			
Predictor**	**Odds Ratio**	**Confidence Interval (CI) of Odds Ratio*****	
		Lower Bound	**Upper Bound**
Documentation of any PH VS	**0.34**	**0.24**	**0.49**
PH Pain Severity Score[1]	**1.26**	**1.20**	**1.32**
Trauma Type			
Penetrating vs. Blunt	**1.99**	**1.57**	**2.52**
Burn/Other vs. Blunt	1.76	0.79	3.90
Penetrating vs. Burn/Other	1.13	0.51	2.54
Mechanism of Injury			
GSW vs. Explosion	1.28	0.95	1.73
MVC/Machinery/Fall vs. Explosion	0.98	0.67	1.42
GSW vs. MVC/Machinery/Fall	1.31	0.82	2.09
Explosion vs. Other	**1.52**	**1.02**	**2.28**
GSW vs. Other	**1.95**	**1.20**	**3.18**
MVC/Machinery/Fall vs. Other	1.49	0.91	2.44
Injury Severity Score			
16-25 moderate vs. < 16 minor	**1.48**	**1.02**	**2.13**
26-50 severe vs. < 16 minor	1.19	0.81	1.76
51-75 critical vs. < 16 minor	1.03	0.31	3.48
26-50 severe vs. 16-25 moderate	0.81	0.49	1.32
51-75 critical vs. 16-25 moderate	0.70	0.20	2.46
51-75 critical vs. 26-50 severe	0.87	0.28	2.73
Year			
2011 vs. 2010	0.93	0.71	1.23
2012 vs. 2010	**1.47**	**1.06**	**2.03**
2013 vs. 2010	1.01	0.65	1.56
2012 vs. 2011	**1.58**	**1.17**	**2.13**
2013 vs. 2011	1.09	0.72	1.65
2013 vs. 2012	0.69	0.45	1.05
Constant	0.46	0.25	0.84

*100 imputations
**Predictors included only if estimation of single-variable model was significant at 0.05
***CI = 95% if binary predictor, 98.33% with Bonferroni correction for post-hoc pairwise comparisons with 3-category predictor; 99.17% with Bonferroni correction for post-hoc pairwise comparisons with 4-category predictor. **Significant** if 1 is not in the interval.
[1]62.2% imputed
[2]Post-hoc comparisons with Bonferroni correction significant at $p < 0.05$
Abbreviations: GSW = Gun Shot Wound; MVC = Motor Vehicle Crash.

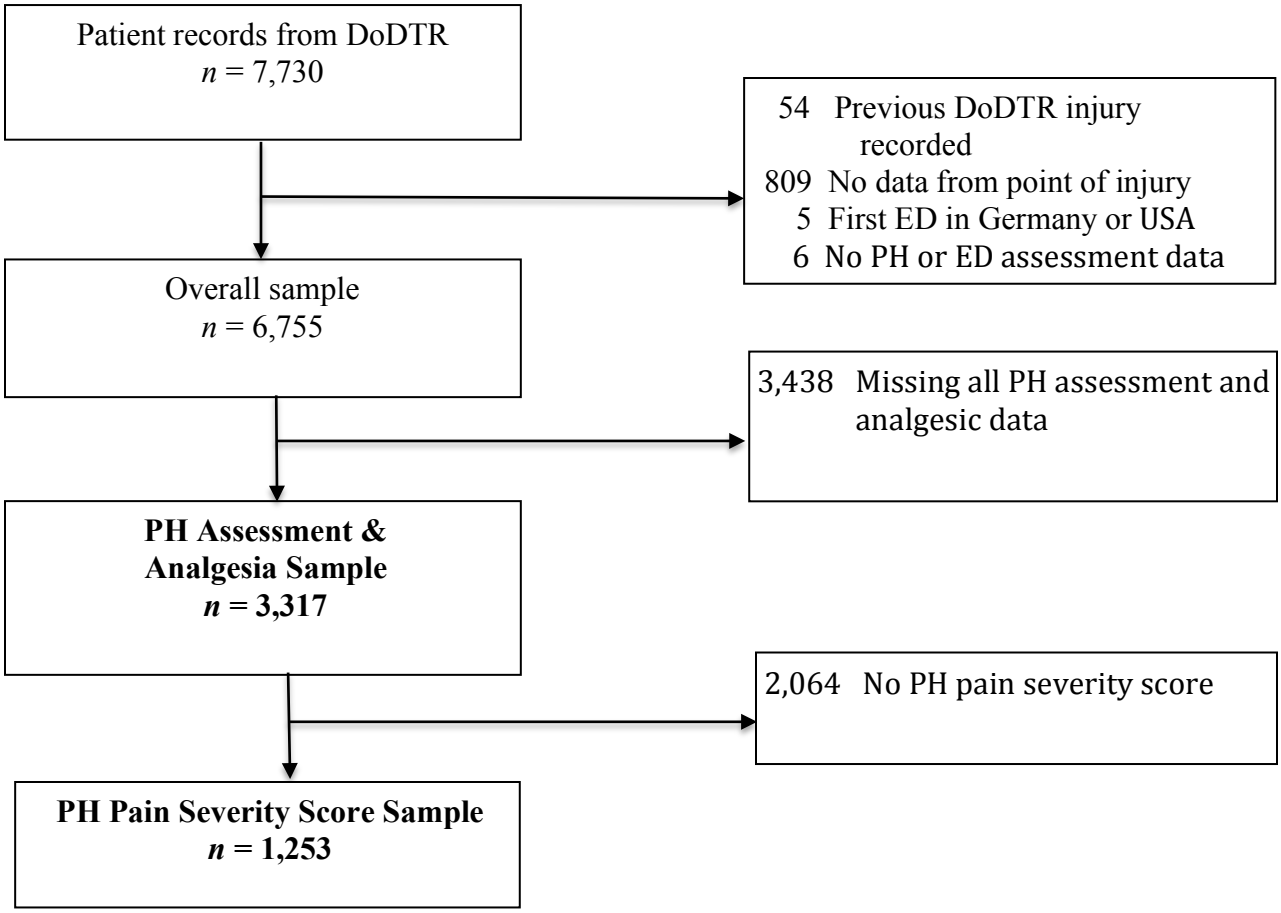
Chapter 3 Figure 1
Conceptual model of influences on PH pain assessment and severity and PH analgesia administration from data fields recorded in the DoDTR.



[1]Documentation of any PH HR, SBP, or RR (dichotomous) was used as a predictor for all outcomes. [2]PH Pain Score was evaluated as both an outcome and (with imputation) as a predictor for PH analgesia. [3]Variables with non-normal distributions had missing values in DoDTR, so multiple imputation with chained equations was used.

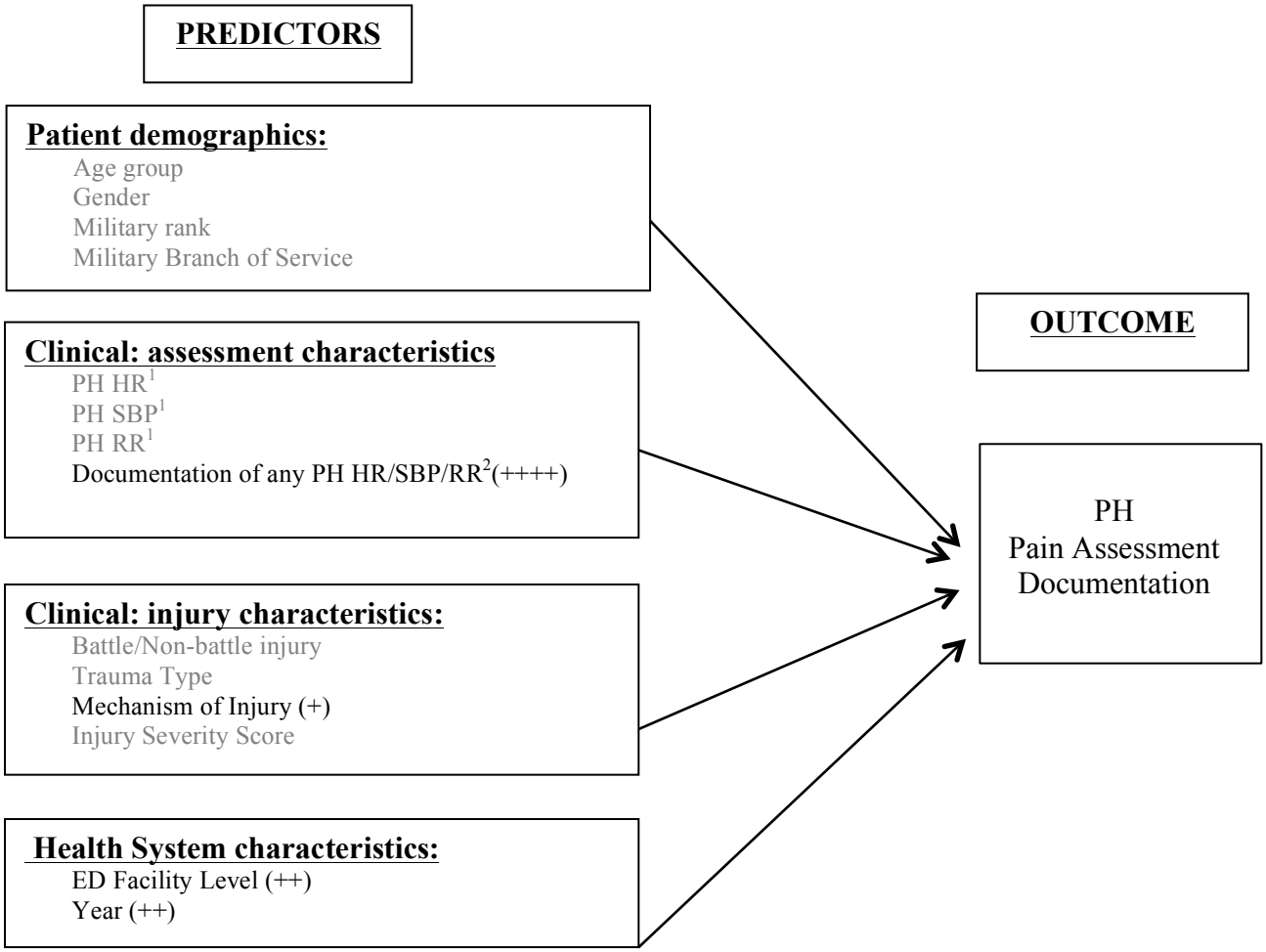
Abbreviations: PH = Pre-hospital; ED = Emergency Department; DoDTR = Department of Defense Trauma Registry; HR = Heart Rate; SBP = Systolic Blood Pressure; RR = Respiratory Rate; GCS = Glasgow Coma Scale; GSW = Gunshot Wound; MVC = Motor Vehicle Crash.

Chapter 3 Figure 2
Study flow diagram



Abbreviations: PH = Pre-Hospital; ED = Emergency Department

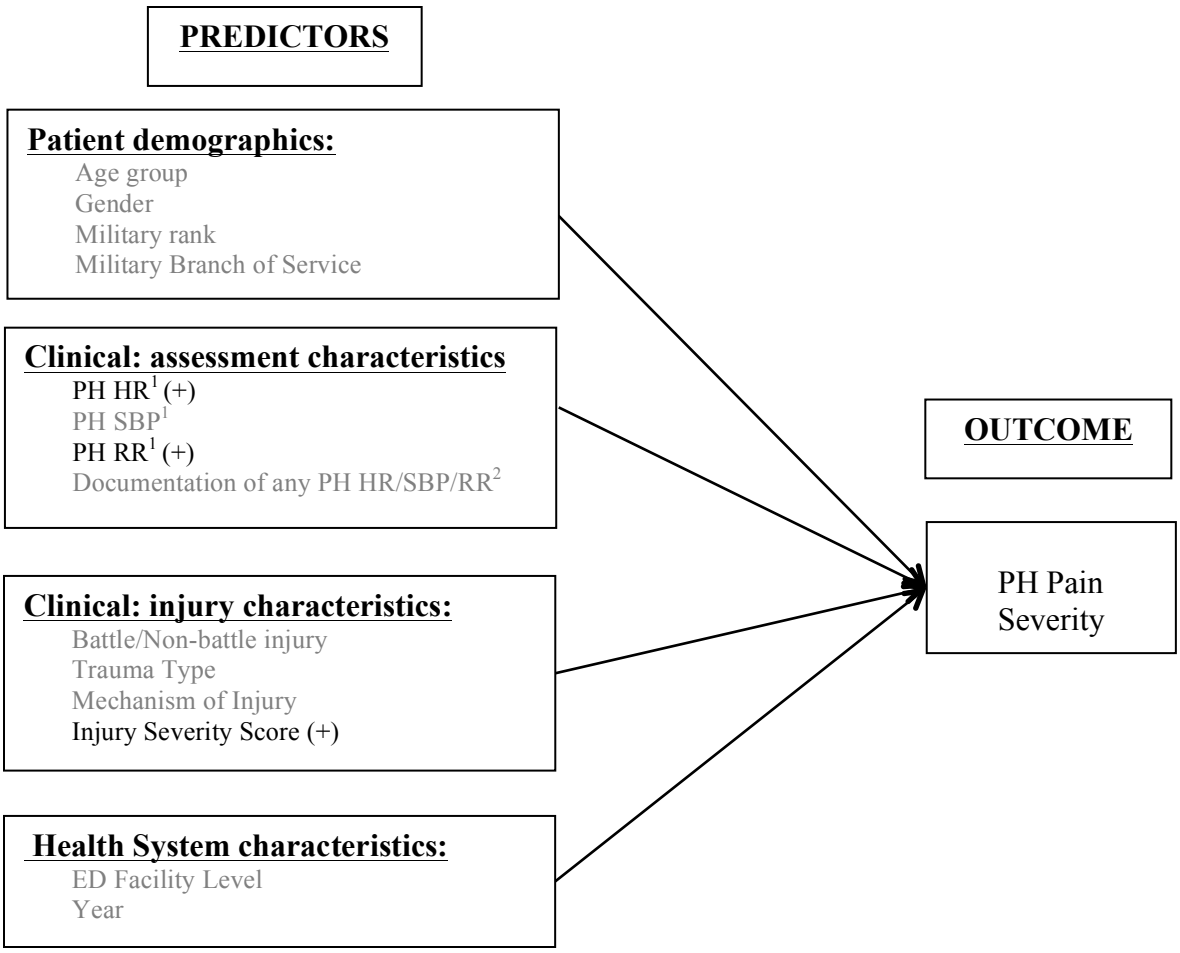
Chapter 3 Figure 3.
Final model of influences on PH pain assessment documentation from data fields recorded in the DoDTR



[1]Variables with non-normal distributions had missing values in DoDTR, so multiple imputation with chained equations was used.
[2]Documentation of any PH HR, SBP, or RR (dichotomous) was used as a predictor for all outcomes. Abbreviations: PH=Pre-hospital; ED=Emergency Department; DoDTR=Department of Defense Trauma Registry; HR=Heart Rate; SBP=Systolic Blood Pressure; RR=Respiratory Rate; GCS=Glasgow Coma Scale GSW=Gunshot Wound; MVC=Motor Vehicle Crash

Chapter 3 Figure 4.

