LOAD CARRIAGE IN MILIARY OPERATIONS: A REVIEW OF HISTORICAL, PHYSIOLOGICAL, BIOMECHANICAL, AND MEDICAL ASPECTS

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INTRODUCTION

Because of mission requirements or the limited transportation assets of some types of units (e.g., U.S. Army light infantry), service members must often depend on their personal mobility to move individual equipment. The carrying of loads by troops is an important aspect of military operations that can become critical in some situations. Overloading with ammunition and equipment can lead to excessive fatigue and impair the ability to fight. Military historians cite numerous examples where heavy loads directly or indirectly resulted in reduced performance, unnecessary deaths, and lost battles (1,2,3,4). The experience of the British in the Falklands and the U.S. Army in Grenada emphasize that overloading of troops is still a problem in modern warfare (5, 6).

The purpose of this paper is to review the historical, physiological, biomechanical, and medical aspects of load carriage. Practical suggestions are offered for reducing the stress of loads on service members and for preventing and treating common load-carriage-related injuries. Other reviews are available (7, 8).

HISTORICAL PERSPECTIVE

Loads Carried During Various Historical Periods

Figure 1 shows loads that were carried by various military units, with emphasis on more recent times. Lothian (9) provides data about a greater number of more ancient military units. Until about the 18th century, troops carried loads that seldom exceeded 15 kg while they marched. Extra equipment was often moved by auxiliary transport including assistants, horses, carts, and camp followers. The extra equipment often consisted of weapons and protection used by troops when they went into battle (e.g., swords and shields). After the 18th century, auxiliary transport was de-emphasized and more disciplined armies required troops to carry their own loads. The latter-day service member often carried more equipment on the march and less in contact with hostile forces (2).

Nineteenth and Twentieth Century Efforts to Study Load Carriage

European Efforts

After the Crimean War, a British "Committee Appointed to Inquire into the Effects of the Present System of Carrying Accouterments, Ammunition and Kit of the Infantry Soldier" recommended that soldier loads be reduced to

21 kg through the elimination of "necessaries", especially underclothing (2, 4). Studies at the Frederick William Institute in 1895 showed that soldiers could "tolerate" marching 24 km with a load mass of 22 kg if the weather was cool. In warm weather, this test caused "minor disturbances" from which the men recovered in 1 day (2). In 1908 a "Committee on the Physiological Effects of Food, Training, and Clothing of the Soldier" developed a much improved load carriage system that was used in WWI. In 1920, the Hygiene Advisory Board of the British Army recommended that the soldier's load should not exceed 18 to 20 kg or 1/3 of his body weight while marching. With the development of indirect calorimetry, Cathcart et al. (10) were able to study the energy cost of two men marching at a variety of paces and with a variety of load masses. They found that energy cost per mass carried was lowest when subjects carried a mass equal to 40% of their body mass.

American Efforts

There is little information about American efforts to formally study load carriage before WWII, if these efforts even existed. Under the direction of the Quartermaster General, CPT H.W. Taylor developed a soldier "pay-load plan". This was an attempt to unburden the soldier by providing him only the items needed for combat. There were also attempts to developed segmented packs: if the tactical situation permitted, a portion of the pack containing non-essential equipment could be left behind (11).

From 1948 to 1950, U.S. Army Field Board 3 (Ft Benning, GA) performed a number of studies. They noted that previous work had ignored the individual soldier's mission within the military unit. In studying individual positions they found that loads ranged from 25 kg for the rifleman to 50 kg for the ammunition carrier. In cooperation with the Surgeon General's Office, the board estimated how load masses should be reduced to make the soldier more combat effective. Metabolic data and stress put on the soldier in combat were considered. Based on a literature review the board determined that the energy available for marching (basal metabolic rate subtracted) could not exceed 3680 kilocalories per day. They recommended that the rifleman carry 18 kg in the worst conditions, and 25 kg was recommended as the maximum march load (12).

About a decade later, the U.S. Army Infantry Combat Developments Agency (13, 14) reinforced the weight recommendations of Army Field Board No. 3. The agency recommended a load of 18 kg or 30% body weight for a conditioned fighting soldier and 25 kg or 45% of body weight for a soldier on the march. They developed the idea of load "echeloning" and defined a "fighting load" and an "existence load".

In 1987, the concept of load echeloning was further developed by the Army Development and Employment Agency (ADEA) (15). They called the load carried by the soldier the "combat load", which was defined as the mission-essential equipment required by soldiers to fight, survive, and complete their combat mission. The combat load was further divided into a "fighting load" and "approach march load". The fighting load was carried when enemy contact was expected or stealth was necessary. It consisted of the soldier's clothing, load-bearing equipment, helmet, weapon, rations, bayonet, and ammunition. The approach march load was carried in more prolonged operations. It included the combat load plus a pack, sleeping roll, extra clothing, extra rations, and extra ammunition. Current U.S. Army doctrine recommends 22 kg (or 30% body weight) for the fighting load and 33 kg (or 45% body weight) for the approach march load (16).

ADEA studied nine light infantry jobs that soldiers may have to perform in a "worst case" situation. The loads carried by soldiers in these positions are shown in Table 1. ADEA (15) proposed five approaches for lightening soldier loads. The first approach was to develop lighter weight components. However, technical developments were expected to reduce loads only by 6% overall (see Table 1) (17). The second approach was the soldier load planning model. This was a computer program that aided the commander in tailoring loads through a risk analysis based on the mission, enemy, terrain, troops and time (METT-T). The third approach was the development of specialized load-carrying equipment. This includes such things as hand carts and all-terrain vehicles. The fourth approach was a reevaluation of current doctrine that might affect load carriage. An example of this was an increased emphasis on marksmanship to reduce ammunition loads. The fifth and final approach was the development of special physical training programs to condition soldiers to develop more physical capability for load carriage.

Historical Perspective of Current U.S. Efforts

Many of the approaches proposed by ADEA are not new. For example, load tailoring had been practiced by commanders and individual soldiers throughout history. Iphicrates of ancient Greece armed his infantry only with a wooden shield, lance and sword. They defeated a Spartan force of heavily equipped Hoplites, presumably because of their greater agility (the Hoplites carried about 37 kg into battle). In the 17th century, Adolphus of Sweden lightened his soldiers' load by removing armor and shortening weapons. The British Army in the Boar War carried only arms,

ammunition, water, and a haversack for a total weight of 11 kg (2). Soldiers in battle have often reduced loads on their own initiative. The confederate troops of Stonewall Jackson during the highly successful Shenandoah campaign discarded extra clothing, overcoats, and knapsacks and carried only rifles, ammunition, food, a blanket (or rubber sheet) and the clothing on their bodies (2, 3). American paratroopers jumping into Normandy in 1944 exited the aircraft with about 36 kg, but once on the ground they quickly discarded equipment they considered unnecessary (3).

A wide variety of load-carrying systems has also been used throughout history. Greek Hoplites used helots to carry their equipment on the march. Carts and packs were used by Roman legions. Cromwell's armies used "pack boys". Napoleon used carts whenever possible to relieve his soldiers of their march loads. Camp followers also carried much of the soldiers' load during various wars (1, 2).

Physical training has been used to improve marching with loads. Roman legionnaires are estimated to have performed road marching three times per month, at a rate of about 5 km/h, carrying a 20-kg pack over a 32-km distance. In Cromwell's army (1640), pay was contingent upon marching 24 km on a regular basis. The French Cahassurs (WWI) marched two times a week over 13 to 18 km carrying a "light kit". Recruit training in WWI in Germany included taking an initial 10-km march, with 1 km added weekly until recruits were marching 20 km with a "full kit" (2). McMichael (18) gives a brief description of the training of Wingate's Chindits who fought as light infantry in the WWII Burma Campaign. "They were loaded with huge 34-kg packs and marched unmercifully through man-killing terrain". They performed a 225-km road march just before their deployment to Burma. Units within the U.S. Army's 10th Mountain Division routinely road marched with their fighting loads about three times per month. Training guidance prescribed a quarterly road march of 40 km (7min/km pace) and a yearly march of 161 km in 5 days (19).

Body Stature and Body Mass as Factors in Load Carriage

The service member's height and weight may be an important factor in load carriage (20, 21). Larger service members may be able to carry heavier loads by virtue of greater bone and muscle mass (22). It has been estimated that humans have increased their height about 10 cm since the Industrial Revolution, possibly because of better nutrition (23). Table 2 provides a summary of the heights and weights of various groups derived from a variety of sources.

Before the Crimean War, only minimum standards are available. U.S. samples show a progressive increase in height and weight since the Civil War, with the increase in weight primarily attributable to an estimated increase in fat-free mass.

PHYSIOLOGICAL AND BIOMECHANICAL ASPECTS OF LOAD CARRIAGE

While historical studies are useful to show that the problems of load carriage have been with us for a considerable time, it is physiological and biomechanical research conducted during the last 50 years that has developed some practical methods of reducing the stress of loads on service members. Many general principles and techniques have emerged, but studies do not reveal a "best" way of carrying loads that applies to all situations. In this case, commanders must consider the mission and terrain in reducing the service members' burden.

