# FRACTURES OF THE ANKLE

## II. Combined Experimental-Surgical and Experimental-Roentgenologic Investigations

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EXACT knowledge of the mechanism, pathologic anatomy, genetic roentgenologic diagnosis and genetic reduction of fractures of the ankle is to be attained by combined experimental-surgical and experimental-roentgenologic investigations.[1] In this study the mechanism of fracture was determined by fracturing, the pathologic anatomy was ascertained by dissection, the genetic roentgenologic diagnosis was established by roentgen examination and the genetic reduction technic of the fractures was found by reduction maneuvers, which will be dealt with in a later paper, "Clinical Use of Genetic Roentgenologic Diagnosis and Genetic Reduction."

In the experimental-surgical investigations free movability of the ankle joint is necessary in order to place the foot in the different positions which are to be considered. Experiments on cadavers were abandoned because of rigor mortis, which limits the movability of the foot and the ankle joint. The experiments have therefore been carried out exclusively on extremities which were amputated at the femur or at the upper end of the crus and which were wrapped up immediately and kept so until the experiments could be carried out a few hours later.

At the beginning of the experiments there was always free movability of the talocrural joint and the various joints of the foot, so that it could easily be placed in any position that a normal foot can adopt. No instruments whatever were used except a vise and nails for the fixing of the foot or the crus. All fractures were produced by hand. Before the results of the experimental investigations are reported, it is necessary to give some explanation of the movements of the foot and the movements in the ankle joint. The following movements of the foot are possible:

*Dorsiflexion and Plantar Flexion.*—These are hinge movements of the foot in the talocrural joint around a transverse axis through the trochlea of the talus. Another movement takes place in the talocrural

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1. Lauge, N.: Fractures of the Ankle: Analytic Historical Survey as the Basis of New Experimental, Roentgenologic and Clinical Investigations, Arch. Surg. **56**:259 (March) 1948.

joint. If viewed from the front or from behind, the sides of "the malleolar fork" are seen to diverge a little because of the distal curving of the articular surfaces of the malleoli and to have a cuplike appearance (fig. 1 *A*). Viewed from the front, the trochlea of the talus has the form of a truncated cone and is widest distally because of the oblique medial and lateral articular surfaces of the trochlea (fig. 1 *B*). Owing to the shape of the malleolar fork, this exercises a positive grip on the talus. When the foot is loaded the talus will move a little proximally—upward in the malleolar fork, exercising a wedge action on this and causing a concurrent movement of the tibiofibular syndesmosis. In this way the syndesmosis plays an important role in the normal mobility of the talocrural joint. The importance of healing lesions of the tibiofibular syndesmosis in anatomically correct position will be clear when this fact is remembered.

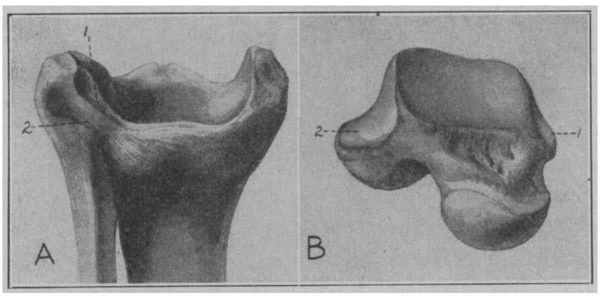


Fig. 1.—*A*, "malleolar fork" seen from behind. *1*, ligamentum malleoli lateralis posterius distale (transverse ligament); *2*, ligamentum malleoli lateralis posterius. (Note that the malleolar fork is rather cuplike.) *B*, talus viewed from the front. *1*, anterior part of medial articular surface of trochlea tali. *2*, lateral articular surface of trochlea tali. (Note the shape of the bone [truncated cone.])

*Supination and Pronation.*—Rotations of the foot internally and externally around a longitudinal axis through the foot occur with supination and pronation respectively. The movements are the results of a combination of the mobility of the articulations between the talus-calcaneus, talus-navicular, calcaneous-cuboid and tarsal-metatarsal bones. During supination and pronation, adduction and abduction, i. e., tibial and fibular flexion of the whole foot (particularly the hindfoot) in relation to the crus around a sagittal axis, and inversion and eversion (inward and outward rotation), i. e., tibial and fibular turning of the tip of the foot, will take place (fig. 2). Supination of the foot is therefore a combined movement constituted of inward rotation, adduction (hindfoot) and inversion (forefoot). Pronation is a combined movement constituted of outward rotation, abduction (hindfoot) and eversion (forefoot) (fig. 2). The supination-pronation movements are always

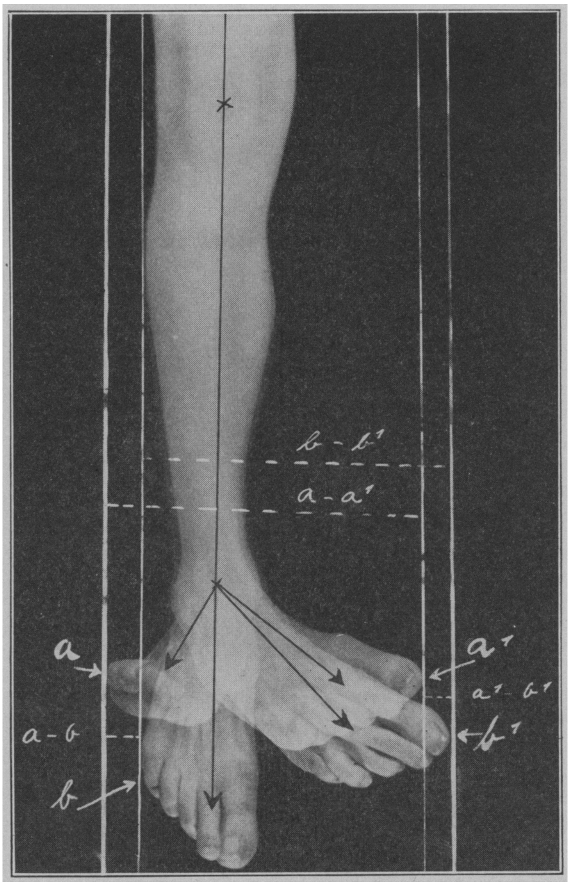


Fig. 2.—Photograph of crus and foot with four exposures on the same film. The crus is held in the same unchanged position, whereas the foot is placed in the following four positions: *a*, maximally pronated and dorsiflexed; *b*, maximally pronated and plantar flexed; *a'*, maximally supinated and dorsiflexed; *b'*, maximally supinated and plantar flexed. It is seen that the distance between *a* and *a'* is equal to the distance between *b* and *b'*, which means that the supination-pronation movement is of the same extent whether it is made with maximally dorsiflexed or maximally plantar flexed foot. As this is the case, the fact that the distances between *a* and *b* and between *a'* and *b'* are equal means that the foot is everted to a less extent, which is due not to the supination-pronation movement but to the talus movement in the malleolar fork from dorsiflexion to maximal plantar flexion.

