Analysis of Orthopaedic Research Produced During the Wars in Iraq and Afghanistan

George C. Balazs MD, Jonathan F. Dickens MD, Alaina M. Brelin MD,
Jared A. Wolfe MD, John-Paul H. Rue MD, Benjamin K. Potter MD

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Abstract

Background Military orthopaedic surgeons have published a substantial amount of original research based on our care of combat-wounded service members and related studies during the wars in Iraq and Afghanistan. However, to our knowledge, the influence of this body of work has not been evaluated bibliometrically, and doing so is

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G. C. Balazs, J. F. Dickens, A. M. Brelin,
J. A. Wolfe, B. K. Potter (✉)
Department of Orthopaedics, Walter Reed National Military
Medical Center, Building 19, Floor 2, 8901 Wisconsin Avenue,
Bethesda, MD 20889, USA
e-mail: Benjamin.k.potter.mil@mail.mil

J.-P. H. Rue
US Naval Academy, Annapolis, MD, USA

B. K. Potter
Department of Surgery, Uniformed Services University of
Health Sciences, Bethesda, MD, USA

important to determine the modern impact of combat casualty research in the wider medical community.

Questions/purposes We sought to identify the 20 most commonly cited works from military surgeons published during the Iraq and Afghanistan conflicts and analyze them to answer the following questions: (1) What were the subject areas of these 20 articles and what was the 2013 Impact Factor of each journal that published them? (2) How many citations did they receive and what were the characteristics of the journals that cited them? (3) Do the citation analysis results obtained from Google Scholar mirror the results obtained from Thompson-Reuters' Web of Science?

Methods We searched the Web of Science Citation Index Expanded for relevant original research performed by US military orthopaedic surgeons related to Operation Iraqi Freedom and Operation Enduring Freedom between 2001 and 2014. Articles citing these studies were reviewed using both Web of Science and Google Scholar data. The 20 most cited articles meeting inclusion criteria were identified and analyzed by content domain, frequency of citation, and sources in which they were cited.

Results Nine of these studies examined the epidemiology and outcome of combat injury. Six studies dealt with wound management, wound dehiscence, and formation of heterotopic ossification. Five studies examined infectious complications of combat trauma. The median number of citations garnered by these 20 articles was 41 (range, 28–264) in Web of Science. Other research citing these studies has appeared in 279 different journals, covering 26 different medical and surgical subspecialties, from authors in 31 different countries. Google Scholar contained 97% of the Web of Science citations, but also had 31 duplicate entries and 29 citations with defective links.

Conclusions Modern combat casualty research by military orthopaedic surgeons is widely cited by researchers in a diverse range of subspecialties and geographic locales. This suggests that the military continues to be a source of innovation that is broadly applicable to civilian medical and surgical practice and should encourage expansion of military-civilian collaboration to maximize the utility of the knowledge gained in the treatment of war trauma.

Level of Evidence Level IV, therapeutic study.

Introduction

The conflicts in Iraq and Afghanistan have resulted in more than 5300 deaths and 52,000 battlefield injuries among American service personnel, including more than 2200 major limb amputations [15]. The unique nature of these wounds, which primarily result from explosive blasts and high-velocity gunshots, has been well documented [4, 9, 10]. Owing largely to advances in personal protective equipment, rapid aeromedical evacuation, and the far-forward movement of advanced medical resources, devastating injuries have become increasingly survivable, even in the face of escalating injury severity, resulting in extremely high musculoskeletal injury burden in combat-wounded survivors [49].

The need to improve care for injured service members has generated large, congressionally funded research initiatives [59]. Musculoskeletal injury research was first listed as a Department of Defense funding priority in fiscal year (FY) 2005. After preliminary funding beginning in FY 2006, administration was subsequently shifted to the Congressionally Directed Medical Research Programs office (subordinate to the US Army Medical and Materiel Command) in FY 2009, which established the Peer-Reviewed Orthopaedic Research Program. To date, these programs have provided nearly USD 250 million for military and civilian researchers [48].

