

Systematic Review of the Parachute Ankle Brace

Injury Risk Reduction and Cost Effectiveness

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Introduction: Military parachuting has been shown to result in injuries. This investigation systematically reviewed studies examining the influence of the parachute ankle brace (PAB) on injuries during military parachuting and performed a cost-effectiveness analysis.

Evidence acquisition: Parachute ankle brace studies were obtained from seven databases, personal contacts, and other sources. Investigations were reviewed if they contained original, quantitative information on PAB use and injuries during parachuting. Meta-analysis was performed using a general variance-based meta-analysis method that calculated summary risk ratios (SRR) and 95% CIs.

Evidence synthesis: Five studies met the review criteria. Compared with PAB users, PAB non-users had a higher risk of ankle injuries (SRR=2.1, 95% CI=1.8–2.5); ankle sprains (SRR=2.1, 95% CI=1.4–3.1); ankle fractures (SRR=1.8, 95% CI=1.1–2.9); and all parachuting injuries combined (SRR=1.2, 95% CI=1.1–1.4). The PAB had little effect on lower body injuries exclusive of the ankle (SRR [no PAB/PAB]=0.9, 95% CI=0.7–1.2). Cost-effectiveness analysis estimated that, for every dollar expended on the PAB, a savings of about \$7 to \$9 could be achieved in medical and personnel costs.

Conclusions: The PAB reduces ankle injuries by about half and is a cost effective device that should be worn during military airborne operations to reduce injury risk.

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Introduction

Training in tactical military parachuting is conducted year-round in the U.S. Army. About 17,000 military personnel train each year at the U.S. Army Airborne School at Fort Benning GA. These individuals must successfully complete five static-line parachute jumps to become Airborne qualified. In addition, the U.S. Army has authorization for about 28,000 Airborne soldiers who must make at least four static-line jumps each year to remain Airborne qualified, although most perform more jumps than this minimum. This amounts to about 200,000 jumps per year.

Military parachuting has been shown to result in about six injuries per 1000 jumps.¹ The ankle has been shown to

be the most common anatomical site of injury, accounting for 21% to 43% of all injuries.^{2–7} Ankle sprains account for 9% to 33% of all parachute injuries,^{2,3,5,7,8} while ankle fractures compose 7% to 23% of all parachute injuries.^{2,3,5,7,8} At 200,000 jumps per year and an ankle injury rate of 2.6 per 1000 jumps,⁹ an estimated 520 ankle injuries occur each year as result of military parachute jumps.

In an effort to reduce ankle injuries in airborne operations, the U.S. Army worked with Aircast[®] Corporation (subsequently purchased by DjOrtho[®] in 2006) in 1992 with the goal of developing an outside-the-boot ankle brace for military airborne operations. This effort was prompted by studies in the sports medicine literature showing that ankle braces could reduce sports-related ankle injuries.^{10–12} An initial study carried out at the U.S. Army Airborne School suggested that the parachute ankle brace (PAB) could effectively reduce inversion ankle sprains.⁴ Since that initial study, several others have been completed.

The principal purpose of this paper was to review the literature on the influence of the ankle brace on injuries during military parachute operations. Secondary goals

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were to (1) determine whether the ankle brace affects injuries in parts of the lower body other than the ankle and (2) determine the cost effectiveness of the brace.

Evidence Acquisition

Literature Review

A literature search was conducted using PubMed (MEDLINE), the Cumulative Index to Nursing and Allied Health Literature (CINAHL), Academic Search Premier, Biomedical Reference Collection (Comprehensive), the Cochrane Database of Systematic Reviews, the Database of Abstracts of Reviews of Effectiveness, and the Defense Technical Information Center (DTIC). Keywords for the searches included parachute ankle brace, ankle brace, brace and parachute, with injury, trauma, wound, morbidity, mortality, lesion. The reference lists of the articles so obtained were also searched for additional pertinent articles. In addition, personal contacts were made to identify other studies or to clarify methods.