Load Distribution

There are many ways to carry loads, and the technique used depends on the characteristics of the load (size, shape, mass, etc.), how far the load may be carried, previous experience, and the equipment available to the service member (24). Two load-carrying systems currently available are the All-Purpose Light Weight Individual Carrying Equipment (ALICE) system and the Integrated Individual Fighting System (IIFS). The ALICE system is more 20 years old but is durable, stable with heavy loads, and provides ventilation to the back since the external frame holds the rucksack away from the body; however, adjustment is limited. The IIFS has a large internal frame pack and a tactical load vest with pockets that allow more flexibility; however, the internal frame pack can be unstable with heavy loads (over 36 kg) and is prone to breakage. The 21st Century Land Warrior program is projected to field a new system of load-bearing components (LBC) that will be lighter, allow greater adjustability, and support mechanical, optical, and electronic technologies that are being developed concurrently (25).

Backpacks and Double packs

Where the load is carried on the body will affect both energy cost and body mechanics. Recent studies have shown that loads can be transported with the lowest energy cost (i.e., the most efficient way) when they are carried on

the head (26, 27). However, this method is impractical for military operations because it requires a very long training time to use effectively, is useful only in unobstructed horizontal terrain, and produces a high profile (greater body signature). A more practical choice is to carry a load as close as possible to the center of mass of the body (28, 29). In this regard, the backpack and double pack (half the load carried on the front of the body and half on the back) methods have been shown to have a lower energy cost than most other forms of load carriage (30,32,33). The double pack produces fewer deviations from normal walking than does a backpack, including less forward lean of the trunk (34, 35). With the double pack, increasing load produces a reduction in stride length and increase in stride frequency which is more desirable because it may reduce stress on the bones of the foot. In contrast, stride length becomes longer as backpack loads increase, which by the same line of reasoning could be potentially harmful (34).

Double packs can be useful in some military situations (e.g., medics carrying their aid bags on the front of their bodies) but backpacks appear to provide greater versatility. The double pack can inhibit movement and may limit the field of vision in front of the body, making it difficult to see obstructions and traps. They can be burdensome to don and doff, and doffing can be very important in situations with sudden or unexpected enemy contact. The double pack can also induce ventilatory impairments (36) and greater heat stress symptoms (37) when compared to the backpack. The double pack may restrict tasks such as firing weapons and donning protective masks.

Service members can take advantage of what has been learned from the double pack by distributing the load more evenly over the torso. Although it is almost impossible to make the load equal on the front and back of the body, both the ALICE and IIFS systems allow a part of the load to be moved forward onto the load-carrying vest. Doing this might be expected to reduce energy cost, improve body posture, and reduce injuries.

Pack frames and Hip Belts

Pack frames and hip belts should be used whenever possible because they reduce shoulder stress. The shoulder straps of a pack exert pressure on the skin, which can be measured with transducers under the straps. Shoulder pressure is considerably lower with a pack frame incorporating a wide hip belt compared to a pack frame without a hip belt. In one study, 10 kg carried in a frameless pack resulted in a peak pressure of 203 mm Hg; the same mass carried in a pack with a frame and wide hip belt resulted in a peak pressure of only 15 mm Hg. The pack with

the frame and hip belt produced less electromyographic (EMG) activity in the trapezius muscle, also suggesting less stress in the shoulder area (38).

Subjective reports of discomfort vary, depending on the design of the pack system. For backpacks with and without frames, the majority of discomfort appears to be in the neck and shoulder region. For a backpack with a hip belt, discomfort is localized to the mid trunk and upper legs (36). Overall, when the load is carried primarily on the waist through use of a hip belt, there is less subjective discomfort compared to shoulder load carriage (39).

Placement of Load in the Backpack

Where the load is placed in the pack will affect body mechanics. While both high and low load placements bring about forward body lean (knees, hips, shoulders and head farther forward), this effect is greater for low placements. This is because the lower load is closer to the ankles, requiring more forward body rotation to bring the pack center of mass over the feet (40). The additional forward body rotation tends to bring the body's center of mass over the front half of the foot, which could increase the likelihood of foot strain and injury.

However, placement of the load high in the pack tends to destabilize posture to a greater extent than lower placements, especially among tall men, as measured by the amount of body sway while standing with the load (41). Dynamic moments are about 40% greater with the high-back placement, an affect attributed to the greater rotational inertia of the high load (42).

A low or mid-back load placement might be preferable for stability on uneven terrain, particularly during unexpected stumbles where high-load placement can necessitate relatively high-muscle forces to maintain postural stability. The high load placement may be best for even terrain because it keeps body posture with a load most similar to that without a load (40).

Load Carriage on the Feet, Thighs and in the Hands

Loads can be carried in places other than the torso, although other body positions result in a higher energy expenditure. Loads carried on the feet result in an energy cost five to seven times higher than an equivalent load carried on the upper body (29, 43). For each kilogram added to the foot, the increase in energy expenditure is 7% to 10% (29, 43-45). This suggests that footwear should be as light as possible, compatible with durability requirements.

Loads carried on the thigh result in energy costs lower than foot carriage but greater than torso carriage. For each kilogram added to the thighs (at about mid-thigh level) the increase in energy cost is about 4% (46, 47). Less

mechanical work is performed when load masses are carried on the thighs (compared to the feet) because of reduced inertia of the body segments; changes in gait with increasing thigh load are minimal (46).

Carriage of loads in the hands also results in a higher energy cost than torso carriage (30, 31) and produces greater cardiovascular strain (48). Hand carriage is more efficient than foot carriage since the energy cost of carrying loads on the ankles exceeds that of carrying loads in the hands by five to six times if the hand load is carried close to the body (29).

Load Carriage Using Carts

Commanders or staff seldom consider using carts to transport loads, but for some missions this may be an option. In a field trial of three combat load carts, both positive and negative aspects emerged. On the positive side, the tested carts were generally durable, able to carry or exceed their rated loads (91 to 181 kg), and were effectively used in flat terrain, in barrier construction, and in resupply. On the negative side, the carts created problems in rugged terrain: they were noisy in brush or rocky areas, thus reducing tactical surprise; equipment could get caught in the wheels of some carts (49).

A combat load cart appropriate for military operations should have a low center of gravity, a wide wheel base, and a large wheel size (50, 51). Compared to body carriage, energy cost was reduced by 88% when a 50-kg load was pushed in a cart on a smooth surface (50). Pulled carts (rather than pushed) appear to be easier to control on uneven terrain and also result in considerable energy cost savings (51). Over mixed terrain (paved road, dirt road, field, and rough trail) a cart pulled by a hip belt resulted in 54% faster march times (compared to a rucksack) over a 3.2-km distance (52). This latter cart, specifically developed for military operations, is available.

Physical Training and Load Carriage

Appropriately designed physical training is another method of increasing service members' load carriage capability. Walking with backpack loads over a period of weeks results in a decrease in the energy cost of carrying the load (53). Australian military recruits with high initial aerobic capacity (predicted VO_2max=51 $ml \cdot kg^{-1} \cdot min^{-1}$) further improved their aerobic fitness by engaging in regular backpack load carriage. Loads were progressively increased during the 11-week basic training program, and improvements in aerobic capacity were similar to those of a control group performing the traditional recruit training program involving running (54).

Twelve-week physical training programs involving a combination of aerobic training (running) and resistance training improved the speed at which men completed a 3.2-km distance carrying 46 kg (55) or women completed a 5-km distance carrying 19 kg (56) even when these load carriage tasks were not included in the training program. Interestingly, neither running nor resistance training alone improved march speed (55), suggesting that both aerobic capacity and muscle strength must be trained to improve road marching capability. When regular road marching with loads (at least twice a month) was included in a training program that also involved running and resistance training, service members marched faster than if march training was not included (57).

Gender Differences

Compared to men, women walk with shorter stride length and greater stride frequency. As loads increase, the women's stride length decreases while that of the men does not show significant change. With increasing load, women also show a more pronounced linear increase in the time both feet are on the ground (double support time) than do men. Difference between men and women persist even when differences in body size and composition are taken into account (58).

When men and women were asked to complete a 10-km road march as quickly as possible carrying loads of 18 kg, 27 kg, and 36 kg, men were about 21% faster, regardless of load. On systematically administered questionnaires, women commented more often than the men that the pack straps were uncomfortable, pistol belts ill fitting, and rucksacks unstable. An independent predictor of march time (when gender was included in the equation) was acromial breath (shoulder breadth). Since pack systems have been designed primarily based on the anthropometry of men, these data suggest that pack systems designed with the anthropometry of women considered may lessen the time gap between men and women (59).

Predicting the Energy Cost of Carrying Military Loads

Studies conducted on treadmills for short periods of time show that energy cost increases in a systematic manner with increases in body mass, load mass, velocity, and/or grade (60-63). Type of terrain also influences energy cost, as shown in Figure 2 (51, 64, 65). Pandolf et al. (66) expanded on the work of Givoni and Goldman (67) to develop an equation to predict the energy cost of load carriage:

$$M_w = 1.5 \cdot W + 2.0 \cdot (W+L) \cdot (L/W)^2 + T \cdot (W+L) \cdot (1.5 \cdot V^2 + 0.35 \cdot V \cdot G)$$

Where: M_w = Metabolic Cost of Walking (Watts)

W = Body Mass (kg)

L = Load Mass (kg)

T = Terrain Factor (1.0 = Black Top Road; 1.1 = Dirt Road; 1.2 = Light Brush; 1.5 = Heavy Brush; 1.8 = Swampy Bog; 2.1 = Loose Sand; Snow, dependent on depth of depression (T=1.30+0.082*D, where D=depression depth in cm)(64)

V = Velocity or Walk Rate (m/sec)

G = Slope or Grade (%)

The Pandolf equation has been independently validated using a range of loads and body masses (68). However, the equation has several limitations. First, it does not accurately predict the energy cost of downhill walking (69, 70). Downhill walking energy cost approximates a U-shape when plotted against grade: it initially decreases, then begins to increase (71, 72). The lowest energy cost appears to occur between -6% to -15%, depending on individual gait characteristics (71). A second limitation of the Pandolf equation may be the fact that it does not account for increases in energy cost over time. In studies used to develop the equation, energy cost was examined for short periods, usually less than 30 minutes. Some studies (73, 74) have shown that the energy cost of prolonged (>2 hours) load carriage at a constant speed increased over time at higher loads and/or speeds. Whether energy expenditure increases over time is important because the individual carrying the load may become more easily fatigued if energy cost increases.