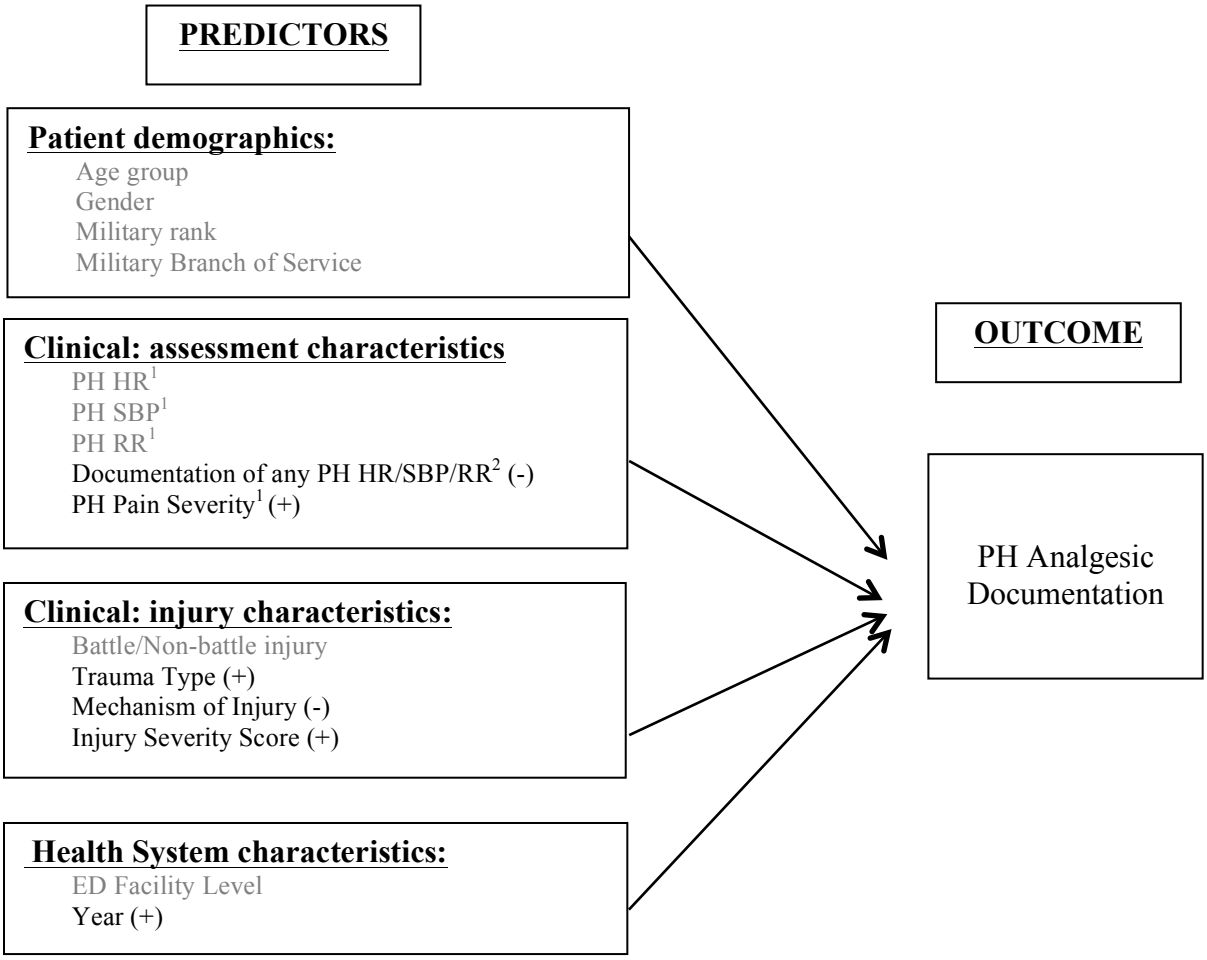
Final model of influences on PH pain severity from data fields recorded in the DoDTR



[1]Variables with non-normal distributions had missing values in DoDTR, so multiple imputation with chained equations was used.
[2]Documentation of any PH HR, SBP, or RR (dichotomous) was used as a predictor for all outcomes. Abbreviations: PH=Pre-hospital; ED=Emergency Department; DoDTR=Department of Defense Trauma Registry; HR=Heart Rate; SBP=Systolic Blood Pressure; RR=Respiratory Rate; GCS=Glasgow Coma Scale GSW=Gunshot Wound; MVC=Motor Vehicle Crash

Chapter 3 Figure 5.

Final model of influences on PH analgesic documentation from data fields recorded in the DoDTR



[1]Variables with non-normal distributions had missing values in DoDTR, so multiple imputation with chained equations was used.
[2]Documentation of any PH HR, SBP, or RR (dichotomous) was used as a predictor for all outcomes. Abbreviations: PH=Pre-hospital; ED=Emergency Department; DoDTR=Department of Defense Trauma Registry; HR=Heart Rate; SBP=Systolic Blood Pressure; RR=Respiratory Rate; GCS=Glasgow Coma Scale GSW=Gunshot Wound; MVC=Motor Vehicle Crash

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Chapter 4

Prevalence and Predictors of Pain Assessment Documentation and Pain Severity in US Military Patients in Combat Zone Emergency Departments

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Acknowledgement:

The authors acknowledge the Department of Defense Trauma Registry (DoDTR) for providing data for this study.

Abstract

Objective: We describe Emergency Department (ED) pain assessments and pain severity in US military personnel injured in Iraq and Afghanistan over a 4-year period (2010 – 2013).

Methods: We performed a retrospective, cross-sectional study using the Department of Defense Trauma Registry. We used multiple imputation to generate missing vital sign data. We tested for associations between demographic, clinical, or health system variables and ED pain assessment documentation and pain severity (0-10 scale). Including only variables with significant associations, we used backward stepwise regression to develop explanatory models for pain assessment documentation and pain severity.

Results: We evaluated 5,518 unique patient records for ED pain assessment documentation. Pain scores were documented in 60.5% (n = 3,339) records. The proportion of records with ED pain scores increased each year: 47.0% in 2010; 52.20% in 2011; 60.6% in 2012; 65.0% in 2013. Severity of pain scores ranged from 0 – 10; mean = 5.5 (SD = 3.1); median = 6. Pain assessment documentation model included any ED vital signs, level III ED, year, PH heart rate, ED Glasgow Coma Scale score, trauma type, and injury severity score (ISS). The pain severity model included military service branch, any PH vital signs, PH pain severity score, ED respiratory rate, ISS; ED facility level, and year, and explained 20.4% of variance in pain severity.

Conclusions: ED pain assessment documentation improved yearly, but remained suboptimal. Few patients had contraindications to self-report. Available data from the trauma registry were poor predictors of pain severity, emphasizing the importance of individual assessment.

INTRODUCTION

BACKGROUND

Inadequate pain care in the emergency department (ED) has been reported as a major problem since 1989.[1] Pain prevalence among traumatically injured patients is as high as 91%, and most patients report moderate to severe pain.[2] Evidence suggests that inadequately treated acute pain contributes to development of chronic pain and development of post-traumatic stress disorder (PTSD),[3-5] observed in 25% of civilian trauma patients[6] and 3-33% of military trauma patients.[7-11] From 46% to 85% of hospitalized trauma survivors report chronic injury-related pain up to six years post-injury,[12-15] and pain is estimated to cost the United States (US) between $560-$635 billion annually.[16]

Assessment is the essential first step in pain care, and documentation is how others know assessment has been completed. Documentation of pain assessment increases the likelihood of analgesic administration in the ED.[17-20] Despite these findings and regulatory mandates to ensure ED pain assessment,[21,22] ED pain assessment using validated pain scales was reported as 5%,[23] 23%,[24] and 56%[25] in Sweden, the US, and Australia, respectively, all countries with mandated pain assessment documentation.

Demographic (age, gender, race/ethnicity)[20,26-32] and health system (ED crowding)[33,34] characteristics influence the likelihood of ED pain assessment documentation, report of pain severity, analgesic interventions, and pain relief. Clinician attitudes and knowledge deficits about pain assessment and treatment contribute to ED practice variation.[35,36]

SIGNIFICANCE

Over 50,000 US military personnel were injured in the last decade of combat operations.[37] Nearly all were young and most survived, yet little is known about their ED pain care, and how it influenced their recovery. We found only one study examining pain assessment in military patients in combat zone EDs.[38] More severe injuries, as measured by the injury severity score (ISS)[39] were correlated with higher pain scores. Patients with a maximum score of 10 on pain severity had a higher respiratory rate than patients who rated their pain severity as 7 or lower. No relationship was found between pain score and heart rate or blood pressure. The investigators did not report the overall proportion of patients with ED pain assessments, nor did their analyses examine the potential influence of pre-hospital care, demographic, or other injury-related characteristics.[38]

GOALS OF THIS INVESTIGATION

The prevalence of combat zone ED pain assessment is currently unknown. Such data are key to estimating intervention effectiveness and minimizing pain and its consequences for military patients in combat-zone EDs. To address this knowledge gap, this study examined 44 months of data (2010-2013) on ED pain assessment documentation and ED pain severity for military personnel in Iraq and Afghanistan to: 1) Determine prevalence of ED pain assessment documentation and ED pain severity; 2) Examine demographic, clinical, and health system variables associated with ED pain assessment documentation and ED pain severity; and 3) Develop explanatory models of ED pain assessment documentation and ED pain severity based on demographic, clinical, or health system factors.

Methods

STUDY DESIGN

The study design was a retrospective, cross-sectional study of de-identified data from the Department of Defense Trauma Registry (DoDTR).[40,41] Because there was no access to personally identifiable information, the study was deemed non-human subjects research and exempt from review by the Committee on Human Research at the University of California, San Francisco. Demographic, clinical, and health system characteristics theorized as potential predictors of ED pain assessment and ED pain severity were examined (Figure 1).

DATA SOURCE

The DoDTR contains records of over 50,000 patients' trauma care since 2004 from point of injury through final disposition.[40,41] The DoDTR is prospectively populated with pre-hospital and ED clinical assessment data, including pain severity scores, by trained trauma nurse registrars at combat zone Level III medical facilities.[42] Records are updated at subsequent facilities until discharge from final DoDTR-participating facility.

STUDY POPULATION & SETTING

The study population was comprised of DoDTR records of US military personnel. Inclusion criteria restricted the sample to patients with traumatic injuries who were alive on arrival to a US military medical facility and required inpatient care from January 1, 2010 through August 31, 2013 in the military operations Operation Iraqi Freedom (OIF), Operation Enduring Freedom (OEF) and Operation New Dawn (OND). All patients in the sample had clinical documentation from point of injury or transit to first emergency department (ED). Excluded from the sample were records of Iraqi or Afghan military personnel, coalition military personnel,

civilians, enemy combatants, and US military personnel who received outpatient care only, had a Glasgow Coma Scale (GCS) score less than 14, or were deceased upon arrival.

DEMOGRAPHIC CHARACTERISTICS

Demographic data included military service and rank, gender and age. Mortality was recorded at each facility and at discharge from last DoDTR-participating facility. Race and ethnicity are not recorded in the DoDTR.

CLINICAL CHARACTERISTICS

Relevant PH and ED clinical data included vital signs [heart rate (HR), systolic blood pressure (SBP); respiratory rate (RR)]; intubation (yes or no), neuromuscular blockade administered (yes or no) and sedation (yes or no); and pain score using the 0-10 Numeric Rating Scale (NRS), where 10 is worst possible pain. Using standard values, PH and ED vital signs were categorized as low (HR < 60, SBP < 110, RR < 12) normal, or high (HR > 100, SBP > 130, RR > 16).[43,44]

PH analgesic data included administration (yes or no) of morphine, fentanyl, and ketamine. Because dose and route of administration were missing for the majority of patients, these data were not extracted. ED assessment data also included Glasgow Coma Scale (GCS) score. ED analgesics are not recorded in the DoDTR.