Note how it is possible to observe the three components of movement in supination: (internal rotation of the foot around its longitudinal axis, adduction of the hindfoot and inversion [inward rotation] of the fore part of the foot) and in pronation: (external rotation of the foot around its longitudinal axis, abduction of the hindfoot and eversion [outward rotation] of the fore part of the foot).

of the same degree whether the foot is plantar flexed or dorsiflexed (fig. 2) or adopts a position between these two extremes.

On dorsiflexion of the pronated foot the tip of it points somewhat laterally, i. e., is everted (outward rotation), and the axis through the middle of the foot forms a laterally open angle with the central axis through the crus. On maximal plantar flexion of the pronated foot these axes are in direct continuation (fig. 2). On dorsiflexion of the supinated foot the tip points medially to a considerable degree, which is even more pronounced in cases of plantar flexion of the supinated foot (fig. 2).

It is important always to bear in mind that supination and pronation are combined movements whose components, adduction (tibial flexion of the hindfoot) and inversion (inward turning of the forefoot) and abduction (fibular flexion of the hindfoot) and eversion (outward turning of the forefoot), each will produce its own particular type of ankle fracture when they occur either as large unphysiologic forced movements or as abnormal forced movements of the foot.

On maximal supination and pronation the foot is transformed into an inflexible stiff entirety because of the tightening of the different ligaments. If forced adduction or eversion of the maximal supinated foot or forced abduction or eversion of the maximally pronated foot is carried out, the power of the forced movements will be transmitted to the malleolar fork because an abnormal rotation of the talus in relation to the malleoli produces abnormal vigorous tension in the side ligaments and abnormal pressure against the malleoli.

An account is given of the results which were achieved by experiments carried out according to the accompanying plan.

Maximal supination of the foot
↓ ↓
↓ + forced *adduction* ⟶ Supination–adduction fracture, stages 1 and 2
↓
+ forced *eversion* ⟶ Supination–eversion fracture, stages 1 to 4

Maximal pronation of the foot
↓ ↓
↓ + forced *abduction* ⟶ Pronation–abduction fracture, stages 1 to 3
↓
+ forced *eversion* ⟶ Pronation–eversion fracture, stages 1 to 4

The types of fracture thereby produced are described according to a dual designation, which denotes the two genetic main factors of the individual type of fracture, viz., the position of the foot at the moment the forced movement of the foot produces the fracture.

### SUPINATION-ADDUCTION FRACTURE, STAGES 1 AND 2

*Mechanism of Fracture and Pathologic Anatomy.* — The lower extremity is placed with the crus vertically. The foot is turned at an angle of considerable supination and fixed in this position to a horizontal support by nails through the medial and lateral edges. The heel region is also fixed by nails medially and laterally.

The adduction of the foot is performed by grasping the knee region and moving the crus medially, at the same time exercising pressure in the longitudinal direction of the crus.

Experiment 1: The foot is fixed by the method just described. When the crus has been moved medially so that it forms an angle of 45 degrees with the support, a sharp crack is suddenly heard, and a fracture in the middle of the lateral malleolus is felt.

When the medial movement of the crus is continued under simultaneous pressure in the longitudinal direction of the extremity, another fractural sound is heard when the extremity forms an angle of 20 to 30 degrees with the support, and a fracture in the basal part of the medial malleolus is now felt. After the occurrence of the latter fracture, it is possible to move the crus even nearer to the support and to produce a rather considerable medial luxation of the talus and both malleoli.

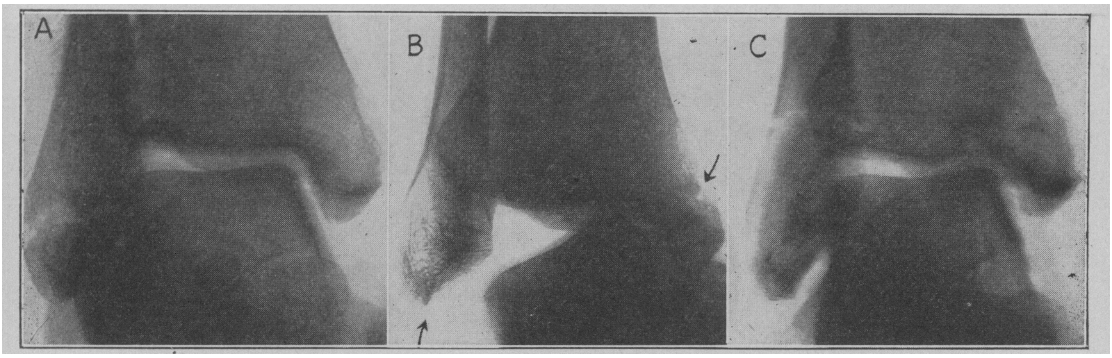


Fig. 3.—*A*, supination-adduction fracture, stage 1, with transverse fracture in the lateral malleolus. *B*, supination-adduction fracture, stage 2, with detachment of the collateral lateral ligaments and fracture in the basis of the medial malleolus (note the varus position of the talus in the "malleolar fork"). *C*, supination-adduction fracture, stage 2, with transverse fracture just proximal to the lateral malleolus (clinically a rare form of the fracture) and fracture in the basis of the medial malleolus.

By this a considerable tightening of the skin is noticed over the lateral malleolar region, which is jutting forth to a certain degree.

