Chapter 10

COLD, CASUALTIES, AND CONQUESTS: THE EFFECTS OF COLD ON WARFARE

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INTRODUCTION

On a bitter, cold night during the Korean War, a US Marine sentry, huddling in a ditch alongside a road near the Chosin Reservoir, peered nervously into the darkness. In the stillness he heard a rhythmical "click-clack, click-clack," slowly becoming louder and louder. Not knowing what the sound could be, he waited, his finger on the trigger. The noise came closer until, around the corner, staggered a dazed Chinese soldier walking on bare feet, frozen so hard that they clattered on the road with each step.[1]

Of all the factors that influence the outcome of wars and battles, the natural environment has been one of the greatest forces for disaster. Cold environments have decided the fate of armies, often causing the deaths of hundreds of thousands of soldiers, confounding plans, and turning victory into defeat. Knowledge of the campaigns in which weather and winter have played a critical part should, rationally, help to avoid similar catastrophes in the future; but even a superficial study of history shows that these lessons have been hard to learn. Faulty command decisions,[2] inadequate logistical preparation,[3] failure to learn from the past, and unwarranted optimism[4] have, time and time again, led to disaster.

The lessons learned have been both military and medical. As casualties have decimated armies, doctors have been stimulated to seek a better understanding of the pathology of cold injuries, and this knowledge has been translated into better management.

Although the mud of spring and fall has had a greater effect on mechanized warfare than the frozen terrain of winter,[5] countless wars have been started in summer and brought to a slower pace during winter. The best-laid plans often came to naught if armies were caught in the grip of winter,[6] ill-equipped and unable to obtain food, far from a home base, and defeated. In the 20th century, better equipment and more sophisticated logistical and supply systems have enabled armies to alleviate the effects of the environment, whether hot or cold. On occasion, armies experienced in winter warfare have used the environment to their advantage. In the battle for Stalingrad, in World War II, the Russians made their final attack during bitter cold,[2] knowing that they were attacking an enemy demoralized by cold and starvation and lacking the resources to resist, despite their courageous defense.

ANCIENT HISTORY TO WORLD WAR I

Xenophon and Hannibal

The greatest epidemics of cold injury have occurred during wars. Xenophon (434–355 BCE) was a young Athenian officer in an army of mixed Greek mercenaries led by Cyrus on a campaign into Asia Minor. At the Battle of Cunaxa (401 BCE), not far from Babylon, the Greeks won but Cyrus was killed.

EXHIBIT 10-1

GLOSSARY

Frostbite, also called Freezing Cold Injury (FCI)	A cold injury involving freezing of tissues. Damage may be temporary or permanent. Gangrene and loss of digits or limbs may result. Long-term sequelae, including pain on exposure to cold, are common.
Nonfreezing Cold Injury (NFCI)	Includes trench foot, immersion foot, sea-boot foot (an injury that results from multiday exposure of limbs [usually the lower limbs] to a cold—but nonfreezing—wet environment. The primary injury is to nerves, but damage to blood vessels and other tissues also occurs. Gangrene may result. Long-term, painful sequelae are common.
Warm Water Immersion Foot (WWIF)	An injury caused by prolonged exposure of feet and legs to a warm, wet environment. The condition responds to drying the affected parts, and long-term sequelae are uncommon.

Xenophon was elected one of the new leaders and became the main inspiration and driving force, leading 10,000 men on a 1,000-mile retreat through the mountains of what is now Armenia, in the depths of the winter of 401/400 BCE.[7] Only 4,000 soldiers survived; most of the others died from exposure and frostbite (Exhibit 10-1).

Hannibal, the famous Carthaginian general, planned to invade northern Italy in 218 BCE by leading an army of 38,000 infantry, 9,000 cavalry, and 80 elephants up the valley of the Rhone, across the Alps, and into the valley of the Po. When he made the passage of the Alps in October 218 BCE, heavy snow had already fallen in the mountain valleys.[8] The altitude, bitter cold, and fierce mountain tribes extracted a heavy toll. Only 19,000 men survived, half-starved and frozen. Surprisingly, some of the elephants also survived to play an important part in victorious battles against the Romans.

Charles XII of Sweden

In 1697 a charismatic young man, aged only 14 years, ascended the throne of Sweden.[6] Charles XII soon won the hearts of his people and, supported by a well-trained army, won a string of victories in the Great Northern War (1700–1721), which only came to an end when he was defeated by the Russians at the battle of Poltava (July 1709). The campaign leading up to that defeat was conducted in one of the coldest winters ever experienced in Europe, and by spring only 20,000 men were fit for action to face 50,000 Russian troops led by Peter the Great. Only 1,500 Swedish troops survived the battle. Charles XII was not the first, and certainly not the last, conqueror to be enticed into the vastness of the Russian steppes, there to be defeated. He fled to the Ottoman Empire, present-day Turkey, where he served in the Ottoman army before returning to Sweden in 1714.

A few years later Charles decided to invade Norway.[9] His first attempt was a failure, but in the autumn of 1718 he returned to battle again, mounting a two-pronged attack on the Norwegians: a southern thrust against Oslo, and a northern attack across the mountains to Trondheim. Both attacks reached their objectives. In the north, the Swedish army, which was composed largely of Finns, surrounded Trondheim without much difficulty because the Norwegians, being wise locals, did not want to become involved in a pitched battle as winter descended on the bleak, treeless ridges.

King Charles, who was renowned for leading from the front, commanded the southern army. While inspecting a forward position on the evening of 11 December 1718, the king was hit in the temple—some reports claimed by a silver button—and died almost instantly. The news of his death spread rapidly and caused consternation in the army. Some of the generals in the south immediately abandoned their troops and fled for home. The news did not reach the northern army until Christmas Eve, when General Carl Gustaf Armfeldt, the commanding general of the northern army, received an order to retreat and return to Sweden.

A severe storm hit on December 27th, a harbinger of what was to come. General Armfeldt struck his headquarters on 4 January 1719 and started up the valley of the Tydal toward the border. The Norwegians used guerilla tactics to attack the retreating army, constantly picking at the edges of the columns. On 13 January, when the main body of the retreating army was crossing the highest ridge, another storm struck and lasted 3 days. By the time the blizzard had abated, 3,700 men (half of Armfeldt's army) had died of hypothermia and frostbite, and another 600 were permanently crippled by the cold.

Contemporary accounts of the disaster told of soldiers who were found lying in the snow with few clothes, and it was thought that the survivors had stripped their freezing comrades to keep themselves warm. A more likely explanation, in light of our 20th-century experience, is that this was an early account of "paradoxical disrobing," that strange phenomenon that makes hypothermic victims take off their clothes because of a feeling of intense warmth.[10] One of the casualties, a young medical officer, froze his feet badly but refused to allow them to be amputated. He recovered and later became a general in the Swedish army—still with two feet. His insistence on waiting saved his feet, showing the advantage of conservative treatment.

This defeat, brought about more by a blizzard than by an enemy, ended Swedish military dominance of the Nordic countries.

General George Washington and Valley Forge

In the annals of American military history few stories equal that of the winter of 1777/78, when Washington's army bunkered down in Valley Forge. Eleven thousand raggle-taggle, retreating men marched into the valley on 18 December 1777.[11] Two thousand were without shoes or boots. During those winter months the hardships endured were severe, although the winter was relatively mild. At times, snow lay on the ground and the temperatures

dropped below freezing. Six months later, after long, hard training, a tough, disciplined force marched out to defeat the British.

Accurate records were not kept of the number of cold injuries, but Lafayette wrote:

> Feet and legs froze until they became black and it was often necessary to amputate them.[12(p45)]

There were many other medical problems. Diarrhea was rampant because of improper sanitation, although the need for latrines and their correct use was well recognized. Smallpox was a threat, and the inoculation campaign that protected thousands of men must have been one of the first large-scale attempts to prevent the disease. The vaccine used was primitive and obtained from men with mild cases. Amazingly, of the 4,000 men vaccinated, only 10 died from the immunization.[12]

Exposure, overcrowding, poor food, scabies, typhoid, and typhus haunted the Continental Army during that fateful winter. Had the army been moving and fighting rearguard actions for those months, the casualties would have been many times greater. As it was, the lack of fighting and the chance to stay in one place and reorganize reduced the casualties and laid the foundation for future victory.

Napoleon in Russia

A century after the army of Charles XII came to grief in Russia, the disaster was repeated on a grander scale. In 1812, Napoleon invaded Russia to suppress Tsar Alexander and consolidate his hold over Europe.[4]

Napoleon studied the problems he might encounter in minute detail and repeatedly read the accounts of the campaign of Charles XII of Sweden, vowing that he would not make the same mistakes.[4] The planners of Napoleon's Grande Armée understood that they would not be able to obtain supplies from the countryside and, therefore, made preparations to set up huge depots along the route and carry many of the supplies in trains of wagons.[4(p757)] The invading army was organized into three lines amounting to 612,000 troops, of whom fewer than half were French. Twenty-six transport battalions with nearly 25,000 wagons pulled by oxen and horses trailed the army, accompanied by herds of cattle to be slaughtered for meat. There were 200,000 animals, including 30,000 horses for the artillery and 80,000 for the cavalry, to be fed and cared for.[4(p758)] Because of the need to feed the animals, the invasion had to be delayed until June, when the plains would be lush with summer grasses.

Despite the massive preparations, one factor—apart from the extremes of weather—had not been considered and could not be controlled. Napoleon, although only 42 years old, was no longer at the height of his military powers. His health was not good and it deteriorated during the campaign.[13] He could not possibly maintain control over a vast multinational army, spread across hundreds of miles, when the fastest means of communication was determined by the speed of a horse. Where Napoleon foresaw only glory, however, others saw disaster. Carl von Clausewitz—who was himself serving in the Russian army in 1812—had forecast that if Napoleon were ever to invade Russia, he would be destroyed.[14]

The River Niemen in Poland was the starting line for the invasion, but no arrangements were made to feed the troops before they reached this point, although some of them came from as far away as Austria and Spain. The soldiers had to live off the country. As a result, many arrived at the Niemen already malnourished and suffering from diseases that included diarrhea, diphtheria, and typhus. In addition, insufficient warm clothing had been ordered. Napoleon believed that he would defeat the Russians quickly in one decisive battle and, unrealistically, hoped that the campaign would be over in 20 days. The Russians had other ideas, and three times they slipped away in the night before a major battle, drawing Napoleon farther and farther from his bases into the emptiness of the plains and forests. The Russians held fast at Borodino in a battle that cost them 44,000 casualties. In the same battle Napoleon lost 30,000 troops, including 47 generals.[4]

The route to Moscow was haunted by frustration and the loss of thousands of men. Two thirds of the army were lost during the advance, due to death from wounds and illnesses, desertion, and capture. The invasion started in June, and Napoleon entered the Kremlin in September. A month later he decided to retreat; by this time, the populace had fled, the city had been reduced to ashes, the Tsar had refused to negotiate a peace, and winter was approaching. The retreat, Napoleon's first, became a frozen nightmare. It was, ultimately, the start of his downfall.

By the time the gates of Moscow were reached, the Grande Armée had been reduced to 110,000 men, and this force started back to France on 19 October 1812. As the troops left Moscow, in a train of 40,000 wagons loaded with loot and supplies, rain

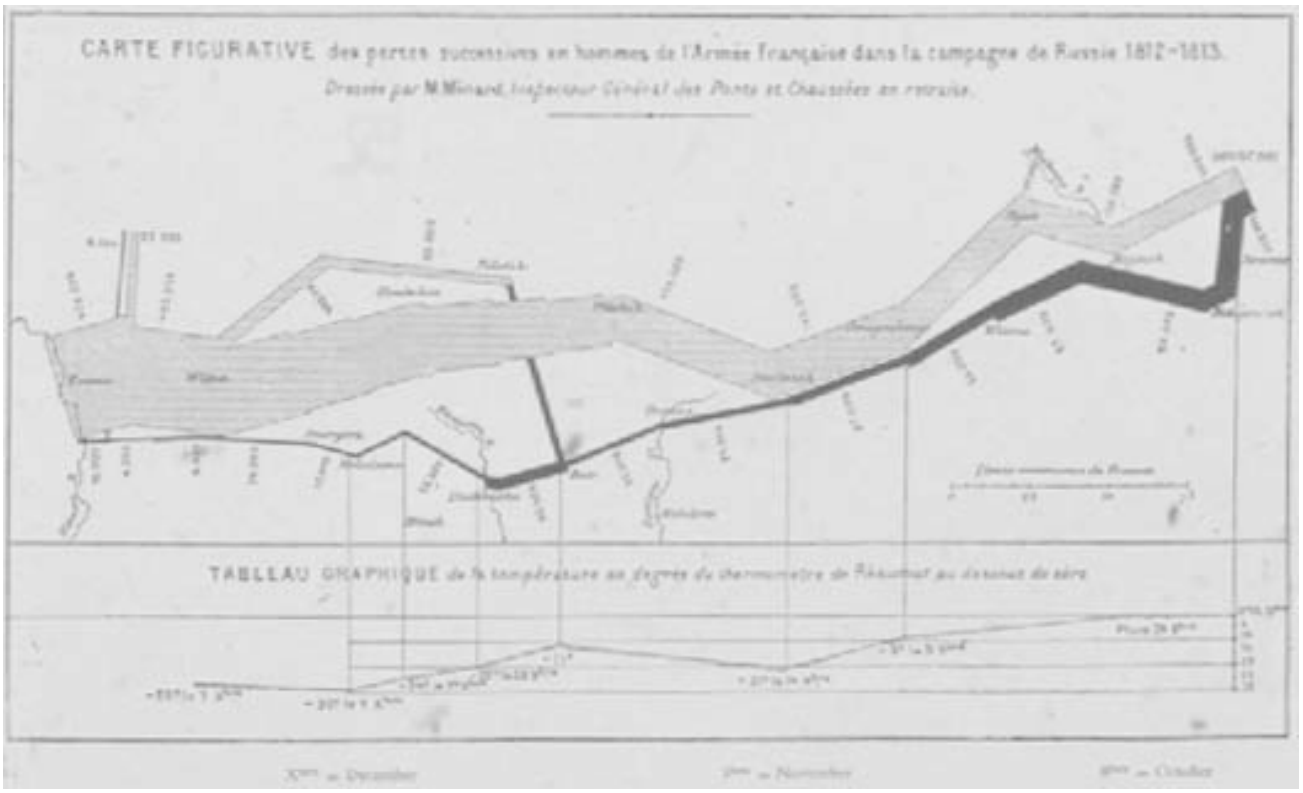

Fig. 10-1. This diagram of Napoleon's Russian campaign in 1812–1813, drawn in 1861 by M. Minard, retired General Inspector of Roads and Bridges for the French Army, has been praised as "the best statistical graphic ever drawn."[1(p40)] Reading from left to right, the shaded area indicates the diminishing size of Napoleon's Grande Armée during its advance to Moscow. Reading from right to left, the dark line shows the size of the Grande Armée as it diminishes further during its retreat from Moscow. The narrower the line, the smaller the army. Interested readers will note that approximately 75% of the Grande Armée had been lost before the retreat from Moscow; the remainder was destroyed during the fall of 1812. The representations of the size of the Grande Armée are superimposed on a map with the names of places and battles. The lower part of the diagram shows a graphical representation of the temperature in degrees Réamur (a temperature scale similar to Celsius, which superseded it) at different points during the retreat. Scale in leagues; 1 league equals approximately 2 mi. (1) Tufte ER. *The Visual Display of Quantitative Information.* Cheshire, Conn: Graphics Press; 1983: 40. Reproduced with permission from Tufte ER. *The Visual Display of Quantitative Information.* Cheshire, Conn: Graphics Press; 1983: 41.

was falling and the temperature was just above freezing. A month later, by the time the army reached Vyazma, only 160 miles from Moscow, the force was down to 50,000 men (Figure 10-1).