Injury-related data included Abbreviated Injury Score (AIS), Injury Severity Score (ISS), trauma type (blunt/penetrating/burn or other), injury classification (battle or non-battle), and primary mechanism of injury (explosion, gunshot, motor vehicle crash/machinery/fall, or "other"). ISS was calculated by DoDTR personnel based on a previously described method.[38] ISS ranged from 0-75 and was categorized as minor (0-15), moderate (16-25), severe (26-50), and critical (51-75).[45]

International Classification of Diseases-9th revision (ICD-9) diagnostic codes were combined with AIS to identify patients with mild and severe traumatic brain injury (TBI). Definitions were adopted verbatim from a study of PTSD outcomes in combat casualties: Mild TBI = head injury with AIS score of 1-2 and ICD-9 codes 800.0 to 801.9 (fractures of the vault or base of the skull), 803.0 to 804.9 (fractures at other or unspecified skull sites and multiple fractures of the skull), 850.0 to 854.1 (intracranial injury, including concussion, contusion, laceration, and hemorrhage), or 873.0 to 873.9 (other open head wounds).[46] Severe TBI included the same ICD-9 codes combined with an AIS score ≥ 3.[46] TBI diagnosis could be assigned at any point in the trajectory of care. All included patients had a GCS of 14 or 15 at ED admission, thus were presumed capable of completing a self-report pain assessment in the ED. Therefore, no patients were removed from the sample based on TBI diagnosis.

HEALTH SYSTEM CHARACTERISTICS

Health system characteristics included military operation supported (Operations Iraqi Freedom and New Dawn were in Iraq; Operation Enduring Freedom was in Afghanistan), injury month and year; and the name and level of first treating facility (ED). Method of PH transport (dedicated medical air or ground versus "lift of opportunity" air or ground) and qualifications of PH medical personnel were only reported for only a small fraction of patients, and therefore were not extracted.

ANALYSIS

INCLUSION OF RECORDS FOR ANALYSIS

Figure 2 shows the derivation of samples for analysis. All analyses were conducted with Stata/SE Release 13 (StataCorp: College Station, TX. 2013).

MANAGEMENT OF MISSING DATA

Missing clinical data is a known deficiency of the DoDTR,[47-49] particularly for the pre-hospital (PH) setting. Complete case analysis would have excluded up to 80% of records, reducing statistical power and creating biased results.[50-52] Therefore, multiple imputation (MI) was used to maximize the available data for analyses and reduce bias in estimation.[53] In MI, multiple copies of the entire data set are generated and regression equations predict the missing variables in each case.[54-56] Analyses are then conducted on all of the imputed data sets, and the findings pooled to provide the least biased estimate.

Percent of cases with non-missing data are shown in Table 1. Distribution of observed data was highly skewed, and the imputation model with categorical vital signs (low, normal, high) failed to converge. Therefore, the low and high categories were combined to create binary variables (normal/abnormal) for HR, SBP and RR.

MI with chained equations is recommended when missing data include dichotomous, ordinal and categorical variables, as it accommodates non-normal distributions.[53,56,57] Therefore, MI with chained equations using logistic regression was used to impute normal/abnormal PH vital signs (HR, SBP, and RR). PH pain score was also imputed, using truncated regression (lower limit = 0, upper limit = 10). No ED pain scores were imputed. To reduce bias in the estimates, 100 imputed data sets were generated.[51,53,58-60] The imputation models included all variables with missing data predicted by all remaining variables, including the two outcome variables.[51]

DESCRIPTIVE ANALYSES

Demographic, clinical, and health system characteristics of the ED pain assessment documentation and ED pain severity score samples are summarized in Table 1.

Proportions and percentages were determined to achieve Aim 1. Relationships between all potential predictor variables and ED pain assessment documentation and ED pain severity were explored using logistic and linear regression models as appropriate.[50,61-63] Post-hoc pairwise comparisons for categorical predictors with $p< 0.05$ were completed using the Bonferroni correction. [63,64]

Finally, for each analysis, all variables with statistically significant relationships ($p < 0.05$) in the single-variable models were entered into a multi-variable model for each main outcome. Backwards step-wise regression was then used to achieve the most parsimonious model.[63,64]

Results

DEMOGRAPHIC CHARACTERISTICS

The final samples for analysis included 5,518 patient records for pain assessment documentation and 3,339 pain severity scores, from a total of 6,755 unique patient records (Figure 2). Demographic, clinical, and health system characteristics for the samples are shown in Table 1. Overall mean patient age was 25.5; 62.5% were 18-25 years old. The proportion of females (3.1% versus 2.6%) was slightly higher in the pain severity score sample. Most patients held a junior enlisted rank in the Army or Marine Corps. Of the patients in the assessment sample, 16 (0.3%) died, 7 (43.8%) at the first facility at which they were treated. Of patients with ED pain severity scores recorded 3 (0.1%) died, 2 at the first facility at which they were treated.

CLINICAL CHARACTERISTICS

Only 40.6% and 43.8% of records from the pain assessment and pain severity samples included any vital signs data from the PH setting, therefore approximately 60% of PH vital signs data were imputed. The data were highly congruent between samples. Over 50% of patients had normal HR (60-100) and RR (12-16) documented, and less than 5% had low HR or RR while in PH care. However, more patients had unstable PH blood pressure; only 35% had normal PH SBP (110-130), 25% had low PH SBP and 40% had a high SBP. In contrast, over 90% of records included vital signs data from the ED, where HR, SBP, and RR were within normal limits for 70%, 31%, and 32% of patients, respectively.

Battle injuries [predominantly explosions, followed by gunshots] comprised 73% of injuries in the pain assessment sample, and 68.6% in the pain severity sample. Non-battle injuries were most commonly the result of motor vehicle crashes, machinery, or falls. The percentages of blunt and penetrating wounds were nearly equal in both the pain assessment and pain severity samples, respectively. Few (less than 2%) had a primary burn injury. Minor injuries (ISS 1-15) were predominant (see Table 1).

HEALTH SYSTEM CHARACTERISTICS

Most patients (approximately 90%) were injured supporting operations in Afghanistan, and most (75.8% of pain assessment and 84% of pain severity samples) were transported to Level III facilities. Injury volume decreased each year, with over 40% of injuries occurring in 2010; 30% in 2011; 17% in 2012; and less than 6% in 2013. Table 1 shows the proportion of patients in each sample by year.

ED PAIN ASSESSMENT DOCUMENTATION AND PAIN SEVERITY – UNIVARIATE ANALYSES

Of the 5,518 records evaluated for ED pain assessment documentation, 60.5% (n = 3339) had pain severity scores, and more than 90% of records had complete ED vital sign data (Figure 2). The proportion of records with ED pain scores increased over time: 47.0% in 2010; 52.2% in 2011, 60.6% in 2012, 65.0% in 2013.

In univariate logistic regression models, documentation of any ED vital signs was associated with an 11.7-fold increase in likelihood of ED pain assessment documentation, while initial treatment at a level III facility increased odds of ED pain assessment documentation by 3-fold. Other variables positively associated with presence of ED pain assessment documentation were documentation of: any PH vital signs; multiple PH vital signs; PH pain assessment; PH analgesic; GCS score of 15 (compared to 14); primary mechanism of injury other than explosion or gunshot wound; and injury year 2011, 2012, or 2013 (compared to 2010).

The likelihood of ED pain assessment documentation was decreased by abnormal PH HR, PH RR, and ED HR; penetrating trauma (versus blunt); battle injury; or an ISS rating of moderate or severe (versus minor). Test statistics, odds ratios and confidence intervals from each logistic regression are shown in table 2. None of the other variables (age group; gender; military rank; military branch of service; PH SBP; ED RR; ED SBP) were significantly associated with likelihood of ED pain assessment documentation.

Severity of ED pain was reported in 3,339 records. Scores ranged from 0-10, with a mean of 5.5 (SD = 3.2) and median of 6. Of these, 752 (22.5%) had a PH pain severity score recorded; 909 (27.2%) had PH analgesics recorded; and 373 (11.2%) had both a PH pain severity score and a PH analgesic recorded. In single predictor regression model estimations, the

following variables were associated with higher ED pain severity scores: age group 26-30 years old (compared to 18-20 years old); abnormal PH HR; PH RR; ED HR; ED RR; penetrating injury; ISS category moderate or severe (versus minor); year 2011, 2012, and 2013 (versus 2010).

Lower pain severity scores were associated with: male gender; service in any military branch other than Army, documentation of any PH vital signs (Table 3). No other variables (military rank; PH SBP; ED SBP; documentation of any ED HR/SBP/RR; battle injury) were significantly related to pain severity.

ED PAIN ASSESSMENT DOCUMENTATION AND PAIN SEVERITY – MULTIVARIATE ANALYSES

All 11 variables in the final model [$F = 49.57$, $p < .001$] made a significant independent contribution to the likelihood of ED pain assessment documentation (Table 4). Documentation of any ED vital signs accounted for the largest amount of variance, and increased the odds of ED pain assessment documentation 13.28. Pain assessment documentation was 3.36 times more likely at Level III ED facilities, and overall increased significantly each year from 2010 to 2012 (56% and 35%, respectively); but not from 2012 to 2013. Four clinical characteristics were retained in the final model of ED pain assessment documentation: PH HR; ED GCS; trauma type; and ISS. Compared to patients with a minor ISS, patients with a moderate or severe ISS were less likely (47% and 56%, respectively) to have pain assessment documentation. Patients with penetrating injuries were 30% less likely than patients with blunt trauma injuries to have pain assessment documentation; none of the other differences between categories were significant. Abnormal HR was associated with a 23% decrease in odds of pain assessment

documentation, while patients without any gross neurological deficits (GCS = 15) were 77% more likely to have pain assessment documentation compared to patients with GCS = 14.

Seven of the 14 variables significantly associated with ED pain severity in single-variable regressions remained significant in the multiple regression model (table 5). The model explained 20.4% of variance [$F(12, 2176.5) = 39.99$, $p < 0.0001$] and included military service; documentation of any PH vital signs; PH pain severity score; ED respiratory rate; ISS; ED facility level; and year.

Patients with moderate and severe injuries reported higher pain severity scores, (1.6 and 1.9 units on the 0-10 scale, respectively), compared to patients with minor injuries. Military service was also a strong predictor, with Marines reporting 1.2 and 0.7 units lower pain severity scores than Army and Navy/Air Force/Coast Guard personnel, respectively. Documentation of any PH vital signs was associated with 1.0 unit lower ED pain severity scores, while scores reported at level III EDs were lower by 0.4 units than scores at level IIa/IIb EDs. Abnormal ED RR was associated with a 0.72 increase in ED pain severity score. Pain scores reported in both 2011 and 2012 were higher than pain scores reported in 2010 (0.58 and 0.94, respectively), but no other differences between years were statistically significant. ED pain severity scores increased 0.32 units for each additional point on the PH pain scale scores.

DISCUSSION

LIMITATIONS

Our study has all of the limitations of a retrospective analysis. As Chisholm and colleagues found in a prospective observational study of civilian ED care for presumably painful conditions, the ED chart is an often incomplete record of pain care in the ED,[38] however, it is the

record on which subsequent clinical decisions are made, and therefore is a valuable and cost-effective source for research and quality improvement.[65] Advanced technologies such as voice recognition software to capture patient assessment data in the ED may help improve documentation, meanwhile brief educational interventions can improve pain assessment documentation.[66]

Missing data, particularly from the PH phase of care, are a known problem in the DoDTR.[47-49] We used multiple imputation, a technique demonstrated to yield good results in a study of pre-hospital data in a state-wide trauma registry[67] to enable analysis of thousands of records that would otherwise have been discarded. Replication in another sample with more complete data should be done to confirm that the relationships we found were not sample-specific. Our sample was comprised almost entirely of young, physically fit males, thus our findings may not be generalizable to other trauma populations.

Our data did not include date and time for any ED assessments or interventions. Previous reports suggest that dose and route of PH analgesic administration, and times from injury to PH care to first ED assessment were likely to be highly variable.[68-70] For these reasons, ED pain severity scores cannot be used to evaluate the effectiveness of PH analgesics. Likewise, while civilian ED researchers have reported a correlation between ED crowding and decreased pain assessment documentation rates,[34] without date and time information, we could not evaluate this potential relationship. Finally, while the ED pain assessments used in this analysis were the first documented in the registry and were recorded with the first set of vital signs, because ED analgesic intervention data were not available and PH records were often incomplete, we cannot be certain that assessment reflects pain severity before intervention.

ED PAIN ASSESSMENT DOCUMENTATION

To our knowledge, this is the first study to describe the prevalence and predictors of pain assessment documentation in combat zone EDs. After excluding patients who were unlikely to be able to provide self-reported pain scores, a majority (5518/6755, 81.7%) of traumatically injured patients presenting to combat zone EDs were able to quantify their pain severity. Pain severity, using the previously validated NRS, was documented for 60.5% of patients who had no contraindications for self-reporting. While similar to rates reported for civilian trauma centers, [17-19,66,71] this leaves ample room for improvement. The annual increase in pain assessment documentation rates was impressive; future research should identify barriers to pain assessment documentation and test strategies to improve these rates further.