Given the large funding resources and federal attention directed toward these medical programs, investigators have an obligation to demonstrate the relevance and success of their sponsored research activities, particularly if additional funding is to be pursued for new project initiation or sustainment of existing programs. Ideally, research programs would improve our understanding of musculoskeletal combat injuries and their management as well as help identify wider applicability within the civilian medical community. In general, the number of times an article is cited (citation analysis) is used to assess its impact [5, 7, 18]. The emergence of indexing services collecting information on citations of individual articles has greatly expanded the ability of researchers and clinicians to quickly access information. The related metric for individual journals is the Impact Factor, frequently used as a surrogate

quality measure and an important element when researchers consider journals to which to submit their work [27, 29, 45, 50]. Consequently, citation analysis is typically performed using results from Thompson-Reuters' Web of Science, whose results form the basis for Impact Factor calculations. Google Scholar also publishes similar information on number of citations. This resource, although free to use, relies on automated web crawlers and publisher-submitted information and so is not commonly used in formal academic research.

During the past decade, the technique of citation analysis has been used across nearly all surgical specialties and subspecialties for a variety of purposes [3, 13, 14, 30, 36, 43, 57]. Within orthopaedic surgery, researchers have used the Web of Science to identify the most cited articles in pediatric orthopaedics [25, 58], spine surgery [12], arthroscopy [6], arthroplasty [21], hand surgery [24, 56], shoulder surgery [35], and foot and ankle surgery [1]. The works provide a ready reference of "citation classics," or articles that can be used by subsequent researchers and students. Although a few studies have assessed the impact of orthopaedic research performed by military surgeons [51, 55] and summarized the effects of war on the surgical literature [38], we are unaware of any formal citation analysis performed on orthopaedic research based on the wars in Iraq and Afghanistan.

We sought to identify the 20 most commonly cited works from military orthopaedic surgeons published during the Iraq and Afghanistan conflicts and analyze them to answer the following questions: (1) What were the subject areas of these 20 articles and what was the 2013 Impact Factor of each journal that published them? (2) How many citations did they receive and what were the characteristics of the journals that cited them? (3) Do the citation analysis results obtained from Google Scholar mirror the results obtained from Thompson-Reuters' Web of Science?

Materials and Methods

Web of Science (Thompson Reuters, San Francisco, CA, USA) and Google Scholar were searched for relevant articles. The Web of Science indexes peer-reviewed scientific articles based on the number of times the article is cited and permits sorting of articles by number of times cited. Similar to PubMed and several other databases, inclusion in the Web of Science is based on scholarly criteria as determined by a literature review committee. In contrast, Google Scholar indexing is performed by automated indexing and publisher-submitted information and also includes conference abstracts, book chapters, patent applications, and government reports. Google Scholar does not publish a metric comparable to Thompson-Reuters' Impact Factor.

Our first research question was: What were the subject areas of the 20 most cited articles from military surgeons related to the wars in Iraq and Afghanistan, and what was the 2013 Impact Factor of each journal that published them? To answer this, two independent physician researchers (GCB, JAW) performed a keyword search in Web of Science using the terms orthop*, military, combat, war, casualty, Army, Navy, Marine*, soldier, Operation Iraqi Freedom, and Operation Enduring Freedom as single terms and in combination. The resulting list was subsequently limited to English language works published between the years 2001 and 2014, yielding a total of 8507 potentially relevant results. The list was sorted by number of citations for each work, and, beginning from the most cited articles, abstracts were screened for articles related or applicable to orthopaedic combat casualty care performed at military healthcare or research facilities. Discrepancies between reviewers were settled through discussion and consensus. Review articles not containing original research were excluded. The 20 most frequently cited articles were identified, and their publishing journal's 2013 Impact Factor was recorded from listings in Web of Science.

Our second research question was: How many citations did each of these 20 articles receive, and what are the characteristics of the journals and researchers that cited them? Using citation listings from Web of Science, the total number of indexed journal articles citing these works was collected as well as the article title, journal name, journal subject area, and country of origin of the authors. Book chapters, conference abstracts, and other nonpeer-reviewed publications were not recorded.

Our third research question was: How do the results of a citation analysis from Google Scholar compare with the results from the Web of Science? To answer this, we examined the citation listings for each of the 20 articles in Google Scholar, recording the article title, journal name, journal subject area, and country of origin of authors. Additionally, we also recorded the number of duplicate entries and "defective links" (entries recorded as citing one of the top 20 most cited articles that did not link to a source publication) in Google Scholar. Book chapters, conference abstracts, and other nonpeer-reviewed publications from both databases were not recorded. The results of this search were compared with the results of the Web of Science search to determine how many entries found in Web of Science did not appear in Google Scholar.