On dissection a transverse horizontal fracture through the middle of the lateral malleolus is seen (fig. 3 *A*). The periosteum on the lateral surface of the malleolus is ruptured at the fracture. There is no ligamentous rupture of any kind. Furthermore, there is a fracture of the medial malleolus, with the fracture line on the articular surface running in the borderland between the articular surface of the medial malleolus and the distal articular surface of the tibia. The fracture line on the subcutaneous side of the bone is slightly curved and convex and runs from the anterior to the posterior corner of the malleolus. There is some dilaceration of the periosteum.

There is no lesion of the deltoid ligament, no fracture in the posterior lip of the tibia and no lesion of the tibiofibular syndesmosis.

Experiments 2 and 5: It is found that the ligaments from the apical part of the lateral malleolus to the talus anteriorly and posteriorly and to the calcaneus have been detached from the insertion of these two bones with finely granular bony substances. There is no traceable fracture of the lateral malleolus. The fracture line in the medial malleolus at the base is straight, running in an anterodorsal direction (fig. 3 *B*).

Experiment 3: Bony avulsions (the size of a bean) from the tip of the lateral malleolus are carried out. The calcaneofibular and posterior talofibular ligaments are anchored to the fragment torn off. The fracture line does not involve the articular surface of the lateral malleolus. The capsule of the talocrural bone is torn laterally.

Experiment 4: A sharp crack is heard, and a fracture of the lateral malleolus occurs. The movement of the crus is continued and is gradually carried so far that the crus adopts a horizontal position, parallel with the support to which the foot is fixed, without any further crack indicating fracture being heard. Toward the end of this maneuver a 5 to 6 cm. cutaneous lesion is produced at the lateral malleolus. The rupture runs in an anterodorsal direction.

On dissection a transverse fracture through the middle of the articular surface of the lateral malleolus is found. The ligamenta talofibulare anterius et posterius and calcaneofibulare are attached to the distal malleolar fragment. The talus is luxated out of the malleolar fork, so that its superior surface looks distally and laterally. The deltoid ligament in its entirety is detached from the medial malleolus, which is not fractured. The joint capsule is torn anteriorly and posteriorly, but there are no signs of lesions at the posterior lip of the tibia.

Experiments 6 and 7: These consist in primary ligamentous detachment with finely granular periosteal avulsions from the tip of the lateral malleolus and then fracture at the base of the medial malleolus.

Experiment 8: Primary fracture at the lateral malleolus and secondary fracture at the medial malleolus are carried out. The dissection discloses a transverse fracture just proximal to the lateral malleolus itself and a couple of millimeters proximal to the distal articular surface of the tibia (fig. 3 *C*). There is no lesion of ligamenta malleoli lateralis anterius et posterius. The fracture of the medial malleolus is found at the base.

*Comment.*—In stage 1 most frequently there was detachment of the ligaments attached to the tip of the malleolus and the lower border (posteriorly) of the lateral surface of the talus in connection with a small fragment of bone. In 1 case the site of the fracture was in the lateral malleolus itself and in 1 case just proximal to it. In both cases the fracture was horizontal and transverse. In stage 2 fracture at the base of the medial malleolus was produced six times and detachment of the deltoid ligament from the same bone once.

Since during these experiments the foot was held maximally supinated and the fractures were produced by forced adduction of the posterior part of the foot, the fractures are termed supination-adduction fractures, stages 1 and 2.

The genetic roentgenologic picture is seen in figure 3. Data on genetic reduction will be given in a later paper.

### SUPINATION-EVERSION FRACTURE, STAGES 1 TO 4

*Mechanism of Fracture and Pathologic Anatomy.*—The skin is dissected from the dorsal part of the foot and from the distal 10 cm. of the anterior and lateral surface of the crus. Some periarticular fatty tissue is also removed in order to obtain a free view of the ankle joint region frontally and of the ligaments from the lateral malleolus. It should be noted that there was no instrumental injury of ligaments, fasciae or tendons. The femur stump is fixed in a vise.

Stage 1: The anterior part of the foot is placed at an angle of maximal supination and then everted. In this position the anterior lateral border of the trochlea tali is felt at the lower border of the ligamentum malleoli lateralis anterius. A vigorous tension of this ligament is felt, and its fibers become distinct, the ligament appearing as several well defined small bundles. Tension of the ligamentum transversum cruris and membrana interossea tibiofibulare and ligamenta calcaneofibulare and talofibulare posterius is also felt.

If the eversion (external rotation) is increased, a considerable angle is formed between the crus and the foot. At a certain stage of the eversion a slight crack is heard, indicating detachment of ligamentum malleoli lateralis anterius from its insertion on and at the anterior tubercle of the tibia (Chaput); a thin bony shell, the size of a large bean, is torn off (fig. 4 *B*). There is an injury in the tibia corresponding to the avulsion of the bony shell. During the eversion the small bony shell is removed some millimeters from the tibia while the distal part of the fibula with the lateral malleolus is displaced laterally and at the same time rotated outward. A slight diastasis appears between the tibia and fibula, and the intermalleolar distance anteriorly may be increased by 2 to 3 mm.

After the occurrence of this lesion it is possible to look into the talocrural joint through the capsular tear which has been produced by the detachment of the ligamentum malleoli lateralis anterius.

When the foot is no longer everted, the lateral displacement of the distal end of the fibula and the lateral malleolus and the outward rotation of these parts disappear, so that the fibula again comes into close contact with the tibia in the incisura fibularis.

The small bony shell adopts its former place, and the intermalleolar distance becomes normal. Thus the diastasis has disappeared, and normal tension of the ligaments is restored. It is the action of the intact ligamentum interosseum tibiofibulare which causes the distal end of the fibula with the lateral malleolus to readopt its normal position.

Stage 2: If the foot is everted again and to a greater degree under simultaneous pressure from the plantar surface toward the heel region, further lateral displacement and outward rotation of the talus and the distal end of the fibula with the malleolus occur under increasing tension of the ligamentum transversum cruris, membrana interossea and ligamentum interosseum tibiofibulare, the structures which chiefly serve the purpose of keeping the fibula in normal relationship to the tibia and which vigorously counteract further lateral displacement and outward rotation of this bone. Considerable tension is felt in the ligaments from the posterior part of the lateral malleolus to the dorsolateral corner and dorsal surface of the tibia and in ligamentum talofibulare posterius, all of which counteract lateral displacement and, in addition, try to maintain the normal position of the posterior margin of the lateral malleolus in relation to the dorsolateral part of the tibia. The lateral displacement and outward rotation and the ensuing increase of tension of the said ligaments are produced during the eversion by the pressure exercised by the trochlea tali against the anterior half of the articular surface of the lateral malleolus. This pressure will twist the fibula around its longitudinal axis, and it affects it in this way with great force because the ligamentum malleoli lateralis anterius has been detached from its tibial insertion and accordingly cannot resist the movement by keeping the anterior margin of the malleolus against the tibia. When the eversion has reached a certain stage, a crack is heard, indicating a fracture of the distal end of the fibula (fig. 4 *B*).