Pain assessment was more than 13 times more likely to occur if ED vital signs were documented. The longitudinal nature of our data enabled us to show year-by-year improvement, continuing the trend of improved data capture.[48] Pain assessment documentation was more likely at larger, more comprehensive facilities (level III) with higher patient volume and DoDTR data entry capacity. Our findings support previous recommendations that regular feedback to clinicians on the clinical knowledge gained through audits of trauma registry data will improve quality of care and registry documentation.[72]

Patients with the most severe injuries were least likely to have documented pain assessments. Further research is needed to determine if patients with the most severe injuries are given analgesics without a pain assessment, and what strategies might be more effective to improve pain assessment and documentation for this high risk group. Research is also needed to determine if patients with different initial pain levels have different risk profiles for development of chronic pain and/or PTSD, and if analgesic interventions in the ED reduce those risks.

Neither PH pain assessment nor PH analgesic was associated with likelihood of ED assessment in the final explanatory model. Similarly, civilian researchers[73-75] found that PH or ED triage pain scores had little impact on ED triage level. Further research is needed to understand the complex interplay between pain assessment and other factors that drive workflow in both civilian and combat zone EDs so pain assessment and analgesic intervention can be improved.

ED PAIN SEVERITY

Mean pain severity reported by patients in our sample was relatively low when compared to pain severity reported by civilian trauma patients.[2,66,76] However, our finding of a mean pain score of 5.5 was similar to the mean pain score of 6.1 reported for a recent combat zone ED sample,[38] and the proportion of "slight" and "moderate" pain reports found by Beecher in his classic study of combat-injured patients in World War II.[77] Interestingly, ED pain scores appear to be much lower than those reported by combat-related trauma patients later in the care trajectory, during intercontinental transport,[78] at outpatient pain specialty clinics,[79] and in acute rehabilitation settings.[80] The lower initial ED pain scores may reflect stress-induced analgesia[81,82] or may be an artifact of assessment of pain severity after unrecorded PH or ED analgesic administration.

Our final model of ED pain severity scores, built from all demographic, vital signs, injury-related information, and health system characteristics available to ED clinicians, predicted 20.4% of the variance in severity scores, leaving 80% of the variance unexplained. This finding demonstrates the difficulty in estimating pain severity based on observable factors and emphasizes the need for a patient-reported pain rating to guide treatment. Previous studies have demonstrated that emergency nurse and physician ratings of patients' pain are lower than

patients' self-reported scores,[83,84] which may lead to under-treatment of pain. Standardized interventions ensure patients receive initial treatment, but continued treatment must be titrated to individual response, which requires baseline and ongoing assessment.[77,85] Because inadequately treated acute pain is a risk factor for development of chronic pain and PTSD,[3-5,46] high quality and consistent ED pain assessment and treatment is essential.

Similar to previous findings,[38] higher ISS ratings were associated with increased pain severity in the ED: patients with moderate and severe injuries reported pain severity scores that were higher by 1.6 and 1.9 units, respectively than patients with minor injuries. These differences were more pronounced than the 0.9 and 1.6 units higher pain severity scores associated with moderate and severe PH pain severity scores (Blackman, et al., in preparation).

Pain severity scores reported by Marines were 1.2 units lower than scores from Army patients and 0.66 units lower than patient scores in other service branches. The Marines' lower pain scores were both clinically meaningful[86-90] and statistically significant and raise interesting questions about how military culture may influence pain perception. To identify if higher early pain reports are associated with worse long term outcomes as shown in other populations, further study is needed.[91]

In summary, this is the first study of ED pain assessment practices in a combat zone. Our findings demonstrate significant increase in documentation rates over time and poor ability to predict pain severity scores based on demographic, clinical or health system factors. Because it has been shown that increased pain assessment documentation in civilian EDs leads to increased administration of analgesics,[17-19] it is also likely that the same relationship exists in military EDs. To gain insight into patient-centered outcomes, future studies should capture both short and long term pain severity ratings, to evaluate how these early pain assessments relate to outcomes such

as chronic pain and PTSD. Such knowledge will enable clinicians to provide the highest quality of care, even in a combat zone.

Chapter 4 Table 1
Demographic, Clinical, and Health System Variables from Each Subsample

	ED Assessment Subsample (YES/NO)	ED Pain Severity Subsample
Number of Patients	5518	3339
DEMOGRAPHIC CHARACTERISTICS		
Age: Mean (SD) Range; Median	25.5	25.6
Age by Group (% of total) 18-20 21-25 26-30 31-60	 885 (16.0%) 2568 (46.5%) 1159 (21.0%) 906 (16.4%)	 531 (15.9%) 1558 (46.7%) 703 (21.1%) 547 (16.4%)
Sex: % female; n	2.6% (n=145)	3.1% (n=103)
Rank by Group:[1](% of total) E1 – E5 E6-E9 Officer Missing	 4473 (81.1%) 723 (13.1%) 320 (5.8%) 2 (.04%)	 2834 (80.5%) 474 (13.5%) 209 (5.9%) 2 (.1%)
Military Service[2] (% of total) Army Marine Corps Navy Air Force (AF) Coast Guard (CG)	 3539 (64.1%) 1694 (30.7%) 150 (2.7%) 132 (2.4%) 3 (.1%)	 2145 (64.2%) 1007 (30.2%) 91 (2.7%) 93 (2.8%) 3 (.1%)
Mortality (% , n died)	0.3% (n=16)	0.1% (n=3)
CLINICAL CHARACTERISTICS[3]		
PREHOSPITAL (PH) ASSESSMENTS		
Number of records with >1 set of PH HR/SBP/RR	224 (4.1%)	166 (5.0%)
Number of records with PH intubated/paralytics/sedated = no	2368 (42.9%)	1537 (46.0%)
PH HR[3] Records with non-missing data, % of total Mean (SD) Range:[§] Low (0-59) = Normal (60-100) = High (>100)	 2238 (40.6%) 91.9 (21.3) 20-298 74 (3.3%) 1538 (68.7%) 626 (28.0%)	 1461 (43.8%) 90.3 (19.6) 20-210 48 (3.3%) 1047 (71.7%) 366 (25.1%)
PH SBP[3] Records with non-missing data, % of total Mean (SD) Range:[§] Low (0-110) = Normal (110-130) = High (>130) =	 1823 (33.0%) 122.8 (23.9) 60-205 460 (25.2%) 628 (34.5%) 735 (40.3%)	 1193 (35.7%) 124.9 (22.5) 60-197 251 (21.0%) 432 (36.2%) 510 (42.8%)
PH RR[3] Records with non-missing data, % of total Mean (SD) Range:[§] Low (0-11) = Normal (12-16) = High (>16) =	 1735 (31.4%) 17.4 (SD=4.5) 8-60 23 (1.3%) 909 (52.4%) 803 (46.3%)	 1146 (34.3%) 17.2 (SD=4.3) 8-60 15 (1.3%) 623 (54.4%) 508 (44.3%)

PH Pain Severity	1105 (20.0%)	752 (22.5%)
EMERGENCY DEPARTMENT (ED) ASSESSMENTS		
Number of cases documented NO ED intubated/paralytics/sedated	5518 (100%)	3339 (100%)
ED heart rate[§]		
Records with non-missing data, % of total	5388 (97.6%)	3312 (99.2%)
Mean (SD)	89.2 (22.4)	87.3 (19.7)
Range:[§]	22-181	22-181
Low (0-59) =	252 (4.7%)	159 (4.8%)
Normal (60-100) =	3812 (70.8%)	2425 (73.2%)
High (>100)	1324 (24.6%)	728 (22.0%)
ED SBP[§]		
Records with non-missing data, % of total	5369 (93.7%)	3311 (99.2%)
Mean (SD)	134.5 (SD=20.1)	135.7 (19.0)
Range:[§]	24-221	24-221
Low (0-109) =	482 (9.0%)	227 (6.9%)
Normal (110-130) =	1681 (31.3%)	1020 (30.8%)
High (>130) =	3206 (59.7%)	2064 (62.3%)
ED respiratory rate[§]		
Records with non-missing data, % of total	4991 (90.4%)	3164 (94.8%)
Mean (SD)	19.4 (SD=5.6)	19.2 (SD=5.2)
Range:[§]	7-73	7-73
Low (0-11) =	91 (1.8%)	50 (1.6%)
Normal (12-16) =	1576 (31.6%)	1037 (32.8%)
High (>16) =	3324 (66.6%)	2077 (65.6%)
Glasgow Coma Scale (GCS)		
Mean (SD)	14=225 (4.1%)	14=106 (3.2%)
Range	15=4293 (95.9%)	15=3233 (96.8%)
ED Pain Severity	3339 (60.5%)	3339 (100%)
INJURY CHARACTERISTICS		
Battle	4027 (73.0%)	2291 (68.6%)
Non-Battle	1491 (27.0%)	1048 (31.4%)
Injury Type[4]		
Blunt	2760 (50.0%)	1806 (54.1%)
Burn	90 (1.6%)	63 (1.9%)
Other	10 (.2%)	1 (0.1%)
Penetrating	2658 (48.2%)	1468 (44.0%)
Mechanism of Injury		
Explosives	3230 (58.5%)	1858 (55.7%)
GSW/Firearm	882 (16.0%)	493 (14.8%)
MVC/Machinery/Fall	711 (12.9%)	483 (14.5%)
All others[5]	695 (12.6%)	505 (15.1%)
Injury Severity Score (ISS) (% total)		
Minor (1-15)	4,730 (85.7%)	3,000 (89.9%)
Moderate (16-25)	488 (8.8%)	222 (6.7%)
Severe (26-50)	285 (5.2%)	111 (3.3%)
Critical (51-75)	15 (0.3%)	6 (0.2%)
Traumatic Brain Injury (using AIS & ICD-9 criteria[6])	Mild: 647 (11.7%) Severe: 234 (4.2%)	Mild: 338 (10.1%) Severe: 124 (3.7%)
HEALTH SYSTEM CHARACTERISTICS		
Iraq (OIF, OND)	516 (9.4%)	381 (11.4%)
Afghanistan (OEF)	5002 (90.7%)	2958 (88.6%)

ED Facility level[7]		
IIa	15 (0.3%)	4 (0.1%)
IIb	1318 (23.9%)	529 (15.8%)
III	4185 (75.8%)	2806 (84.0%)
Injury Year		
2010	2416 (43.8%)	1347 (40.3%)
2011	1718 (31.1%)	1083 (32.4%)
2012	1041 (18.9%)	667 (20.0%)
2013	343 (6.2%)	242 (7.3%)

[1]For analyses, E-1-E5 vs. E-6 and up
[2]For analyses, Navy, AF, CG combined
[3]For analyses, high and low HR, SBP, RR combined
[4]For analyses, Burn/Other combined
[§]HR/SBP/RR=0 verified by medical record review; patients were undergoing CPR
[5]Causes of "other" injuries included sports, crush injuries, blunt objects, aviation mishaps, or flying debris.
[6]Applied criteria described in Holbrook, et al (2010)
[7]For analyses, IIa/IIb vs. III
Abbreviations: PH=Pre-hospital; ED=Emergency Department; AIS= Abbreviated Injury Score GSW=Gunshot Wound; MVC=Motor Vehicle Crash;

Chapter 4 Table 2.

Simple Logistic Regressions
Dependent Variable: ED Pain Assessment Documentation, N=5518*

Predictor**	**Overall Model F Test**	**P value of overall Model**	**Odds Ratio**	**Confidence Interval (CI) of Odds Ratio[1]**	
				Lower Bound	**Upper Bound**
DECREASING FACTORS					
PH heart rate <60 or>100[1]	15.67	0.0001	**0.69**	**0.58**	**0.83**
PH respiratory rate <12 or >16[2]	8.55	0.0038	**0.74**	**0.61**	**0.91**
ED heart rate <60 or>100[3]	24.44	<0.0001	**0.74**	**0.65**	**0.83**
Trauma Type	29.81	<0.0001			
Penetrating vs. Blunt***			**0.65**	**0.57**	**0.74**
Burn/Other vs. Blunt			0.98	0.59	1.64
Penetrating vs. Burn/Other			0.66	0.40	1.10
Battle Injury vs. Non-battle Injury	80.65	<0.0001	**0.56**	**0.49**	**0.63**
Injury Severity Score	38.67	<0.0001			
16-25 moderate vs. <16 minor***			**0.48**	**0.37**	**0.62**
26-50 severe vs. <16 minor***			**0.37**	**0.26**	**0.51**
51-75 critical vs. <16 minor			0.38	0.09	1.55
26-50 severe vs. 16-25 moderate			0.76	0.51	1.14
51-75 critical vs. 16-25 moderate			0.80	0.19	3.28
51-75 critical vs. 26-50 severe			1.04	0.25	4.36
INCREASING FACTORS					
Documentation of any PH HR/SBP/RR	36.52	<0.0001	**1.41**	**1.26**	**1.57**
PH Pain Assessment documented	32.64	<0.0001	**1.50**	**1.31**	**1.73**
Documentation of PH Analgesic	4.21	0.0401	**1.14**	**1.01**	**1.29**
ED GCS Total score (15 vs. 14)	17.22	<0.0001	**1.76**	**1.35**	**2.30**
Documentation of any ED HR/SBP/RR	68.39	<0.0001	**11.66**	**6.52**	**20.88**
Mechanism of Injury	25.96	<0.0001			
GSW vs. Explosion			0.94	0.76	1.14
MVC/Machinery/Fall vs. Explosion***			**1.56**	**1.24**	**1.97**
GSW vs. MVC/Machinery/Fall***			**0.60**	**0.45**	**0.79**
Other vs. Explosion***			**1.96**	**1.54**	**2.50**
Other vs. GSW***			**2.10**	**1.57**	**2.80**
Other vs. MVC/Machinery/Fall			1.25	0.92	1.71
ED facility level Level III vs. IIa /IIb	296.25	<0.0001	**3.05**	**2.69**	**3.47**
Year	15.71	<0.0001			
2011 vs. 2010			**1.35**	**1.14**	**1.61**
2012 vs. 2010			**1.42**	**1.16**	**1.73**
2013 vs. 2010			**1.90**	**1.37**	**2.65**
2012 vs. 2011			1.05	0.84	1.30
2013 vs. 2011			**1.40**	**1.00**	**1.97**
2013 vs. 2012			1.34	0.94	1.92

