THE EFFECTS OF FROSTBITE IN CHILDHOOD*

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Frostbite of the extremities of children produces serious changes in the bony structure in later years. Thirteen patients with frostbite of the hands in childhood are presented in this paper, all of whom had the loss of one or more epiphyses when seen four to fifty years after exposure.

Epiphysial changes from frostbite were first reported by Löhrr (1930) in a sixteen-year-old boy who had lost the distal phalangeal epiphyses of the four fingers of the right hand. He described the changes of oedema, vesiculation and loss of finger nails. Nine months later the patient complained of distal interphalangeal joint pain and deformity. Bennett and Blount (1935) reported an eight-year-old girl who had frozen her left hand three years before, which resulted in the loss of the epiphyses of the middle phalanges of the index, middle and ring fingers and all the distal phalangeal epiphyses. Thelander (1950) described the radiographic changes and thought that vascular damage might be the cause. Dreyfuss and Glimcher (1955) presented an excellent study of the clinical course of the right hand of a child of two and a half after frostbite. Plethysmographic studies were not helpful, and the skin temperature of the involved hand was raised 3 or 4 degrees. Epiphiolysis was found after Volkman’s ischaemic contracture by Ruckensteiner (1947), and after severe arm injuries by Bennett and Blount (1935). Thiemann (1909) reported a peculiar entity in which the epiphysis of the phalanges disappeared during puberty, only to reappear a few years later.

PATHOLOGY

Frostbite is freezing of the tissues in dry cold, but before this there may have been exposure to dampness and wind, augmenting the degree of injury. In all our patients the frostbite was so severe that the fingers, and sometimes part of the hand, became solid, white and icy. The damage to soft tissues and bones that will result is difficult to assess at the time of freezing. Vinson and Schatzki (1954) discussed the bone changes seen in the American forces in Korea after frostbite and used the classification of Orr and Fainer (1952). The extent of the freezing was assessed after the tissues had thawed and the four groups were: 1) erythema, oedema and superficial desquamation; 2) vesiculation of partial skin thickness; 3) loss of full skin thickness and loss of nails; 4) involvement of bone.

Soft-tissue changes have been discussed thoroughly in other papers (Edwards and Leeper 1952, Blaustein and Siegler 1954). We are concerned here with the effects of freezing on growing bone and cartilage, and the changes shown in the vascular pattern by arteriography.

The effects of frostbite on the vascular tree have been reported by several authors. Studies by Shumacker, White and Wrenn (1948), and Shumacker and Lempke (1951) confirm that the vascular channels are closed while the extremity is frozen and that capillaries become contracted just before freezing. This constriction contributes to tissue anoxia. Within a few minutes of the return of the flow of blood on thawing—which occurs first along the blood vessels—there is oedema of the subcutaneous tissues, a precapillary cuffing of eosinophils (Blaustein and Siegler 1954) and the capillary endothelium becomes swollen and engorged. The oedema itself is because of increased permeability of the capillary walls from freezing and

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anoxia. The pulse is bounding, the skin is warm and a mild dilatation of the vascular tree is found (Pirozynski and Webster 1953a and b). The oedema continues and extracapillary pressure develops (Crismon and Fuhrman 1947), which increases capillary stasis. Conglutination of the blood cells occurs in the small vessels, which also obstructs the circulation (Greene 1943; Shumacker, White and Wrenn 1948). Thrombi can occur in the veins and venules. After a few hours there is a dissolution of the endothelium of the small arteries with further vascular occlusion, tissue oedema, transudation of fluid and perivascular haemorrhage. Tissue necrosis results because the sudden demands of the increased metabolism cannot be met. Hurley (1957) has shown by angiography that the vascular supply in the surviving tissue is abundant because of the opening of side branches and the development of new capillary outgrowths in both the arterial and venous side of the vascular tree. The budding and revascularisation are prolific especially in the borderland zone between necrotic and viable tissue.