The fracture line has here a somewhat oblique spiral course from the front backward, from below upward and from the medial side laterally. It commences anteriorly at the line of the talocrural joint and just proximal to the most anterior prominent upper corner of the lateral malleolus and then runs dorsally, at first almost horizontally and later on more obliquely and backward.

The proximal fragment consists of the part of the fibula which is held firmly against the tibia by the ligamentum transversum cruris, membrana interossea and ligamentum interosseum tibiofibulare. These ligaments are intact. The distal fragment consists of the lateral malleolus and a distal, dorsal, smaller part of the fibula, from the dorsal border of which the upper part of the ligamentum malleoli lateralis posterius

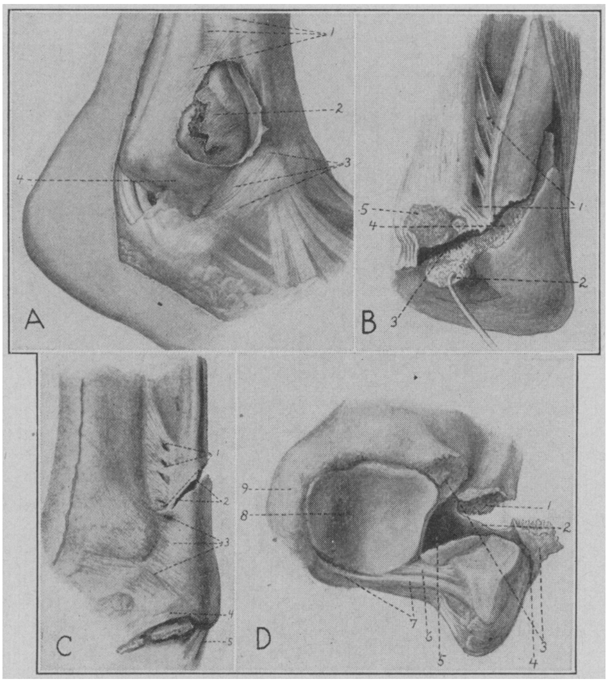


Fig. 4.—*A,* supination-eversion fracture, stage 1. *1,* ligamentum transversum cruris. *2,* detachment of ligamentum malleoli lateralis anterius with a small bony flake torn from the lateral malleolus. *3,* ligamentum cruciatum cruris. *4,* ligamentum talofibulare anterius. *B,* supination-eversion fracture, stage 2. Ligamentum transversum cruris and interosseous membrane removed. Fractures seen in relation to ligamentum interosseum tibiofibulare. *1,* ligamentum interosseum tibiofibulare intact. *2,* ligamentum malleoli lateralis anterius with bony flake avulsed from its tibial insertion at tuberculum anterius tibiae. (The bony flake is torn from the anterior surface of the tibia.) *3,* cavity of the talocrural joint. *4,* oblique spiral fracture in distal end of fibula in supination-eversion fracture, stage 2. *5,* surface of the fracture in tuberculum anterius tibiae. *C,* supination-eversion fracture, stage 2. Soft parts removed. Ligaments at the lateral malleolus and the ligamentum interosseum tibiofibulare are uninjured. Oblique spiral fracture in fibula seen from behind and the course of its fracture line in relation to the proximal bundles of the ligamentum malleoli lateralis posterius and to the distal bundles of ligamentum interosseum tibiofibulare. *1,* ligamentum interosseum tibiofibulare intact. *2,* oblique fracture in fibula in supination-eversion fracture, stage 2. *3,* ligamentum malleoli lateralis posterius. *4,* ligamentum talofibulare posterius. *5,* ligamentum calcaneofibulare. *D,* supination-eversion fracture, stage 2. *1,* surface of fracture on proximal fragment in oblique spiral fracture in distal end of fibula. *2,* rupture in the joint capsule laterally in oblique spiral fracture in distal end of fibula. *3,* surface of the fracture through tuberculum anterius tibiae. *4,* ligamentum malleoli lateralis anterius with a bony flake torn from tuberculum anterius tibiae. *5,* sac of the capsule of the talocrural joint up between the tibia and the fibula (torn through proximally). *6,* ligamentum malleoli lateralis posterius distale (transverse ligament). (Note the insertion in relation to the articular surface of the tibia and lateral malleolus.) *7,* ligamentum malleoli lateralis posterius. (Note the insertion of the ligament along the entire posterior lip of the tibia [and in its posterior surface, in *C* of this figure]. It is easy to distinguish it from ligamentum malleoli lateralis posterius distale). *8,* distal articular surface of tibia. *9,* medial malleolus.

comes and against the medial surface of which the small sac from the talocrural joint rests. This capsular sac is torn proximally and laterally (fig. 4 *B* and *D*).

Thus to the distal fragment belongs the part of the bone to which the following ligaments are attached dorsally: ligamenta malleoli lateralis posterius, malleoli lateralis posterius distale (transverse ligament), talofibulare posterius, calcaneofibulare, talofibulare anterius, all intact, and malleoli lateralis anterius, which is detached (fig. 4 *B, C, D.*).

During the eversion pressure, it is seen how ligaments, fasciae and membranes belonging to each of these fragments try to keep their own particular part of the fibula in normal relationship to the tibia and how it is possible, because of detachment of the ligamentum malleoli lateralis anterius from pressure of the talus against the anterior half of the lateral malleolus, to displace the distal end of the fibula with the lateral malleolus externally and to rotate the fibula outward, by which this bone is exposed to a torsion so violent that fracture occurs. The oblique spiral fracture of the distal end of the fibula occurs when the eversion has caused so great a tension in the portion of bone situated between the two systems of ligaments which are attached (fig. 4 *B* and *D*) to the proximal and distal fragments of the fibula respectively that it exceeds the resistance of the bony tissue.