MEDICAL PROBLEMS ASSOCIATED WITH LOAD CARRIAGE

Injuries associated with load carriage, while generally minor, can adversely affect an individual's mobility and thus reduce the effectiveness of an entire unit. This section reviews some of the potential injuries, lists known and potential risk factors, and discusses preventive measures and medical management of these injuries. Table 3 summarizes common injuries as well as prevention and treatment strategies.

Foot Blisters

Foot blisters are the most common load-carriage-related injury (75-77) (Figure 3). They result from friction between the socks and skin (78-80) as a result of point pressures exerted by the boot. Blisters can cause extreme discomfort, may prevent service members from completing marches, and can lead to many days of limited activity (75, 76, 81, 82). Especially in field conditions, if they are not properly managed, they can progress to more serious problems such as cellulitis or sepsis (81, 83), as shown in Figure 4.

Heavy loads have been shown to increase blister incidence (59, 84, 85), possibly by increasing pressure on the skin and causing more movement of the foot inside the boot through higher propulsive and breaking forces (35). Other blister risk factors include tobacco use, low aerobic fitness, and ethnicity other than black (86, 87)

When loads are very heavy (61 kg), the double pack has been shown to have a lower blister incidence than the backpack (88), suggesting that better load distribution can reduce blisters. Spenco® shoe insoles have also been shown to reduce foot blister incidence, possibly because they absorb frictional forces in anteroposterior and mediolateral directions (89-91). Regular physical training with load carriage may induce skin adaptations that reduce the probability of blisters (80). Blisters may thus be less of a problem in units that march regularly; however, sudden increases in march intensity or distance will probably make blisters more likely, regardless of training regularity.

Moist skin increases frictional forces and probably increases blister incidence (80, 81, 92). Acrylic socks decrease the number and size of blisters (93), possibly by conducting sweat away from the foot (94). A nylon sock worn inside a wool sock reduces the incidence of blisters on soldiers who are road marching (95, 96). Recently it was shown that a polyester sock worn inside a very thick wool-polypropylene sock reduced blister incidence during Marine recruit training (97).

Antiperspirants also reduce foot sweating (98, 99), and some anecdotal reports and case studies suggest they may be effective in reducing blisters (100-102). A 20% solution of aluminum chloride hexahydrate in an anhydrous ethyl alcohol base (e.g., Drysol®, Person and Covey, Glendale CA) is effective in reducing the likelihood of march-related blisters if the preparation is applied to the entire foot for at least three nights before a march (87). Once the antiperspirant effect has been achieved, it may be maintained with applications once per week (103). However, many individuals report irritant dermatitis using this preparation (87), which may require the application of a topical steroid.

Other options in this case include using a lower concentration preparation (e.g., Xerex®, Person and Covey, Glendale CA), changing the treatment schedule (same number of applications but over a longer period of time), or discontinuing use. Antiperspirants in emollient bases are not effective in reducing blisters, presumably because emollients interfere with the antiperspirant effect (104).

There are few studies of blister treatment, so care is based on clinical experience and common sense. Small blisters (<5mm) are usually self-limiting and should not be drained unless they are painful because of the risk of infection (105). A small doughnut-shaped moleskin pad can be placed over the blister to prevent rupture. If the blister is greater than 5 mm and on a weight-bearing area, it should be drained. To promote blister top adhesion and healing, blister drainage should occur at the proper time. For blisters less than 24-h old, several punctures should be made with a sterile needle or a #11 surgical blade (see Figure 5). For older blisters, a single puncture is recommended (106). Tops should be kept in place to serve as functional dressings (107). A pressure dressing (e.g., gauze pad and adhesive tape) can be applied to assure that the blister roof adheres to the underlying tissue. If the top of the blister is almost completely torn off, it should be removed (108) and the site treated as an open wound. In addition to antiseptic treatments (e.g., antibiotic ointment), a surgical bandage should be applied (106). For smaller blisters, a doughnut moleskin pad affixed with a porous adhesive knit cover (e.g., Coverlet) will protect the blister as shown in Figure 6; for larger blisters a larger dressing will be needed (109, 110). Hydrogel dressings (see Figure 7) such as Spenco Second Skin® (Spenco Medical Corporation, Waco TX) or polyurethane films (e.g. Tegaderm®, 3M Company, St Paul MN) can be affixed to the blister and covered with a pad and tape (106, 110). Hydrocolloid dressings (e.g., Duoderm®, E.R. Squibb, Princeton, NJ) may also be helpful in allowing mobility (111) and may promote healing (110, 112, 113).

At times a hot spot will form before a blister. This presumably pre-blister stage is characterized as a local red and tender area (see Figure 8). A doughnut pad or covering (e.g., Duoderm®) should be applied to reduce friction and possible blister development (109).

Metatarsalgia

Metatarsalgia is a descriptive term for nonspecific painful overuse injury of the foot. The usual symptom is localized tenderness on the sole of the foot under the second or third metatarsal head (see Figure 9). Sutton (114)

reported a 20% incidence of metatarsalgia during a strenuous 7-month Airborne Ranger physical training program that included regular load carriage. One study (75) reported a 3.3% incidence after a single strenuous 20-km walk with soldiers carrying 45 kg.

Metatarsalgia is usually associated with foot strain caused by rapid changes in the intensity of weight-bearing activity (115). Walking with heavy loads may be a predisposing factor for metatarsalgia since this may cause the foot to rotate anterio-posteriorly around the distal ends of the metatarsal bones for more prolonged periods of time, resulting in more mechanical stress in this area (35).

Treatment is conservative and includes rest, ice, elevation, and anti-inflammatory medications. A metatarsal pad can be used. If symptoms persist despite these conservative measures, further evaluation for more serious problems (e.g. fractures, tumors) is warranted (116).

Stress Fractures

Lower extremity stress fractures are common in military recruits (117-122) and have also been reported in trained soldiers (122). During the Central Burma campaign in WWII, 60 stress fracture cases were reported in one infantry unit during a 483-km road march (123).

Stress fractures are attributable to repetitive overloading of bones during activities such as road marching. The most common areas of involvement are the metatarsals of the feet (123). Tenderness is generally localized on the dorsal side of the metatarsal shafts, which distinguishes the pain from metatarsalgia (see Figure 10). Figure 11 shows an X-ray of a metatarsal stress fracture that is 6-weeks old. Other common stress fracture areas include the tibia (124), as shown in Figure 12, and fibula of the leg (125).

Demonstrated risk factors for stress fractures include female gender (117, 122), white ethnicity, older age (117), taller body stature (120), prior physical inactivity (120, 126), and smoking (127). Other factors that may increase risk include load-carriage distance (122, 128) and walking style (120, 129). Treatment includes rest, ice, and anti-inflammatory medication. If the patient must be mobile, crutches are needed.

Knee Pain

Knee pain is another condition that has been associated with load carriage. Dalen et al. (130) reported a 15% incidence (17 cases of 114) of knee pain during their load-carriage study. Knapik et al. (75) reported only a 0.6% incidence of knee pain (2 cases of 335) following a single strenuous walk, but the two cases resulted in a total of 14 days of disability.

Knee pain is difficult to diagnose. Various disorders include patellofemoral pain syndrome, patellar tendinitis, bursitis, and ligamentous strain. These conditions can arise from an abrupt increase in road marching mileage or intensity or from climbing hills if service members have not been conditioned for this. Treatment includes rest, ice, and anti-inflammatory medication. Quadriceps and hamstring strengthening and stretching exercises, along with heel cord stretching, are important for the prevention of recurrence (131).

Low Back Injuries

Low back injuries can pose a significant problem during load carriage. In one study (75) 50% of the soldiers who were unable to complete a strenuous 20-km walk reported problems associated with the back. Dalen et al. (130) reported frequent problems with back strain during a 20 to 26-km walk. Low back injuries are difficult to define because the pain may result from trauma to a variety of structures including spinal discs, the ligaments connecting the vertebral bodies, nerve roots, or supporting musculature (115).

Heavy loads may be a risk factor for back injuries (84). This could be because heavier loads lead to changes in trunk angle that can stress back muscles (132-134), or because heavier loads do not move in synchrony with the trunk (134, 135) causing cyclic stress of the back muscles, ligaments, and the spine (133, 134). It has been suggested that the double pack may help reduce the incidence of back problems because it results in a more normal posture and eliminates prolonged bending of the back (35). Thus, better load distribution could reduce back injuries. Also, a general overall strengthening and stretching-warm-up program involving the back, abdomen, hamstrings, and hip muscles may assist in prevention (115).