Results

The 20 articles encompassed three distinct subject areas: epidemiologic studies of combat casualties [2, 11, 26, 32,

39, 40, 46, 52, 53]; basic and translational science of combat wounds and heterotopic ossification [16, 17, 19, 20, 37, 47]; and infectious complications of combat injuries [23, 34, 41, 42, 54]. The median Impact Factor of journals publishing the 20 most cited articles (based on 2013–2014 data) was 3.635 (range, 1.54–9.416; Table 1). The journal with the highest impact factor was *Clinical Infectious Diseases* (Impact Factor 9.41), and the lowest was the *Journal of Orthopaedic Trauma* (Impact Factor 1.54). Four of the 20 studies were funded with external US government research grants. Seven of the 20 studies were performed at the US Army Institute of Surgical Research, which is directly funded by Congressionally directed research monies.

The median number of English language peer-reviewed citations (per Web of Science data) per study was 41 (range, 28–264). Most authors citing the top 20 articles were American (981 of 1235 [79%]) and British (109 of 1235 [9%]) with a smaller number of citing authors from 29 other countries (Table 2). The highest percentage of citing works appeared in orthopaedic journals (353 of 1235 [28%]) followed by general surgery/trauma journals (313 of 1235 [25%]) and biotechnology/basic science journals (124 of 1235 [10%]). Citations were found in 279 different peer-reviewed journals across 26 medical and surgical specialties (Tables 3, 4).

Within Google Scholar, the 20 articles received 2198 citations. Of these, 305 were nonpeer-reviewed sources (book chapters, graduate student dissertations, editorial articles, patent applications, and conference abstracts), and 165 were non-English language sources. A total of 32 entries were duplicates (the same peer-reviewed article listed twice), and 29 were listed citations that contained no information on the citing source and did not link to an external source ("defective links"). When manually compared with the results from the Web of Science, Google Scholar failed to list 36 of the 1235 (3%) Web of Science citations.

Discussion

The wars in Iraq and Afghanistan have resulted in over 50,000 combat-wounded American service members, the vast majority of whom sustained orthopaedic injuries. The care provided by military surgeons has resulted in a large body of research whose impact has not been previously described in a quantitative manner. Citation analysis is the generally accepted method for assessing research impact by specifying the number of peer-reviewed articles indexed in a scholarly database (Thomson-Reuters' Web of Science) citing an initial work. Although this tool is far from perfect, it does give some idea of the degree of dissemination an article has received and the subsequent

Table 1. Top 20 most cited military orthopaedic research articles produced during the wars in Iraq and Afghanistan (peer-reviewed journal articles in Thompson-Reuters' Web of Science)