By a closer examination of the medial surface of the fibula along the fracture line, it is seen that anteriorly this runs through part of the bone where the small sac from the talocrural joint rests on the distal end of the fibula, and where there is no ligament to keep this portion of the fibula against the tibia, and posteriorly it runs through the smooth narrow part of the bone between the site of insertion of the distal dorsal part of the ligamentum interosseum tibiofibulare and that of the proximal part of the ligamentum malleoli lateralis posterius (fig. 4 *C*).

The fracture line is thus found in the medial surface of the fibula in a portion of the bone which, because of lack of ligamentous attachments, is weak against a rotational force which tries to twist the fibula by vigorous pressure against the anterior half of the lateral malleolus. Thus it is unnecessary to assume local reduced resistance of bone (Slomann) or special conditions of the compact substance of this bone (Svend Hansen) in order to explain the seat and course of the fracture, which depend on the anatomic conditions of the ligaments.

The fracture is of the characteristic spiral type. The fracture line anterolaterally and, to some extent, dorsally in the bone has a twisted course, while medially it runs more vertically. The twisted fracture line corresponds to a left handed helical line (right leg) and thus has a course which agrees with the views advanced by Kock, Filehne and Zuppinger to the effect that the twisted fracture line of a spiral fracture is left handed when produced by a left handed twist. Thus the fracture of the distal end of the right fibula, produced by eversion of the foot, will be left handed, and that of the left fibula right handed.

The proximal line of the fracture is 3 cm. longer dorsally than frontally. The surface of the fracture has an oblique spiral appearance, owing to the course of the fracture line; the surface of the proximal fragment looks downward, laterally and backward, whereas that of the distal fragment looks upward, medially and forward. In the surfaces of the fracture there are irregularities in the form of larger or smaller projections and indentations which when the surfaces are joined fit together like the teeth of cogwheels. Because of the helical course, the form of the surface of the fracture may be compared with the walls of a winding staircase, the width of the stairs indicating the size of the fractural diastasis. The dorsal corner of the distal fragment comes 6 to 7 cm. above the tip of the malleolus and is somewhat tapered proximally. The ligaments attached to the fragments are all intact except the ligamentum malleoli lateralis anterius. The strong periosteum on the subcutaneous portion of the fibula and the lateral malleolus is torn a little proximal to the fracture line on the anterolateral surface of the fibula. The joint capsule, which is found as the small sac up between the tibia and the fibula distally, is torn, as already mentioned.

Stage 3: If the eversion is continued after the occurrence of the oblique spiral fracture, a further outward rotation of the malleolar fragment will take place, so that the lateral surface of the malleolus will look backward; besides, a displacement of the malleolar fragment will occur laterally, dorsally and a little proximally. These movements are due to the pressure exercised by the talus. The position of the talus is also changed; it is dislocated laterally, with simultaneous rotation partly around its longitudinal and partly around its vertical axis. By rotation around its own longitudinal axis the articular space between the tibia and the talus is increased medially (valgus position). By outward rotation of the talus around a vertical axis, an increase of width of the space between the talus and the medial malleolus occurs anteriorly. Lateral subluxation of the talus may thus take place even though the deltoid ligament is not torn. Rotation of the talus around the vertical axis will place it a little crosswise in the malleolar fork, so that the anterior part of the foot is everted.

Thus there are, at the same time, lateral subluxation, valgus position and outward rotation of the foot. When the talus has adopted this position by eversion, the width of the articular space anteriorly between the talus and the tibia is also increased, and the talus is slightly subluxated dorsally. Only the dorsolateral corner and the dorsal margin of the tibia rest on the talus. If the everting pressure against the anterior part of the foot is now further increased while at the same time attempts are made to move the foot in a proximal direction by pressure against the heel, a considerable tightening of the ligaments connecting the dorsal part of the lateral malleolus with the posterior lip of the tibia sets in, and at the same time the lateral malleolus will exercise a certain pressure from the lateral side against the dorsal distal part of the tibia and the talus will push against the dorsal lip of the tibia from below. When the everting pressure and the pressure against the plantar part of the heel have reached a certain degree, avulsion of a triangular fragment from the dorsal lip of the tibia occurs (fig. 5 *A*).

Viewed laterally, this fragment is triangular and conical and extends for 2.5 cm. in a proximodistal direction with the apex upward.

The upper limit of the fragment is level with the proximal fibers of the ligamentum malleoli lateralis posterius. The distal end consists of

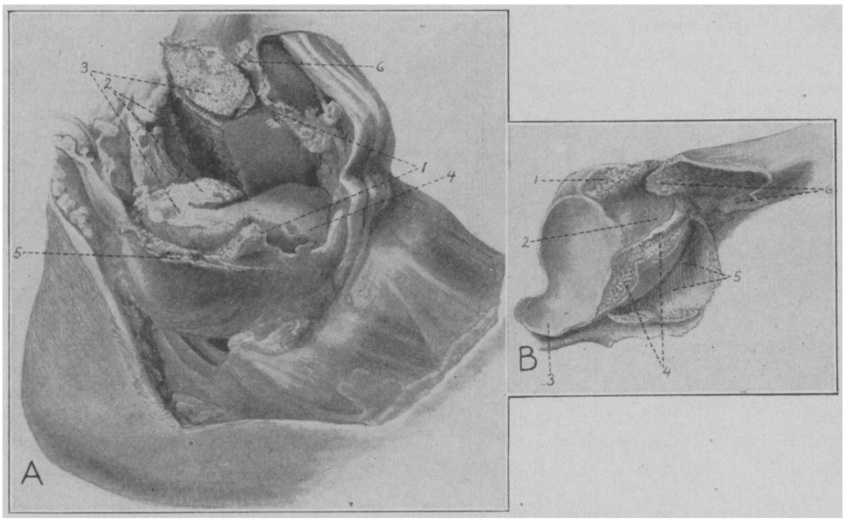


Fig. 5.—*A*, supination-eversion fracture, stage 3 (large fragment from posterior lip of tibia). *1*, ligamentum malleoli lateralis anterius torn off at the sites of insertion. *2*, surface of fracture in posterior lip of tibia. *3*, surfaces of the oblique spiral fracture in distal end of fibula. *4*, talus. *5*, ruptured periosteum over oblique spiral fracture in fibula. *6*, proximal fibers of ligamentum malleoli lateralis anterius or distal fibers of membrana interossea tibiofibularis. *B*, specimen of supination-eversion fracture, stage 3. *1*, surface of fracture at tuberculum anterius tibiae. *2*, seat of the sac from the talocrural joint. *3*, articular surface on medial malleolus. *4*, flaky avulsion corresponding to the tibial insertion of ligamentum malleoli lateralis posterius et malleoli lateralis posterius distale. *5*, detachment of periosteum to an extent corresponding to avulsion of large fragment from posterior lip of tibia. *6*, surface of fracture on proximal fragment of oblique spiral fracture in distal end of fibula.