Studies were selected for review if they (1) contained original quantitative information regarding injuries during military parachute operations and (2) contained groups that wore and did not wear the ankle brace. Because the goal was to compare injury risk between brace users and non-users, articles were required to contain four pieces of information: (1) the number of jumps (parachute descents) resulting in injury while wearing the brace, (2) the number of jumps not resulting in injury while wearing the brace, (3) the number of jumps resulting in injury while not wearing the brace, and (4) the number of jumps not resulting in injury while not wearing the brace. Articles were also considered if the four pieces of information could be calculated from the numeric data contained therein.

The methodology of each study was evaluated using a scoring instrument modeled on previous systems used for similar purposes.^{13,14} Four reviewers independently evaluated each study to determine the extent to which it met the review criteria shown in Table 1. Following the independent ratings, the reviewers met to examine the other reviewers' scores and to reconcile major differences. The average score from the four reviewers served as the methodologic quality score.

Meta-Analysis

A meta-analysis was performed on injury information contained in the articles that met the review criteria. A general variance-based technique was employed that used risk ratios and confidence intervals for calculations.¹⁵ This technique produced a summary risk ratio (SRR) and 95% CIs for studies examining particular types of injury. SRRs and 95% CIs were calculated comparing brace users and non-users for ankle injuries, ankle sprains, ankle fractures, all para-

Table 1. Methodologic criteria and quality scoring

Criteria	Max score
Statement of research question (prior hypothesis)	5
Source of sample	5
Exclusion of potential participants	5
Power (sample size) calculation	3
Prospective study	10
Retrospective study	4
Selection bias	3
Information bias	3
Description of intervention	6
Comparison of participants with nonparticipants	4
Appropriateness of methods	12
Addressed possible confounders	6
Description of statistical tests	6
Use of relative risk or odds ratios	4
Use of confidence intervals or <i>p</i> -values	4
Consideration of confounders	6
Use of multivariate techniques	4
Collinearity	2
Demographics	2
Confounders	2
Comparability of groups	2
Tables/graphs	2
Total	100

chuting injuries, and injuries to the lower body exclusive of the ankle.

Cost-Effectiveness Analysis

Cost-effectiveness analysis was conducted by estimating annual medical and personnel costs resulting from parachute-related ankle injuries, then calculating cost differences with and without the ankle brace.¹⁵ Separate analyses were conducted for the U.S. Army Airborne School and for operational airborne units.

Ankle injury rates were 2.6/1000 jumps for airborne students^{4,7} and 4.5/1000 jumps for operational units.⁹ The brace was assumed to reduce ankle injuries by half.^{4,7,9,16} Estimates suggested that for every four ankle injuries, three were sprains and one was a fracture.^{4,7} Experienced army physical therapists estimated eight follow-up visits per ankle sprain and 21 follow-up visits per ankle fracture. Estimates of annual ankle injury hospitalizations for airborne students

($n=57$) and operational units ($n=75$) were based on data in Schmidt.¹⁶

Medical costs were obtained from the Military Health-Care System Management and Analysis Reporting Tool (M2), which provides financial data from all military health system regions worldwide and includes direct and purchased care data. The average costs for an initial medical visit, median cost for an ankle sprain and fracture hospitalization, and cost for a follow-up visit were estimated at \$237, \$8203, and \$100, respectively.

The U.S. Army Airborne School provided the number of service members jumping (17,000 per year) and the number of jumps (five per service member). Other data, obtained from the 82d Airborne Division at Fort Bragg NC included the estimated number of airborne soldiers in operational units (28,000), the number of required jumps (four per year), and the number of actually executed jumps (4–12 per year).

Limited-duty prescriptions were estimated at 14 days for an ankle sprain and 120 days for an ankle fracture based on estimates from experienced physical therapists. Because, as with most injuries, the soldier could normally perform some activity, limited duty was considered 50% of full duty. For lost-duty salaries, soldier pay tables (pay by rank and years of service) and tables indicating the number of soldiers in each rank (enlisted and officers) were used to obtain a weighted average salary of \$92 per day.