Rucksack Palsy

Rucksack palsy is a disabling injury and has been widely reported in association with load carriage (114, 136-140). It is hypothesized that the shoulder straps of a backpack can cause a traction injury of the C5 and C6 nerve roots of the upper brachial plexus. In minor cases, compression results in entrapment of the long thoracic nerve. Symptoms include numbness, paralysis, cramping and minor pain in the shoulder girdle, elbow flexors, and wrist extensors. Long thoracic nerve injuries usually present with "scapular winging" (see Figure 13) because of weakness of the serratus anterior muscle. Sensorimotor deficits from rucksack palsy injuries are usually temporary but in some cases, may result in a chronic condition. Nerve conduction studies and EMG studies may be necessary to document this condition (136, 140).

Use of a frame and hip belt has been demonstrated to reduce the incidence of rucksack palsy (136), presumably by reducing pressure on the shoulders (38). Hypothetical risk factors for rucksack palsy include heavy loads, load distribution, and longer carriage distances (84, 136).

INFLUENCE OF LOAD CARRIAGE ON THE PERFORMANCE OF OTHER TASKS

A significant consideration from a military perspective is how well service members are able to perform military tasks during load carriage. Load mass, load volume, and load distribution appear to be important variables. As the mass increases, there are systematic decrements in the performance of tasks such as short sprints, agility runs, ladder climbs, and obstacle courses (39, 141). The decrement in performance of such tasks is estimated at about 1% per kilogram load (39). Loads of greater volume inhibit movement under obstacles. The distribution of the load within the backpack can also influence performance of specific tasks (39).

In some operations, service members are required to walk long distances and perform critical military tasks at the completion of the march. Very strenuous marches (maximal speed with loads of 34 to 61 kg over 10- to 20-km distances) lead to post-march decrements in marksmanship and grenade throw distance (59, 85, 142). The decrements in marksmanship are presumably attributable to small movements of the rifle resulting from fatigue of the upper body muscle groups, fatigue-induced tremors, or elevated heart rate or respiration (85, 142, 143). The decrements in grenade throw distance may be due to a nerve entrapment syndrome (136, 140) or pain in the shoulder area, both

resulting from pressure of the rucksack straps. Lower body muscular power (as measured by the vertical jump and Wingate test) and muscle strength do not appear to be adversely affected by prolonged pack load carriage (59, 85, 142, 144).

CONCLUSIONS: FACILITATING LOAD CARRIAGE

This review indicates that there are several ways of improving military load carriage. The techniques most available to unit commanders are load reductions, load redistribution, and physical training. Load reductions can be accomplished by tailoring the load to the specific objective and by using special load-handling devices. Commanders must make realistic risk analyses and take only the equipment necessary for the mission. Special combat load carts are available that could be useful in special situations such as marches on unobstructed terrain or in close resupply operations (15, 52).

Load redistribution can be accomplished by placing equipment more evenly around the torso. Current load carriage systems have attachment points and pockets that can be useful for moving some items from the rucksack to the front of the body. Items carried on the front of the body should be those likely to be needed suddenly or needed often. The most advantageous distribution of the load in the pack may depend on the type of terrain. On roads or well graded paths, placement of heavy items high in the pack is preferable to maintain a more upright body posture and possibly reduce low back problems. On uneven terrain a more even distribution of the load within the pack is more helpful to maintain stability. Load reductions and redistribution can reduce energy cost, decreased injuries, and improve performance on tasks following the load carriage.

Physical training that includes aerobic exercise, resistance exercise, and road marching should be performed on a regular basis. The unit master fitness trainer can design appropriate programs tailored to unit needs based on previously successful programs (55,56,57, 145). Road marching should be conducted at least twice a month with loads that service members are expected to carry in unit operations (this could be in place of one day's regular physical training). Load and distance should be increased gradually over sessions until a maintenance level has been achieved. New unit members should be given time to adapt through the same gradual program. Regular physical training has been shown to increase march performance and may reduce injuries.

To some extent, the selection and proper use of equipment can assist in reducing load-carrying stress. The IIFS pack has a frame with a well-padded hip belt that reduces pressure on the shoulders, results in less perceived

strain, and reduces the incidence of some injuries. Frames and hip belts may improve service members' performance on tasks requiring the use of the upper body. Equipment such as "sternum strap" on the IIFS pack reduces stress by allowing pressure to be distributed to other parts of the body. There are disadvantages to the IIFS pack: it is less durable than the ALICE pack and it lies against the back, reducing body cooling. The reduced body cooling may be favorable in a cold climate. The ALICE pack provides some ventilation across the back because of its external frame construction.. New load carriage technologies that are being tested and will become available will employ many of the ideas and principles discussed here (25).

It is desirable to reduce load-carriage-related injuries that impair performance, cause discomfort and disability, and result in a loss of manpower. The use of hip belts can reduce the incidence of rucksack palsy. Blister incidence can be reduced by keeping the feet dry by the use of an acrylic, polyproplene or nylon inner socks combined with wool or wool-polypropylene outer socks. Antiperspirants (applied at least three consecutive days before a march) and frequent sock changes may also be helpful. Blister incidence can also be reduced by using Spenco® insoles and by distributing the load more evenly around the torso (both of which may reduce frictional forces around the foot). Physical training directed at improving aerobic fitness along with regular load carriage marches may reduce the incidence of stress fractures and blisters.

Load carriage can be facilitated by lightening loads, improving load distribution, appropriate physical training, proper equipment selection, and specific techniques directed at injury prevention. Suitable changes will allow service members to continue missions at lower energy costs, with fewer injuries, and be better able to perform other tasks.

DISCLAIMERS

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TABLE 1
CURRENT AND PROJECTED LOAD MASSES
(INCLUDING CLOTHING AND PERSONNEL EQUIPMENT)
FOR NINE U.S. ARMY LIGHT INFANTRY POSITIONS (17)

POSITION	CURRENT MASS (KG)	EXPECTED MASS DUE TO NEW TECHNOLOGIES (KG)
Assistant Dragon Gunner	76	74
Assistant Machine Gunner	69	59
Radio Telephone Operator	68	64
Dragon Gunner	64	61
Rifleman	62	64
SAW Gunner	59	57
Platoon Leader	58	54
Machine Gunner	58	53
Grenadier	56	53

TABLE 2
PHYSICAL CHARACTERISTICS OF SOLDIERS

	HEIGHT (CM)	BODY MASS (KG)	FAT FREE MASS (KG)[a]	BODY FAT (%)[a]
FRENCH SAMPLES				
French (Crimean War)[b]	163	56	NA	NA
French (Post WWI)[b]	163	NA	NA	NA
BRITISH SAMPLES				
British (Post WWI)[b]	168	59	NA	NA
British Recruits (1978)[c]	175	70	NA	NA
British Infantry (1976)[c]	175	73	NA	NA
UNITED STATES SAMPLES				
U.S. Soldiers (1864)[e]	171	64	53	16.9
U.S. Soldiers (1919)[e]	172	66	55	15.7
U.S. Soldiers (1946)[e]	174	70	60	14.4
U.S. Male Soldiers (1984)[e]	174	76	63	17.3
U.S. Army Male Recruits (1986)[f]	175	71	59[g]	15.6[g]
U.S. Army Male Soldiers (three groups,1986)[f]	175-176	69-77	58-63[g]	15.9-19.5[g]

NA=Not Available
[a] Estimated from neck and waist girth (146), with exception of last 2 rows
[b] From 2
[c] From 147
[d] From 148
[e] From 149
[f] From 150
[g]Estimated from skinfolds using equations of Durnin and Womersley (151)

TABLE 3.
SUMMARY OF COMMON LOAD CARRIAGE INJURIES
WITH PREVENTION AND TREATMENT STRATEGIES
(see text for full descriptions and applications)

INJURY	SIGNS AND SYMPTOMS	PREVENTION	TREATMENT
Foot Blisters	Elevated area, lighter in color than surrounding skin, and filled with fluid. Pain, burning, warmth, erythema	1. Acrylic, nylon, or polyester inner sock; thick, snug, dense weave outer sock with inner sock 2. Spenco insoles 3. Antiperspirants 4. Load distribution more evenly around body center of mass 5. Reduce load mass 6. Pre-condition feet through physical training and road march practice 7. Improve aerobic fitness 8. Smoking/tobacco cessation	Intact: drain, leave top in place, light pressure dressing. Torn: remove top, antibiotic ointment, surgical bandage. Hydrogel or hydrocolloid dressings; polyurethane films
Metatarsalgia	Pain, swelling on sole of foot	1. Pre-condition feet through physical training and road march practice 2. Reduce load mass	RICE[a] Anti-inflammatory medication[b]
Stress Fractures	Persistent, boney pain	1. Smoking/tobacco cessation 2. Pre-condition feet and legs through physical training and road march practice	RICE[a] Anti-inflammatory medication[b]
Knee Pain	Pain, swelling, crepitus, instability	Lower extremity strengthening and stretching	RICE[a] Anti-inflammatory medication[b]
Low-Back Pain	Pain, muscle spasm, neurological symptoms	1. Load distribution more evenly around body center of mass 2. Reduce load mass 3. Trunk and abdominal strengthening and stretching	RICE[a] Anti-inflammatory medication[b]
Rucksack Palsy	Upper extremity numbness, paralysis, cramping; scapular winging	1. Framed rucksack 2. Use of hip belt on rucksack	RICE[a] Anti-inflammatory medication[b]

[a]RICE=rest, ice, compression, elevation
[b]Anti-inflammatory medication=aspirin or a non-steroidal anti-inflammatory

Figure Legends

Figure 1. Loads carried by various infantry units through history. Solid bars are the estimated load masses that soldiers carried while on the march. Cross-hatched bars are the estimated total mass of all equipment the soldier took with him. After WWI most historical sources only provide the load carried on the march. Information was assembled from a number of sources (9, 152, 153, 154, 155). Abbreviations: JRTC=Joint Readiness Training Center (Ft Chaffee, AR); INF=Infantry

Figure 2. Influence of terrain on the estimated energy cost of backpack load carriage. Values were obtained using the Pandolf Equation with available terrain coefficients (64,65,66). Values assume a 70-kg service member, carrying an approach march load of 33 kg, at a speed of 4 km/h on level ground (no grade). Numbers after the snow estimates are the depression the shoe makes in the snow.