Bone changes are seen in the radiographs of frostbite. These changes are considered secondary to vascular damage, both when the skin is intact and when infection and soft-tissue damage leave the bone exposed. Blair, Schatzki and Orr (1957) have carefully studied 100 soldiers with frostbite of the Korean war. The bone changes they found were: 1) early transient osteoporosis; 2) acromutilation of terminal tufts secondary to loss of skin and exposure to air; 3) late changes close to the joints with small punched-out lesions opening into or immediately below the surface of the joint, and 4) some punched-out areas showing healing, and others showing marginal sclerosis. The symptoms in the feet, of which these soldiers complained, included intolerance to cold, pain, excessive sweating, paraesthesia, abnormal colour and joint complaints.

The freezing of articular cartilage produces changes immediately after thawing (Ariev 1940). The articular surface becomes darker and the nuclei of the cartilage cells lose their staining properties. Cartilage degeneration is revealed by shrivelling, and eventually the cartilage may be completely absorbed. Lohr (1930) said that epiphysial cartilage as well goes through a series of degenerative stages, and the destruction may be such that the cartilaginous tissue is replaced by connective scar tissue.

CASE REPORTS

Thirteen patients have been carefully studied, and the characteristic deformities of the bony structure of the hand from epiphysiolysis after frostbite are exemplified in the case reports.

Case 2—A man, now fifty-eight, had frozen both his hands when eight years old; the left hand had been frozen white as far as the metacarpophalangeal joints and his doctor had wanted to amputate all the fingers. The father refused and treated the child with salve and ointment. At the time of review he was asymptomatic; on examination of the right hand the thumb was normal, but the distal phalanges of the index, ring and little fingers were stubby, as also were the nails (Fig. 1). There was a flexion deformity and radial deviation of the distal interphalangeal joint of the little finger. On flexion the index finger reached to one inch from the thenar eminence, and none of the fingers could touch the distal palmar crease. The left hand had shortened middle and distal phalanges of all fingers, with a mild flexion deformity of the interphalangeal joints of the index and middle fingers. There was radial deviation of the middle and little fingers at the interphalangeal joints, and also at the distal interphalangeal joint of the ring finger. There were radiographic changes in all the digits involved clinically, with shortening of the affected phalans and enlargement of the joints (Fig. 2). Some narrowing of the joint spaces was apparent, with hypertrophic lipping at the margins. Apart from the obvious shortening and the flexion and radial deviation, these changes are indistinguishable from those of degenerative arthritis.

Case 4—A woman, now fifty-one, at the age of three fell with her mother through the ice of a river and froze her right hand, which was white from the middle of the metacarpal area distally. The hand was rubbed till circulation was restored. After some hours the fingers and hand became black. Amputation was advised but refused, and sterile dressings and a cast were used for some weeks. When reviewed the patient had marked weakness of finger extension, with deformity, awkwardness and occasional
Case 2—Frostbite of both hands. Radiograph shows left hand.

Case 4—Frostbite of right hand. The left hand was normal.
symptoms referable to the interphalangeal joints. There was a mild intolerance to cold, but no sensory deficiency. On examination of the right hand the thumb was normal, but the index finger was straight with considerable stubbiness of the middle and distal phalanges, as well as the nail (Fig. 3); the proximal interphalangeal joint would extend but was very weak. The distal interphalangeal joint had a range of movement from 158 to 115 degrees. The middle finger appeared to be normal. The ring finger was straight but was stubby, with an enlarged distal interphalangeal joint. The range of movement at this joint was 150 to 122 degrees. There was a flexion deformity of 30 degrees, both actively and passively, with severe weakness. The little finger had an enlarged distal interphalangeal joint, with a stubby phalanx and both a flexion deformity and radial deviation. The range of movement of the distal interphalangeal joint was 127 to 90 degrees. Radiographs of the right hand revealed short and under-developed terminal phalanges of the index, ring and little fingers and the middle phalanx of the index finger was also shortened (Fig. 4). The associated joints were very much enlarged, with well-marked flaring of the articular ends of the bones. A flexion deformity, radial deviation and subluxation were also present at the distal interphalangeal joint of the little finger.