The first snow storm hit on 6 November[13] and was followed by intermittent snow, rain, and thaw until early December, when the weather became bitterly cold. During the next 6 weeks the temperature fell to nearly –40°C, and the size of the Grande Armée was further depleted to 12,000 men (Figure 10-2). During one battle, the crossing of the ice-filled Berezina River, the French army had 30,000 casualties, many of whom drowned in the river, having been swept off the hastily built bridges by a flood of retreating men and horses. When the army finally crossed the River Niemen into Poland, fewer than 10,000 effective soldiers remained.[4]

More than 100,000 men had been killed in action, 200,000 died from other causes, 50,000 were left sick in hospitals, 50,000 deserted, and 100,000 became prisoners of war. The exact number who died from cold can never be known, but in addition to those who died from cold alone, thousands of wounded who might have lived must have died from the combined effects of their wounds and the cold. Russian casualties numbered at least 250,000, and must also have included many who died from cold and exposure.

Count Phillipe-Paul de Ségur, a brigadier and aide to Napoleon, who wrote a definitive history of the campaign that was both a literary and military

Fig. 10-2. *Retreat From Moscow;* hand-colored contemporary aquatint after Johann Adam Klein; circa 1815; originally published in Vienna by Artaria. Napoleon, huddled in a cape and riding his horse, marches alongside his defeated troops during the retreat from Moscow. The ground is littered with frozen bodies and abandoned artillery. Reproduced with permission from Peter Harrington, Curator, Anne S. K. Brown Military Collection, Brown University Library, Providence, Rhode Island.

masterpiece,[13] described the first snow as it fell on the retreating army:

> Russian winter in this new guise attacked them on all sides; it cut through their thin uniforms and worn shoes, their wet clothing froze on them, and this icy shroud molded their bodies and stiffened their limbs. The sharp wind made them gasp for breath, and froze the moisture from their mouths and nostrils into icicles on their beards.[13(p170)]

The depth of the final defeat and degradation of the Grande Armée can hardly be described. According to de Ségur, one division that started from Moscow with 12,000 men arrived in France with fewer than 400 in good health:

> Here were the same valleys down which had poured those three long columns of dragoons and heavy cavalry, three streams of steel and brass, flashing in the hot sunlight. But now, men, weapons, eagles, horses, sunlight, even the frontier river they had crossed in such ardor and hope - everything had disappeared. The Niemen was just a long mass of blocks of ice piled up and welded together by the breath of winter. In place of the three French bridges, brought fifteen hundred miles and erected with such daring speed, there was only one Russian bridge. Instead of the four hundred thousand companions who had fought so many successful battles with them, who had pushed so valiantly into Russia, they saw issuing from the white, ice-bound desert only one thousand foot soldiers and troopers still armed, nine cannon and twenty thousand beings clothed in rags, with bowed heads, dull eyes, ashy, cadaverous faces and long ice-stiffened beards. Some of them were fighting in silence for the right to cross the bridge which, despite their reduced number, was still too narrow to accommodate their precipitate flight. Others had rushed down the bank and were struggling across the river, crawling from one jagged cake of ice to another. And this was the Grand Army.[13(p280)]

Napoleon's Surgeon-General, the Baron Larrey, wrote graphically of the retreat and the cold injuries of the soldiers:

> Woe to the man benumbed with cold ... if he entered suddenly into a too warm room, or came too near to the great fire of a bivouac. The benumbed or frozen extremities ... were struck with gangrene, which manifested itself at the very instant, and developed itself with such rapidity that its progress

> was perceptible to the eye. Or else, the individual was suddenly suffocated by a kind of turgescence, which appeared to seize upon the pulmonary and cerebral systems: he perished as in asphyxia. Thus died the chief apothecary of the guard. … Weakened by cold and abstinence, a refuge was offered him in a very warm room of the hospital pharmacy, scarcely had he passed a few hours in this warm atmosphere, which was new to him, when his limbs, which he no longer felt, became bloated and swollen, and he expired soon afterwards in the arms of his son and one of his colleagues, without being able to utter a single word.[15(p83)]

The mechanism of death in these men can only be conjectured. They were in the final stages of exhaustion. They had probably received little food or drink, and what they drank may well have been polluted. Terror and exhaustion were their constant companions. Their feet were excruciatingly painful, afflicted with a combination of trench foot and frostbite. Severely depleted of fluids, and perhaps suffering from infections—for typhus was rife in the army—they exposed themselves to heat and vasodilated both centrally and peripherally. They placed their frozen feet too close to a strong source of heat, now recognized to be disastrous treatment.[16] The combination of a burn and frostbite guaranteed massive tissue loss and destruction. Massive extravascular extravasation further reduced their intravascular volume. They probably died from hypovolemic shock, peripheral and pulmonary edema, and, in many instances, infection.

Larrey not only described the condition of the men but also advocated treatment for frostbite that, because of the authority of his position and experience, would become the standard for the next hundred years. He believed vehemently that rapid warming was fatal and advised rubbing frozen limbs with snow. His explanation, although understandable, sounds strange to our ears:

> For it is well known that the effect of caloric on an organized part, which is almost deprived of life, is marked by an acceleration of fermentation and putrefaction.[15(p84)]

Larrey's contributions to military surgery and the handling of battle casualties, his astute observations on the pathogenesis of frostbite and his analytic approach to the understanding of trauma, make him a true surgical giant. He observed that cold weather, by itself, need not necessarily result in casualties. When the weather warmed up—and when the roads and battlefields turned to mud—cold injuries appeared. He described how the soldiers, after one battle in February, had no cold injuries although the temperatures at night dropped to –20°C. But when there was a sudden thaw with heavy rain, the temperature rising to 8°C to 10°C, soon many soldiers complained of

> vivid pains in the feet, congestion, heaviness, and unpleasant creepings in the extremities. ... All of those patients who had gone to the town or to the camp fires to warm themselves became the most mistreated.[15(p67)]

The description fits the early symptoms of trench foot, a problem that must have been very common (although it was not yet separated clinically from frostbite).

Larrey also recognized that the external appearance of gangrene in a frozen extremity does not conform to the deeper damage:

> One must not confuse the gangrene of the foot with the gangrene of the skin. Indeed it often happens that a more or less extended part of the skin is mortified without loss of life to the tendons, ligaments, vessels, deep nerves or the bones.[15(p74)]

Larrey was not expounding a new theory. Hippocrates had warned of the danger of heat:

> In some instances blisters arise as if from burning with fire, and they do not suffer from any of those unpleasant symptoms until they become heated.[17(p22)]

Crimean War

Trench foot has afflicted armies for centuries, although the association between prolonged exposure to wet cold and gangrene was not made until World War I.[18,19] (Trench foot, immersion foot, shelter foot, and sea-boot foot are all now classified as nonfreezing cold injuries [NFCIs], but for purposes of this historical overview, the earlier terminology will be used.)

During the Crimean War (1853–1856), prolonged exposure to the cold mud in which the combatants fought was ideal for the development of trench foot.[20] The British and French sustained thousands of cold injuries (Figure 10-3).[21] During the first winter of the war the British had 1,942 cold casualties out of an army of 50,000 soldiers. The doctors recognized, as had Baron Larrey, that injuries often appeared when the weather warmed and a thaw started. Then the frozen ground on which the troops could stand turned to icy mud into which they sank. The soldiers spent more than 24 hours in the

Fig. 10-3. *Before Sebastopol;* November 1854. *The Sentry,* an unsigned ink and watercolor drawing by Miss H. J. Wilkinson after one done by Captain Wilkinson of the 9th Foot, British army, shows a cold, wet sentry, the hood of his jacket wrapped around his neck, his hands in his armpits. He is standing in a mud puddle, and the bones of a carcass can be seen near his feet: a picture of misery and inattention to duty. Reproduced with permission from Peter Harrington, Curator, Anne S. K. Brown Military Collection, Brown University Library, Providence, Rhode Island.

trenches, often in mud and snow up to their knees. Their boots were inadequate and their clothing unsuited to cold weather. As would be expected, the infantry had many more casualties than the cavalry, but even the horses suffered from ill-treatment, the terrible cold, and mud:

> The horses had one handful of barley each day as their day's food and the same the next day. They were standing knee deep in mud, with bitter Crimean wind cutting their emaciated bodies. … An order had been issued that no horse was to be destroyed ... [so] ... they lay in the mud in their death agony for three days while no one dared to shoot them.[20(p262)]

By the second winter of the war the army had begun to learn its lessons (Figure 10-4). Supplies had improved, and commanders understood the connection between length of exposure to wet, cold conditions and the injuries. Soldiers did not have to spend such long periods in the line, and their

Fig. 10-4. *Huts and Warm Clothing for the Army;* original watercolor by William Simpson, 1855. Soldiers march through the frozen landscape of the Crimea. On the left, a man driving an ox before him is lucky enough to wear a sheepskin cover. In the background, a camp is being raised with a tent and a few wooden huts. The artist, Simpson, went to the Crimea in fall, 1854, and spent several months sketching the campaign for a series of lithographs published in London, England. This watercolor was the subject of one of the lithographs. Reproduced with permission from Peter Harrington, Curator, Anne S. K. Brown Military Collection, Brown University Library, Providence, Rhode Island.

experiences of the previous winter had taught them how to care for themselves. The case mortality death rate fell from 23.75% during the first winter to 1.3% in the second.[21] The decreasing mortality was not entirely due to a reduction in cold injuries. Cholera and typhus also extracted a high death toll, and a storm—which on 14 November 1855 had destroyed 30 transports carrying food and clothing for the first winter—had added to the high early mortality.[22] William Howard Russell, the correspondent for *The London Times,* reported such a grim picture of privation and inefficiency that the public uproar resulted in intensive efforts to improve the lot of the troops and to reorganize the medical facilities under Florence Nightingale.[20]

Wars of the Late 19th and Early 20th Centuries

During the American Civil War (1861–1865) there were more than 15,000 cold injuries, of which 1,075 were serious. Amputations were common, with a mortality rate of about 30%; many were for frostbite. Of 259 amputations that were carefully documented, 44 were for frostbite.[21]

During the next few decades the Franco–Prussian War (1870–1871), the Russo–Turkish War (1877–1878), the Sino–Japanese War (1895), the Russo–Japanese War (1904–1905) (Figure 10-5), and the Boer War (1899–1902) all extracted their tolls of thousands of cold injuries. Much was learned by the military in various countries about the treatment and prevention of cold injuries. The Japanese, according to a British observer,[23] learned to wear greased waterproof boots and to change their socks and boots at regular intervals. "Foot care" became an important part of military discipline. Casualties were reduced significantly. Nevertheless, the Russians had more than 1,000 frostbite injuries in one battle[24] and claimed that the Japanese had many more than were reported. Although the Japanese certainly improved the care of their soldiers and reduced the number of men incapacitated by cold,

Fig. 10-5. *Japanese Troops in a Snowstorm During the War With China;* original wash drawing by John Schönberg, 1895. The bitter winter conditions of the Sino–Japanese War of 1895 are vividly portrayed in this drawing of Japanese troops during a snowstorm. One man, exhausted and cold, has fallen to the ground and is being helped to his feet by his companions. Others appear indifferent to his trouble. The artist, Schönberg, covered the war for the *Illustrated London News*. Reproduced with permission from Peter Harrington, Curator, Anne S. K. Brown Military Collection, Brown University Library, Providence, Rhode Island. Jap. O. 1895 F-1.

the lessons were slow to be learned by other nations. World War I, only a few years in the future, would show, once again, how the medical lessons of one war are slow to be transferred to the next.

The Balkan War of 1912, between the Turks of the Ottoman Empire and the Balkan Alliance, one of the seemingly endless conflicts in that area, was another example of war under difficult, cold, wet conditions with the inevitable toll of thousands of injured soldiers. Page[25] reported many cases of symmetrical gangrene of the legs, often associated with enteritis. All these men had spent at least 24 hours in wet trenches with a ground temperature below 5°C; the cases were considered to be almost identical to frostbite.

By this time theories about treatment were beginning to change. Passive rewarming was being advised, although rubbing with snow was still commonly used.[26]

WORLD WAR I

World War I—the Great War, as it was known for a generation—began on 4 August 1914, and within a short time the politicians and generals were talking about "being home before Christmas." Disillusionment was soon in coming. By Christmas, after a German attack that nearly captured Paris had been turned back on the River Marne, both sides had settled into 4 years of unrelenting, stalemated trench warfare that claimed millions of lives and even more millions of wounds and injuries.[27]

Trench Warfare

Hundreds of thousands of soldiers spent days, even weeks, in trenches filled with near-freezing mud, sometimes above their knees. Within 4 months of the outbreak of war, the British army had 9,000 cases of what was named "so-called" frostbite. By the end of the war they would have sustained 115,000 cold and frostbite injuries (Figure 10-6).[28]

The conditions under which the troops, both Allied and German, had to live and fight were a prescription for disaster. Pierre Berton,[29] describing the conditions under which Canadian troops lived on Vimy Ridge, wrote:

> For most of that record winter the Canadians were cold, wet, hungry, tired, and, although they did not admit it, frightened. The cold was unbelievable. The temperature did not rise above zero Fahren-

Fig. 10-6. *Winter Conditions in the Yser Country: A Scene on the Snow-Covered Road Leading to the Rear;* uncolored photogravure after Fortunino Matania, 1916. In October 1914, the German army attacked the valley of the Yser River in Flanders to reach the coast of the North Sea. They were halted by a much smaller but determined British army. This photogravure shows British troops escorting German prisoners of war along a frozen, poplar-lined Belgian road. One of the Germans is blowing on his hands, while the two men at the head of the column seem to be holding each other for support and perhaps for warmth. The artist, Mantania, visited the British troops on the western front in 1915 on behalf of *The Sphere,* an illustrated newspaper of London, and produced a series of 12 photogravures (of which this is one) which were originally published in *With the British Army on the Western Front* by *The Sphere* in 1916. Reproduced with permission from Peter Harrington, Curator, Anne S. K. Brown Military Collection, Brown University Library, Providence, Rhode Island.