approximately one fourth of the distal articular surface of the tibia, and the piece of articular surface of the fragment is practically of the same width medially and laterally. The fracture line in the articular surface runs to the dorsal corner of the medial malleolus. The fragment is anchored to the lateral malleolar fragment by ligamenta malleoli lateralis posterius et malleoli posterius distale.

The periosteum on the dorsal surface of the tibia is torn at the proximal corner of the avulsed fragment.

According to the observations described, which have been made immediately before and during the fracturing of the dorsal lip of the tibia, this fracture must be regarded as produced partly by pressure from the talus against the dorsolateral corner of the distal surface of the tibia and against the dorsal lip of the tibia itself, which are the only structures resting on the talus at the moment when the fracture occurs, partly by pressure in a dorsomedial direction exercised against the dorsal and distal part of the tibia by the lateral malleolar fragment and partly by a pull in the proximodorsal direction exerted on the same portion of the tibia by the ligaments attached to the avulsed fragment. These three components all affect, each in its own way, the dorsal, distal part of the tibia at the moment of fracture, and however differently they affect this part of the bone, they will nevertheless all try to detach it from the rest of the tibia.

It is emphasized that during the fracturing the foot is held dorsiflexed.

The ligamentous pull and the pressure from the lateral malleolar fragment depend on the force by which the supinated foot is everted, while the force by which the talus tries to chip off the fragment from the dorsal lip of the tibia is determined by the pressure which is transmitted to the talus through the tibia. The form and size of the fragment depend on these two components and must be presumed to be variable and dependent on the relatively greater effect of one or the other component and on the nature of the bony tissue.

Stage 4: When this fracture has been produced, the eversion of the foot can be continued to a considerable degree without any resistance worth mentioning until the axis of the foot forms a right angle with the sagittal plane through the crus. The lateral subluxation of the talus is only immaterially increased, while the outward rotation of the talus in the malleolar fork around a vertical axis is greatly increased and the rotation of the talus around its own axis is also increased. The lateral malleolar fragment is moved farther dorsally and proximally under marked outward rotation and now also medially with a simultaneous proximal, dorsal and somewhat medial dislocation of the dorsal fragment of the lip of the tibia. During this dislocation, a dorsal subluxation of the talus will take place, so that it is now subluxated laterally and dorsally, rotated outward and turned into a valgus position. Medially the talus is still anchored to the intact deltoid ligament and the tip of the medial malleolus stands fast at the posterior part of the medial upper margin of the talus.

If the foot is kept in the vise unchanged and fixed in this position and the crus is moved laterally and forward by grasping the knee region, a fracture at the base of the medial malleolus and the adjacent part of the tibia is produced. The fracture is produced by bending as the medial malleolus, held fast by the deltoid ligament at its tip, is fractured across the dorsomedial corner of the trochlea tali (fig. 6).

Anteriorly the fracture line commences at the base of the medial malleolus and runs in the articular surface in anterodorsal direction on the border between the articular surfaces of the medial malleolus and the distal end of the tibia. In the medial surface of the malleolus the

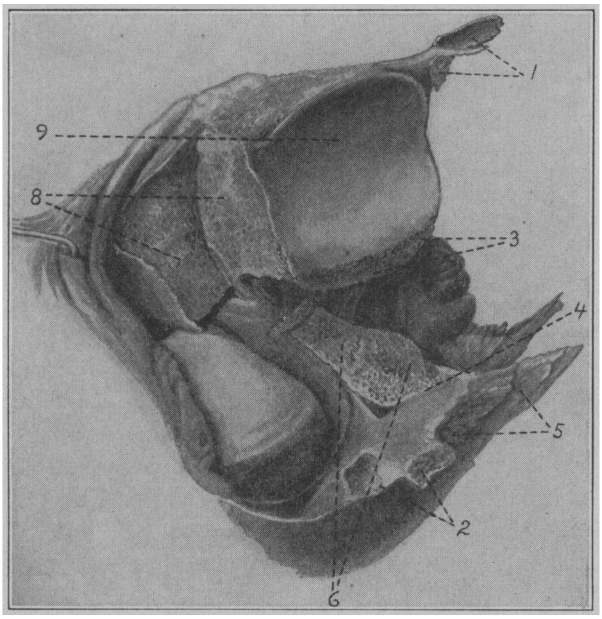


Fig. 6.—Supination-eversion fracture, stage 4. *1,* rupture of ligamentum malleoli lateralis anterius with a small bony avulsion from the insertion on the lateral malleolus. *2,* rupture of ligamentum malleoli lateralis anterius with a small bony avulsion from the insertion at tuberculum anterius tibiae. *3,* surface of the fracture in posterior lip of tibia. *4,* ligamentum malleoli lateralis posterius intact. *5,* surface of malleolar fragment of oblique spiral fracture in distal end of fibula. *6,* surface of fracture of large triangular avulsion from posterius lip of tibia. *7,* superior surface of trochlea tali. *8,* surfaces of the fractures through the base of the medial malleolus and adjacent part of tibia. *9,* distal articular surface of tibia.

fracture line has a slightly curved course in proximodorsal direction. The fractural surface of the tibia is slightly convex and looks downward and medially, while that of the medial malleolus is slightly concave and looks upward and laterally. The remaining part of the distal articular surface of the tibia is now a square, but greatly reduced in size. The connection between the foot and the crus is loose, and at the moment of fracture of the medial malleolus total dorsal luxation of the talus occurs, by which the remaining part of the articular surface of the tibia will come to rest on the dorsal part of the collum and the caput tali, while the talus with both malleoli, which are still in normal ligamentous connection with each other, is displaced dorsally and a little proximally. The dorsal fragment of the lip of the tibia is also displaced dorsally and proximally.