*Note: 100 imputations. Documentation of ED Pain Assessment was not related to: age group; gender; military rank or service; PH SBP; ED RR; ED SBP.
**Predictors included only if model was significant at 0.05
***CI with Bonferroni correction for post-hoc pairwise comparisons =95% if binary predictor, 98.33% with 3-category predictor; 99.17% with 4-category predictor. Significant if 1 is not in the interval and **bold**.
[1]Proportion of imputed data =59.4% [2]Proportion of imputed data =65.7% [3]Proportion of imputed data =2.4%
Abbr: PH=Pre-hospital; ED=Emergency Department; HR=Heart Rate; SBP=Systolic Blood Pressure; RR=Respiratory Rate

Chapter 4 Table 3.
Simple Linear Regressions
Dependent Variable: ED Pain Severity Score, N=3339*

Predictor**	**Overall Model F Test**	**P value of overall Model**	**Coefficient**	**Confidence Interval of Coefficient*** **		**R^2**
				Lower Bound	**Upper Bound**	
Age Group***	3.43	0.0163				0.31%
21-25 vs. 18-20			0.19	-0.24	0.62	
26-30 vs. 18-20			**0.56**	**0.07**	**1.05**	
31-60 vs. 18-20			0.23	-0.29	0.75	
26-30 vs. 21-25			0.37	-0.01	0.76	
31-60 vs. 21-25			0.04	-0.38	0.47	
31-60 vs. 26-30			-0.33	-0.82	0.16	
Gender – Male vs. Female	12.88	0.0003	**-1.16**	**-1.79**	**-0.53**	0.38%
Military Service***	121.03	<0.0001				6.8%
Marine Corps vs. Army			**-1.86**	**-2.14**	**-1.57**	
USN/USAF/USCG vs. Army			**-0.58**	**-1.15**	**-0.01**	
Marine Corps vs. USN/USAF/USCG			**-1.28**	**-1.87**	**-0.68**	
PH Heart Rate <60 or >100[1]	10.89	0.0011	**0.56**	**0.22**	**0.89**	0.64%
PH Respiratory Rate <12 or >16[2]	8.06	0.0050	**0.56**	**0.17**	**0.96**	0.72%
Any PH HR/RR/SBP (yes/no)	39.02	<0.001	**-0.70**	**-0.92**	**-0.48**	1.16%
PH Pain Severity score[3]	51.50	<0.0001	**0.34**	**0.25**	**0.43**	7.5%
Any PH Analgesic	30.16	<0.0001	**0.69**	**0.44**	**0.93**	0.90%
ED Heart Rate <60 or >100[4]	19.70	<0.0001	**0.56**	**0.31**	**0.81**	0.59%
ED Respiratory Rate <12 or >16[5]	86.29	<0.0001	**1.13**	**0.89**	**1.37**	2.72%
Trauma Type***	4.42	0.0122				0.26%
Penetrating vs. Blunt			**0.33**	**0.06**	**0.61**	
Burn/Other vs. Blunt			-.04	-1.02	0.94	
Penetrating vs. Burn/Other			0.37	-0.61	1.35	
Mechanism of Injury***	6.64	0.0002				0.59%
GSW vs. Explosion			-0.24	-0.68	0.19	
MVC/Machinery/Fall vs. Explosion			0.23	-0.21	0.66	
GSW vs. MVC/Machinery/Fall			-0.47	-1.02	0.07	
Other vs. Explosion			**-0.60**	**-1.03**	**-0.17**	
Other vs. GSW			-0.36	-0.90	0.18	
Other vs. MVC/Machinery/Fall			**-0.83**	**-1.37**	**-0.29**	
Injury Severity Score***	53.63	<0.0001				4.60%
16-25 moderate vs. <16 minor			**2.16**	**1.58**	**2.74**	
26-50 severe vs. <16 minor			**2.52**	**1.71**	**3.32**	
51-75 critical vs. <16 minor			2.89	-0.52	6.30	
26-50 severe vs. 16-25 moderate			0.36	-0.61	1.33	
51-75 critical vs. 16-25 moderate			0.73	-2.72	4.19	

51-75 critical vs. 26-50 severe			0.37	-3.12	3.87	
ED Facility – Level III vs. IIa/IIb	61.41	<0.0001	**-1.19**	**-1.48**	**-0.89**	1.81%
Year	16.80	<0.0001				1.49%
2011 vs. 2010			**0.60**	**0.25**	**0.95**	
2012 vs. 2010			**1.03**	**0.63**	**1.43**	
2013 vs. 2010			0.49	-0.10	1.09	
2012 vs. 2011			**0.43**	**0.01**	**0.84**	
2013 vs. 2011			-0.11	-0.71	0.50	
2013 vs. 2012			-0.53	-1.17	0.10	

*Note: 100 imputations

**Predictors included only if model was significant at 0.05

***95% Confidence interval if binary predictor; 98.33% CI with Bonferroni correction if 3 categories of predictor; 99.17% CI with Bonferroni correction if 4 categories of predictor. Significant if 0 is not in the interval and **bold**.

[1]Proportion imputed = 56.2%

[2]Proportion imputed = 65.7%

[3]Proportion imputed = 77.5%

[4]Proportion imputed = 0.8%

[5]Proportion imputed = 5.2%

ED Pain Severity was not related to military rank; PH SBP; ED SBP; ED GCS; documentation of any ED HR/SBP/RR; battle injury.

Abbreviations: ED=Emergency Department; GCS=Glasgow Coma Scale; PH=Pre-hospital; HR=Heart Rate; SBP=Systolic Blood Pressure; RR=Respiratory Rate

Chapter 4 Table 4.

Multiple Logistic Regression
Dependent Variable: ED Pain Assessment Documentation, N=5518*

Overall Model F (12, 75419.2) = 40.40; P value of overall model <0.0001			
Predictor**	**Odds Ratio**	**Confidence Interval of Odds Ratio*****	
		Lower Bound	**Upper Bound**
PH heart rate <60 or>100[1]	**0.77**	**0.63**	**0.94**
ED GCS (15 vs. 14)	**1.77**	**1.33**	**2.36**
Documentation of any ED HR/SBP/RR	**13.28**	**7.25**	**24.36**
Trauma Type			
Penetrating vs. Blunt***	**0.70**	**0.60**	**0.81**
Burn/Other vs. Blunt	0.93	0.54	1.60
Penetrating vs. Burn/Other	0.75	0.43	1.29
Injury Severity Score			
16-25 moderate vs. <16 minor***	**0.53**	**0.40**	**0.69**
26-50 severe vs. <16 minor***	**0.44**	**0.31**	**0.63**
51-75 critical vs. <16 minor	0.38	0.09	1.65
26-50 severe vs. 16-25 moderate	0.84	0.55	1.29
51-75 critical vs. 16-25 moderate	0.72	0.16	3.20
51-75 critical vs. 26-50 severe	0.86	0.19	3.87
ED Facility Level (III vs. IIa/IIb)***	**3.36**	**2.93**	**3.85**
Year			
2011 vs. 2010***	**1.56**	**1.30**	**1.87**
2012 vs. 2010***	**2.10**	**1.68**	**2.63**
2013 vs. 2010***	**3.01**	**2.08**	**4.33**
2012 vs. 2011***	**1.35**	**1.07**	**1.70**
2013 vs. 2011***	**1.93**	**1.33**	**2.80**
2013 vs. 2012	1.43	0.97	2.10
Constant	0.03	0.27	0.51

*100 imputations
**Predictors included only if single-variable model was significant at 0.05
***Confidence intervals adjusted with Bonferroni correction for post-hoc pair-wise comparisons: 95% CI for binary predictors; 98.33% for 3-category predictors; 99.17% for 4 category predictors. Significant if 1 is not in the interval and **bold**.
[1]Proportion imputed = 59.4%
GCS=Glasgow Coma Scale; ISS=Injury Severity Score

Chapter 4 Table 5.

Multiple Linear Regression

Dependent Variable: ED Pain Severity Score, N=3339*

Overall Model F (12, 2176.5) = 39.99; P value of overall model <0.0001			
Overall R^2 =20.35%			
Predictor**	**Coefficient**	**Confidence Interval of Coefficient*****	
		Lower Bound	**Upper Bound**
Military Service			
Marine Corps vs. Army	**-1.23**	**-1.56**	**-0.90**
USN/USAF/USCG vs. Army	-0.57	-1.17	0.03
Marine Corps vs. USN/USAF/USCG	**-0.66**	**-1.30**	**-0.02**
Any PH vital signs documented	**-1.00**	**-1.46**	**-0.53**
PH Pain Severity score[1]	**0.32**	**0.24**	**0.39**
ED Respiratory Rate <12 or >16[2]	**0.72**	**0.48**	**0.96**
Injury Severity Score			
16-25 moderate vs. <16 minor	**1.60**	**1.02**	**2.18**
26-50 severe vs. <16 minor	**1.88**	**1.10**	**2.66**
51-75 critical vs. <16 minor	2.31	-0.92	5.54
26-50 severe vs. 16-25 moderate	0.28	-0.66	1.22
51-75 critical vs. 16-25 moderate	0.71	-2.56	3.99
51-75 critical vs. 26-50 severe	0.43	-2.88	3.75
ED Facility - Level III vs. IIa/IIb	**-0.42**	**-0.73**	**-0.11**
Year			
2011 vs. 2010	**0.58**	**0.19**	**0.96**
2012 vs. 2010	**0.94**	**0.50**	**1.37**
2013 vs. 2010	0.47	-0.14	1.07
2012 vs. 2011	0.36	-0.07	0.79
2013 vs. 2011	-0.11	-0.70	0.48
2013 vs. 2012	-0.47	-1.06	0.13
Constant	4.14	3.35	4.93

*100 imputations

**Predictors included only if single-variable model was significant at 0.05

*** Confidence intervals adjusted with Bonferroni correction for post-hoc pair-wise comparisons: 95% CI for binary predictors; 98.33% for 3-category predictors; 99.17% for 4 category predictors. Significant if 0 is not in the interval.

[1]Note: 80.0% imputed.

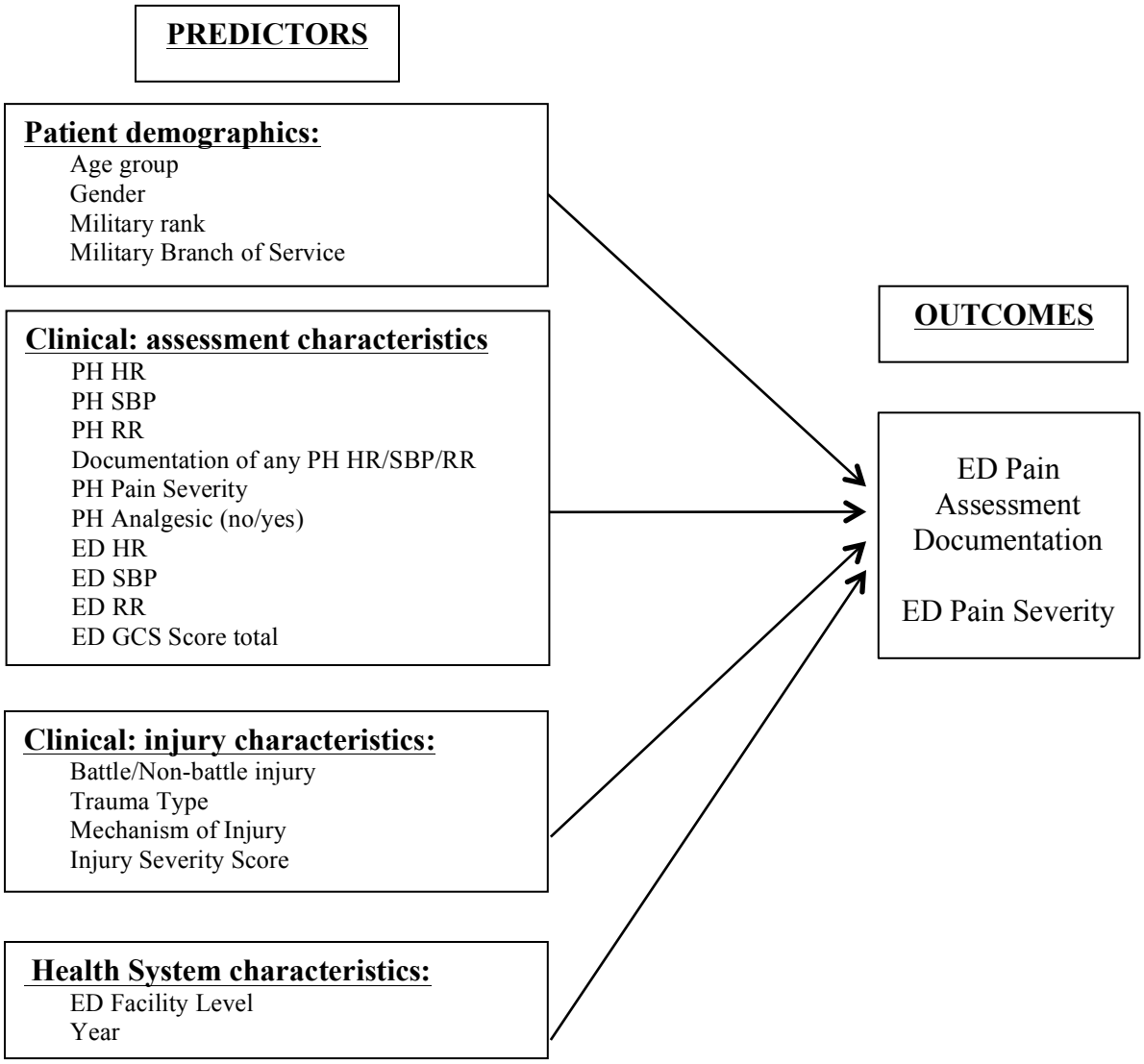
[2]Note: 5.2% imputed

USN=US Navy; USAF=US Air Force; USCG=US Coast Guard; ISS=Injury Severity Score GSW=Gun Shot Wound; MVC= Motor Vehicle Crash