> heit for one month. The ground froze two feet deep, making it impossible to bury the horses and mules that died of cold and exposure. This was not the dry cold that the men of the prairies and Northwest were accustomed to. Fog and rain mingled with snow and sleet, the water in the shellholes froze overnight, the mud turned hard as granite so that the men were actually wounded by flying chunks of earth. They clumped along the duckboards swathed in greatcoats and jerkins, hooded by balaclavas under their steel helmets, their rifles wrapped in sacking; and they took their boots to bed with them to keep them from freezing stiff. It was so cold the bread froze after it came from the ovens and had to be cut apart with a hacksaw. Colds were so common that before a man could be sent to the rear he had to be suffering from pneumonia.[29(p85)]

When the mud was not frozen the trenches became a hell of slush and water, in some places so deep that a man falling into a shell hole could drown (Figure 10-7):

> ... and the mud, the dreadful clinging mud, reappeared. Nothing sapped the soldier's morale more than this ever-present gumbo, so glue-like that the strongest boots had their seams wrenched apart by men's efforts to struggle out of the morass. … The mud flowed like gruel around men's puttees, filled their boots, squeezed into their socks, and had to be scraped from between the toes with a knife.[29(p86)]

Conditions on the eastern front were equally harsh. Colonel Knox, British Military Attaché with the Russian armies in 1914, noted: "If we have to advance in the winter our losses will be three times as great."[27(p107)] Sentries froze to death at their posts, and it was impossible to provide hot food for the troops. Not only the men were affected: sometimes their weapons did not work either. Rifles and machine guns became clogged with mud and, at every level, military efficiency was reduced to a primitive struggle to survive.

On the eastern front the Russians reported 12,000 cases of frostbite.[27] Eight percent of all casualties were due to cold, and the Germans reported 10,000 cases of frostbite in *a single night*.[30] Only rudimentary treatment could have been applied to so many cases in a single night. Most of the frozen limbs must have thawed spontaneously. Those with lesser injuries made satisfactory recoveries; those with severe injuries lost their limbs.

In the Dardanelles, where the British made an abortive attempt to bypass the conflict in France and relieve the pressure on Russia, the troops, many from Australia and New Zealand, were unprepared

Fig. 10-7. *Extricating a British Soldier From the Mud of the Somme District;* drawing by Christopher Clark based on material received, 1917. In World War I the mud of France, churned into deep pools by constant bombardment, claimed the lives of thousands of men. *The Sphere,* a well-known British illustrated newspaper, printed this picture on its cover on 10 February 1917 during the Battle of the Somme, with the following legend:

> This man has slipped into a particularly soft spot en route to the trenches. He has become firmly stuck in the soft clinging soil, so much so that his efforts to liberate himself are quite unavailing. A rope is fastened to his arms and planks are pushed into the oozy hole. On these the rescuers slip and pant as they haul away at the unfortunate man. No result is obtained until others with spades begin to dig and loosen the mud. Then gradually the upward pressure tells, and the man is carried, not a little exhausted, to firmer ground.

What the original legend does not state is that even as the soldiers worked to free the trapped man, they were in danger of falling into the same morass themselves. Reproduced with permission from Peter Harrington, Curator, Anne S. K. Brown Military Collection, Brown University Library, Providence, Rhode Island. Originally printed by *The Sphere.* London, England; 10 Feb 17; LXVIII(890): cover 1.

for cold weather. On 27 November 1915, a freezing thunderstorm hit the peninsula. More than 100 soldiers were drowned in flooded trenches.[27,31] The rain turned to snow. There were more than 14,000 cases of frostbite, with a death rate of 0.58/1,000, a rate 10-fold greater than the death rate associated with frostbite in Europe. Dysentery was a common concurrent problem, as it had been in the 1912 Balkan War,[25] and other wounds or illnesses added to the dangers of the cold injuries. The snowstorm brought one blessing, though: it killed the swarms of flies that flew in thick clouds around the dead.[27]

In 1916 the Russians were locked in bitter fighting against the Turks. The city of Erzerum was heavily defended and surrounded by snow-filled valleys with few roads.[27,32] The British newspaper correspondent Philips Price wrote:

> The Russian troops had to cross mountains with deep snowdrifts at 10,000 ft and go for at least three days cut off from food supplies, with nothing but the few crusts of bread they could carry with them.[32(p209)]

Two thousand Russians died from frostbite and exposure in two nights.

In northern Italy a hotly contested mountain war was fought between the Italians and Austrians. Both sides had specially trained mountain troops, and scaling peaks and hauling artillery up and lowering wounded down cliffs were part of the regular pattern of fighting. Killian[30] quotes an Italian authority who claimed that there were 300,000 Italian cold injuries. The official number (38,000) was much smaller (Table 10-1).

Definition and Treatment of Trench Foot

At first the distinction between "true" (or "ground") frostbite and trench foot (or immersion foot) was not clear, but as World War I progressed it became clear that "trench foot" was distinct from "true frostbite."[33] In trench foot, the limbs were not frozen, and the water in which the men stood was not freezing, whereas in frostbite, tissues are frozen

TABLE 10-1

COLD INJURY IN WORLD WAR I

Army	Theater of War	Dates	Cold Injuries (N)
British	France	1914–1915	29,000
	Dardanelles	1915–1916	14,584
	All theaters	1914–1918	115,361
French	France	1914–1918	79,465
Italian	Italy / Alps	1915–1918	38,000
German	East and West	1914–1918	12,848*
United States	France	1917–1918	1,994†

*The accuracy of this number is doubtful because another report[1] indicated 10,000 cases in one day on the eastern front. (1) Gilbert M. *The First World War*. New York, NY: Henry Holt & Co; 1994.
†Most of these cases occurred in one battle on the Meuse / Argonne front in October–November 1918. An additional 67 cases occurred during training in the United States.

and ice crystals develop between cells. The salient points in the development of trench foot were

- prolonged exposure to cold and wet;
- dependency of the feet; and
- pressure around the lower leg caused by boots or the encircling, bandagelike "puttees," which were too tight.

Johns[33] thought that the condition was due to pressure on anesthetic feet. The men entered the trenches with their feet and legs swollen and hot from rapid marching and then stood up to their knees in ice-cold water and mud, which caused shrinkage of the boots and puttees. Localized gangrene, due largely to circulatory interference, developed in the feet.

Treatment of trench foot was largely symptomatic; amputation was rarely needed, but long-term disability was common. Tetanus and gas ("emphysematous") gangrene were constant threats because most of the trenches had been dug in farmland heavily fertilized with manure. The mixture of human and animal carcasses in the stinking mud only added to the risks of infection.[34]

One form of treatment was to rub the feet with whale oil every day. Berton[29] describes how the freezing whale oil was brought to the trenches every day, and the loathing with which the men applied the obnoxious cure to their feet. The penalties for not using the oil daily were severe, not only for the man who failed to apply the oil but also for his senior officer. Other oils were suggested: eucalyptus; methyl salicylate; and a mixture of castor oil, glycerine, and atropine.[34]

Delépine,[35] professor of public health in Manchester, England, devised a waterproof sock of oiled silk that was thin enough to be worn between the ordinary sock and the boot. The idea was ingenious but impractical for men standing in water and mud several feet deep.

One of the salient symptoms of trench foot was a feeling of intense warmth in the feet and lower legs. The casualties with trench foot were nursed in a cool atmosphere, with feet uncovered and protected from the bedclothes by a cradle.[36] The treatment of true frostbite, in contrast, was to put the casualty in a cool room and rub the frozen parts with snow or cold water.[37] Only later was the patient transferred to a warmer environment. The official advice to the US Army and Navy in 1917, still reflecting the teaching of Larrey, was to rub the frozen part "vigorously" with wet snow or ice water, "never with dry snow as the temperature of dry snow may be much below freezing."[38(p125)]

COLD INJURY RESEARCH TO 1939

Investigations During World War I

The number of cold injuries in World War I (see Table 10-1) must have taxed the medical services of the armies on both sides. If anything was learned it was that conservative management was better than precipitate amputation. The gangrene that followed trench foot was more likely to be "wet" (ie, ischemic

necrosis with bacterial infection), whereas the gangrene that followed "true" frostbite was more likely to be "dry" (ie, shriveled or mummified necrosis). But amputation owing to gangrene was relatively rare.[34] The number of injuries, and the impact on the fighting strength of the armies, stimulated research into an increased understanding of the pathology, particularly of trench foot.

Lake[39] investigated the effects of freezing on cell cultures and determined that –6°C is a critical temperature, below which serious damage occurs. With the acute interest at the time in trench foot, much of his work was directed to elucidating the pathogenesis of the lesions. High capillary pressure was found to be an important secondary factor, although cold was the primary etiologic influence.

Lorrain-Smith, Ritchie, and Dawson,[40] from the University of Edinburgh, studied 51 cases of "trench frostbite" of the feet and legs. They described how soldiers spent 48 to 72 hours in the front line, although the period was occasionally as long as 6 to 11 days. The mud was frequently mixed with ice crystals, and fires were not available in the dugouts for warming or drying. They advised that soldiers massage their legs before going up to the front line, that duties in the trenches should be restricted to 48 hours, and that all constricting clothing be avoided. They also advised that at the development of the first symptoms soldiers should not be allowed to walk before receiving treatment. The feet were to be rested and not warmed.

Page[41] tried a controlled study in 332 patients, treating one foot with dusting powder and the other with a variety of counterirritants, hot fomentations, massage, or electrical stimulus. He found that counterirritants relieved pain for a short time, hot baths accelerated the development of hyperesthesia, massage sometimes became difficult to bear but it expedited cure, and stroking the legs with a faradic current cured anesthesia. It was not possible to draw conclusions about the efficacy of one treatment over another.

The advice given by these authorities and others was heeded and the incidence of cold injuries decreased steadily throughout the years of the war.[21] When the war started there were few medical officers who had either knowledge or experience of cold injuries. It did not take long, however, for the field commanders to become aware that prevention was possible. Under the conditions described by Berton,[29] prevention was difficult if not impossible, but to some extent it was successful with the introduction of rubber boots and wooden duckboards for the men to stand on. The British army's trench foot rates for 1914 and 1915 were 33.97 and 38.43 per 1,000 hospital admissions, respectively; but in 1916 the rate was down to 12.82, in 1917 it was 11.34, and in 1918 it had plummeted to 3.82.[21]

Between the Wars: 1918–1939

Between the two world wars the treatment advised for frostbite was, almost universally, rubbing with snow or the application of cold. The reasoning behind this advice was that rapid warming caused more pain, swelling, and tissue destruction than did very slow rewarming.

Robert Greene,[42] a doctor with several major British mountaineering expeditions in the 1930s, advised that frozen feet be exposed to a cold environment, although there was little experimental evidence to support this view, with which not all experts agreed. Scott,[43] of Antarctic fame, had in 1905 described warming frozen parts by placing them on the warm, bare skin of an associate. Other famous polar explorers, such as Byrd in 1935, similarly advised the use of body heat and condemned the use of friction with snow.[44] But, overall, the advice was still to use cold, rubbing with snow, or gentle friction with cloth or fur.

During the mid to late 1930s, a group of scientists at the Kirov Military Medical Academy of the USSR Army, including T. V. Ariev, proved that rapid warming was preferable to older methods using cold.[45] Ariev was both a surgeon and scientist, and he found that frozen rabbit ears, rewarmed rapidly, sustained less damage than ears allowed to warm spontaneously in air. Historically unsubstantiated evidence against rapid warming did not deter Ariev from looking at the possibility of using this method. In 1940 he wrote:

> The great majority of recent observers and some of the older observers claim that rapid warming of frozen extremities aids (or may even lead directly to) development of gangrene, and that rapid warming in cases of generalized freezing causes death. … Although there is no basis for this argument, it is widely accepted. ... 1) No concrete evidence proving the injurious effect of rapid warming which could withstand criticism has been encountered in the literature. And, 2) The experiments used to prove the value of slow warming are insufficient in number and the methods used are inadequate.[46(p99)]

WORLD WAR II

On 1 September 1939, when Germany invaded Poland, war once more engulfed Europe. Before the war ended in 1945, more than 55 million people had died. The Russians had more than 10 million military and civilian casualties. Cold injuries alone numbered in the millions. The Germans fighting in Russia had more than 250,000 frostbite injuries, most in one winter.[30] The Americans, in other theaters, lost the equivalent of several divisions temporarily or permanently because of cold injuries.[21] The "phony war," as the first months were called in Europe, produced a sizable crop of cold injuries despite the absence of serious fighting (the winter of 1939/40 was unusually cold, one of the coldest in recent memory[47]). The French, sitting in the relative comfort and security of the Maginot Line, sustained 12,000 cold injuries during the first winter of the war.[20]

The Russo–Finnish War

On 30 November 1939, Stalin invaded Finland. Four Russian armies launched a preemptive strike into untracked forests. By the end of the campaign, 1 million Russian troops had been thrown against 300,000 Finnish soldiers, most of whom were reservists.[2] The Finns were fighting to protect their homeland and their soldiers were trained to fight on skis; they appeared suddenly, attacking Russian convoys that were bogged down on forest roads, and then blended back into the forests (Figure 10-8). In the battle for Suomussalmi, the Russians lost 27,500, killed or frozen to death.[8] The Finns lost only 900 killed and 1,770 wounded. The Russians lost 200,000 men in the campaign, many from exposure to cold or starvation, compared with 25,000 lost by the Finns.