The cost of the ankle brace (\$28.50 per pair) was obtained from the manufacturer in April 2008. Extensive experience with the brace at U.S. Army Airborne School indicated an estimated life expectancy of 25 jumps.

Medical costs (dollars/year) were calculated as:

$$\begin{aligned} &(\text{jumps/soldier-year}) \times (n \text{ of soldiers}) \\ &\times (\text{injuries}/1000 \text{ jumps}) \times (\text{medical costs}/\text{injury}). \end{aligned}$$

Separate calculations were performed for ankle sprains and ankle fractures considering first visit, follow-up outpatient visits, and hospitalizations. Limited duty costs (dollars/year) were calculated as:

$$\begin{aligned} &(\text{jumps/soldier-year}) \times (n \text{ of soldiers}) \\ &\times (\text{injuries}/1000 \text{ jumps}) \\ &\times (\text{days limited duty}/\text{injury}) \times \$92/\text{day} \times 0.50 \end{aligned}$$

where \$92 is the average weighted daily pay and 0.50 is the factor from the assumption that soldiers can perform 50% of their duties despite injuries.

Total annual costs without the ankle brace were obtained by summing annual medical costs and annual limited duty costs. To determine the annual cost savings achieved with brace use, the sum of the annual medical and limited duty costs was divided by 2 as the brace appeared to reduce ankle injuries by about half.^{4,7,16} The annual cost savings was divided by the annual cost of purchasing and replacing the ankle braces to yield a return on investment.

Evidence Synthesis

The literature search found ten studies that provided data on ankle brace use and injury. Five met the initial review criteria requiring original, quantitative information for brace users and non-users.^{4,7,9,16,17} In one of the selected studies,¹⁷ the data-collection period partially overlapped that of another study,⁷ but the data-collection methods of the two investigations were quite different. One¹⁷ used a questionnaire, while the other⁷ collected injuries as injured personnel reported for medical care. The questionnaire study may have captured some less serious injuries not reported to the medical community and for this reason was included in the review.

Five articles were not considered for review. Three U.S. Army technical reports^{18–20} contained most of the same information reported in peer-reviewed journal articles,^{4,7,17} so the latter were selected. In some cases, the technical reports were used to add information to the analysis, especially in one case where an analysis of ankle injuries was included in the technical report²⁰ but not in the journal article.¹⁷ In one book chapter,²¹ the findings of a previous, original study¹⁸ were described, but no new data were presented. In another case,²² the ankle brace was used during ground operations by Israeli border patrol soldiers and not during military parachuting.

Only one of the five selected studies used a prospective randomized control design;⁴ the other four investigations were observational in nature.^{7,9,16,17} Among the observational studies, two^{9,16} involved retrospective cohort designs examining periods before and after ankle-brace wear. The other two observational studies^{7,17} used concurrent cohort designs in which the brace was used by one group but not the other in the same time period.

Table 2 provides a summary of the methodology of the five selected studies, showing participants, data-collection procedures, injury case definitions, and methodologic quality scores. In terms of participants, four studies were conducted with students at the U.S. Army Airborne School,^{4,7,16,17} while one study involved U.S. Army Rangers.⁹ In terms of data-collection procedures, three studies collected injuries primarily on the drop zone and/or with follow-up in hospitals or clinics;^{4,7,9} one study collected injuries from a surveillance database¹⁶ and another from questionnaire responses.¹⁷

Injury case definitions varied. Among studies that collected all parachuting injuries,^{4,7,9,17} the definitions generally included any physical damage to the body as a proximate result of a parachute jump. The case definitions for ankle injuries included the anatomic location, but the exact diagnoses differed somewhat among stud-