NOTE: When model run with complete case analysis for PH pain scale scores, n=752, impact of PH pain scale score was smaller (95% CI 0.25- 0.38), but overall Model R-square was higher (26.12%;F 12, 736.9=21.57). When PH pain scale score was removed from the model, the overall model R-square dropped to 14.35% (F 11,3324.3 = 50.25)

Chapter 4 Figure 1

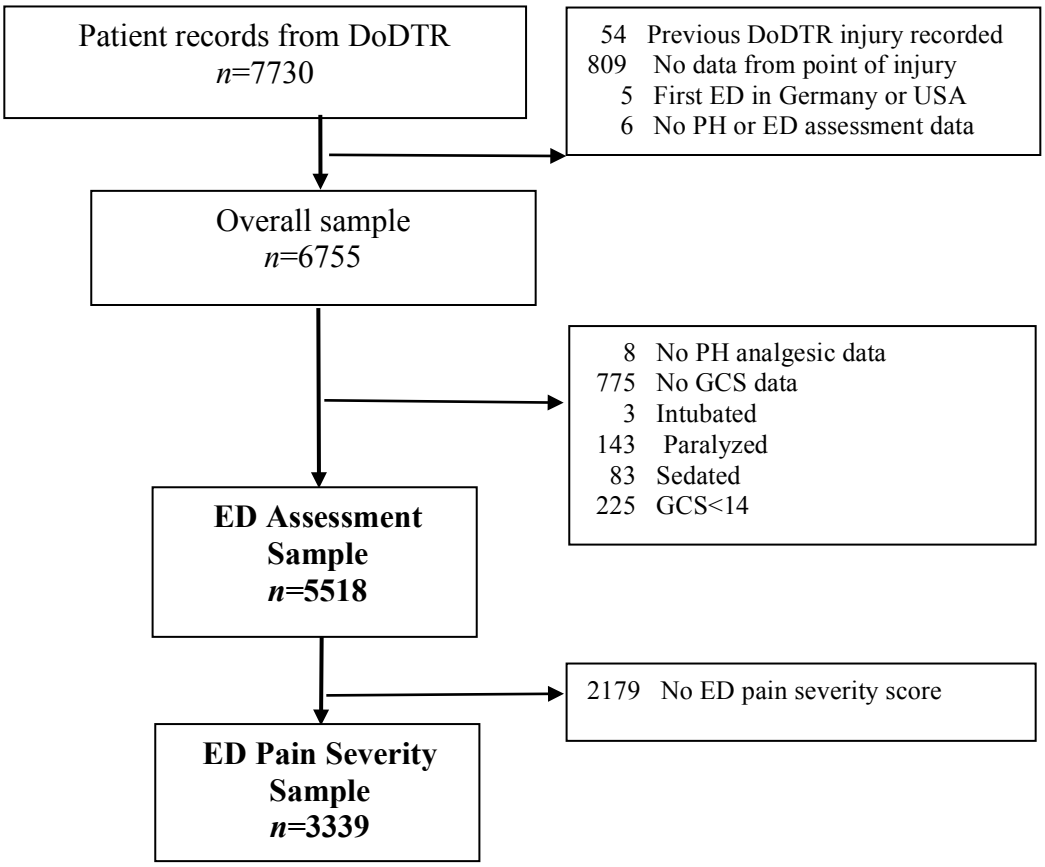
Conceptual model of influences on ED pain assessment and severity from data fields recorded in the DoDTR



Abbreviations: PH=Pre-hospital; ED=Emergency Department; DoDTR=Department of Defense Trauma Registry; HR=Heart Rate; SBP=Systolic Blood Pressure; RR=Respiratory Rate; GCS=Glasgow Coma Scale

Chapter 4 Figure 2.

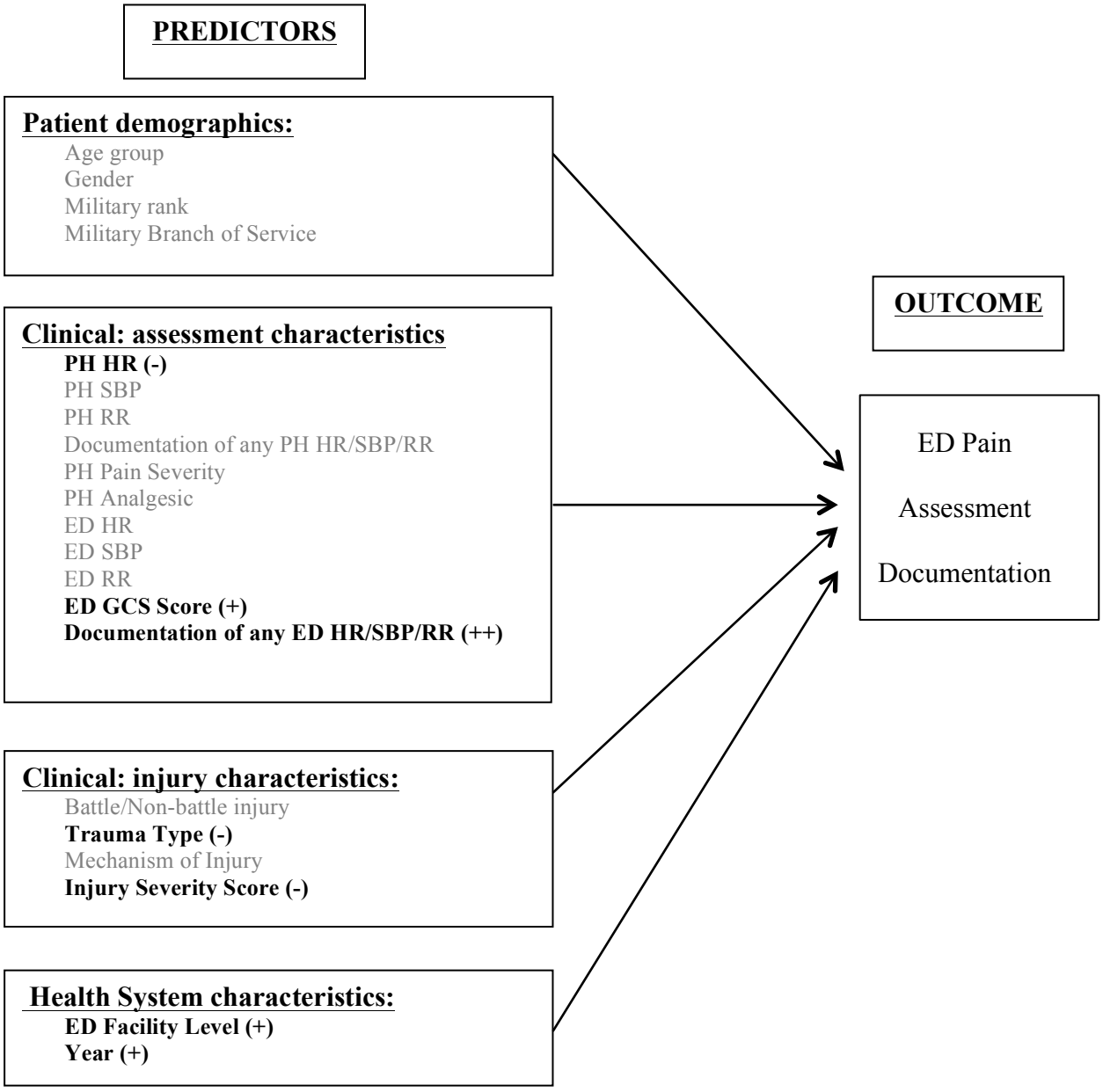
Study flow diagram



Abbreviations: PH=Pre-hospital; ED= Emergency Department; GCS=Glasgow Coma Scale

Chapter 4 Figure 3.

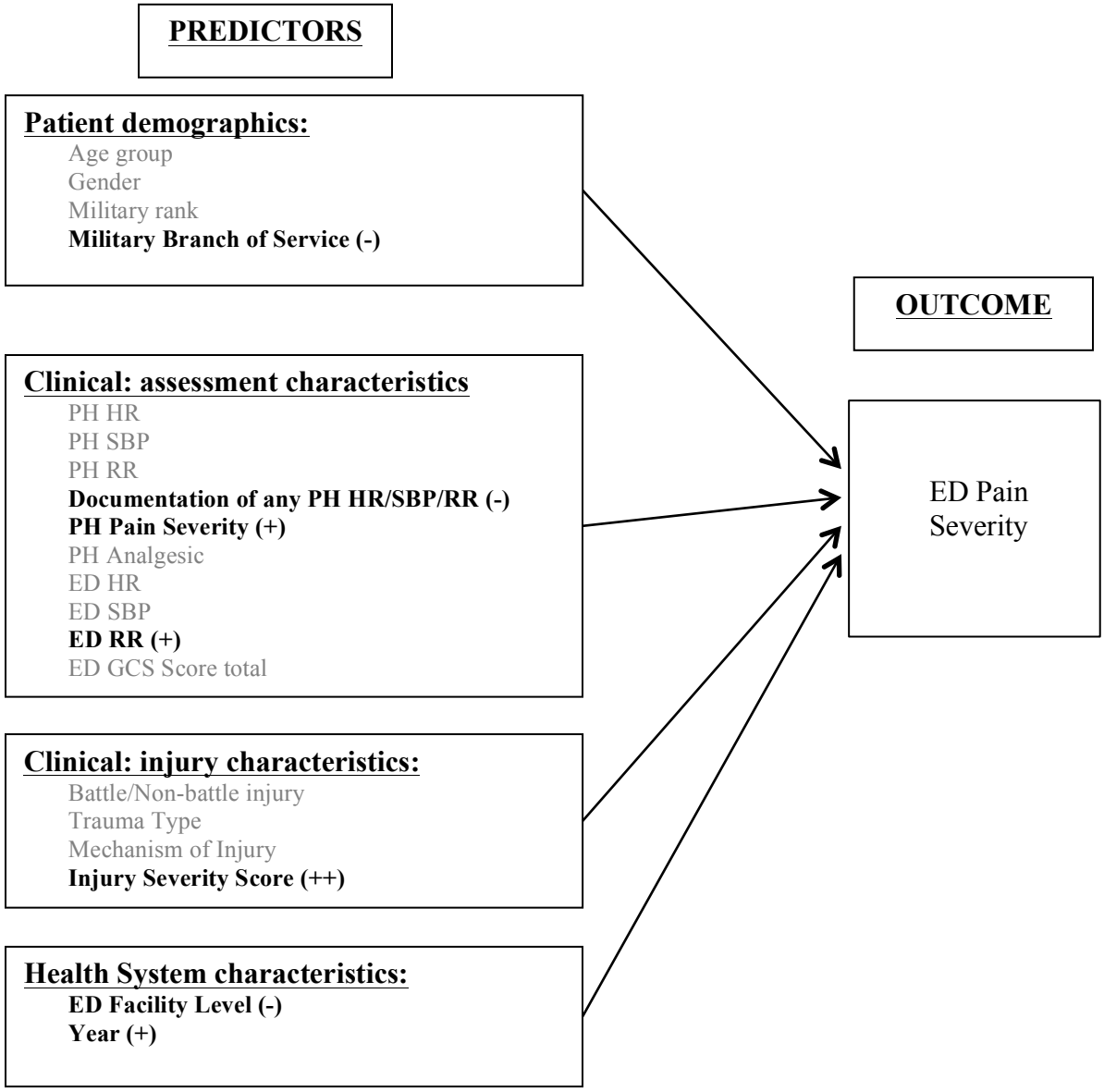
Final model of influences on ED pain assessment documentation from data fields recorded in the DoDTR



(+/-) = statistically significant ($p<0.05$) increase or decrease in odds of pain assessment documentation, but OR <3.0
(++/--) = statistically significant ($p<0.05$) increase or decrease in odds of pain assessment documentation, OR =3.0-4.0
(+++/----) = statistically significant ($p<0.05$) increase or decrease in odds of pain assessment documentation, OR >10.0
Abbreviations: PH=Pre-hospital; ED=Emergency Department; DoDTR=Department of Defense Trauma Registry; HR=Heart Rate; SBP=Systolic Blood Pressure; RR=Respiratory Rate; GCS=Glasgow Coma Scale

Chapter 4 Figure 4.