Fig. 10-8. Sketch by an unknown Finnish artist. During the Russo–Finnish War of 1939/40, the Finns were vastly outnumbered but made up for the disparity in numbers with their skill as ski troops. Finnish troops, known as the "White Death," were able to make quick attacks on the Soviet columns laboring along the poor forest roads. The Red Army troops, who proved inadequately armed and poorly trained for the winter campaign, could not reply. For a time, it was thought that the Finns might win the war. Eventually the USSR overwhelmed the Finnish army, but not before the White Death had extracted a terrible toll in the Russian campaign. Reproduced with permission from McCormick K, Perry HD. *Images of War: The Artist's Vision of World War II.* New York, NY: Orion Books; 1990: 9.

The massive weight of the Russian attack finally wore down the Finnish defenses, but the Russian military leadership, decimated and weakened by Stalin's prewar purges, discovered that their troops were ill-trained for winter warfare, and that their clothing and equipment were inadequate. They also learned the value of ski troops and how to manage cold injuries. The Russians would benefit from this experience a year later.

German Invasion of Russia: Operation Barbarossa

On 22 June 1941, 3 million German troops smashed into Russia in the start of Operation Barbarossa.[2,48] The Russians fell back on all fronts. A German victory seemed certain before the summer ended, but the advance petered out in the vastness of the Russian plains. A winter campaign became inevitable. The German High Command was aware of impending problems, but it was not until August 1941 that an order went out from Generaloberst Franz Halder, chief of staff of the German army, that a report should be made on the winter clothing needed.[2]

Confusing Decisions: The Start of Winter, 1941

According to a postwar report written by Colonel Paul Hagendorn,[3] a staff officer involved with supplies and logistics, the German High Command made a fateful decision on 15 October 1941, at 4:30 pm, that marked a turning point in the war. The original plan of the General Staff was to advance as far as Moscow and then dig in for the winter, conserving troops and supplies for a campaign in the spring of 1942. After the invasion slowed and the autumn rains turned the Russian roads into impassable quagmires, members of the German High Command disagreed over the correct course to take. After much indecision, Hitler personally reversed the plans to dig in for the winter. There would be no pause, although the troops were already struggling and the first cold winds of winter were blowing across the steppes. Moscow must be taken. The commanders were ordered to fill their transport vehicles only with ammunition, food, and fuel, and to leave winter clothes behind. With typical thoroughness, the German supply corps had accumulated enough winter equipment for the 50 divisions expected to occupy defensive winter positions, but they had neither prepared for nor obtained sufficient winter clothing for the 150 divisions required for the attack. The fate of thousands of men was sealed by a dictatorial afternoon decision.

The attack stalled a mere 18 miles from the gates of Moscow.[48] Some advanced German patrols even entered the suburbs,[49] but the main body of troops was exhausted, cold, and short of food and fuel. Before the winter of 1941/42 was finished, 200,000 German soldiers had been frostbitten.[21] General Winter reigned supreme. The ghost of Napoleon, who said he had been defeated by Generals January and February, must have been saying, "I told you so."

The early part of the winter was not unduly severe, but as December progressed into January and February the weather became bitterly cold. The Panzer chief, General Guderian, reported the temperature to be –63°C. In a moment of depression he wrote to his wife:

> The icy cold, the lack of shelter, the shortage of clothing, the heavy losses of men and equipment, the wretched state of our fuel supplies, all this makes the duties of a commander a misery.[2(p174)]

Learning from the Finnish experience, the Russians had thousands of ski troops who out-maneuvered the Germans, attacking from many sides. The snow was so deep that horses pulling the German guns floundered up to their bellies, and retreating soldiers had to spend their nights digging roads along which they could retreat the next day. (The German army used 2,750,000 horses during World War II, most of which died.[50])

The conditions under which the Germans fought were cruel. No one described the conditions better than General Guderian:

> Only he who saw the endless expanse of Russian snow during this winter of our misery ... who drove for hour after hour through that no-man's land only at last to find too thin shelter, with insufficiently clothed half-starved men; and who also saw, by contrast, the well fed and warmly clad and fresh Siberians, fully equipped for winter, only a man who knew all that can truly judge the events that now occurred.[2(p175)]

Winter clothing never reached the front—a frequent complaint in many armies—and when it arrived the quantities were totally inadequate. Complaints were made at the highest levels: Deighton[48] recounts a telephone conversation between Generalfeldmarschall Fedor von Bock, commander in chief of Army Group Center in Russia, and Generalfeldmarschall Walter von Brauchitsch, commander in chief of the German army, in which Bock complained bitterly that all the cold weather supplies were stored in areas hundreds of miles

from the front. Brauchitsch's response was, "The Fuehrer wants to know when Moscow will be captured."[48(p213)]

One battalion of 800 men received only 16 winter greatcoats and 16 pairs of fur-lined boots (Figure 10-9).[2(p217)] The temperature fell to –40°C to –60°C. Men urinated on their freezing hands to warm them. The cracked skin bled with every movement.[51] Soup that came boiling from the pot was frozen before it could be eaten. The tank engines could not be started. The recoil mechanisms of the guns froze,[48] and fingers froze to exposed metal. The wounded or the exhausted who fell froze to death if they could not be roused into action.

After the war, Colonel Hagendorn claimed that German winter equipment was good, but that inadequate supplies resulted in too few soldiers being appropriately dressed; in other words, they were ill-equipped for the Russian winter (Figure 10-10).[3] When the temperatures were bitterly cold and the snow was dry, the Russians fought in felt-lined boots,[49] while the Germans wore leather, calf-high

Fig. 10-9. Painting, title and date unknown, by W. F. Gebhardt; captured German art, formerly held at US Army Center of Military History, Washington, DC, has been returned to the German government. Two German sentries of an SS unit stand watching over the bleak Russian landscape. Because they were SS troopers they were well supplied with thick winter clothing; most German soldiers were inadequately clothed and never had access to the type of clothing worn by these troopers. Reproduced with permission from McCormick K, Perry HD. *Images of War: The Artist's Vision of World War II.* New York, NY: Orion Books; 1990: 142.

Fig. 10-10. *Ill-Equipped for Russian Soil, December 1941;* photograph by Galina Sankova. The picture tells the story: two dead Germans, one hatless and the other wearing the standard open-topped boots of the German army. The soles of the boots were thin, with metal studs that conducted heat from the feet to the ground. The open tops of the boots allowed snow to blow in and surround the feet. Frostbite was inevitable. Reprinted with permission from Mrazkova D, Remes V, eds. *The Russian War: 1941–1945.* New York, NY: Dorset Press; 1975: unpaginated.

boots filled with rags and paper. The Russians had quilted clothes; the Germans, standard woolen field uniforms; and the Germans had to increase the insulation of their uniforms by stuffing newspapers between the layers. One German recalled how he used propaganda leaflets telling the Russians to surrender as insulation.[2]

The Russians, and especially the Siberian troops brought from the East to support the winter counterattack, knew how to live in the cold and treat cold injuries. They knew how to improvise stoves to keep themselves warm. The Germans burned precious gasoline. Shelter was impossible to find because the ground was too hard to dig. Everything confirmed the well-known experience that in winter, the losers have more casualties and a greater number of frostbite victims than the victors.[21] The number of casualties alone made treatment impossible in the retreating troops. As Professor Hans Killian, a surgeon with the German 16th Army, later wrote, the occurrence of cold injuries in every war waged in the cold should not be taken as an indictment of the medical officers, quartermasters, and commanders, but is a consequence of war itself. The cold injury is "the badge of depression, demoralization and defeat."[30]

In 1942 a German medical officer who had served in Russia outlined the treatment used.[52] Warming was gradual. Frozen parts were elevated to reduce edema. Blisters were incised and covered with antiseptic powders. Hasty amputations were avoided and surgery used sparingly. The same account described how the frozen parts were "bathed" in water at 25°C to 30°C, which was gradually heated until it reached 40°C. Rewarming in water was, therefore, already being used, although more conservatively than later. Alcohol and coffee were given as stimulants.

The Germans learned the same bitter lessons as had previous armies that had invaded Russia. Training, personal discipline, supervision by the noncommissioned officers of the troops, strong morale, good food, and equipment reduced the number of casualties. Some factors, such as the decisions of the High Command, were beyond the control of the fighting men and, sometimes, the press of battle made protection against the cold impossible. Given equal circumstances, a well-disciplined unit had fewer cold injuries than one with lax control and lazy supervision.

Professor Killian personally supervised the treatment of 5,243 cases of first-degree frostbite, 12,937 cases of second-degree, and 1,455 cases of third-degree with 393 amputations, all in the winter of 1941/42. The German army pathologists at that time reported that one third of the autopsies showed evidence of frostbite. Of the German troops who were frostbitten, 40% were out of commission for 3 months, 10% for 6 months, and 2% were fit only for service at bases in Germany.[30]

The Germans suffered in every winter of the campaign. Early in 1944 a retreating German unit was halted by a river 30 feet across and 6 feet deep. Floundering horses drowned. Men flung themselves into the river only to have their clothes freeze on them. When they came out on the far side, "they

were turned into blocks of ice."[2(p377)] Many of them tore off their clothes. A witness described how

> soon hundreds of soldiers, completely naked and red as lobsters were thronging the other bank … . Under the fire of tanks, thousands upon thousands of soldiers, half clothed, streaming with icy water or naked as the day they were born, ran through the snow to the distant cottages of Lysianka.[2(p377)]

After the war a young German soldier, Hans Burtscher, who had been a member of the No. 4 High Mountain Infantry Battalion in Italy, wrote a bitter account of his earlier experiences with the German mountain troops in the Caucasus and Italy.[53] His unit had defended a high (9,100-ft) pass against repeated Russian attacks for 2 months. Their supplies could not reach them and they were starving:

> Winter clothing consisted of two sheepskin coats, teeming with lice, for the sentries. They probably had been on loan from the Italians, because the German fur coats, as well as other useful items, reportedly were found only about 350 miles behind the front lines where they kept party functionaries warm and comfortable. But, as mentioned above, such subjects could not be discussed openly, because there always existed the likelihood of being turned in by a snitch.
>
> For weeks there was no way to prepare warm meals in positions above an altitude of 9,000 ft, no firewood was to be found, and portable cook stoves were not available. The daily ration consisted of a thin slice of bread, a small chunk of blood sausage, a tablespoonful of jam and dab of margarine, two pieces of candy and 10 French cigarettes. Bread and sausage were usually covered by ice crystals, and it all barely filled a man's hand. We were occasionally able to break up captured weapons and dismantle enemy grenades and mortar rounds to get powder to start a fire from broken rifle stocks and melt snow to prepare some tea. Deplorable conditions such as these, as well as others too numerous to list here, and the unfolding Stalingrad disaster, increasingly fueled doubts, even among the younger soldiers about the strategic talents of the Fuhrer. But he had his informers everywhere, who made sure that any mutineer was sentenced without delay to do time in a murderous penal battalion, or worse. No wonder the preferred conduct was therefore to remain a silent coward, instead of becoming a dead martyr, or traitor, accused of undermining the morale of the army.[53(pp2–3)]

A photograph in his account of a group of soldiers has the caption: "Of the group seated in front, only one was alive, four weeks later, with hands and feet amputated."[53(following p3)]

German Cold-Weather Training Manual, 1942

Despite the terrible conditions and heavy casualties from the cold, the official German army training manual, entitled *Winter Warfare*,[54] published in 1942, and based on experience in the Russian campaign, failed to sound the warnings that might have been expected and gave a falsely optimistic impression of how the German soldier had coped with the winter conditions of the previous year:

> Experience teaches us that the German soldier knows how to master the difficulties of the Russian winter, and that he is superior to the enemy even in winter. He is capable, not only of defending himself against the Russian but also of annihilating him in the attack.
>
> Prerequisites for this superiority are as follows: psychological preparation for the hardships of winter warfare, appropriate training and adaptation, familiarity with winter combat methods, and proper equipment and employment of expedients.
>
> In building up endurance against the rigors of the Russian winter, mental discipline is the determining factor. Many cases of freezing are caused by the slackening of attention and by indifference. The danger of freezing is especially great when one is exhausted after great exertion or after a long period on guard. Then the soldier must summon all his will power in order to keep awake and alert. The code of comradeship demands that soldiers must assist each other in this effort and in stimulating the will to live. The most serious danger begins when confidence in one's own strength is extinguished.[54(pp4–7)]
>
> . . . .
>
> In addition to the fight against the enemy in winter, there is also the struggle against nature—against cold, snow, wind, poor visibility and prolonged darkness. ... Knowledge of the following fundamental subjects is necessary: clothing and equipment—rations—maintenance of health—care of weapons, equipment and ammunition, care of motor vehicles—care of horses—heating facilities. Generally speaking the danger of illness resulting from cold is slight, provided blood circulation is normal. It is impossible to warn too forcefully against the use of alcohol as protection against the cold. It dilates the pores and simply stimulates a feeling of warmth. It abets exhaustion and death by freezing and, therefore, must never be taken prior to physical exertion. If alcohol must be used, it is best administered in hot beverages such as tea.