Figure 3. Foot blisters

Figure 4. An infected blister

Figure 5. Drainage of a large blister <24 hours old (multiple sites).

Figure 6. Blister dressing with a doughnut pad and adhesive covering for small open blisters

Figure 7. Hydrogel dressing with gauze pad and tape cover for a large open blister

Figure 8. Foot hot spots

Figure 9. Sole of the foot showing that tenderness is localized under the second or third metatarsal

Figure 10. Dorsum of the forefoot showing that tenderness is localized on the dorsal areas of the metatarsal shafts

Figure 11. X-ray showing metatarsal stress fracture 6 weeks old

Figure 12. X-ray showing tibial stress fracture

Figure 13. Scapular winging secondary to a long thoracic nerve injury from rucksack

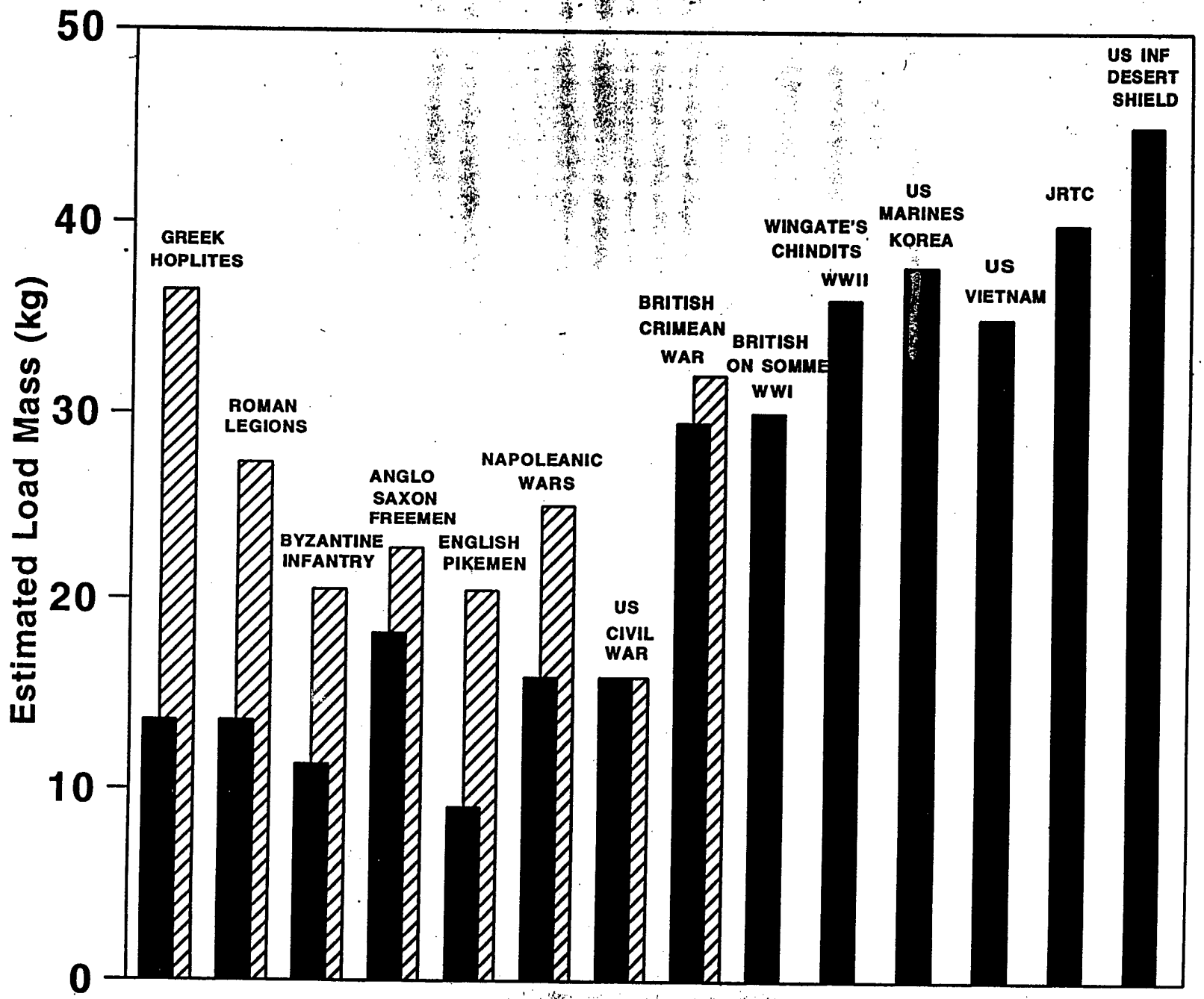

Estimated Load Mass (kg)
0
10
20
30
40
50
GREEK HOPLITES
ROMAN LEGIONS
BYZANTINE INFANTRY
ANGLO SAXON FREEMEN
ENGLISH PIKEMEN
NAPOLEANIC WARS
US CIVIL WAR
BRITISH CRIMEAN WAR
BRITISH ON SOMME WWI
WINGATE'S CHINDITS WWII
US MARINES KOREA
US VIETNAM
JRTC
US INF DESERT SHIELD