Rank order	Citation	Web of Science citations	2013 Impact Factor
1	Owens BD, Kragh JF Jr, Wenke JC, Macaitis J, Wade CE, Holcomb JB. Combat wounds in operation Iraqi Freedom and operation Enduring Freedom. <i>J Trauma</i> . 2008;64:295–299. [41]	263	2.961
2	Owens BD, Kragh JF Jr, Macaitis J, Svoboda SJ, Wenke JC. Characterization of extremity wounds in Operation Iraqi Freedom and Operation Enduring Freedom. <i>J Orthop Trauma</i> . 2007;21:254–257. [40]	160	1.54
3	Johnson EN, Burns TC, Hayda RA, Hospenthal Dr, Murray CK. Infectious complications of open type III tibial fractures among combat casualties. <i>Clin Infect Dis</i> . 2007;45:409–415. [24]	96	9.416
4	Nesti LJ, Jackson WM, Shanti RM, Koehler SM, Aragon AB, Bailey JR, Sracic MK, Freedman BA, Giuliani JR, Tuan RS. Differentiation potential of multipotent progenitor cells derived from war-traumatized muscle tissue. <i>J Bone Joint Surg Am</i> . 2008;90:2390–2398. [38]	79	4.309
5	Patel TH, Wenner KA, Price SA, Weber MA, Leveridge A, McAtee SJ. A US Army Forward Surgical Team's experience in Operation Iraqi Freedom. <i>J Trauma</i> . 2004;57:201–207. [47]	78	2.961
6	Potter BK, Burns TC, Lacap AP, Granville RR, Gajewski DA. Heterotopic ossification following traumatic and combat-related amputations. Prevalence, risk factors, and preliminary results of excision. <i>J Bone Joint Surg Am</i> . 2007;89:476–486. [48]	53	4.309
7	Cross JD, Ficke JR, Hsu JR, Masini BD, Wenke JC. Battlefield orthopaedic injuries cause the majority of long-term disabilities. <i>J Am Acad Orthop Surg</i> . 2011;19(Suppl 1):p. S1–7. [12]	51	2.403
8	Stansbury LG, Lalliss SJ, Branstetter JG, Bagg MR, Holcomb JB. Amputations in US military personnel in the current conflicts in Afghanistan and Iraq. <i>J Orthop Trauma</i> . 2008;22:43–46. [52]	51	1.54
9	Forsberg JA, Pepek JM, Wagner S, Wilson K, Flint J, Andersen RC, Tadaki D, Gage FA, Stojadinovic A, Elster EA. Heterotopic ossification in high-energy wartime extremity injuries: prevalence and risk factors. <i>J Bone Joint Surg Am</i> . 2009;91:1084–1091. [18]	48	4.309
10	Belmont PJ Jr, Goodman GP, Zacchilli M, Posner M, Evans C, Owens BD. Incidence and epidemiology of combat injuries sustained during 'the surge' portion of operation Iraqi Freedom by a US Army brigade combat team. <i>J Trauma</i> . 2010;68:204–210. [2]	43	2.961
11	Masini BD, Waterman SM, Wenke JC, Owens BD, Hsu JR, Ficke JR. Resource utilization and disability outcome assessment of combat casualties from Operation Iraqi Freedom and Operation Enduring Freedom. <i>J Orthop Trauma</i> . 2009;23:261–266. [33]	39	1.54
12	Stinner DJ, Burns TC, Kirk KL, Ficke JR. Return to duty rate of amputee soldiers in the current conflicts in Afghanistan and Iraq. <i>J Trauma</i> . 2010;68:1476–1479. [53]	38	2.961
13	Hawksworth JS, Stojadinovic A, Gage FA, Tadaki DK, Perdue PW, Forsberg J, Davis TA, Dunne JR, Denobile JW, Brown TS, Elster EA. Inflammatory biomarkers in combat wound healing. <i>Ann Surg</i> . 2009;250:1002–1007. [20]	35	7.188
14	Helgeson MD, Potter BK, Evans KN, Shawen SB. Bioartificial dermal substitute: a preliminary report on its use for the management of complex combat-related soft tissue wounds. <i>J Orthop Trauma</i> . 2007;21:394–399. [21]	33	1.54
15	Mody RM, Zapor M, Hartzell JD, Robben PM, Waterman P, Wood-Morris R, Trotta R, Andersen RC, Wortmann G. Infectious complications of damage control orthopedics in war trauma. <i>J Trauma</i> . 2009;67:758–761. [35]	31	2.961
16	Svoboda SJ, Bice TG, Gooden HA, Brooks DE, Thomas DB, Wenke JC. Comparison of bulb syringe and pulsed lavage irrigation with use of a bioluminescent musculoskeletal wound model. <i>J Bone Joint Surg Am</i> . 2006;88:2167–2174. [54]	31	4.309
17	Owens BD, White DW, Wenke JC. Comparison of irrigation solutions and devices in a contaminated musculoskeletal wound survival model. <i>J Bone Joint Surg Am</i> . 2009;91:92–98. [43]	29	4.309
18	Forsberg JA, Elster EA, Andersen RC, Nylen E, Brown TS, Rose MW, Stojadinovic A, Becker KL, McGuigan FX. Correlation of procalcitonin and cytokine expression with dehiscence of wartime extremity wounds. <i>J Bone Joint Surg Am</i> . 2008;90:580–588. [17]	29	4.309
19	Owens BD, Wenke JC. Early wound irrigation improves the ability to remove bacteria. <i>J Bone Joint Surg Am</i> . 2007;89:1723–1726. [42]	24	4.309
20	Keeling JJ, Gwinn DE, Tintle SM, Andersen RC, McGuigan FX. Short-term outcomes of severe open wartime tibial fractures treated with ring external fixation. <i>J Bone Joint Surg Am</i> . 2008;90:2643–2651. [27]	23	4.309