In this state of dislocation and luxation the talus, together with the malleoli, stands in a valgus position and is rotated outward, by which the medial malleolar fragment is carried forward and laterally, while the lateral malleolus is carried dorsally and medially.

If the dorsal luxation is overcome, there is a possibility of an almost collective displacement of the talus together with both malleoli in lateral direction. The talus slides into valgus position, so that the medial edge of the foot looks downward, the lateral edge upward, the planta outward and the dorsum pedis a little inward; medial displacement will not occur because of the intact ligaments to the lateral malleolar fragment and the tendons of the muscles which run behind it from the crus to the foot. Anteriorly the joint capsule is torn almost completely, and the cavity of the talocrural joint is now widely open toward the soft parts for the whole extent of the joint. The foot is then attached to the crus only by the soft parts, muscles, tendons, nerves, vessels, interstitial tissue and skin. All ligaments which normally tie the foot to the crural bones are detached from them with larger or smaller fragments. Laterally this is brought about by detachment of the tibial insertion of the ligamentum malleoli lateralis anterius, by fracture through the distal part of the fibula and by avulsion of a large fragment from the posterior lip of the tibia; medially it is effected by fracture through the medial malleolus.

Fractures have been produced by the mechanism described in eighteen amputated lower extremities. A few variations appeared in some of the experiments.

Experiment 2: It was found that detachment of the ligamentum malleoli lateralis anterius had taken place with a shell-shaped avulsion at the site of insertion of the ligament on the anterior border of the lateral malleolus (fig. 4 *A*). Oblique spiral fracture as in experiment 1 was produced. Instead of a large avulsion from the posterior lip of the tibia there were a shell-shaped avulsion of bone from the dorsolateral corner of the tibia, a similar avulsion from its posterior lip and detachment of the periosteum from the posterior surface of the tibia to an extent of 2.5 cm. proximally from the posterior lip (fig. 6). The deltoid ligament was detached from its insertion on the medial malleolus, a bony shell being carried with it. Dorsal luxation of the talus was possible after detachment of the deltoid ligament and not until then.

Experiment 3: This consisted in detachment of the ligamentum malleoli lateralis, with a fragment the size of a hazelnut torn off at its insertion on the anterior border of the lateral malleolus. The other fractures were as stated in experiment 2.

Experiment 4: The ligamentum malleoli lateralis anterius was detached partly at its tibial, and partly at its malleolar insertion, with small granular avulsions.

Experiment 7: The lower extremity used in the experiment came from an elderly patient who had been suffering from tuberculosis of the knee for some time. The bones were halisteretic, and arteriosclerosis of the arteries was seen. Eversion of the supinated foot was carried out by some force, and a fracture of the tibia occurred.

Roentgenologic examination demonstrated that an oblique spiral fracture had been produced proximally in the distal half of the tibia. At dissection of the specimen a helical fracture line was found anteriorly and laterally in the tibia, corresponding to the roentgenologic finding, while posteriorly and medially it had an almost straight, slightly oblique course.

*Comment.*—The summary of the stages of supination-eversion fractures produced is as follows:

| | |
|---|---|
| **Stage 1** | |
| Ligamentum malleoli lateralis anterius detached from tibia | 8 |
| Ligamentum malleoli lateralis anterius detached from lateral malleolus | 5 |
| Ligamentum malleoli lateralis anterius detached from both | 4 |
| | 17 |
| **Stage 2** | |
| Oblique spiral fracture of distal end of fibula | 17 |
| **Stage 3** | |
| Splitting-off of large fragment from tibia dorsally | 4 |
| Avulsion of dorsolateral corner of tibia and of a bony rim along dorsal lip of tibia | 8 |
| Splitting-off of dorsolateral corner of tibia and of bony rim along dorsal lip of tibia plus detachment of periosteum on dorsal surface of tibia | 2 |
| | 14 |
| **Stage 4** | |
| Fracture of medial malleolus at base | 6 |
| Avulsion of a bony rim at insertion of deltoid ligament on medial malleolus | 8 |
| | 14 |
| ***Variant*** | |
| Oblique spiral fracture in distal half of tibia | 1 |
| | 1 |

The lesion in the dorsal distal part of the tibia varied a little, but nevertheless there was invariably fracture in all cases, and in the cases in which the fragment was not large there was found partly a small fragment and partly an avulsion of a bony rim plus detachment of the periosteum from the tibia dorsally to an extent corresponding to a large fragment from the lip of the tibia. Therefore it presumably is justified to regard the lesion in these cases as being analogous to a large fragment torn off from the posterior lip of the tibia. It should particularly be noted that at the moment of production of this fracture the foot is dorsiflexed and that it is presumably produced by pressure from the talus against the posterior part of the distal surface of the tibia, by ligamentous pull and perhaps also by pressure from the lateral malleolar fragment against the distal part of the tibia.

The fourth lesion was either fracture of the medial malleolus at the base or in the adjacent part of the tibia or detachment of the deltoid ligament together with a bony shell from the medial malleolus. These two lesions must be presumed to be analogous to the same traumatic

Fig. 7.—Supination-eversion fracture, stage 4. Detachment of ligamentum malleoli lateralis anterius (not to be seen). Oblique spiral fracture in the fibula above the lateral malleolus. Fracture in the posterior lip of the tibia. Fracture in the basis of the medial malleolus.

injuries which will produce one or the other according to the individual anatomic and physiologic conditions.

By these experiments fractures are produced the sequence and pathologicoanatomic picture of which (apart from inessential variations) are uniform. The experiments show that it is possible to produce fractures of the ankle in four stages by forced eversion of the supinated foot.

As the supination position of the foot and the forced eversion movement of it are the two decisive factors of the mechanism of this type of fracture, it is designated supination-eversion fracture, stages 1, 2, 3 and 4.

The genetic roentgenologic picture is seen in figure 7. Data on genetic reduction will be given in a later paper.