Table 2. Summary of original studies examining the parachute ankle brace

Study	Participants	Injury data-collection procedures	Case definitions for all injury	Case definitions, ankle injury, ankle sprain, and ankle fracture	Case definitions, lower body injury exclusive of the ankle	Methodologic quality score (mean±SD)
Amoroso (1998) ⁴	Students in airborne training	Diagnoses on drop zone supplemented with physical examinations by orthopedic staff and screening of medical records from clinic, hospital, and emergency room	Any musculoskeletal or traumatic event from aircraft exit to drop zone clearance that resulted in inability to clear the drop zone or an injury diagnosis in medical records	Ankle injury: any injury to ankle joint (inversion sprain, syndesmosis sprain, fracture); ankle sprains: ligament injury of ankle joint (inversion sprain, syndesmosis sprain); ankle fracture: open or closed bone breakage around ankle joint	Knee sprains, leg strains, foot fractures, lower limb contusions	67±2
Schumacher (2000) ⁹	U.S. Army Rangers	From database of all clinic and emergency room visits that resulted in prescription of a physical limitation	Injuries from parachuting that resulted in a visit to a medical care provider and a prescribed physical limitation	Ankle injury: “any ankle pain, swelling, or deformity caused by grade I to III ankle sprains and distal tibia/fibula contusion or fracture” excluding metatarsal contusions and fractures; ankle fracture: (undefined in article)	Injuries with anatomic location of knee, foot, hip/femur, and leg	58±4
Schmidt (2005) ¹⁶	Students in airborne training	Airborne student rosters matched to military inpatient data records and hospital coding of a parachute-related injury for 1-week period of airborne jumps plus 4 weeks after training (to include some presumed delay of injury care)	NA ^a	Ankle injury: primary or secondary diagnosis of ankle fracture, ankle sprain, or ankle dislocation resulting in hospitalization ^b	NA ^a	72±3
Knapik (2008) ⁷	Students in airborne training	Diagnoses by medics on the drop zone supplemented with hospital consults, medical records, radiologic, and orthopedic reports	Any physical damage to the body listed on the operational injury report	Ankle injury: specific entry of ankle fracture, ankle sprain or ankle contusion on operational injury report; ankle sprain: specific entry of ankle sprain on operational injury report; ankle fracture: specific entry of ankle fracture on operational injury report	Injuries with anatomic location of pelvis, hip, thigh, knee, calf, shin, or foot/toe as listed on operational injury report	81±4
Knapik (2008) ^{17,20}	Students in airborne training	Questionnaire self-report	“Yes” response to questionnaire item “Were you injured during jump week?” ^c	Ankle injury: self-reported ankle injury during parachuting as listed on questionnaire	NA ^a	68±5

^aNot applicable. This case definition not was not included in article and/or could not be determined from data provided.

^bInvolves specific ICD-9 codes

^cIn the U.S. Army Airborne School, “jump week” is the final week of training when five parachute jumps are performed from aircraft.

ies.^{4,7,9,16,17} Ankle fractures appeared to always include broken bones around the ankle,^{4,7,9} but one study⁹ specifically excluded metatarsal fractures. Ankle sprains were very specifically defined in one study,⁴ while another took the general diagnosis provided by medical personnel on an operational injury report.⁷

Methodologic quality scores ranged from 58⁹ to 81.⁷ Generally, higher scoring studies included more covariates in the analysis.

Meta-Analysis

Table 3 contains the SRRs and 95% CIs produced using the general variance-based method. Summary risk of ankle injury or ankle sprain was more than two times higher among individuals not wearing the ankle brace. Summary risk of ankle fracture was about 1.8 times higher among those not wearing the brace. Overall summary injury risk (all injury) was about 1.2 times higher among

Table 3. Data on studies comparing PAB users and non-users on various types of injuries