Fig 1

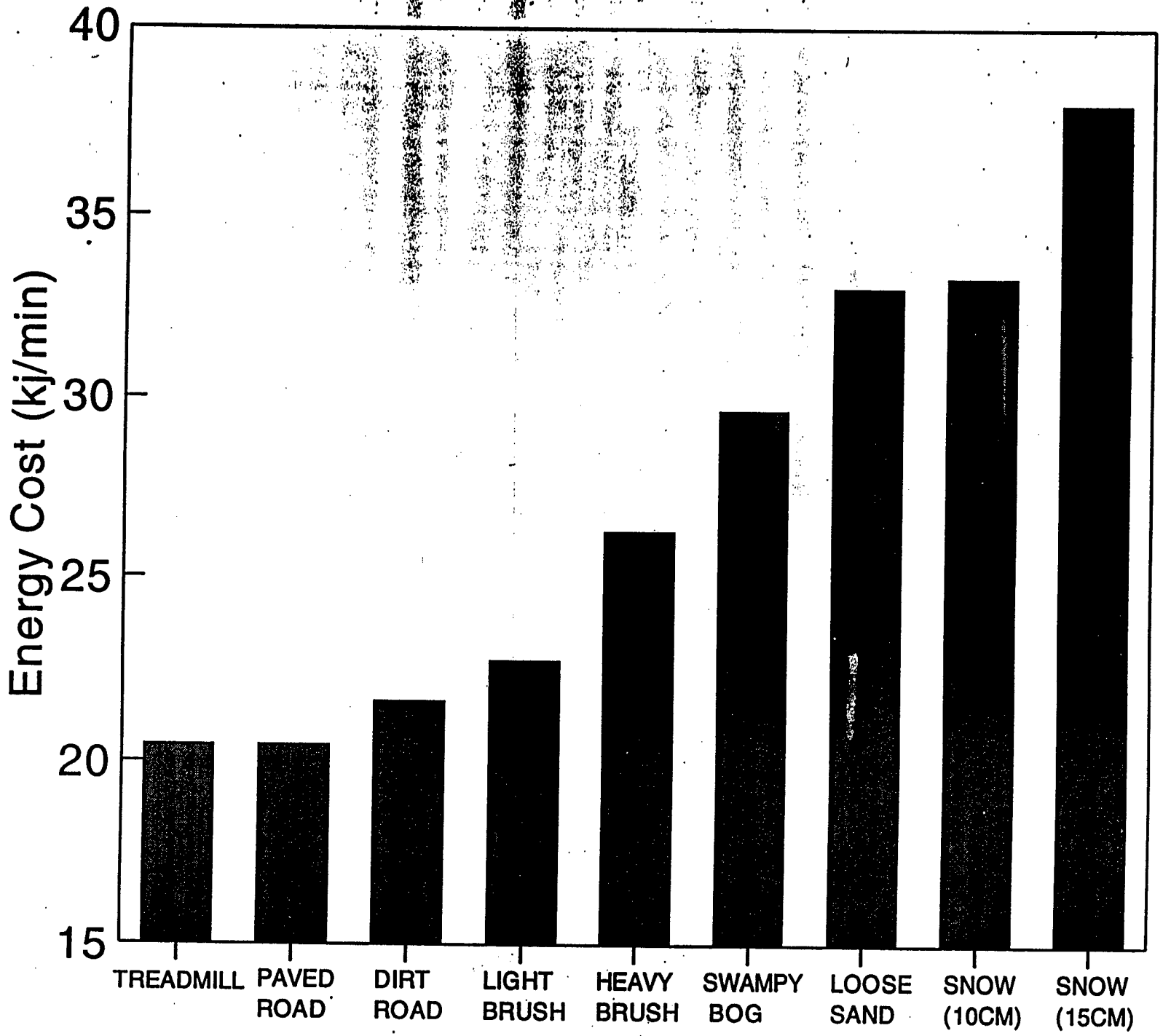
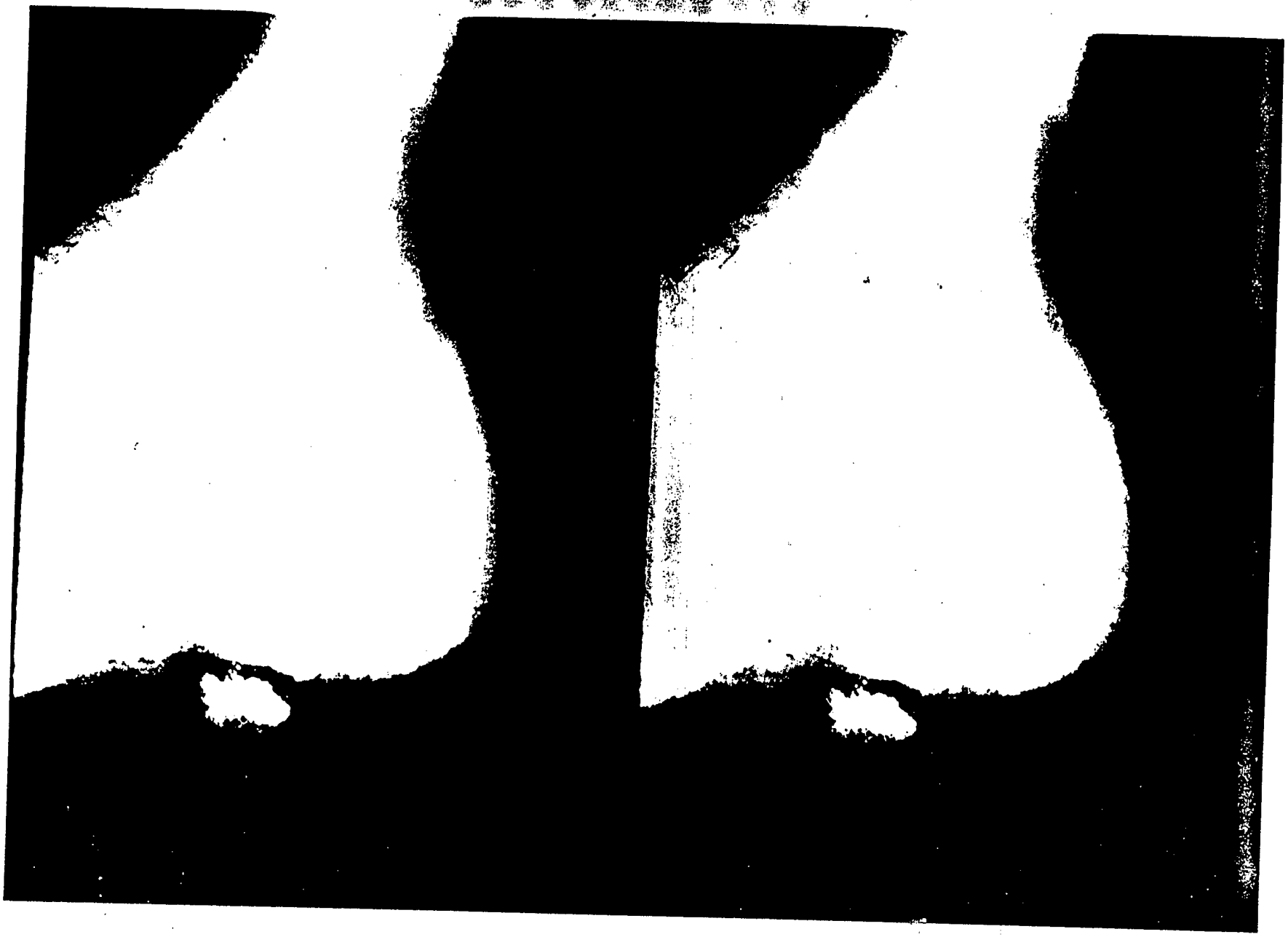

Energy Cost (kj/min)
40
35
30
25
20
15
TREADMILL
PAVED ROAD
DIRT ROAD
LIGHT BRUSH
HEAVY BRUSH
SWAMPY BOG
LOOSE SAND
SNOW (10CM)
SNOW (15CM)

Fig 2

Fig 3

Fig-1



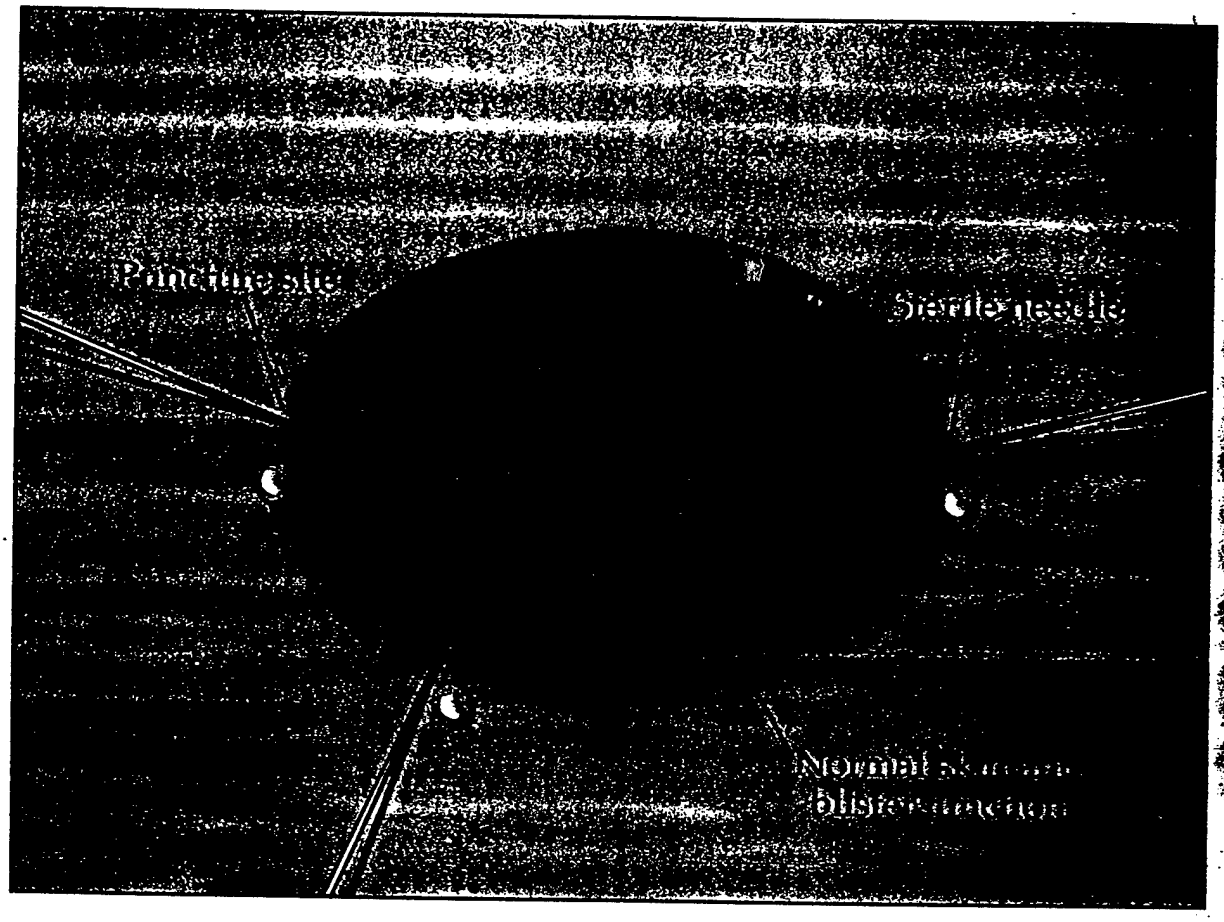


FIGURE 5. Drainage of large blister < 24 hours old (multiple sites).

Figure 6. Doughnut pad with adhesive cover for small open blister.