Case 8—This girl, now twelve, froze both hands at the age of two. The fingers were white and stiff as far as the metacarpo-phalangeal joints. Her mother placed both hands in cool water and rubbed them lightly for fifteen minutes until they were pink; she then noticed a swelling of both hands and a cyanosis beginning at the finger tips. The child was admitted to hospital. Both hands were swollen and cyanotic, and the joints were stiff and extremely painful. Two days after admission there was blistering of the fingers. On the seventh day all surface corium was removed, and on the tenth day improvement was noticed, dressings were applied and she was discharged. Now she has few complaints except for deformity (Fig. 5). Periodically she loses nails, but new ones grow. The index finger of the right hand had radial deviation at the metacarpo-phalangeal and interphalangeal joints. The metacarpo-phalangeal joint had a range of movement from 180 to 125 degrees, lacking complete flexion. The interphalangeal joints lacked complete active extension but had good power in flexion. The middle, ring and little fingers all had radial deviation at the proximal interphalangeal and distal interphalangeal joints, the middle finger having the greatest deformity. There was lack of complete active extension of the ring and middle fingers at the proximal interphalangeal joints and all the distal
Case 9—Frostbite of both hands. Radiograph shows left hand.

Case 10—Frostbite of left hand. The right hand was normal.
interphalangeal joints. The index finger of the left hand had a range of movement at the metacarpo-
phalangeal joint of 180 to 100 degrees. The proximal interphalangeal joint extended fully but the distal
interphalangeal joint lacked complete extension. There was slight radial deviation at the proximal
joint. The middle, ring and little fingers all had loss of complete extension at both interphalangeal
joints, at which there was radial deviation. The metacarpo-phalangeal joint of the little finger had
an ulnar deviation because of partial involvement of the epiphysis of the proximal phalanx. All
fingers of both hands were shortened to produce a spade-like appearance. Obvious radiographic
changes were present, with destruction of the epiphysis for the middle and distal phalanges of both
hands (Fig. 6). There had been incomplete epiphysiolyis on the radial aspect of the proximal
phalanges of both little fingers producing ulnar deviation at the joint. Premature fusion on the radial
side of the epiphysial line of the proximal phalanges of the right index finger was also present.

Case 9—A child of eleven froze both his hands when two years old. They were rubbed with snow and
immersed in cold water. One hour after freezing he was seen in hospital. The fingers at that time
were reported as being oedematosus and red, and a sterile Jellonet dressing was applied. The next
day there was blistering of all digits except thumbs, and the nail sloughed off the left little finger.
Eight days after freezing, radiographs were taken and reported as normal. The child, on review, had
few complaints regarding the hands with the exception of intolerance to cold and the deformity. Skin
temperatures were done and an intact vasomotor apparatus was found with no apparent difference
between the left middle finger—the only normal finger—and the others. In the right hand the distal
phalanx of the thumb was involved with little residual deformity. The little finger had radial deviation
at both interphalangeal joints. All fingers had a flexion deformity at the distal interphalangeal joint,
with a loss of complete active extension, and all were short and stubby with deformed nails (Fig. 7).
The left hand had ulnar deviation at the distal interphalangeal joint of the index finger. The ring and
little fingers were in radial deviation at both interphalangeal joints, especially the distal interphalangeal
joint. The middle finger was normal. The index, ring and little fingers were short, stubby, with
deformed nails, and would not extend completely at the distal interphalangeal joints; the power of
flexion was good. Radiographs showed the involvement of the distal and middle phalanges of all the
fingers of both hands with the exception of the left middle finger which was normal (Fig. 8). The
distal phalanx of the right thumb was also affected. The interphalangeal joints involved were enlarged,
with flexion and radial deviation at the distal interphalangeal joints of the ring and little fingers.