Injury type	Study	Injury incidence (injuries/10,000 jumps)		Risk ratio no PAB/PAB (95% CI)	Summary risk ratio no PAB/PAB (95% CI)
		PAB	No PAB		
Ankle injury	Amoroso (1998) ⁴	27.40	54.08	1.97 (0.68, 5.76)	2.13 (1.80, 2.53)
	Schumacher (2000) ⁹	15.18	44.55	2.93 (1.41, 6.10)	
	Schmidt (2005) ^{16,a}	3.02	6.68	2.21 (1.78, 2.74)	
	Knapik (2008) ⁷	13.15	25.24	1.92 (1.38, 2.67)	
	Knapik (2008) ²⁰	74	117	1.58 (0.63, 4.00)	
Ankle sprain	Amoroso (1998) ⁴	16.40	48.91	2.96 (0.80, 10.92)	2.07 (1.40, 3.08)
	Knapik (2008) ⁷	8.36	16.73	2.00 (1.32, 3.02)	
Ankle fractures	Amoroso (1998) ⁴	10.96	5.43	0.50 (0.05, 5.46)	1.77 (1.07, 2.94)
	Schumacher (2000) ⁹	5.06	11.45	2.26 (0.61, 8.36)	
	Knapik (2008) ⁷	4.48	8.22	1.83 (1.04, 3.24)	
All injury	Amoroso (1998) ⁴	93.15	109.35	1.16 (0.61, 2.21)	1.22 (1.07, 1.40)
	Schumacher (2000) ⁹	131.58	168.00	1.27 (0.97, 1.69)	
	Knapik (2008) ⁷	52.60	60.59	1.15 (0.97, 1.37)	
	Knapik (2008) ¹⁷	89.97	154.99	1.72 (1.11, 2.69)	
Lower limb injury exclusive of ankle	Amoroso (1998) ^{4,b}	43.84	32.56	0.74 (0.26, 2.13)	0.88 (0.67, 1.15)
	Schumacher (2000) ^{9,c}	67.45	57.35	0.85 (0.55, 1.31)	
	Knapik (2008) ⁷	14.35	13.14	0.92 (0.65, 1.30)	

^aConsiders only the pre-brace and brace period in article

^bIncludes knee sprains and leg strains

^cIncludes knee, foot, hip/femur, and leg injuries

PAB, parachute ankle brace

those not wearing the brace. Summary risk of lower limb injury exclusive of the ankle was slightly and not significantly elevated among those wearing the brace.

Cost-Effectiveness Analysis

Table 4 shows the figures calculated for individual factors that contributed to the total cost of jump-related ankle injuries. Overall annual dollar cost savings were determined by subtracting brace costs from cost savings with the brace (Table 4). Overall annual cost savings for Airborne School injuries were about \$0.6 million, while overall annual cost savings for operational units ranged from about \$1.1 million (with four jumps/year) to about \$3.4 million (with 12 jumps/year). The return on investment was about \$7 to \$9 saved in medical and lost duty costs for each \$1 spent on the brace.

Discussion

This review indicates that the parachute ankle brace is a cost-effective intervention that reduces by about one half

the incidence of ankle injuries, ankle sprains, and ankle fractures during military parachuting. Given the assumptions in the cost analysis, the brace returned \$7 to \$9 in combined medical and lost duty costs for every dollar spent on the brace. More important, the overall injury risk is lower in brace users, likely due to a reduction in ankle injuries, the anatomic location with the largest proportion of injuries.^{2-5,7-9,23} Also of importance is the fact that injuries to other parts of the lower body show only small differences between brace users and non-users (see last three rows of Table 3). This addresses anecdotal concerns in the operational airborne community that the brace might be associated with higher injury risk in parts of the lower body other than the ankle.