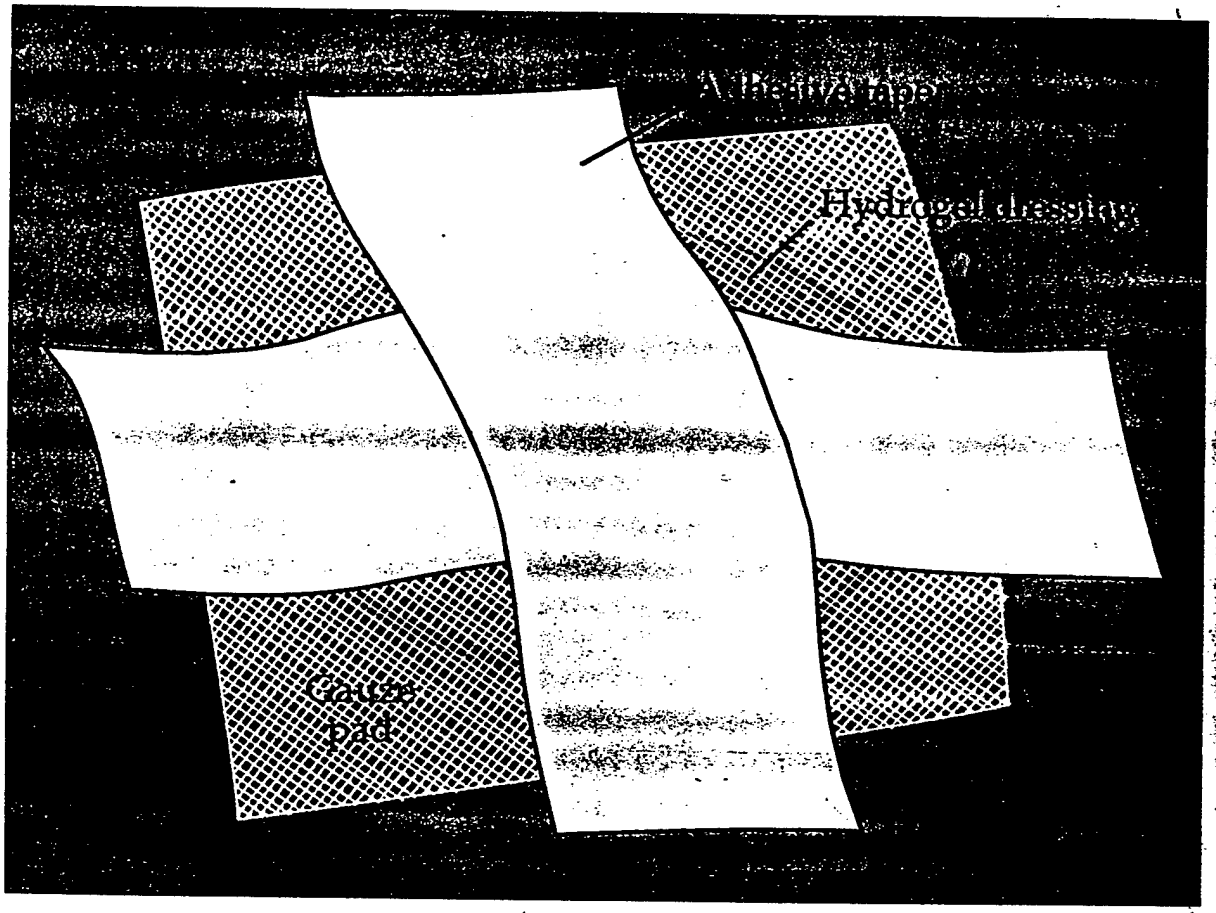


Figure 7. Hydrogel dressing with gauze pad and tape cover for large open blister.

Fig 7

Fig 8

FIGURE 9. Metatarsalgia. Tenderness is localized under the second or third metatarsal head.

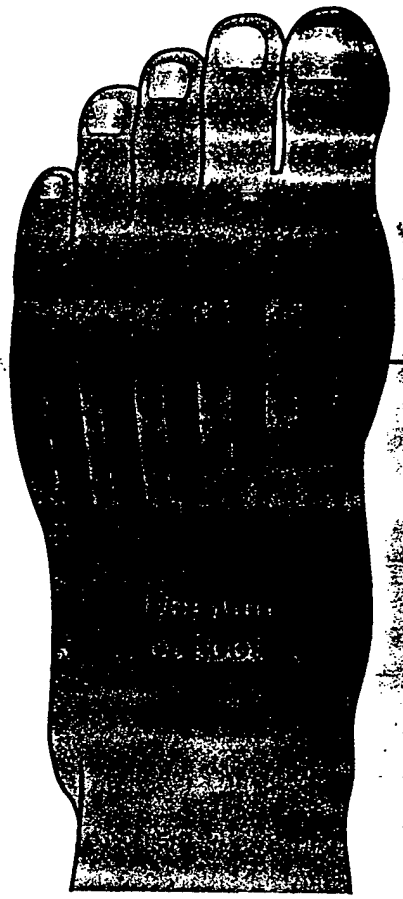
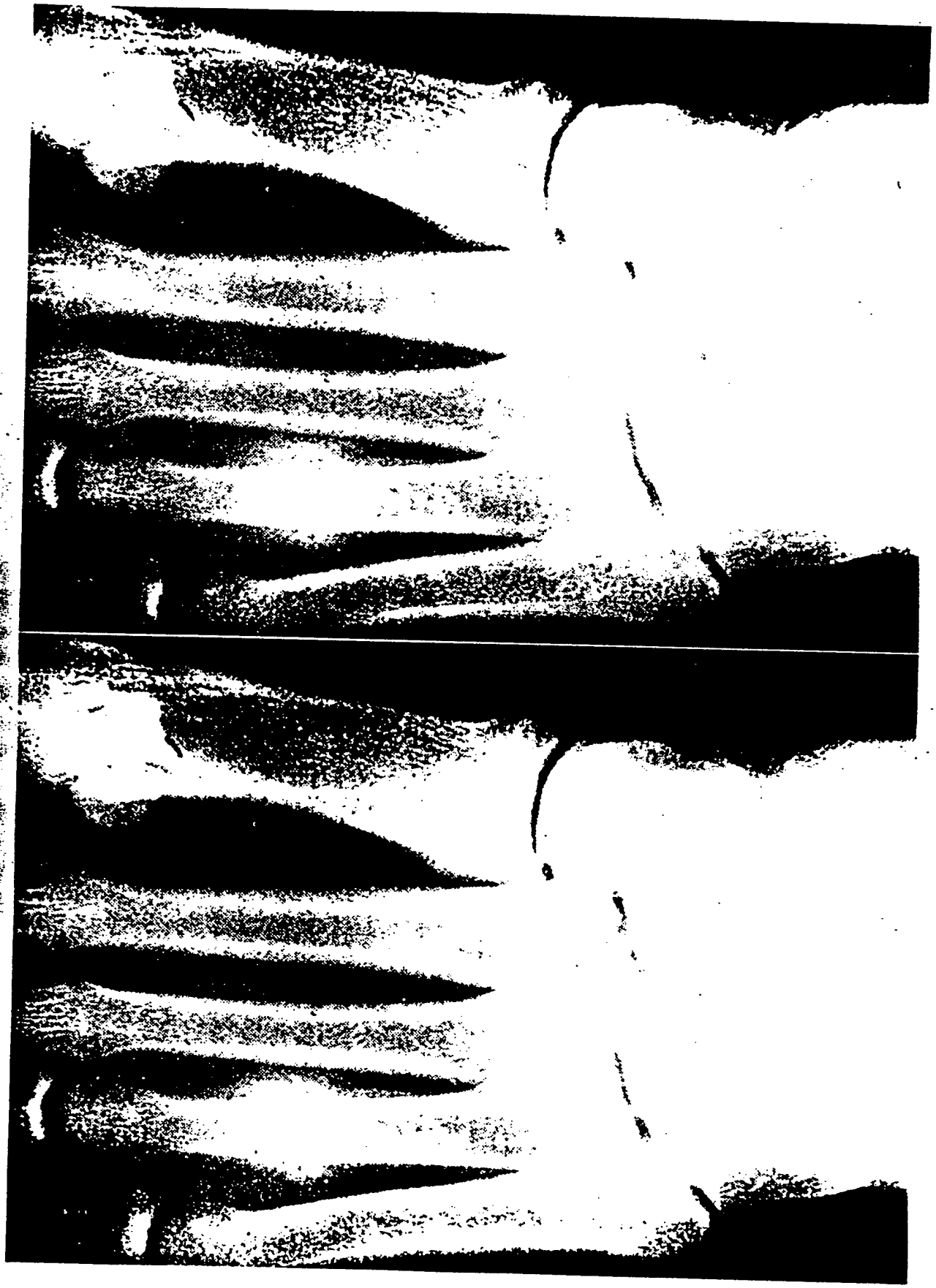
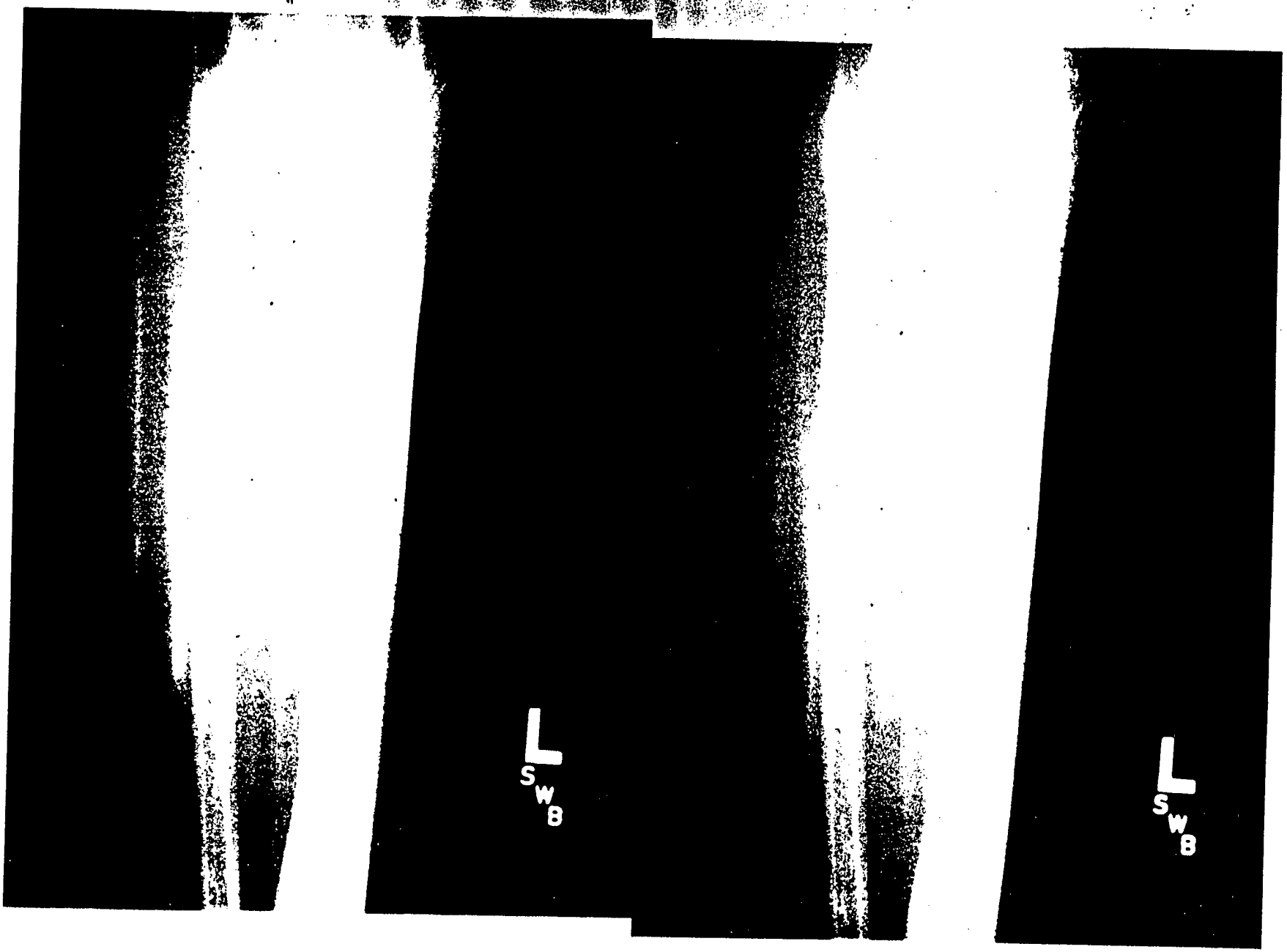