Case 10—A woman of thirty-seven had had her left hand frozen at three years of age. She could not
recall the treatment, but remembered that she lost her nails four to five times during childhood. Her
complaints at present are referred to the distal interphalangeal joints, and slight injuries are painful.
She has some intolerance to cold. On examination the thumb of the left hand was normal; the index
and middle fingers were shortened with a flexion deformity of the distal interphalangeal joint (Fig. 9).
The distal interphalangeal joint of the ring finger had radial deviation and a flexion deformity. The
distal interphalangeal joint of the little finger had a severe flexion deformity with radial deviation.
Radiographs of all the fingers showed short, small phalanges with splaying of the articular margins and
irregularity of the joint surfaces (Fig. 10).

Case 13—An Eskimo girl of thirteen had suffered severe frostbite of the right hand when she was a
baby. On examination she was found to have had all the distal, middle and proximal phalanges of all
fingers and thumb involved, as were the second to fifth metacarpal bones. The hand was short, stubby
and spade-like. Movements of the fingers were clumsy, because of their abnormal shape, but there
was a functional range of movement in all joints. The hand was weak. The radiographs (Fig. 11) had
the most pronounced and extensive changes seen in all the patients studied. They showed epiphysiolyis
and growth disturbance of all the digits of the right hand with involvement of the second to the
fifth metacarpal bones. Epiphysiolyis is only partial in the proximal phalanx of the thumb and middle
phalanx of middle and ring fingers.

Fig. 11

Case 13—Severe frostbite of right hand.
ARTERIOGRAPHIC STUDIES

In four patients brachial arteriographs were obtained using the method described by Lynn, Steiner and Van Wyk (1955).

Case 4—Radiographically and clinically the right index and middle fingers were the most severely involved. In these two fingers the vascular supply appeared more tortuous than normal, particularly in the region of the shortened phalanges (Fig. 12). The superficial palmar arch was incomplete. The first common digital artery arose from the deep arch. The princeps pollicis and the radialis indicis arteries arose as a common stem from the deep arch.

Case 8—No obvious vascular abnormality was apparent in the region of the affected phalanges. The superficial palmar arch was completed by a branch of the princeps pollicis (Fig. 13). The first common digital artery supplied the ulnar side of the index finger, while a separate branch of the deep palmar arch supplied the radial side of the middle finger. The radialis indicis and princeps pollicis arteries arose from the deep palmar arch by a common stem.

Case 9—No clear-cut abnormality was apparent but the number of anastomotic channels present in the involved fingers appeared to be increased when compared to the uninvolved middle finger (Fig. 14). The superficial palmar arch was completed by a branch of the princeps pollicis. The radialis indicis artery arose as a separate branch of the superficial arch.

Case 10—The left involved hand showed tortuosity of the arterial supply in the region of the shortened phalanges (Fig. 15). The number of arteriovenous communications also appeared to be increased when compared to the right side. The superficial palmar arch was completed by a branch of the princeps pollicis, while the radialis indicis was a branch of the first common digital artery which arose from the deep palmar arch.

Arteriographs after frostbite have been done by several investigators. Pirozynski and Webster (1954) did serial arteriographs on the extremities of animals thirty minutes to seventy-two hours after freezing. Immediately after thawing they noticed general dilatation of the arterial tree. As swelling and oedema increased, the number of filled channels diminished but the main arterial trunks were dilated. Phlebography revealed persistent dilatation of venous system following thawing and a restriction of venous drainage in the first seventy-two hours. This dilatation followed a brief constriction during the freezing stage and immediately thereafter for a very short time. The veins were affected more rapidly and extensively by cold than the arteries.

RADIOLOGICAL FINDINGS

This study of thirteen patients with frostbite in eighteen hands included seven adults and six children. All had suffered the frostbite in childhood and there was no sex predilection. The shortest interval between the frostbite and review was four and a half years and the longest fifty years. The index and little fingers were involved in every frostbitten hand, the ring finger only slightly less, while the middle finger was the least often involved. The thumb was involved in only three patients. In all definite and clear-cut bony changes were seen in the involved digits.

The distal phalanx and distal interphalangeal joints were the most often involved. A proximal phalanx and proximal interphalangeal joint were never involved without involvement of the distal phalanx of the same digit.