> It may be issued only if a subsequent protracted stay in heated accommodation is expected. Those who must again go out-of-doors (sentries) must not receive alcohol.[54(p27)]

The authors of this manual must have been aware of the inefficiency and inadequacy of the logistical system that led to so many casualties. But the bitter pill had to be sugared:

> If supplies issued to the unit are not sufficient, they must be augmented by improvisations and substitutes of all kind. The ingenuity of the individual soldier and of the leader keeps the unit efficient and reduces casualties. … In case of a shortage of felt boots, sentries and drivers may wear shoes of straw over their regular footwear. Use the natives to manufacture straw shoes. … Nevertheless it is necessary that the unit should try to overcome the cold independently by using winter clothing as effectively as possible and by devising additional expedients.
>
> Emergency precautions against the cold. Put felt lining inside the steel helmet—preferably the crown of an old felt hat. If nothing else is available, use a handkerchief or crumpled newspaper. … The feet are especially susceptible to frostbite. Socks should be changed frequently. A proved measure for preventing frostbite of the feet is to use inner soles of straw, cloth or paper. The straw should be cut to the right size and arranged carefully, if newspaper is used it should be wrapped carefully around the foot to avoid wrinkles. An especially effective measure for protecting the feet is to wear paper between two pairs of socks and another layer of paper or foot cloths over the top pair of socks. All wrinkles must be smoothed out.
>
> Special protective measures for the genitals should be taken if the weather is very cold or the wind very strong. The soldier should wear short trunks, if they are available, in addition to his underwear or should place paper between his drawers and his trousers.[54(p131)]

Some of the advice bore little relation to the realities of warfare in the Russian winter:

> Always have warm water ready for drinks. ... If it is not possible to feed the troops from a field kitchen, they should be given instant coffees or tea. Every man should know how to cook.[54(p128)]

It was noted that red wine does not keep well in the cold and that supplies of flour could be supplemented:

> Flour rations can be stretched by adding sawdust flour, made preferably from the pine tree, but birch may also be useful for this purpose.[54(p140)]

US Army: 10th Mountain Division

Mountain warfare demands special skills and training. Deep snow and icy slopes and cliffs pose unique problems in the evacuation of casualties. Freezing temperatures and strong winds add to the difficulties. Standard US infantry battalions were not prepared to fight in this environment. While the Russian campaign was being fought, the US Army was training its first mountain warfare troops. During World War I there had been hard fighting in the mountains of northern Italy, in the Carpathians, and the mountains of Asia Minor. For more than a century the British had been fighting the mountain people of Afghanistan and the Pathans, who controlled the Khyber Pass. The Germans entered World War II with four specially trained mountain divisions, and added four more as the war progressed.[55] The US Army, however, had no mountain troops until 1940, when a group of US civilians—Robert Livermore, Roger Langley, C. "Minnie" Dole (founder of the National Ski Patrol), and Alexander Bright—urged the Department of Defense to start a mountain unit capable of fighting in extreme conditions of cold and altitude, trained in all the skills of survival and battle necessary for that environment.[56]

On 15 November 1941, the 87th Mountain Infantry Battalion (Reinforced) was activated at Fort Lewis, Washington. The National Ski Patrol was one of the official recruiting agencies, and each candidate for the regiment required three letters of recommendation even to be considered. Major Robert Cook described the first days at Fort Lewis when he was assigned there to be the supply officer:

> About noon a solder walked in with a pair of skis on his shoulder. He said he had been captain of the Dartmouth ski team. I gave him some keys and requested that he open one of the barracks and turn on the heat. It was getting cold in November. The next soldier was carrying an ice axe. He was from the Teton Mt area. The third day a 1st Lt from the Reserves reported. I asked him if he knew anything about army paperwork. Yes, he replied. I told him to take a seat as he was now the Adjutant of this outfit. His name was Townsend.[57]

By 8 December 1941, one day after the Japanese attack on the United States at Pearl Harbor, Hawaii, 8,000 recruits had been accepted out of 15,000 applicants.

The 87th Regiment was later joined by the 85th and 86th Regiments to form the 10th Mountain Division, which trained in Colorado and saw action in the Aleutians and Italy. The selection, training, and equip-

Fig. 10-11. Troops of the US 10th Mountain Division train in the Colorado mountains in winter 1944 at Camp Hale. They are wearing specially designed mukluks on their feet and large mittens on their hands. Their anoraks are designed to keep out wind and snow but permit ventilation. Despite good clothing many men were frostbitten on training exercises, usually owing to their inexperience in dealing with winter conditions. Reprinted with permission from Denver Public Library. Call Number TMD-905.

ping of this new division was a huge endeavor that made use of a combination of civilians, expert in skiing and mountaineering, and career military personnel, capable of molding an unusual group of men into a fighting unit. A camp, which eventually housed 20,000 men and thousands of mules, was built at Camp Hale, in the middle of the Colorado mountains on the site of an old mining railroad stop (Figure 10-11).

Special equipment had to be tested and manufactured. Well-known mountaineers were recruited to conduct expeditions in the Saint Elias Range of the Yukon, Mount McKinley, and Mount Rainier to test new sleeping bags and tents, socks and boots, skis and ski bindings, and compact food and stoves.[58] The tests revealed that the first single-layer sleeping bags supplied by the US Army Quartermaster Corps provided inadequate protection against the cold, so a double-layer bag was designed. In addition, special boots—suitable for both climbing and skiing—became standard issue, and the felt-lined "shoepac" boot, with a rubber foot and leather, calf-high top, which is still popular today, proved to be useful but was not always available.

The winter conditions under which the 10th Mountain Division trained were severe and the men sustained more frostbite during the training exercises than during subsequent campaigns. In the early days, maneuvers were started before the men were fully trained:

> From the onset the maneuvers were a fiasco. It was midwinter in Colorado. Icy blizzards were sweeping the mountains. Because of their lack of training men became casualties from the elements with terrifying rapidity. The tactical situation was forgotten, lost in the simple struggle for survival, bewildered troops staggered down the mountains with frost-bitten feet hands and faces. Some of them were raw recruits with only a few days of military training of any kind.[59]

A soldier recorded in a letter home:

> Some of the fellows froze their toes or feet while in Colorado. Our Lt H. froze his hands and foot, and they wanted to amputate them, but he took a discharge from the service instead. Lt H. was one of the smartest officers I [have] ever known, so I hated to see him go.[60]

In 1944 a notorious exercise, named Series D, was held to test the ability of the division to function in extreme conditions. The maneuvers lasted 3 weeks. The temperature fell to –36°C and there were numerous cases of frostbite. The men spent most of the period camping but, despite problems, the exercise proved that the division was ready to fight in the mountains under all conditions (Figure 10-12). They were able to carry packs that contained 58 items and weighed 80 to 100 lb, and still travel on skis. They had become skilled at cliff and rock climbing. Their artillery was carried by mules that could operate as effectively in 4 ft of snow as in the heat of summer. "I really like them critters,"[61] said the officer in charge of the mule trains. With characteristic military logic, the division's final training was on the hot, dry flatlands of Texas.

During the period of training, great emphasis was placed on the principles for keeping warm and preventing freezing to death:

- avoid overheating,
- reduce sweating,
- minimize evaporation and condensation, and
- layer clothing.

Recognition was also given to psychological factors. Conditioning to exposure to cold and freezing temperatures, to thirst, hunger, and exhaustion, and above all, to the demoralizing effects of cold was the basis of all training. At that time the pathogenesis of frostbite was ascribed to vasoconstriction and stagnation of the circulation. The etiologic importance of dampness was recognized and, with one exception, the standard warning about treatment was not to rewarm rapidly.

One winter warfare manual (1944) went against traditional advice and stated:

> In treating freezing the frozen part should be thawed as quickly as possible without injury to the

Fig. 10-12. Camp Hale, high in the Colorado Rockies, housed more than 20,000 men training in the 10th Mountain Division. A memorial with a picture of the camp as it once was now stands along the nearby highway, but there are few remains of the camp except the concrete bases for huts long-since removed. Not far away, in the ski resort of Vail, Colorado, one of the most popular runs, Riva Ridge, is named after the Division's most famous battle, in Italy. Reprinted with permission from Denver Public Library, Denver, Colorado. Call Number TMD-784.

> tissue. This can best be accomplished by putting the frozen part of the body in luke warm water.[62]

No attribution was given for this advice, which was contrary to all current opinion, but it predated by 6 years the advice on rapid rewarming given by Furhman,[63] although it came several years after the work of Ariev.[46]

There were many similarities between the advice given to German troops and that given to the 10th Mountain Division. One essential factor in the training of both armies was the emphasis on personal responsibility for keeping warm and preventing frostbite. One US manual finished with this injunction:

> Let there be no mistake about who must do the learning. It is not the squad leader, not the aid man, not the commanding officer, but you [the] soldier.[62(p114)]

In May 1943 an American offensive was launched to retake the island of Attu in the Aleutian Islands from the Japanese. The amphibious assault met stiff resistance and the battle was viciously contested. Although the operation was conducted during the spring, daily temperatures were low and fell below freezing at night. There was almost constant rain or snow, and cold injuries were as frequent as wounds. The operation was, perhaps unrealistically, planned to last 3 days but lasted for 20, and ended with the mass suicide of the last 500 Japanese defenders. Garfield, a historian, wrote later of the operation:

> The cold was intense. Men limped on frozen feet and vomited silently. In training, W. had lectured them on health measures; but, W. recalls, "The ones who suffered were the ones who did not keep moving. I tried to keep everyone on the move, but I didn't catch some of them. They stayed in their holes with wet feet. They didn't rub their feet or change socks when they needed to."[64(p163)]

In the battle for Attu, 1,148 soldiers were wounded and there were 1,200 cold injuries, a 1:1 ratio that could not have been sustained for a longer campaign.[64] The troops involved were inexperienced and some were not equipped for the cold, wet environment in which they had to fight. It is unlikely that the commanders had taken into account the possibility of so many cold injuries.

In August 1943, the Aleutian island of Kiska, which had also been occupied by the Japanese, was retaken without resistance because the island had been evacuated 2 weeks earlier. The assaulting force, which included the 87th Mountain Infantry Regiment from Camp Hale, was unaware that they were attacking an empty island. The troops, none of whom had been in action before, climbed the steep mountains in swirling mist and oncoming darkness. Cold, wet, nervous soldiers imagined that they saw Japanese troops advancing to attack them.[65] They could not distinguish between the vague figures of their own men and possible enemy. Firing was undisciplined and haphazard. Casualties included 23 deaths from friendly fire, 45 wounded or severely sick, and 130 cases of trench foot.[64]

In 1945 the 10th Mountain Division fought with distinction in Italy, but only in the battles for Mt. Belvedere and Riva Ridge were their mountaineering skills required.

COLD INJURY RESEARCH DURING WORLD WAR II

The magnitude of the morbidity and mortality rates among troops, aircrews, and submarine crews due to cold was a compelling stimulus to the major powers to embark on research programs to solve the problems of the etiology and treatment of frostbite, trench foot, and hypothermia.

German and Japanese Research

The Germans and the Japanese were deeply concerned about cold injuries. The Germans not only had catastrophic casualties in Russia, but their U-boat crews also had the highest mortality and casualty rate of any branch of any service in World War II.[48] Of 40,000 men in the U-boat service, 28,000 (70%) lost their lives. Many of those deaths were due to exposure or a combination of hypothermia and drowning. In attempting to find methods for rewarming men and preventing frostbite, both nations carried out ethically abhorrent cold research.

German experiments in the concentration camp at Dachau were related more to the treatment of hypothermia than frostbite; their experiments with frostbite contributed nothing to our knowledge. The experiments on immersion hypothermia, designed to find a way to rewarm airmen and U-boat crews, confirmed that soaking in warm water was the best and safest way to rewarm victims of immersion cooling.

Soon after the war ended these experiments were investigated by Major L. Alexander, MD, Medical Corps, US Army.[66] He had access to Himmler's per-

sonal copy of the report on experiments, which was found, when hostilities ceased, in a cave full of archives. The prime investigator was named Dr Rascher, who was married to Himmler's former secretary. Through this relationship he obtained permission to use concentration camp prisoners as experimental subjects. Although large volumes of data were obtained, the experiments were ill conceived, and there has been considerable discussion about whether results obtained under such terrible conditions should be used, or even believed.[67]

The Japanese also used thousands of prisoners, including at least 37 Americans, in experiments on biological warfare. These experiments were carried out at a secret establishment in Manchuria called Unit 731.[68] Although the main purpose of the work was to develop methods of spreading plague and anthrax, Miyaoshi Watanabe, a midlevel scientist, was assigned the task of investigating frostbite.[69] He was interested in two aspects of cold injury: first, the best treatment of frostbite, and second, the development of a test that would distinguish between men who were resistant to cold and men who were susceptible to cold. The hope was that military units could be assembled in which all the soldiers would be resistant to cold.

Men were lined up in temperatures of –20°C to –30°C with their hands extended in front of them. Observers went up and down the lines measuring the time taken for fingers to become dead white. The times ranged from 1.5 minutes to 1.5 hours. Various methods of rewarming were then tested. The Japanese, as had the Russians, found that immediate thawing in warm water was best. Legitimate experiments by Yoshimura, which had been done during the hostilities but published after the war, confirmed the same findings.[70]

At the end of the war Unit 731 was overrun by the Russians, who did not realize the importance of the place they had captured. Most of the records had been destroyed or removed, and the workers were naturally reluctant to say what they had been doing. Watanabe was interviewed by US military intelligence, but the interrogator had no medical background and probably did not realize the significance of what he was hearing. Watanabe reported that he had used soldiers (not prisoners) as experimental subjects. This is unlikely because of his position as a scientist at Unit 731, where prisoners were routinely used for experiments. Once again, thousands of humans were subjected to unethical experiments to obtain information that was already known to the Russians and was being rediscovered by the Americans. (German and Japanese experimentation on prisoners is discussed in detail in *Military Medical Ethics*, a forthcoming volume in the Textbook of Military Medicine series.)

US Army: Management of Cold Injuries

The US Army, Army Air Corps, and Navy had 90,000 cold injuries during World War II. The land casualties occurred mostly in the Aleutians in 1943, in Italy in the winter of 1943/44, and in the European theater in the winter of 1944/45.[21] Thousands of cases of immersion foot occurred in the US Navy and merchant marine, in sailors who had tossed for days in lifeboats and rubber rafts in the North Atlantic. In the Army Air Corps, gunners in blister turrets on the flanks of Flying Fortresses unjammed their machine guns with bare hands, and only a few seconds of exposure to the cold and metal resulted in frostbite. "High-altitude" frostbite became a recognized entity.[71] The first recorded case of frostbite in a flyer occurred in World War I in 1915 and was reported in the *Journal of the Royal Naval Medical Service* in a pilot at 15,000 ft, where the temperature was calculated to be –36°C.[72]

Cold injury, particularly trench foot, was early recognized by the US military to be a major and, in many instances, a preventable cause of troop losses. The drain on German resources during the Russian campaign may have influenced the final outcome of that campaign. While the extent of American cold casualties never reached those proportions, thousands of servicemen were incapacitated. According to Whayne (discussed below),[21] 55,000 cases of cold injury were reported, with an average loss of time per case of 50 days: 2,757,300 man-days.