Table 2. First author's country of origin among citing works

First author's country of origin	Times cited
United States	981
United Kingdom	109
France	16
China	5
Israel	11
South Korea	3
Germany	10
Spain	5
The Netherlands	4
Turkey	8
Australia	8
Canada	11
Italy	7
Japan	7
India	2
Greece	5
Iran	4
New Zealand	6
Poland	6
Switzerland	4
Taiwan, China	4
Egypt	2
Brazil	3
Czech Republic	2
Lebanon	3
Malaysia	1
Montenegro	3
Serbia	2
Singapore	1
Hungary	1
Denmark	1

research it has influenced. The major findings of this study are the identification of the 20 most cited articles by military surgeons dealing with the care of injured service members, the primary subject areas of these articles (epidemiology of combat injuries, basic and translational science, and infectious complications of war trauma) and that these articles have influenced research in medical and surgical specialties well beyond orthopaedic surgery.

The first and most important limitation of this study is that the results of citation analysis do not necessarily equate to the actual clinical importance of a body of research nor does it necessarily equate to impact on orthopaedic surgery or the wider field of medicine. This problem remains inherent to the technique of citation analysis. Similar to the Impact Factor metric for journals, citation analysis demonstrates who is citing a particular

Table 3. Journals publishing 10 or more citing works

Journal	Citations
<i>Journal of Trauma & Acute Care Surgery</i> (and predecessors)	185
<i>Military Medicine</i>	63
<i>Journal of Orthopaedic Trauma</i>	78
<i>Journal of Bone and Joint Surgery (American)</i>	47
<i>Journal of the American Academy of Orthopaedic Surgeons</i>	52
<i>Journal of the Royal Army Medical Corps</i>	36
<i>Clinical Orthopaedics and Related Research</i> [®]	33
<i>Injury</i>	34
<i>The Spine Journal</i>	29
<i>Journal of Rehabilitation Research and Development</i>	26
<i>Foot and Ankle Clinics</i>	23
<i>Plastic and Reconstructive Surgery</i>	18
<i>Journal of Head Trauma Rehabilitation</i>	11
<i>Journal of Orthopaedic Research</i>	14
<i>Journal of Surgical Research</i>	15
<i>Annals of Surgery</i>	11
<i>Philosophical Transactions of the Royal Society B: Biological Sciences</i>	10
<i>The Bone & Joint Journal</i> (and predecessors)	15

article in their work, but it does not tell us the context in which the work was cited or the degree to which that work actually influenced the development of subsequent studies. Unfortunately, no other accepted quantitative metric currently exists to more accurately reflect the impact of research. The results of this study, and the many previous similar studies in other areas of orthopaedic surgery and medicine, remain useful despite this imperfection.

The second limitation of this study was our inclusion criterion requiring studies to have been performed at military healthcare or research facilities. This requirement was placed to ensure that only research conducted by uniformed surgeons was included. However, the US military has developed extensive partnerships with civilian institutions, and healthcare is no exception. There are uniformed surgeons working in civilian facilities across the country, and it is possible that some of these surgeons are conducting research potentially relevant to this study. In the event these surgeons did not list a military institutional affiliation, we would have assessed their work. We believe, however, that the likelihood of such a scenario is low, because the vast majority of orthopaedic care provided to combat casualties has occurred in military facilities, and combat casualty research tends to rely on access to these patients to complete relevant studies.

The third limitation of our methodology is that we were unable to include combat casualty research conducted by

Table 4. Subject area of journals publishing citing articles

Subject area of citing publication	Citations
Orthopaedics	353
General surgery/trauma	313
Basic science/biotechnology	124
Military medicine	102
Physical medicine and rehabilitation	61
General medicine/critical care	60
Infectious diseases/immunology	55
Neurosurgery/neurology	36
Plastic surgery	29
Oromaxillofacial surgery/ear, nose and throat	22
Radiology	9
Pharmacology	9
Vascular surgery	8
Emergency medicine	7
Anesthesia/pain medicine	6
Pediatric medicine	6
Urology	6
Mental health	5
Gastroenterology	5
Ophthalmology	5
Veterinary medicine	4
Nursing	4
Pathology	3
Dermatology	1
Obstetrics and gynecology	1
Rheumatology	1

civilian researchers with military or other governmental funding. This important source extends and supports the work of uniformed personnel, and it would have been quite interesting to explore this facet of combat casualty research. Unfortunately, although the major government funding agencies publish the names and institutions of awardees, it is not always possible to determine which published studies directly benefited from these awards or the degree to which they were reliant on this funding. As active-duty surgeons, we primarily sought to highlight the effect of military combat casualty research, so we limited our methodology accordingly.