In children the radiographic appearances are quite characteristic, particularly at the articular ends of the bones on both sides of the joint. The affected phalanges are short and smaller than normal, the juxta-articular bone is expanded and irregular with the spongiosa altered to show a coarse cancellous pattern; the same expanded and irregular appearance is seen on the contiguous surface of the more proximal phalanx, where there is no epiphysis.

The joint surfaces are irregular and uneven but the width of the joint space does not appear to be altered. Usually the epiphysis appears to have disappeared completely, but in some there is only partial destruction with the undestroyed portion remaining and taking part
in the joint disfiguration. Not uncommonly the base of an involved phalanx had a pronounced V-shape, presumably due to persistence of the central portion of the epiphysis. Occasionally there was evidence of fragmentation with some of the fragments persisting as loose bodies.

There may be no obvious destruction of the epiphysis, but simply premature fusion of a part of the epiphysial line. Varus or valgus angulation, depending on the side of the epiphysial line not affected, is often seen.

In the adult the radiographic changes are not so distinctive, and the joint changes cannot be differentiated from a long-standing chronic polyarthritis. The joint space may be narrowed
with splaying and sharpening of its margins, at least some of which is from a secondary
degenerative osteoarthritis. The changes indicative of previous frostbite are the short and
stubby phalanges in comparison with the normal, and a flared and moderately thickened
metaphysis and epiphysis. The alteration in the cancellous pattern seen in children does
not occur.

No clear-cut or significant abnormality of the vascular pattern is found. The vessels
are somewhat more tortuous in the region of the shortened phalanges, and there appears to
be an increase in the number of arteriovenous anastomoses. Ruckensteiner (1947) in a single
case found no relationship between the arteriograph and the bone changes.

Although only four patients were studied by arteriography the fact that the arrangement
of the digital and palmar arteries did not conform to the classical description of their arrangement
was not considered to be significant. The variations in the arrangement of these arteries is
consistent with the observation of others such as Weathersby (1955), McCormack, Cauldwell
and Anson (1953) and Hollinshead (1958) who found the so-called classical arrangement in
only 15 to 36 per cent of cases studied.

DISCUSSION

The patients in this series show the late effects of frostbite on epiphysial cartilage. The
deformities in the fingers occurred insidiously, and it appears that the patients accepted these
changes because they were gradual; they admitted their intolerance to cold and the cosmesis
associated with the epiphysial destruction. As yet none of them has found enough disability
to request surgery to improve the function or appearance. The consequences are, however,
disabling for such activities as playing musical instruments, typing and the finer motions of
dressing. The weakness in the power of extension found in the affected joints was directly
proportional to their degree of involvement, which, in turn, depended on the number of
phalanges affected in any one digit and on the age of the patient at the time of freezing;
an essentially normal extensor apparatus has to work over a shorter course, thus decreasing
both range and power of function.

A persistent finding was the rarity of thumb involvement. This was explained by the
inherent characteristic of thumb clutching when the hand is cold being more predominant in
infants than in children.

There were several instances of one-half of the epiphyses being involved, usually in the
little or index finger. This could be explained on the basis that exposure to cold was greater
on the ulnar side of the little finger and the radial side of the index finger.

Freezing has to be in the category of a third degree of frostbite before epiphysial damage
ensues.

SUMMARY

1. Frostbite in a child may be severe enough to destroy the cartilage cells of the epiphysial
plate of a digit, and produce clinical deformity.
2. Both the direct effect of the freezing itself and the vascular changes secondary to such
frostbite appear to cause necrosis of the growing epiphysis with destruction of the epiphysis
and disappearance of the epiphysial line or plate. The disappearance of the epiphysial plate
is obvious, but whether the epiphysis itself is actually destroyed and disappears or simply
fuses with the metaphysis is a question now being studied.
3. It is suggested that the deformities may be helped by interphalangeal fusion of severely
involved joints in the position of function, and phalanges that become angled into varus or
valgus may be improved by open wedge osteotomy or epiphysiodesis of the side of the epiphysis
still functioning.

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