Final model of influences on ED pain severity from data fields recorded in the DoDTR



(+/-) = statistically significant ($p<0.05$) increase or decrease in Pain Severity Score, but less than clinically meaningful threshold (1.3)
(++/--) = statistically significant ($p<0.05$) increase or decrease in Pain Severity Score expected to be clinically meaningful
Abbreviations: PH=Pre-hospital; ED=Emergency Department; DoDTR=Department of Defense Trauma Registry; HR=Heart Rate; SBP=Systolic Blood Pressure; RR=Respiratory Rate; GCS=Glasgow Coma Scale

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Chapter 5

Discussion

Trauma is a global epidemic[1,2] resulting in significant painful injuries. Often, pain related to injury persists years after objective healing has occurred.[3-5] This dissertation has summarized current theories of transition from acute to chronic pain and suggested that early intervention, such as administering PH analgesics, may present an opportunity to decrease risk for development of persistent, chronic pain.

A review of recent research literature from the PH setting demonstrated that randomized controlled trials with trauma patients are possible. Additionally, observational cohort studies from around the world demonstrated that PH pain assessment and intervention can be incorporated into routine care, providing baseline data that can be evaluated at both individual patient and whole system levels. However, despite increased research on safety and effectiveness of PH analgesic interventions, findings show wide and unexplained variation in PH pain assessment and analgesic practices for traumatically injured patients.

To evaluate the prevalence of PH and ED pain assessment documentation, pain severity, and PH analgesic administration in the setting of military combat casualty care, a study of the DoDTR was conducted. Using all available data, explanatory models were constructed using logistic and linear regression, as appropriate.

SUMMARY AND EXPLANATION OF FINDINGS

Overall, findings from both the PH and ED studies provide evidence that documentation of pain assessment markedly improved over the years 2010-2013, but remains inadequate.

PH Pain Assessment Documentation: Specifically, our study found that 18.6% of all records had PH pain assessments, and 37.8% of records with PH vital signs also contained PH

pain assessments, compared to the previously reported 6.7% documentation of PH combat-zone pain assessments.[6] The final model of PH pain assessment included any documented vital signs, mechanism of injury, injury year, and ED facility level and explained 19.26% of variance (figure 1). Records with any PH vital signs (heart rate, systolic blood pressure, respiratory rate) were 22.6 times more likely to include pain assessments. While capturing any PH assessment data with written documentation remains a challenge, PH pain assessment documentation is more likely to co-occur with vital sign assessment documentation. This suggests that emphasizing pain assessment as part of vital sign assessment might be one strategy to improve overall PH pain assessment documentation. Each year from 2010 to 2013, likelihood of PH pain assessment increased between 1.93 and 2.71 times. PH pain assessment documentation was 2.05 times more likely if the first ED at which the patient was treated was level III compared to level IIa or IIb.

It is unknown if the difference in PH assessment documentation was dependent on the practices of PH providers, the availability of transferrable documentation (i.e., a paper chart compared to markings on the patient's skin or bandages), or greater personnel and equipment resources at the level III ED, which facilitated more complete DoDTR data entry for PH care. The interactions between the delivering PH personnel and receiving ED providers might have also influenced PH practices. For example, an ED team that positively recognizes PH pain assessment documentation may be more likely to continue receiving such documentation compared to a team that ignores or discounts such documentation. PH pain assessment documentation was also more likely (1.69-1.81) if the mechanism of injury was anything "other" (not explosion, gunshot wound, or motor vehicle/machinery/fall). Possible explanations of this finding relate to the likelihood of multiple casualties, or that pain assessment documentation was less likely for patients with injuries more likely to present with life-threatening hemorrhage.

PH Pain Severity: PH pain severity scores on the 0 to 10 Numeric Rating Scale (NRS), where 0 is no pain and 10 is the worst pain imaginable, were reported on 1253 records. Pain severity (mean = 5.5, median 6) was lower in the DoDTR sample than in recent PH studies[7,8] of civilian trauma patients. The final model of PH pain severity [$F(5, 1239.2) = 12.57$, $p < 0.0001$] included only heart rate, respiratory rate, and injury severity score and explained only 5.0% of variance (figure 2). Not surprisingly, pain severity scores were higher (1.04 and 1.41 units) on records from patients with moderate or severe injuries compared to minor injuries, but no differences were noted between critical injuries and other categories. Pain severity scores on records from patients with abnormally high or low heart rate or respiratory rate were also slightly higher (0.41 and 0.68 units, respectively) than patients with normal heart rate or respiratory rate. Because other studies with emergency patients have found that the minimum clinically meaningful difference on the NRS is 1.39,[9] these findings suggest that individual patient queries must remain the mainstay of pain assessment, because the available data poorly predict pain severity.

PH Analgesic Administration: The final model of PH analgesic administration [$F(13, 12508.0) = 22.90$, $p<0.0001$] included 6 variables, of which PH pain score required 62.2% imputation (figure 3). Patients with penetrating trauma were 1.99 times more likely to receive PH analgesics than patients with blunt trauma; there was no difference when compared to patients with burns. Interestingly, while records with mechanisms of injury "other" were more likely to have pain assessment documented than records of patients injured by explosions or gunshot wound, explosion and gunshot wound were associated with 1.52 and 1.95 times the odds, respectively, of PH analgesic administration compared to records of patients injured by "other" mechanisms. Possible explanations for these differences might be a heightened

recognition of pain based on clinician empathy or visible tissue damage. Additionally, heightened clinician concern about negative effects of opioid analgesics in patients with traumatic brain injury may explain lower PH analgesic rates among patients injured by explosion compared to gunshot. Patient records with moderate injury severity were 1.48 times more likely to report PH analgesic administration compared to minor injury; no other variation was identified between injury severity. Each unit increase in PH pain severity score was associated with 1.26 times the odds of PH analgesic administration, suggesting that pain assessment may have been used to guide practice. This conclusion was reinforced by the finding that 82.2% of patients with a pain severity score of 4-10 received analgesics compared to 25% overall, and 51.5% of patients with a pain assessment. The finding that patients injured during 2012 were nearly 50% more likely than patients in either 2010 or 2011 to have received PH analgesics was unexplained by the available data, and demonstrates variability in care practices. Possible explanations include changes in PH response system leadership, staffing, equipment or priorities.

ED Pain Assessment Documentation: Our study of ED pain assessment found that 60.5% of records over the 44 month study period included pain assessment documentation. The final model of ED pain assessment [$F(12, 75419.2) = 40.40$), $p < 0.0001$] included: PH HR; documentation of any ED vital signs; ED Glasgow Coma Scale score; trauma type; Injury Severity Score; facility level; and year (figure 4). Each variable made a significant independent contribution to the model. The final model was an estimation pooling 100 imputed data sets, therefore percent of explained variance is not available.

Documentation of any ED vital signs increased the odds of ED pain assessment documentation by 13.28 times, and treatment at a level III facility was associated with 3.36 times greater odds of pain assessment documentation that treatment at a level IIa or IIb facility.

Likelihood of ED pain assessment documentation increased significantly each of the first three years of the study period (1.56 – 1.93 times); the change from 2012 to 2013 was not significant within the multivariable model when the Bonferroni correction was applied. Patients with no gross neurological deficits (GCS = 15 compared to 14) were 1.77 times more likely to have an ED pain assessment recorded, while patients with abnormally low or high PH heart rates were 23% less likely to have an ED pain assessment recorded. Finally, patients with moderate and severe injuries were only half as likely (OR = 0.53 and 0.44) as patients with minor injuries (by ISS category) to have ED pain assessments. These variations may reflect prioritization of care, such that pain assessment, or at least the documentation of pain assessment, is deferred in patients who present to the ED with more complex injuries or are more physiologically unstable.

ED Pain Severity: Identical to findings from the PH sample, mean pain severity in the ED sample, reported in 3,339 records, was 5.5 and the median was 6. The overall model was significant [$F (12, 2176.5) = 39.99$, $p < 0.0001$], and included seven predictors: military service, documentation of any PH vital signs, PH pain severity score, ED respiratory rate, ISS, ED facility level, and year (figure 5). The largest coefficients of pain severity were associated with injury severity; patients with moderate and severe injuries reported scores 1.60 and 1.88 higher than patients with injuries scored as minor. Marines reported significantly lower pain scores than patients in the Army (1.23) or other service branches (0.66). The presence of documented PH vital signs was associated with a 1 unit lower ED pain severity score. All other coefficients were between 0.32 and 0.94, and therefore changes that would not meet previously established thresholds for clinically meaningful change.[9] The final model explained 20.4% of variance, four times that which was explained in the PH model. While this finding is unexplained by the available data, potential influences to be explored in future studies include unmeasured

phenomena as stress-induced analgesia.[10] Socially-mediated influences on pain reporting may have also influenced the findings, such as differences in clinician empathy[11-13] or variation in pain reporting based on patient - clinician gender concordance. Gender-mediated differences in pain reporting are reported in experimental pain studies.[14,15] Albrecht and colleagues reported differences in PH analgesic use between male and female physicians caring for trauma patients.[16] For the present study, the personnel assignment policies of the US military during the study period meant that PH assessments were more likely to be completed by male providers (gender concordant with injured). Conversely, many more female clinicians were deployed to combat zone EDs, suggesting a greater likelihood that pain assessments in the ED were completed by female health care personnel (gender discordant with injured). Because data on clinician gender was not available in the DoDTR, gender concordance between patient and provider could not be evaluated in this study. While the ED pain severity model yielded greater predictive power than the PH pain severity model, 80% of variance in ED pain severity remains unexplained by all available variables and further research is needed.

IMPLICATIONS FOR FUTURE RESEARCH

Evidence that early analgesic intervention to halt pain processing may reduce the risk for development of persistent pain suggests that research examining how PH pain care practices are associated with the long-term pain outcomes of trauma patients is needed. These studies are a first step towards that goal, as they demonstrate that adequate baseline data exist in the DoDTR to support such research. Moreover, the homogeneity of the DoDTR sample (young, fit males with minimal comorbidities) and the delivery of care within the integrated military health care system should facilitate data capture.

Post-traumatic stress disorder (PTSD) is also a significant risk for trauma survivors.[17-20] Existing research suggests that early analgesic delivery is associated with reduced risk for PTSD development,[21,22] and that persistent pain and PTSD are often co-occuring.[23,24] Future longitudinal studies are needed to evaluate how PH and ED pain care is associated with these critical outcomes.

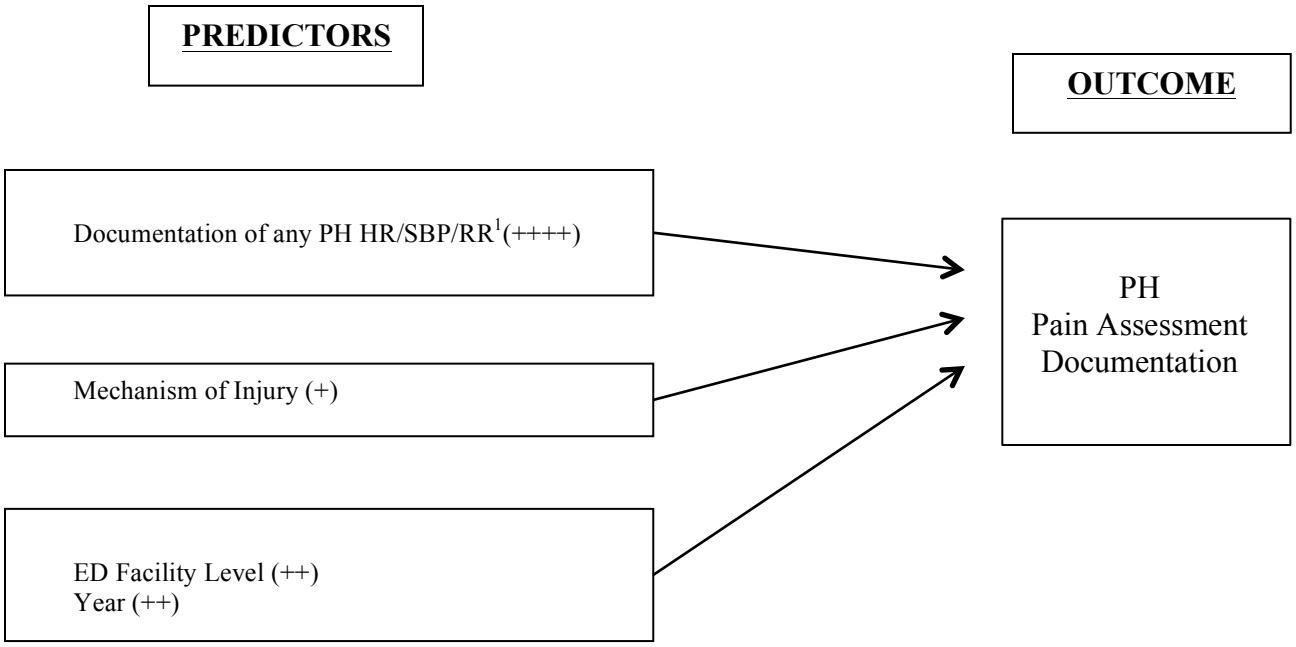
IMPLICATIONS FOR CLINICAL PRACTICE

The need for pain assessment at all levels of care, with re-assessment after intervention is paramount. Education of clinical personnel at all levels (Hospital Corpsmen and medics, Registered Nurses, and all credentialed providers) on the need for pain assessment may help to improve practice and documentation.[25-27] Likewise, regular feedback to frontline personnel on how their documentation forms an irreplaceable[28] data bank on which care improvements can be based may help persuade clinicians to ensure complete pain-related documentation.[29]

CONCLUSION

Pain after traumatic injury can become a chronic, persistent condition that robs survivors of quality of life and creates an economic burden. Findings from this study suggest that even in the austere combat zone PH and ED environments, pain assessment and analgesic interventions are possible. These data suggest that improvements in pain care even in this dramatic setting are possible, but more research is needed to determine how these interventions, and other related factors influence the patient's trajectory of pain experience.