Fourth, although we believe this is the first study to compare the results of citation analysis from Google Scholar with those from the Web of Science, we recognize that our comparison is incomplete. We have detailed the number of duplicate entries, defective links, and non-English publications we encountered during our search. We also identified that most of the citations listed in Web of Science were found in Google Scholar. The two issues we were unable to address were: (1) Are these results

generalizable to citation analysis performed on other works; and (2) what is the quality of the peer-reviewed articles found in Google Scholar but not in Web of Science? Most citation analyses use only Web of Science because only journals indexed in this database contribute to the Impact Factor of a journal. However, it may be that the additional citations in Google Scholar provide a more complete picture of research impact of particular works. Alternatively, these additional citations may be of low quality and provide no additional useful information. Our comparison did not allow us to address these types of questions.

Finally, we also determined that results of citation analysis performed using Google Scholar suffer from large numbers of non-English citations that must be manually screened out as well as multiple duplicate entries and defective links. As a result of the lack of automated results filtering in Google Scholar, we were only able to identify these duplicate and defective entries by manually examining each link, which was highly laborious and time-consuming. Additionally, our study methodology was limited in that we cannot assess the quality of the several hundred citations contained in Google Scholar that were not Web of Science. The fact that these were articles from journals not indexed by Web of Science may potentially indicate a lower scientific quality. We did find, however, that 97% of the entries identified in Web of Science were also contained in Google Scholar. This emerging resource is attractive in that it does not require a subscription fee. However, we recommend that future researchers approach this database with some measure of skepticism.

We are aware of only one previous study similar to ours. Orman et al. performed a citation analysis on combat casualty care in the medical and surgical literature at large, identifying the top 50 most cited articles from the first decade of Operations Iraq Freedom, New Dawn, and Enduring Freedom [39]. The authors identified damage control resuscitation and combat casualty epidemiology as the most influential works produced by researchers during this time period (2001–2011). Specifically, military surgeons defined the proper plasma-to-red blood cell ratio in massive transfusion protocols, which has since been incorporated as standard practice in civilian centers. The authors also discussed the military literature on hemorrhage control using tourniquets, which led directly to a resurgence in use by civilian prehospital trauma providers [33]. No mention was made in Orman et al.'s study of orthopaedic-specific literature, although it is worth noting that #2 and #7 on their list of most cited articles are #1 and #2 in our study. It is also interesting that the total number of citations in Web of Science for the two articles has approximately doubled in the intervening 2 years since Orman et al.'s article was published, demonstrating the

ongoing relevance of this type of research, even as our involvement in Iraq and Afghanistan has decreased.

Any time military surgeons conduct research on combat casualties, there is the risk that any result will only be applicable within the military population. However, there are numerous examples of commonplace orthopaedic interventions that were originally developed in war. Stabilization of fractures before transport [31], meticulous débridement of open fractures [44], and use of tourniquets to prevent exsanguination from extremity wounds [28] all found their start in combat. Even today, ongoing innovations such as negative pressure wound therapy [8] and refined prosthetics and rehabilitation techniques [22] all owe their proliferation, at least in part, to the knowledge gained by the treatment of combat-wounded in military hospitals around the world. War and orthopaedic surgery have always been intimately related.

In summary, the 20 most cited articles from military surgeons related to the wars in Iraq and Afghanistan garnered a median of 41 citations each. These works were used by dozens of medical and surgical subspecialties in subsequent works by authors from around the world. This suggests that military research continues to impact civilian orthopaedic practice in meaningful ways. Our findings further argue for the continued importance placed on military orthopaedic research by federal funding programs and suggest that the military continues to be an important source of orthopaedic innovation. We believe that the results of this study should encourage further military-civilian collaborative research to maximize the use of the knowledge gained in the treatment of war trauma.

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