FIGURE 10. Metatarsal stress fractures. Tenderness localized on the dorsal areas of the metatarsal shafts.

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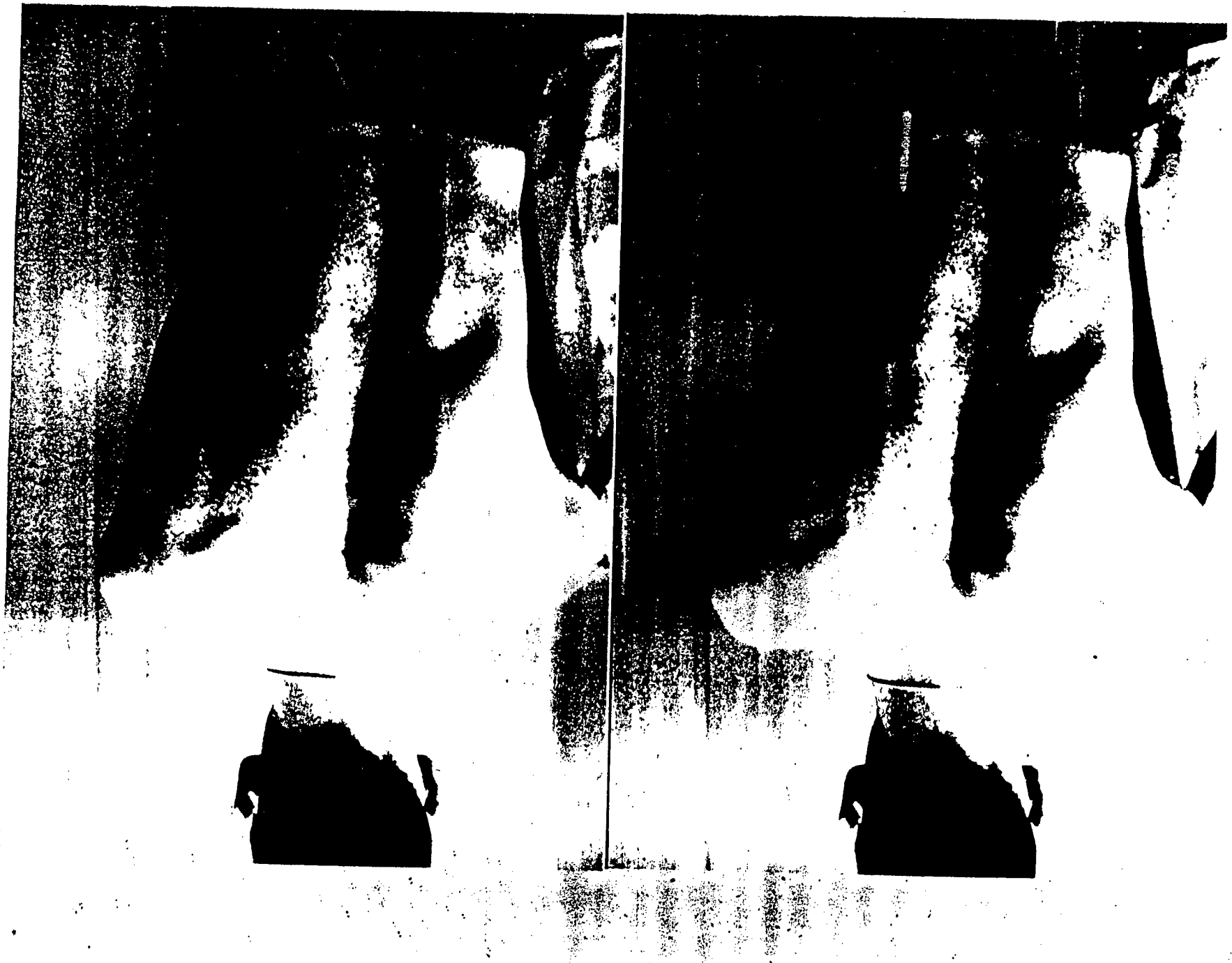

Lessons Recorded

Omaha Beach, France (1944)

"In the initial assault waves at Omaha Beachhead there were companies whose men started ashore, each with four cartons of cigarettes in his pack--as if the object of the operation was trading with the French. Some never made the shore because of the cigarettes. They dropped into deep holes during the wade-in, or fell into the tide nicked by a bullet. Then they soaked up so much weight they could not rise again. They drowned. Some were carried out to sea but the great number were cast up on the beach. It impressed the survivors unforgettably-that line of dead men along the sand, many of whom had received but trifling wounds.... No one can say with authority whether more men died directly from enemy fire than perished because of the excess weight that made them easy victims of the water....This almost cost us the beachhead. Since it is the same kind of mistake that armies and their commanders have been making for centuries, there is every reason to believe it will happen again." (3)

Grenada (1986)

"Unfortunately too few commanders enforced load discipline. Consider this soldier's observation: 'We attacked to secure the airhead. We were like slow moving turtles. My rucksack weighed 120 pounds. I would get up and rush for 10 yards, throw myself down and couldn't get up. I'd rest for 10 or 15 minutes, struggle to get up, go 10 more yards, and collapse. After a few rushes, I was physically unable to move and I am in great shape. Finally, after I got to the assembly area, I shucked my rucksack and was able to fight, but I was totally drained.' Consider another soldier's telling comment: 'I was scared I was going to get killed because I couldn't really run with that rucksack on'. Even allowing for some exaggeration by the soldiers, no one can doubt they were overloaded". (5)

Saudi Arabia and Iraq (1990)

"During Operation Desert Shield, a brigade conducted a live fire training assault to seize a bridge. The brigade commander noticed that the equipment the soldiers were carrying was interfering with the mission. At the after action review he directed the battalion commanders to investigate the weight the soldiers carried in their battalions. At the brief back one commander indicated that the average soldier in his battalion carried more than 100 pounds".

"At Christmas 1990 the [2d Brigade, 82d Airborne Division] was conducting training far to the South of the front. During this relatively peaceful time, and especially as a result of the holiday, the soldiers had accumulated many items they could not take into combat. When the order came for the brigade to spearhead the French 6th Light Armored Division's attack into Iraq, the chain of command took steps to care for the soldier's personal effects and excess baggage. They made a list of what a soldier would carry on his person (fighting load), what he would carry in his rucksack (approach march load), what he would carry in his A-bag (sustainment load), and what would go in his B-bag (contingency load). Items that did not fit in these categories, the soldier shipped home...The battalions that entered the Euphrates River Valley had learned a valuable lesson as a result of their earlier training attack on the bridge. Although their fighting and approach march loads were still heavy, they knew better how to manage them. When units arrived at their landing zones, the battalions secured their rucksacks (approach march load) with a minimum guard force while the rest of the soldiers occupied their positions. As soon as practicable, soldiers went back, a few at a time, to retrieve the rucksacks. In at least one instance, a unit placed excess ammunition and water in kick-out bundles that could then be taken forward and stored in a central location for further distribution". (154).

Acknowledgments

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