The mechanism whereby the brace reduces ankle injuries is not known, but can be speculated upon. The brace provides stiff medial and lateral support to the ankle, effectively serving as a splint. Upon ground impact, these supports probably reduce the velocity and/or extent of ankle inversion or eversion, thereby preventing the exces-

Table 4. Estimated injury and limited duty costs and projected cost savings achieved by PAB use

	Medical costs (\$)				Limited duty costs (\$)		Total costs (medical and limited duty) without PAB (\$) ^a	Cost savings with PAB (\$) ^b	Brace costs (purchasing and replacing) (\$)	Return on investment ^c
	Outpatient		Inpatient		Sprain	Fracture				
	Initial visit	Sprain follow-up	Sprain follow-up	Fracture follow-up						
Airborne school	52,377	132,600	116,025	587,271	106,743	304,980	649,998	96,900	6.7	
Operational units										
4 jumps/yr	119,448	302,400	264,600	772,725	243,432	695,520	1,199,063	127,680	9.4	
6 jumps/yr	179,172	453,600	396,900	1,164,239	365,148	1,043,280	1,801,170	191,520	9.4	
12 jumps/yr	358,344	907,200	793,800	2,318,175	730,296	2,086,560	3,597,188	383,040	9.4	

^aSum of medical and limited duty costs assuming PAB is not used

^bOne half of total medical and limited duty costs without PAB

^cCalculated as cost savings with PAB/brace cost. This is \$ saved on medical/limited duty for each \$ spent on PAB. PAB, parachute ankle brace

sive range of ankle motion that often leads to injury. The brace likely transfers some of the force that would be transmitted to the ankle joint to the lower calf, which apparently can absorb it with much less risk of injury.

The analysis presented here considers the effect of the ankle brace alone and does not consider other known risk factors that could mediate injury differences between brace users and non-users.^{17,24} One study⁷ that examined ankle sprains, ankle fractures, and overall ankle injuries included the ankle brace as a covariate in a multivariate analysis that controlled for the principal extrinsic injury risk factors, including high wind speeds, combat loads, and night jumps. Compared with the univariate analysis, multivariate analysis including these risk factors showed only modest reductions in injury risk ratios. For ankle injuries, consideration of covariates reduced risk ratios (no PAB/PAB) from 1.9 in univariate analysis to 1.8 in multivariate analysis; for ankle sprains, covariate consideration reduced risk ratios from 2.0 in univariate analysis to 1.9 in multivariate analysis; for ankle fractures, covariate consideration reduced risk ratios from 1.8 in the univariate analysis to 1.5 in the multivariate analysis.

Likewise, two other studies^{16,17} found that the injury-risk difference between brace users and non-users was similar in the univariate analysis and in a multivariate model that included age, gender, body weight, physical fitness, repeating airborne school, aircraft exit problems, and prior injuries. Thus, even when other risk factors are considered, injury risk appears substantially lower when the brace is worn.

Most studies in this review^{4,7,9} collected injury data from outpatient/inpatient medical information; however, two studies were unique in terms of injury data collection. Schmidt et al.¹⁶ captured ankle injuries from a historical surveillance database and was the only investigation to exclusively examine hospitalizations. Knapik et al.²⁰ obtained data from a self-report questionnaire that would be expected to exclude hospitalizations (i.e., hospitalized individuals were not available to fill out the questionnaire) and capture both injuries where medical care providers were involved and less serious injuries where medical personnel were not consulted. Eliminating these two studies^{16,20} from the ankle injury meta-analysis had only a minor influence on the overall summary risk. Before eliminating these two studies, the SSR (95% CI) was 2.13 (1.80–2.53); after eliminating them, it was 2.05 (1.53–2.74). Eliminating the study that examined all parachute injuries combined¹⁷ had only a minor effect on the summary risk for that outcome measure. Before eliminating the study, the SSR (95%) was 1.22 (1.07–1.40); after eliminating the study, it was 1.18 (1.03–1.36).

The cost effectiveness analysis conducted here used approximations based on gross estimates of medical care and lost work productivity. These estimates should be considered a first approximation and subject to change. Numerous factors that could influence cost analysis were not considered, such as costs from issuing and recovering braces during training, reordering and shipping, reengineering braces with equipment changes, obtaining specialty medical care (e.g., orthopedic surgeons, casting), and making disability payments for the most serious airborne injuries.

This review and analysis strongly suggest that the parachute ankle brace should be worn during military airborne operations. The brace has been demonstrated to be a cost effective prophylaxis that reduces the incidence of parachute injuries.

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