The general policy in the US military services during World War II was to warm frozen parts slowly. The *Military Medical Manual* (1942)[73] advised:

> No temperature higher than the normal temperature of the body should be used in the treatment of frostbite. … The person suffering from freezing should be removed to a moderately warm shelter and permitted to reestablish gradually the normal circulation without undue disturbance.[73(p560)]

A 1943 document entitled *Burns, Shock, Wound Healing and Vascular Injuries*,[74] prepared by the Committee on Surgery of the Division of Medical Sciences of the National Research Council, advised:

> The frostbitten individual should be kept in cool, not hot, surroundings. … The frostbitten part must (be) warmed slowly—it cannot respond to heat as yet by vasodilation—by gentle kneading with the

> normally warm hand or by contact with the normal body. Never apply heat.[74(p248)]

In 1945 the *US Maritime Service Hospital Corps School Training Manual*[75] read:

> Treatment of these conditions (frostbite) consists of elevation of the affected part to improve the return of blood flow and the gradual elevation of the temperature by allowing it to thaw in a cool room at room temperature. … Friction or heat should never be applied to these injuries.[75(p308)]

US Army: Cold Injuries in Europe, 1944–1945

A detailed study of trench foot casualties among American servicemen in World War II was written in 1950 by Thomas F. Whayne, Colonel, Medical Corps, US Army, and submitted as a thesis to the Harvard School of Public Health for the degree of Doctor of Public Health.[21] Colonel Whayne analyzed all the cold injuries in the European theater in US and British troops during the last months of 1944 through March 1945. Statistics on the number of casualties were correlated with time of year, temperature, weather, battle activity, clothing, supplies, and other factors that influence the incidence of injury. Whayne analyzed data obtained from the records of 21 divisions that served in Italy in the European theater. When circumstantial factors were correlated with the incidence of cold injury, combat action and shelter were the two with the greatest statistical significance. Terrain and rotation out of battle were marginally significant. If the weather was bad enough to make trench foot likely, the incidence depended more on the battle action than the terrain or shelter available.

Whayne collected statistics down to regiment and platoon levels, and from them he drew important conclusions:

- Training. Better trained and experienced units had fewer cold injuries than units with less training. One unit that had been stationed in Iceland before transfer to the European theater had received extensive training and practical experience with cold. They had few cases of cold injury except during a period of heavy fighting. On the other hand, some inexperienced units had many cases of trench foot even before reaching the active zone. One battle-tried division with excellent leadership had only 164 cold injuries during the entire winter of 1944/45. Another unit, a regiment with inexperienced leaders, had 400 cases in their first week of fighting; these men were fully equipped with winter clothing and overshoes. The connection between discipline and training is obvious.[21] Experience and an understanding of the potential problems, with good personal discipline, reduced the incidence of injuries.
- Command decisions. There are military situations in which prevention of cold injuries has to play second fiddle to the exigencies of battle. There are other situations, however, in which overly optimistic or rash decisions have resulted in thousands of casualties and influenced the course of battle. Hitler's decision to invade Russia in the face of opposition from the general staff stands as a warning to all high command officers.
- Personal factors. Fatigue is related to nutrition and increases the possibility of cold injuries. Most of the US troops in the European theater in World War II were well fed, even though they sometimes spent many days on "K" rations. In contrast, many German units were very badly fed.[76]
- Previous cold exposure. Individual susceptibility to cold has been of interest to the military of many nations. In Japan, Watanabe[69] believed that he could distinguish between cold-susceptible and cold-resistant men. A first cold injury can lead to an increased chance of subsequent injury; and the more severe the first injury, the greater the chance of a second injury. In Italy in 1943 and 1944, 50% of cold-injured men returned to duty. But in 1944 and 1945, only 2.1% of injured men were returned to full duty because many men had recurrent injuries.[21] Men who had suffered once from trench foot were not able later to undertake long marches. Soldiers who had been frostbitten or had trench foot in Italy had an increased incidence of disability in the invasion of the South of France when the weather became cold. Of all men returned to duty after suffering trench foot, 15% had recurrent problems.[21]
- Race. There were no data to substantiate a view that racial differences in susceptibility exist. There were instances in which troops from Brazil and Hawaii had a high incidence of cold injury, but other factors such as training and experience may have been more important than racial back-

ground. Later data from the Korean War[77] suggested that black soldiers sustained more frostbite than white soldiers.

- Weather, temperature, and combat. While most cold injuries occur in cold weather, the more important factor is the influence of the weather and environment on heat loss. A cool, wet environment, maintained for several days, may be more damaging than a short, dry snap of very cold weather. Trench foot has an incubation period of 3 days. Frostbite develops in a few minutes to a few hours, and the colder the temperature, the shorter the period required to inflict damage.[21] (A detailed correlation of temperature and battle conditions enabled Whayne to pinpoint the days when trench foot or frostbite injuries were frequent, and to show that this often happened when weather conditions joined with intense battle conditions to increase the chances of injury.—B.C.P.)
- Clothing. The US Army researched the design of clothes for many environments.[58] The delivery of appropriate winter clothing did not always meet the needs of the troops, however, and the result was an increase in injuries in those units that did not receive winter clothing. In February 1945 a representative of the War Department was sent to the European theater to investigate the clothing situation. He reported that winter clothing had been supplied in insufficient quantities and was often too late in arriving.[21]

During the winter of 1944/45, units supplied with winter clothing in November had an incidence of only 4.3 per 1,000 men per year of trench foot in the following months. Units supplied later, in December, had an incidence of 10.5 per 1,000 men per year, and units still not equipped by January had an incidence of 11.5 per 1,000 men per year.[21]

The incidence of cold injury was much lower in British and Canadian units than in American units. The British 21st Army Group had fewer cold injuries during the European campaign than comparable American units fighting in the same areas.[21] Many factors, some of them small but perhaps significant, were thought to be responsible:

1. The British troops were well supplied with small hexamine stoves that enabled them to heat drinks and food when hot food could not otherwise be provided.
2. They drank, on an average, four cups of hot tea per day. Many American troops went days without hot food.
3. The rotation of British troops in and out of the line was more frequent, so that periods of rest and reorganization, during which the soldiers could change clothes and warm up, were more frequent than in the US Army.

In Italy it was the British policy to have troops spend a total of 400 days in the combat theater but with no more than 10 to 12 days continuously in the front line at a time. The American policy was to have troops spend 40 to 80 days at the front, but with only 200 days in the theater.

The woolen "battle-dress" of the British and Canadians was "indisputably superior,"[21] and their woolen-lined leather jerkins were a warm, windproof outer layer that could be worn in battle. Many British troops were supplied with rubber "Wellington" boots when serving in wet environments. The British also wore thick socks and loose boots that could accommodate two pairs of socks. Most American soldiers, perhaps based on their civilian tastes, tended to wear boots that fit snugly and would only take a single pair of socks.

In his final chapter, Whayne evaluated cold injury as a military problem and concluded that the cost of cold injuries cannot be weighed in dollars and cents, but by the number of men removed from active duty and the length of time they are out of commission (Tables 10-2 and 10-3). During World War II, the estimated time lost was 50 days per case, which calculates to a total of 2,757,300 man-days, or 7,579 man-years, lost. The loss was equivalent to a whole division's being eliminated for 6 months, or an army of 250,000 being out of action for 11 days.[21]

Staggering as these numbers are, they become even more important when we consider that cold injuries affect the frontline infantryman more than any other branch of the service. If the losses, based on Whayne's statistics,[21] are calculated in relation to an infantry division and not to the whole army, the population at risk is much smaller, and the losses proportionately greater. The cold injury losses in the winter of 1944/45 alone were equivalent to three divisions of 15,000 men each. As those lost were nearly all riflemen and a division has about 4,000 riflemen, the loss really amounted to the fighting strength of 12 divisions.

The lessons of the winter campaign in Italy in 1943 were only partially passed on to the commanders in Europe, although they were well understood by the medical corps. It is also possible that the initial victories and rapid advances in the European theater after

TABLE 10-2

FROSTBITE IN THE US ARMY DURING WORLD WAR II

Year	Geographical Area	Total Cases	Days Lost* (Total)	Average Duration† (Days)
1942	Total Army	1,021	11,360	11.1
	CONUS	717	7,880	11.0
	Overseas	304	3,480	11.4
1943	Overseas	665	10,402	16.1
1945	Total Army	11,510	553,420	46.8
	CONUS	385	4,610	12.0
	Overseas	11,125	528,810	48.0

CONUS: continental United States
* Includes days lost for readmissions
† Days excluded from duty
Adapted from Whayne TF. *Cold Injury in World War II: A Study in the Epidemiology of Trauma*. Boston, Mass: Harvard School of Public Health; 1950: 218. Thesis.

D day (6 June 1944) encouraged commanders to believe that the war would be over before the winter.

The number of men out of action at any one time varied from season to season and month to month, depending on weather and battle conditions. Between 30 December 1944 and 2 March 1945 there were never fewer than 20,000 men hospitalized or in rehabilitation, and another 1,000 to 6,000 similarly decommissioned because of frostbite,[21] many from the Ardennes, known as the Battle of the Bulge (Figure 10-13). For example, 28,042 men were affected by trench foot and 7,382 disabled by frostbite during the week of 3–9 February 1945. Calculated another way, and based on 4,000 riflemen per division, this was equivalent to sidelining the fighting strength of more than 8 divisions.

No commander can ignore numbers such as these. The need for adequate training, proper equipment, good discipline, and command awareness of the problem are self-evident. If any of these factors are missing, then weather, terrain, and battle—over which a commander has limited control—combine to ensure a high, and potentially disastrous, rate of casualties.

TABLE 10-3

TRENCH FOOT IN THE US ARMY DURING WORLD WAR II

Year	Geographical Area	Total Cases	Days Lost* (Total)	Average Duration† (Days)
1942	Total Army	32	220	6.9
	CONUS	—	—	—
	Overseas	32	220	6.9
1943	Overseas	489	5,167	11.0
1945	Total Army	24,555	1,380,160	56.7
	CONUS	110	3,985	36.2
	Overseas	24,445	1,376,175	56.8

CONUS: continental United States
* Includes days lost for readmissions
† Days excluded from duty
Adapted from Whayne TF. *Cold Injury in World War II: A Study in the Epidemiology of Trauma*. Boston, Mass: Harvard School of Public Health; 1950: 217. Thesis.

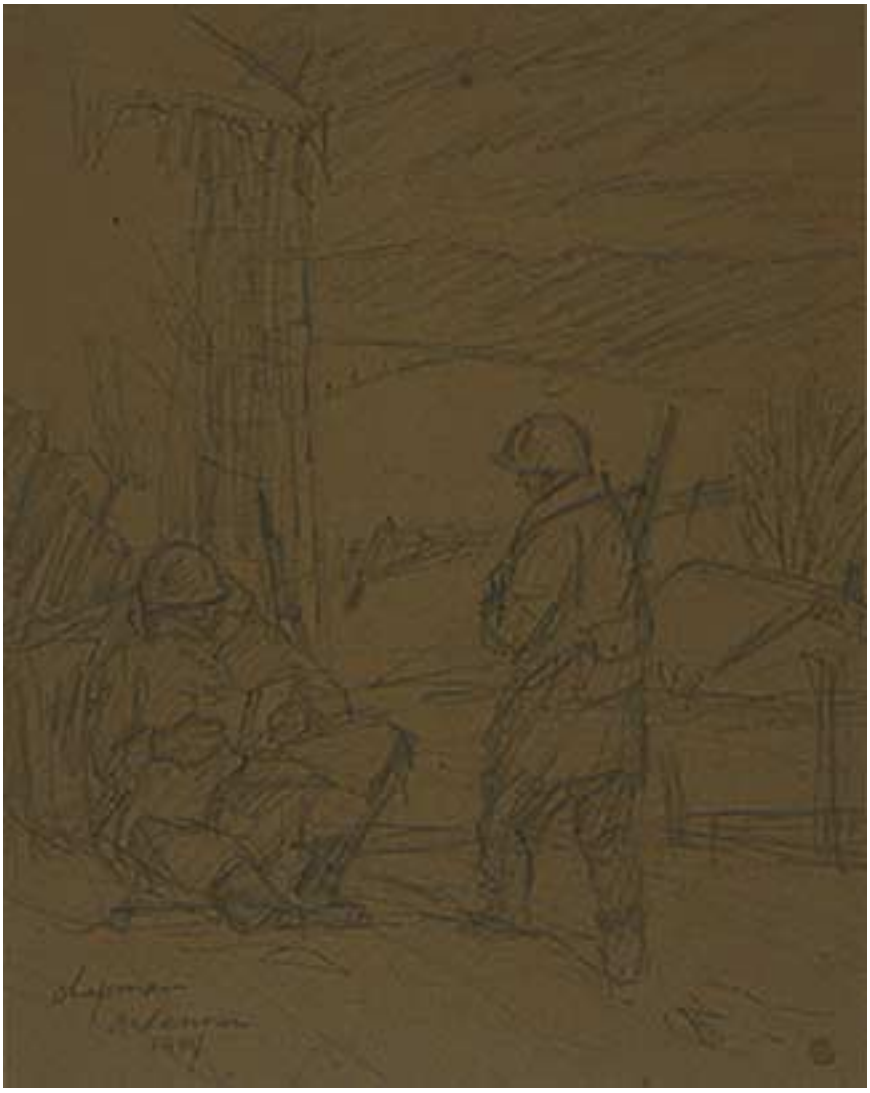

Fig. 10-13. *US Troops in the Ardennes, Winter 1944;* pencil sketch by Walter Chapman, 1944. This rough sketch, done on the spot, shows the cold conditions experienced by the US Army in the Ardennes Forest region in France and Luxembourg during the Battle of the Bulge in 1944 in World War II. One soldier, sunk into his greatcoat, sits reading, while another seems to walk, perhaps to keep warm, while standing guard. The artist, Chapman, worked for the Public Relations and Historical Section of the 84th Infantry Division in 1944 and 1945. Reproduced with permission from Peter Harrington, Curator, Anne S. K. Brown Military Collection, Brown University Library, Providence, Rhode Island.

KOREAN WAR: 1950–1953

The scientific knowledge acquired after World War II would soon be put to the test in the Korean War, where there were between 5,000 and 6,000 cases of frostbite. Many of them occurred during the first winter of the war, when the army was ill-equipped to deal with the extreme cold.[77]

During the night of 25/26 November 1950, 180,000 Chinese Communist troops swarmed across the Yalu River to hammer the right flank of the US Army, sending a flood of men through the gap between the 8th Army and X Corps. On 27 November, X Corps was hit by the advancing Chinese, who made a pincer thrust around the Chosin Reservoir. The 1st Marine Division was surrounded and isolated, and, in what was called "attacking in a different direction," fought their way out of the trap to join the 3rd Division. The Marines had thousands of frostbite injuries.[78]

In February 1951, Captain Norman Allen of the 5th Cavalry wrote:

> The weather is terrible; cold wind and driving rain. I was soaked to the skin for two days and nights and just froze. Despite the weather the lads fought hard.[79(p83)]

And Private First Class James Cardinal, in the same unit, wrote home:

> It's a cold gray day and the wind chills me to the bone … and the cold hurts them [the Chinese] much more than us.[79(p83)]

In a classified report written in 1951 and later declassified, S. L. A. Marshall[78] critiqued the actions of the Chinese Communist forces and also commented on the effects of cold. He held that the 1st Marine Division was as well prepared for cold-weather fighting as any US division could be with existing weapons and equipment. Strong discipline and the availability of warming tents maintained the fighting efficiency of the men. The wounded were kept in warming tents; men suffering from extreme shock or exhaustion from the cold were similarly kept in warming tents for 24 hours before returning to their units. Of the 2,700 nonbattle casualties, 2,000 (74%) were cases of frostbite, of which 95% affected the feet. A careful study indicated that only 20% of the frostbite injuries were due to carelessness and 80% were due to the conditions of battle.