Chapter 5 Figure 1
Final model of influences on PH pain assessment documentation from data fields recorded in the DoDTR

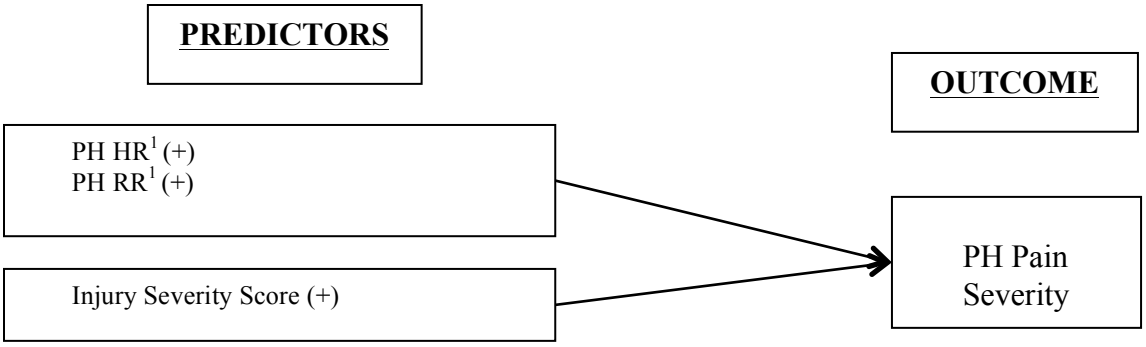


[1]Documentation of any PH HR, SBP, or RR (dichotomous)

Abbreviations: PH=Pre-hospital; ED=Emergency Department; DoDTR=Department of Defense Trauma Registry; HR=Heart Rate; SBP=Systolic Blood Pressure; RR=Respiratory Rate; GCS=Glasgow Coma Scale GSW=Gunshot Wound; MVC=Motor Vehicle Crash

Chapter 5 Figure 2.

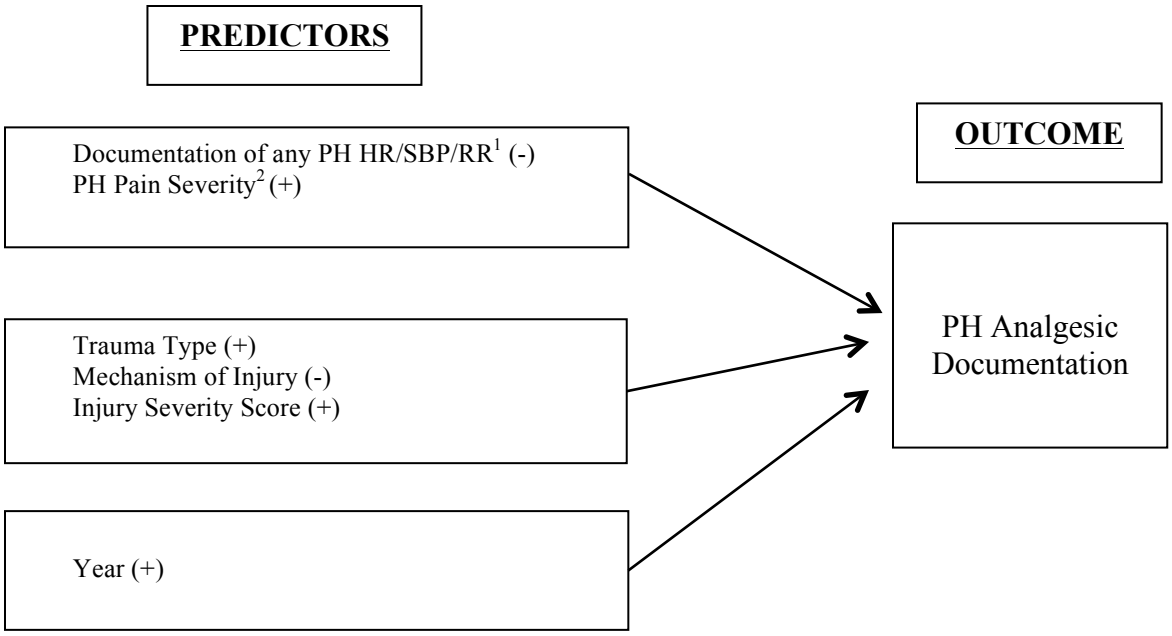
Final model of influences on PH pain severity from data fields recorded in the DoDTR



[1]Variables with non-normal distributions had missing values in DoDTR, so multiple imputation with chained equations was used.
[2]Documentation of any PH HR, SBP, or RR (dichotomous) was used as a predictor for all outcomes. Abbreviations: PH=Pre-hospital; ED=Emergency Department; DoDTR=Department of Defense Trauma Registry; HR=Heart Rate; SBP=Systolic Blood Pressure; RR=Respiratory Rate; GCS=Glasgow Coma Scale GSW=Gunshot Wound; MVC=Motor Vehicle Crash

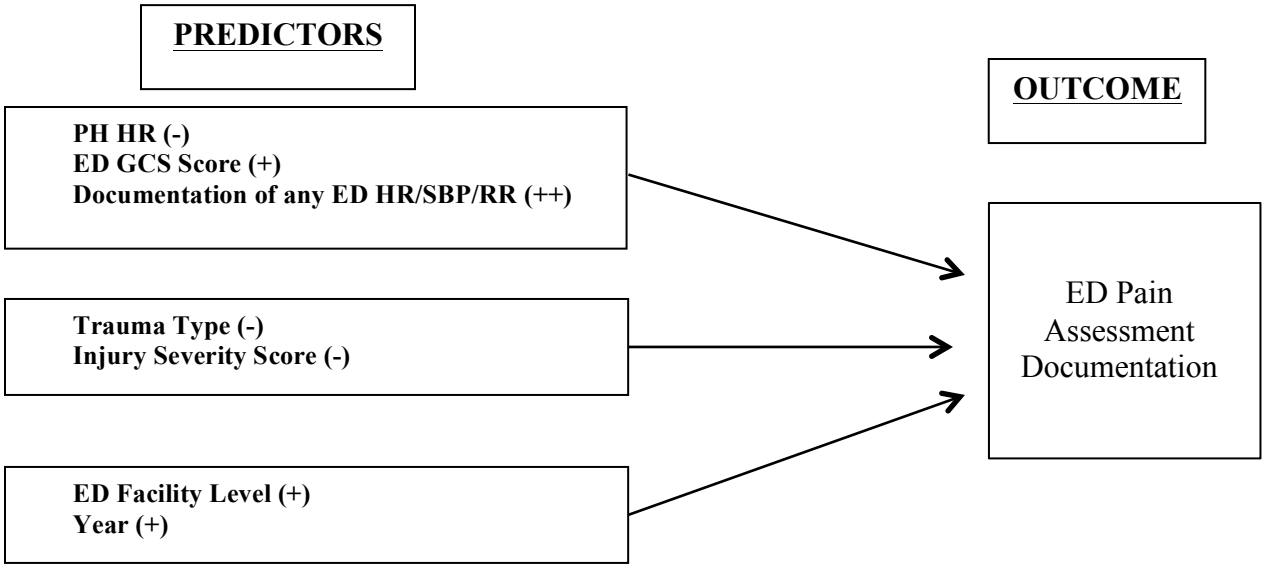
Chapter 5 Figure 3.

Final model of influences on PH analgesic documentation from data fields recorded in the DoDTR



[1]Documentation of any PH HR, SBP, or RR (dichotomous)
[2]Variables with non-normal distributions had missing values in DoDTR, so multiple imputation with chained equations was used.
Abbreviations: PH=Pre-hospital; ED=Emergency Department; DoDTR=Department of Defense Trauma Registry; HR=Heart Rate; SBP=Systolic Blood Pressure; RR=Respiratory Rate; GCS=Glasgow Coma Scale GSW=Gunshot Wound; MVC=Motor Vehicle Crash

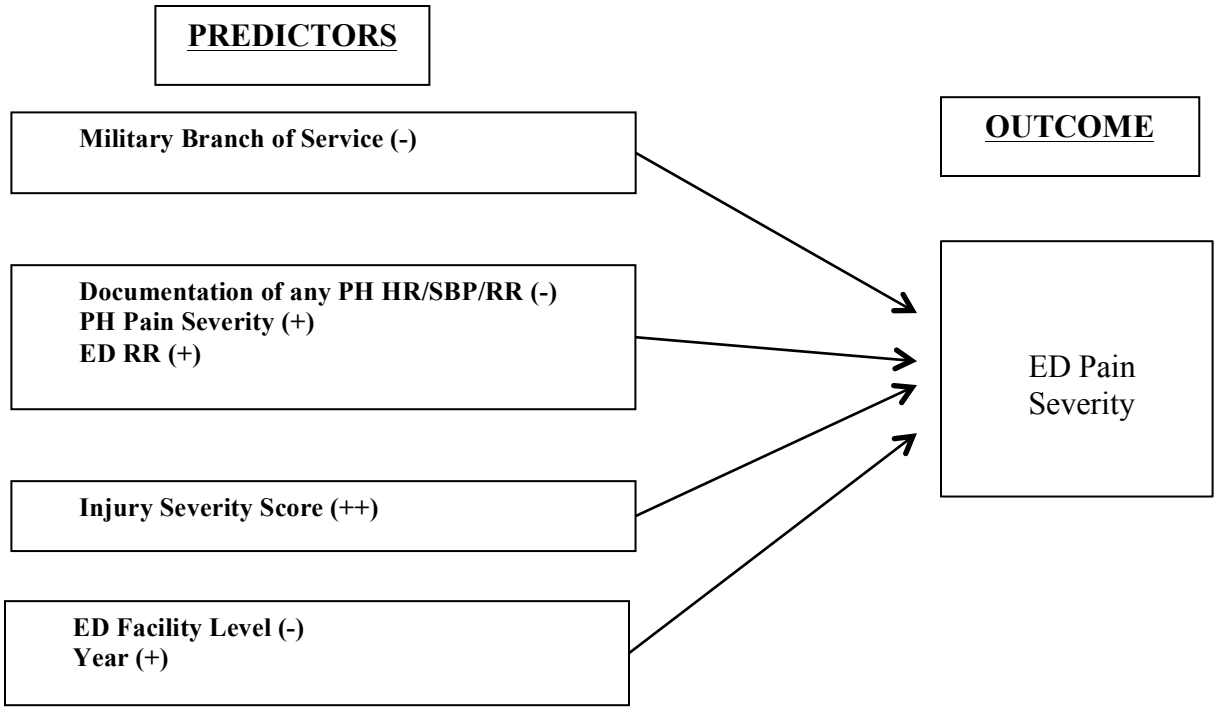
Chapter 5 Figure 4
Final model of influences on ED pain assessment documentation from data fields recorded in the DoDTR



(+/-) = statistically significant ($p<0.05$) increase or decrease in odds of pain assessment documentation, but OR <3.0
(++/--) = statistically significant ($p<0.05$) increase or decrease in odds of pain assessment documentation, OR =3.0-4.0
(+++/----) = statistically significant ($p<0.05$) increase or decrease in odds of pain assessment documentation, OR >10.0
Abbreviations: PH=Pre-hospital; ED=Emergency Department; DoDTR=Department of Defense Trauma Registry; HR=Heart Rate; SBP=Systolic Blood Pressure; RR=Respiratory Rate; GCS=Glasgow Coma Scale

Chapter 5 Figure 5.

Final model of influences on ED pain severity from data fields recorded in the DoDTR



(+/-) = statistically significant ($p<0.05$) increase or decrease in Pain Severity Score, but less than clinically meaningful threshold (1.3)
(++/--) = statistically significant ($p<0.05$) increase or decrease in Pain Severity Score expected to be clinically meaningful
Abbreviations: PH=Pre-hospital; ED=Emergency Department; DoDTR=Department of Defense Trauma Registry; HR=Heart Rate; SBP=Systolic Blood Pressure; RR=Respiratory Rate; GCS=Glasgow Coma Scale

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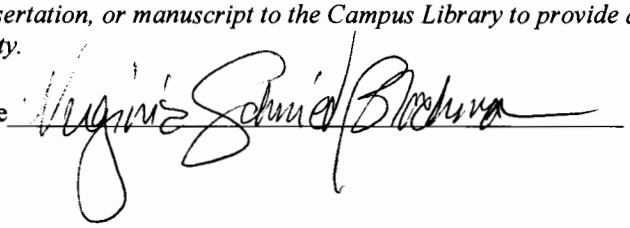
Author Signature  Date 20 Dec 2014