Many men became sick from eating half-frozen C-rations, and the rations did not supply the nutritional needs of troops in combat under conditions of extreme cold, conditions that may have contributed to some injuries.[78]

Medical officers noted a shocklike state in hundreds of men due to the cold and unrelated to other battle stresses.[78] This condition was similar to that described 140 years earlier by Larrey.[15] Respirations were suppressed and stumbling men stared, unresponsive, into space; some sobbed. Warmth and a shot of brandy restored them to normality. After a few days of fighting in these extreme conditions this state of shock disappeared as though the troops had, in some way, become acclimatized physically or psychologically to the conditions.

The shoepac was condemned because it was impermeable to moisture, and excessive sweating during marching froze when the troops came to rest. Ice formed within the shoes and battle conditions made changing socks—the only effective treatment—impossible. Weapons were affected by the cold, and the Marines cleaned their weapons in gasoline rather than with oil, which congealed and rendered weapons useless.[78]

The US Army Medical Corps was prepared to study what had happened and, in 1952, Orr and Fainer outlined the injuries and their two-phase treatment[77]:

1. Emergency. Rapid rewarming was known as an effective treatment but was not feasible under the conditions of battle. Only 2.1% of the casualties were seen before blisters developed, and the majority of limbs had thawed spontaneously before treatment could be started.
2. Hospital. Treatment included bed rest, no smoking, room temperature at 70°F to 78°F, bullae left intact, and penicillin.

Many adjunctive methods were used, but in their report, Orr and Fainer stated that no specific therapeutic agents or procedures conclusively reduced the tissue damage, shortened the process of healing, or prevented sequelae. Parts that became cold and remained cold were lost, and parts that were vesiculated were usually not lost. Nonvesiculated areas distal to the vesicles and bullae were frequently lost.[77]

A follow-up paper[80] demonstrated a high incidence of late symptoms that included hyperhidrosis, deformities, and sensitivity to cold, and radiological evidence of damage to the bony surfaces of small joints. The survivors of the battle at the Chosin Reservoir still meet and many have residual symptoms and damage from their injuries sustained during the Korean War (see Chapter 14, Clinical Aspects of Freezing Cold Injury).

FALKLAND WAR: 1982

This description of the Falkland Islands, from a guide to the birds of the islands, can hardly have been in the minds of the British Royal Marines and troopers of the Parachute Regiment landing at San Carlos on the west coast of East Falkland on May 21st, 1982:

> The land appears bleak due to the absence of native trees, but the white sand-beaches, brilliant green grass around ponds or the coastal clumps of tussock-grass, contrast pleasantly with the wind-

> swept uplands. … The silence, broken only by the cries of animals and birds and the thunder of the surf, the solitude, and the strong, cool winds, combine to give a sense of exhilaration and freedom.[81(p14)]

Although the fighting stopped less than a month later, it left behind a huge legacy of cold injury in the armies of both Great Britain and Argentina.

The battlefields were boggy moors where trenches and foxholes were dug—when they could be dug—in oozing peat. In the assault on Mount Longdon, British Royal Marines and Paratroopers marched 50 mi in 3 days across rough, wet terrain. Their feet were never dry and there was no opportunity to rest, dry their feet, or put on dry socks. The high incidence of injuries affected the fighting ability of the entire force. Many of those injured still suffer from residual symptoms. The Army of Argentina did not keep statistics, but it can be presumed that they suffered as many, or more, cold casualties, because many of their units were stranded without supplies and without adequate cold-weather clothing. For further information, interested readers should also see Chapter 15, Nonfreezing Cold Injury, especially Exhibits 15-1 and 15-2.

TRENDS IN MANAGEMENT

Until the end of World War II, the management of cold injuries had remained remarkably unchanged for more than 100 years. But during the war, research in many countries had demonstrated the usefulness and importance of rapid rewarming of frozen limbs. Within the space of a few years, rapid warming became the treatment of choice. Later, basic laboratory research, growing out of an increasing understanding of inflammation, wound healing, and reperfusion injuries, transformed our ideas about the pathology of frostbite.

Rapid Rewarming in the Field

Until Fuhrman and Crismon's work in the late 1940s,[63] rapid warming was generally thought by authorities in North America and Western Europe to be harmful. There seemed to be more pain, swelling, and subsequent tissue loss if the frozen body part was warmed quickly.

The 1950s and 1960s were a golden era in frostbite research. The US defense organizations, motivated by the possibility of war against the USSR, invested heavily in research and produced numerous reports on the pathology, physiology, and treatment of frostbite. As early as 1952, rapid rewarming had become the official method for treating frostbite. The North Atlantic Treaty Organization handbook, *Emergency War Surgery*,[82] published that year, instructed:

> If the injured parts are still frozen they should be rapidly rewarmed by immersion in water at 90–104°F, by placing warm hands on the part or merely by exposure to warm air. Walking, massage, exposure to an open fire, cold water soaks, or rubbing with snow are contraindicated.[82(p43)]

In the 1940s and early 1950s there was little clinical evidence to back up the laboratory work, and there was criticism that animal experiments did not imitate the clinical situation with sufficient accuracy. Most experiments had been done with very rapid, deep cooling of small areas in small animals—rabbit ears or feet, rat tails or feet—with immediate warming, a situation quite different from clinical frostbite. In the early 1960s, William J. Mills, Jr., an orthopedic surgeon in Anchorage, Alaska, who had been a student at Stanford University, in Palo Alto, California, under Professor Fuhrman and later served in the US Navy during World War II, had a unique opportunity to see many cases of frostbite. A succession of clinical reports and conference transcripts, backed by an ever-increasing number of treated patients, confirmed that rapid warming of a frozen part resulted in a better outcome than slow or spontaneous warming.[83]

Many factors influence the possibility and severity of damage, and numerous therapeutic methods were tested: anticoagulants,[84] hyperbaric oxygenation,[85] medical or surgical sympathetic blockade,[86,87] vasodilators,[88,89] antispasmodics,[90] agents to affect viscosity,[91] steroids[92] and other antiinflammatory agents,[93] and compression[88,93] to reduce edema. None were shown to be consistently successful.

The best technique, which is essentially followed to this day, was warming of the frozen limb in water at 42°C to 48°C for about 20 to 30 minutes; followed by careful drying; care in a sterile environment; daily whirlpool bath debridement; and late, conservative surgery.[83] Mills discovered both what was and what was not effective. In a report in 1960 of 51 patients, 21 treated with rapid warming and 30 by other methods, he warned that of all the factors analyzed in the treatment of frostbite that might influence the result, premature surgical intervention was the greatest contributor to a poor result.[83]

There have been few fundamental changes in the management of frostbite since the late 1960s. The work of Heggers and associates[94] improved our understanding of the underlying pathophysiology and altered treatment, but very little evidence has been produced that these changes have resulted in significantly fewer casualties.[95]

Recent developments in the understanding of frostbite as a reperfusion injury may, in the long run, change methods of treatment and even provide protection against injury. With an increase in knowledge of reperfusion injuries, inflammation, and immune responses, improved therapeutic methods will undoubtedly be developed that may improve the field treatment of both frostbite and immersion foot.[96]

The field management of hypothermia still remains difficult, because effective methods for rewarming safely in the field have yet to be developed.

Warm Water Immersion Foot Syndromes

The exact temperature at which true cold water immersion foot develops has never been precisely defined. During World War II in the Pacific theater, a medical officer named Frank Glenn, who later became Chairman of Surgery at Cornell Medical School, New York, New York, examined 120 men in Leyte, Philippines, within 12 hours of their admission to a medical treatment facility, all with a condition that he diagnosed as immersion foot.[97] In the Vietnam War similar injuries were found in men who had been slogging through paddy fields and jungles for protracted periods, their feet constantly wet. Although there were similarities between this condition and cold water immersion foot, it became apparent that the two conditions were not the same. The one seen in Vietnam, called tropical immersion foot (TIF), affected only the feet and ankles and was quickly cured by a few days in a dry environment. There were no serious complications, such as gangrene, that necessitated amputation.[98]

A similar syndrome, warm water immersion foot (WWIF), was also identified. The stratum corneum of the sole of the foot became waterlogged, turning the skin into a pale, soggy, painful layer. Walking became difficult and men had to be evacuated from the field because of it. Cure, however, only required 1 to 3 days in a dry place.[98]

LESSONS FROM THE PAST, IMPLICATIONS FOR THE FUTURE

Early historians related that many soldiers died or were frozen but did not describe how cold injuries were treated. Frozen feet were warmed at a fire. Soldiers with mild frostbite and hypothermia probably survived, but many others died. Modern armies are still being exposed to the risk of cold injury. No statistics are available from the fighting in Bosnia and Yugoslavia during the late 1990s, but the winter conditions, the nature of the battles, and the inadequacy of medical supplies must have resulted in large numbers of cold injuries and limbs lost.

In Northern India and the adjacent area of Pakistan, a high-altitude war has been fought intermittently for several years, extracting a heavy toll of frostbite and high-altitude illness. This war has been fought in the highest, most inhospitable environment faced by any military, with troops regularly stationed as high as 20,000 ft. It is likely that there have been more casualties from the environment than from enemy action.

General Carl Tiedman of the Norwegian Army analyzed the causes of the disaster that overtook Charles XII of Sweden,[99] and the lessons learned from the mistakes of that campaign are as relevant today as they were in 1719:

1. The campaign was started in the autumn, in the belief that it could not extend into the winter. Circumstances changed and disaster struck. Commanders should anticipate that a campaign will last longer than anticipated.
2. Provision of cold-weather clothing, tentage, and shelter was inadequate.
3. The supply lines were long, overextended, and easily attacked.
4. The troops, mostly Finns from flat country, were accustomed to cold weather but not to mountain warfare. Their training and experience were no match for the conditions of battle. Special training is necessary for troops to fight successfully in winter conditions. They must be trained psychologically and physically, know how to prevent cold injuries, and how to maintain their weapons.
5. The campaign had not been going well and the troops, cold and ill-fed, had to find their own food by raiding the local villages. The death of the king caused a catastrophic collapse of troop discipline and was the final blow to morale. Low morale, despair,

and defeat are certain precursors for cold injuries. Victory, discipline, and high morale are the best protection against frozen limbs.

6. While the army was retreating it was constantly attacked from the flanks, causing further disorganization, increased casualties, and loss of supplies. A retreating, chaotic army inevitably sustains heavy casualties.
7. The retreat was over high, bare passes without trees (and, therefore, without fuel for making fires) and shelter. The combination of cold, snow, and wind; hostile terrain; poor leadership; inadequate supplies; and defeat was a prescription for disaster.

Commanders of every era have made the same mistakes. Sometimes those mistakes have been unavoidable, sometimes they could have been prevented; but the lessons of the past cannot be ignored. The commander of today, however, has to consider medical factors that never troubled the army of Charles XII. The modern serviceman expects to be supported by a quick, efficient medical service. In the harsh environments of winter warfare, special arrangements are necessary to maintain the integrity of the medical service. The means to rewarm casualties with frostbite or hypothermia should be close to the front line; the risks of damage and death are increased by delays in treatment. The casualty with a cold injury, possibly combined with a wound, must be transported to a medical treatment facility in a warmed vehicle, whether by land or air. Helicopter evacuation may not always be possible in winter conditions; special overland vehicles should be available.

Success in winter warfare requires special training and preparation, not only in the techniques of fighting in snow and ice but also in protection against the elements. The individual soldier must be psychologically prepared to cope with the unrelenting harshness of winter—cold, wind, blizzards, deep snow, or steel-hard ground that makes it impossible to dig a shelter for protection from either the weather or the enemy. Cold, even above the definitive level for hypothermia, has a peculiarly depressing and inhibiting effect on resolve and activity, an effect that can only be reversed by reaching warmth. If he is to maintain fighting efficiency and survive, a freezing soldier must draw on deeper wells of courage, determination, and discipline than one who is warm.

Officers at the highest levels of command must understand the logistical and medical problems of fighting in the cold, so as to avoid the unrealistically optimistic outlook that caught both Napoleon and Hitler in an icy trap. To ensure that equipment and clothing will be ready when needed, they must be available in quantities that in peacetime seem to be unreasonable. Special over-the-snow vehicles, for instance, may have to be designed and manufactured, yet they will seldom be used in peacetime. Medical facilities require heating and insulated shelter that are unsuitable for use in tropical climates. History has repeatedly shown that a failure to make preparations will, eventually, lead to defeat.

The history of cold in war is a tribute to the determination and endurance of the human body and spirit. Despite hostile environments, poor leadership, lack of food and shelter, the wrong clothes, frozen weapons, and the myriad tribulations of moment-to-moment survival, soldiers of all nations and in all eras have fought in storms and freezing cold. Sometimes they were victorious, sometimes defeated, but always winter was neutral, an impassive onlooker to be used by the prepared and ready to destroy the unprepared.

NOTE: On 3 July 1951, Colonel Tom F. Whayne delivered a lecture, entitled "Cold Injury," as part of the Medical Service Officer Basic Course at the Army Medical Service Graduate School, Army Medical Center (now Walter Reed Army Medical Center), Washington, DC. In his lecture, Colonel Whayne analyzed the available medical information on the effects of cold on military operations in selected wars from the Revolutionary War to the end of World War II, emphasizing those in which US fighting forces were involved. The text of the lecture has been available only as a mimeographed handout distributed to a relatively few students, or bound, with other lectures delivered during the course, in a volume housed in the main library at Walter Reed Army Institute of Research, Washington, DC.[100] The editors of this textbook believe that the Whayne lecture deserves a wider readership; it is reprinted in its entirety as Appendix 2 to Volume 3 of *Medical Aspects of Harsh Environments*.

REFERENCES

1. Hammel EM. *Chosin*: *Heroic Ordeal of the Korean War*. Novato, Calif: Presidio Press; 1990.

2. Clark A. *Barbarossa*: *The Russian–German Conflict, 1941–45*. New York, NY: Quill; 1965.

3. Hagendorn P. In: Toppe A. *Frostbite Problems in the German Army During World War II.* Washington, DC: War Department; US Military Intelligence Division; 1945.

4. Chandler DS. *The Campaigns of Napoleon*. Vol 1. New York, NY: Scribner; 1966.

5. Glantz DM, House JM. *When Titans Clashed: How the Red Army Stopped Hitler.* Lawrence, Kan: University Press of Kansas; 1955: 80, 148.

6. Hatton RM. *Charles XII of Sweden*. New York, NY: Weybright and Talley; 1968.

7. Xenophon. *The Persian Expedition*. Warner R, trans. Edinburgh, Scotland: R and R Clark; 1949: 151.

8. Dupuy RE, Dupuy TN, eds. *Harper Encyclopedia of Military History*. 4th ed. New York, NY: Harper Collins; 1993.

9. Godley E. *Charles XII of Sweden*. London, England: W. Collins & Sons; 1928.

10. Wedin B, Vangaard L, Hirvonen J. Paradoxical undressing in fatal hypothermia. *J Forensic Sci.* 1974;24:543–553.

11. Meier LA. *The Healing of an Army*. Norristown, Pa: Historical Society of Montgomery County; 1991.

12. Trussell JBB Jr. *Birthplace of an Army*. Harrisburg, Pa: Pennsylvania Historical and Museum Commission; 1990.

13. de Ségur P-P. *Napoleon's Russian Campaign*. Townsend DJ, trans. New York, NY: Time, Inc; 1965.

14. Dodge TA. *Napoleon*. Boston, Mass: Houghton, Mifflin and Co; 1904.

15. Larrey D-J. *Surgical Memoirs of the Campaigns of Russia, Germany, and France*. Mercer JC, trans. Philadelphia, Pa: Carey and Lea; 1832.

16. Lewis RB. Local cold injury: Frostbite. *The Military Surgeon.* 1952;110:25–40.

17. Chadwick J, Mann WN. *The Medical Works of Hippocrates.* Oxford, England: Blackwell Scientific Publications; 1950: 22.

18. Grattan HW. Trench foot. In: MacPherson FG, ed. *History of the Great War: Surgery of the War*. Vol 1. London, England: His Majesty's Stationery Office; 1922: 169.

19. Francis TJR. Non-freezing cold injury: A historical review. *J Roy Nav Med Serv*. 1984;70:134.

20. Woodham-Smith C. *Florence Nightingale*. New York, NY: McGraw-Hill; 1951.

21. Whayne TF. *Cold Injury in World War II. A Study in the Epidemiology of Trauma*. Boston, Mass: Harvard School of Public Health; 1950. Thesis.

22. Woodham-Smith C. *The Reason Why*. New York, NY: Konecky and Konecky; 1953.

23. MacPherson WK. *The Russo–Japanese War: Medical and Sanitary Reports From Officers Attached to the Japanese Forces in the Field*. London, England: His Majesty's Stationery Office, 1908.

24. Toke RT. The Effects of Cold During the Battle of Hei-Kon-Tai, 25th–29th January, 1905. In: MacPherson WK. *The Russo–Japanese War: Medical and Sanitary Reports From Officers Attached to the Japanese Forces in the Field*. London, England: His Majesty's Stationery Office; 1908.

25. Page CM. Gangrene in war. *Br Med J*. 1914;Aug 29;389.

26. Rose W, Carless W. *Manual of Surgery*. 8th ed. New York, NY: Wm. Wood and Company; 1911: 253.

27. Gilbert M. *The First World War*. New York, NY: Henry Holt & Co; 1994.

28. Mitchell TJ, Smith GM. *Casualties and Medical Statistics.* In: MacPherson FG, ed. *Official Medical History of the War*. Vol 1. London, England: His Majesty's Stationery Office; 1941: 87.

29. Berton P. *Vimy*. London, England: Penguin Books; 1987.

30. Killian H. *Cold and Frost Injuries: Rewarming Damages, Biological, Angiological and Clinical Aspects*. Berlin, Germany: Springer-Verlag; 1981.

31. Moorehead A. *Gallipoli.* New York, NY: Harper & Brothers; 1971.

32. Hopkirk P. *Like Hidden Fire*. New York, NY: Kodansha America; 1994: 199.

33. Johns FA. A note on the after-treatment of so-called "frost bite." *Br J Surg.* 1916;4:336–337.

34. Miller C. Some observations on 376 cases of "frostbite." *Lancet.* 1915;i:801–803.

35. Delépine S. The prevention of frostbites. *Lancet.* 1915;i:271–272.

36. Moynihan B. Frostbite. *Lancet.* 1915;i:401. Letter.

37. Mayo-Robson AW. Frostbite. *Lancet.* 1915;i:117–119.

38. Mason CF. *A Complete Handbook for the Sanitary Troops of the US Army and Navy*. 4th ed. New York, NY: William Wood; 1917: 125.

39. Lake NC. An investigation into the effects of cold upon the body. *Lancet.* 1915;2:557–562.

40. Lorrain-Smith J, Ritchie J, Dawson J. On the pathology of trench frostbite. *Lancet.* 1915:2:595–598.

41. Page CM. Frostbite in the present war. *Lancet.* 1915;i:590–592.

42. Greene R. Cold in the treatment of damage due to cold. *Lancet.* 1942;2:695–696.

43. Scott RF. *The Voyage of the* Discovery. London, England: Smith and Eldor; 1905.

44. Byrd E. *Discovery*. New York, NY: Putnam and Son; 1935.

45. Girgolav SS. Modern findings on frostbite. Defence Research Board, Canada, trans. *Klinicheskaya Medicsina.* 1944;21:3–6.

46. Ariev TJ. *Monograph on Frostbite*. Defence Research Board, Canada, trans. Narkomzdrav, USSR: State Health Committee; 1940. Translated 1955.

47. Brown N. Climate change, history and the future. In: Thompson RD, Perry A, eds. *Applied Climatology: Principles and Practice*. New York, NY: Routledge; 1997: 322.

48. Deighton L. *Blood, Tears and Folly*. Vol 2. New York, NY: Harper Collins; 1994.

49. Keegan J. *The Second World War*. New York, NY: Viking Penguin; 1989.

50. Keegan J. *A History of Warfare*. New York, NY: Vintage Books; 1993.

51. Holmes R. *Firing Line*. London, England: Random House; 1994.

52. Schreiber. Trench nephritis in World War II. In: Toppe A, ed. *Frostbite Problems in the German Army During World War II.* Washington, DC: War Department; US Military Intelligence Division; 1945. Held at US Army Research Institute of Environmental Medicine, Natick, Mass. MS P-062.

53. Burtscher H, Imbrie J, eds. *Memoirs: A Report From the Other Side*. Denver, Colo; 1994: Chap 1: 2–3. Held at Denver Public Library, Denver, Colo; Personal papers section, 10th Mt Division Resource Center Collection.

54. Military Intelligence Division, trans. *German Winter Warfare.* Washington, DC: War Department; 15 Dec 1943. Special Series 18.

55. Military Intelligence Division, trans. *German Winter Warfare*. Washington, DC: War Department; 15 Dec 1943. MID-461: 21.

56. Dole CM. Held at Papers Section, Western History Collection, Denver Public Library, Denver, Colo; 1940. Letter.

57. Cook RL. *Memoirs: A Brief History of the 10th Mt Division.* Held at Personal Papers Section, 10th Mt Division Resource Center, Denver Public Library, Denver, Colo.

58. Bates RH. *The Love of Mountains is Best*. Portsmouth, NH: Peter E. Randall; 1994.

59. Black A, Hampton C. *Memoir.* Held at 10th Mt. Recon/Mtg Western History Collection, Denver Public Library, Denver, Colo; 1996.

60. Anonymous. Handwritten letter from a soldier to his wife; 1943. Held at Personal Papers Section, 10th Mt Division Resource Center, Denver Public Library, Denver, Colo.

61. Dusenberry H. *Ski the High Trail: A Personal Account of the D Series Training Exercises of the 10th Mt Division at Camp Hale, Colorado.* Held at Personal Papers Section, 10th Mt Division Resource Center, Denver Public Library, Denver, Colo.

62. US Department of the Army. *Operations in Snow and Extreme Cold.* Washington, DC: DA; 1944. US Training Manual FM70-15.

63. Fuhrman FA, Crismon JM. Studies on gangrene following cold injury, VII: Treatment of cold injury by means of immediate rapid rewarming. *J Clin Invest.* 1947;26:476–485.

64. Garfield B. *Thousand-Mile War: World War II in Alaska and the Aleutians*. New York, NY: Doubleday; 1969.

65. Delaney AC. *Memoirs: An Aleutian Interval: World War II Reaches Kiska; 1997.* Held at Personal Papers Section, 10th Mt Division Resource Center, Denver Public Library, Denver, Colo.

66. Alexander L. *The Treatment of Shock From Prolonged Exposure to Cold, Specially in Water.* Washington, DC: Combined Intelligence Objective Subcommittee; 1945. Item 24, File 26-37.

67. Pozos RS. Scientific enquiry and ethics: The Dachau data. In: Caplan AL, ed. *When Medicine Went Mad*. Totowa, NJ: Humana Press; 1992: 95–108.

68. Harris SH. *Factories of Death.* London, England: Routledge; 1994.

69. Thompson AT. *Report on Japanese Biological Warfare (BW) Activities; 31 May 1946*. US Army Intelligence report, on file at US Army Research Institute of Environmental Medicine, Natick, Mass.

70. Yoshimura H. Treatment of frostbite by rapid thawing. In: *Essential Problems in Climatic Physiology*. Kyoto, Japan: Nakoda Publishing Co; 1960: 285–299.

71. Davis L, Scarff JE, Rogers N, Dickinson M. High altitude frostbite. *Surg Gynecol Obstet*. 1943;77:561–575.

72. Wells HV. Some aeroplane injuries and diseases, with notes on the Aviation Service. *J Naval Med Serv.* 1916;2(1):65–71.

73. n.a. *Military Medical Manual*. Harrisburg, Pa: Military Service Publishing Company; 1942: 560.

74. Division of Medical Sciences, National Research Council. *Burns, Shock, Wound Healing and Vascular Injuries.* Philadelphia, Pa: WB Saunders; 1943: 248.

75. US Maritime Service Hospital Corps School. *Training Organization*. Washington, DC: War Shipping Administration; 1945: 308–310. Training Manual.

76. Hoepner E. Quoted by: Chant C, ed. *Warfare and the Third Reich.* New York, NY: Smithmark Publishers; 1996.

77. Orr KD, Fainer DC. Cold injuries in Korea during the winter of 1950/51. *Medicine.* 1952;31:177–220.

78. Marshall SLA. Quoted by: Hopkins WB. *One Bugle and No Drums*. Chapel Hill, NC: Algonquin Books; 1986: 260.

79. Knox D. *The Korean War: Uncertain Victory*. New York, NY: Harcourt Brace Jovanovich; 1988.

80. Blair JR, Schatzki R, Orr ND. Sequelae to cold injury in 100 patients: Followup study four years after occurrence of cold injury. *JAMA.* 1957;163:1203.

81. Woods RW. *The Birds of the Falkland Islands*. New York, NY: Nelson and Lindblad Travel; 1975: 14.

82. n.a. *Emergency War Surgery.* Washington, DC: US Department of Defense; 1952. US Armed Forces Issue of NATO Handbook.

83. Mills WF Jr, Whaley R. Frostbite: Experience with rapid rewarming and ultrasonic therapy. *Alaska Med*. 1961:3:28–36.

84. Theis FV, O'Connor WB, Wahl FJ. Anticoagulants in acute frostbite. *JAMA.* 1951;146:992–995.

85. Okuboye JA, Ferguson CC. The use of hyperbaric oxygen in the treatment of experimental frostbite. *Can J Surg*. 1968;11:78–84.

86. Shumacker HB, Kilman JW. Sympathectomy in treatment of frostbite. *Arch Surg*. 1964;89:575–584.

87. Bouwman DL. Early sympathetic blockade for frostbite: Is it of value? *J Trauma.* 1980;20:744.

88. Shumacker HB, Radigan LR, Ziperman HH, Hughes RR. Studies in experimental frostbite, VI: Effect of rutin and benadryl with some notes on plaster casts and the role of edema. *Angiology.* 1951;2:100–107.

89. Entin MA. The effect of rapid thawing, vasodilatation and ACTH in the treatment of acute frostbite. *Surg Forum.* 1953;4:658–665.

90. Gulati SM, Talwar JR, Kapur BML. Large doses of nicotinic acid therapy in frostbite in monkeys. *Ind J Med Res*. 1969;57:1579–1586.

91. Mundth ED, Long DM, Brown RB. The treatment of experimental frostbite with low molecular weight dextran. *J Trauma.* 1964;4:246–257.

92. Glenn WL, Maraist FG, Braatens OM. Treatment of frostbite with particular reference to the use of ACTH. *N Engl J Med.* 1952;247:191–200.

93. Crismon JM, Fuhrman F. Studies on gangrene following cold injury, VIII: The use of casts and pressure dressing in the treatment of severe frostbite. *J Clin Invest.* 1947b;26:486–496.

94. Heggers JP, Phillips LG, McCauley RL, Robson MC. Frostbite: Experimental and clinical evaluations of treatment. *Journal of Wilderness Medicine*. 1990:1:27–32.

95. Richard A, Butson C. Note on frostbite. *Journal of Wilderness Medicine*. 1990;1:33–35.

96. Milseki WJ, Raymond JF, Winn RW, Harlan JM, Rice CL. Inhibition of leukocyte adherence and aggregation for treatment of severe cold injury in rabbits. *J Appl Physiol.* 1993;74:1432–1436.

97. Glenn FC. *Trench Foot*. Letter from the Surgical Consultant, Office of the Surgeon General, Headquarters, Sixth US Army; to the Surgeon, Sixth US Army; 27 Nov 1944.

98. Allen AM, Taplin D. Tropical immersion foot. *Lancet*. 1973;ii:1185–1189.

99. Tiedman C. Personal communication, 1995.

100. Whayne TF. Cold injury. Lecture delivered 3 July 1951. In: US Army Medical Service Graduate School. *Notes: Medical Service Company Officer Course 8-0-1 (b)*. Vol 2. Washington, DC: US Army Medical Service Graduate School; 1951. Walter Reed Army Institute of Research, Washington, DC: Library call number RC971/.U5/v.2.