PRONATION-ABDUCTION FRACTURE, STAGES 1 TO 3

*Mechanism of Fracture and Pathologic Anatomy.*—The foot is fixed by nails near to the proximal phalanx of the great toe and at the dorsal medial part of the heel, so that the nail goes through the calcaneus without injuring the achilles tendon or the ligaments from the medial malleolus. The pronation of the foot is maintained by wedging up the lateral edge of the foot.

The extremity is grasped at the knee joint region and the amputation stump of the femur. The crus is moved laterally and at the same time a little forward, and pressure is also exercised in the longitudinal direction of the crural bones. Vigorous tension of the deltoid ligament and some tightening of the ligamentum malleoli lateralis anterius occur.

When the crus forms an angle of about 60 degrees with the support, a distinct crack is heard, indicating the occurrence of a fracture of the basal part of the medial malleolus, the fracture line of which runs almost horizontally (fig. 8). Now the crus may be moved farther still without any application of force worth mentioning until the angle is approximately 45 degrees. In this way the periosteum corresponding to the fracture of the movement, the periosteum corresponding to the fracture of the medial malleolus and the malleolus are dislocated distally and a little in a fibular direction, so that the fractural space becomes wide.

Stage 2: If under increase of the pressure in the longitudinal direction of the bone the pressure on the crus in the same direction is continued, the angle between the crus and the support will be smaller still. When the applied force has reached a certain value, great tension of the ligamenta malleoli lateralis anterius et posterius et posterius distale is noticed, and these ligaments are detached, carrying with them a small bony flake anterolaterally from the tibia and a fragment the size of a hazelnut from the posterolateral corner of the tibia (stage 2, fig. 8). A small portion of the distal articular surface of the tibia is found on the dorsolateral fragment. If the force remains unchanged after the detachment, the membrana interossea, ligamentum cruciatum cruris and ligamentum interosseum tibiofibulare will stretch, as a result of which the distal end of the fibula and the lateral malleolus may be somewhat displaced laterally, i.e., the width of the syndesmotic space may be increased. The talus will, to a certain extent, adopt a valgus position and be subluxated laterally. Simultaneously with the subluxation of the talus, a distal and lateral displacement of the medial malleolar fragment will take place. The subluxation and valgus position of the talus and the distal-lateral dislocation of the medial malleolar fragment will recede considerably, and the syndesmotic space becomes almost normal when the abduction pressure is discontinued.

Stage 3: If the crus is moved farther laterally from the position at which detachment of the ligaments from the tibia anterolaterally and dorsolaterally is produced, a sharp crack is heard once more, and a straight but oblique fracture in the distal end of the fibula occurs 0.5 to 1 cm. above the distal articular surface of the tibia (fig. 8). The crus may now be moved farther laterally without application of great force until its longitudinal axis is almost parallel with the support. The fracture line in the fibula is not at all helical and runs medially and laterally

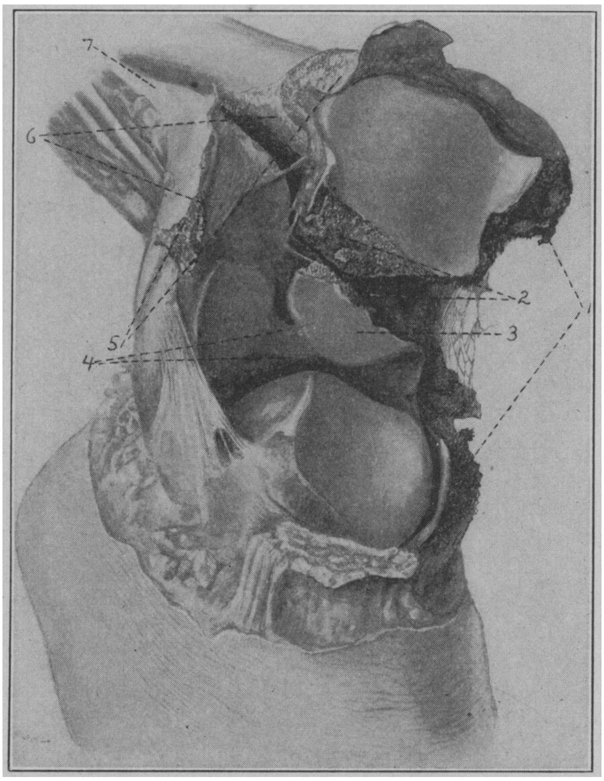


Fig. 8.—Pronation-abduction fracture, stage 3. *1,* surfaces of the fracture of the medial malleolus. *2,* surfaces of the fracture in posterior lip of tibia. *3,* large fragment torn from posterior lip of tibia. *4,* ligamentum malleoli lateralis posterior distale intact. (Note its relation to fragment torn from tibia dorsolaterally.) *5,* ligamentum malleoli lateralis anterius with a bony avulsion from tibia. *6,* rupture of ligamentum interosseum tibiofibulare distally. *7,* oblique fracture of fibula 3 cm. above the articular space of the talocrural joint.

upward. The fracture commences a little above the space of the talocrural joint in the part of the fibula covered by a small sac of the capsule of the joint.

The fibular fracture is produced by bending. This will be understood when the circumstances in which it takes place are considered. When the ligamentous detachment has taken place anterolaterally and posterolaterally, the abduction of the foot will affect the lateral malleolus in a lateral and proximal direction because of the nature of the articular surface involved, the more so because the ligaments which otherwise anchor the lateral malleolus to the tibia frontally and dorsally do not now retard the motion. That the fracture of the fibula occurs just above the lateral malleolus is explained by the fact that this part is not, as is the case with the more proximal part of the fibula, held on to the tibia by powerful structures such as the ligamentum interosseum tibiofibulare, ligamentum transversum cruris and membrana interossea cruris. These ligaments are intact after the production of the fracture. After the occurrence of the fibular fracture the valgus position of the talus will increase, as this bone is dislocated in a lateral direction together with both malleoli, with which it is in normal ligamentous connection.

On examination of the posterolateral tibial fragment a small area of facies articularis distalis tibiae is seen, and the extent of the fragment along the posterior lip and the lateral surface of the tibia roughly corresponds to the extent of the insertion of the ligamentum malleoli lateralis posterius distale.

Experiment 2: Primarily an almost horizontal, transverse fracture in the basal part of the medial malleolus is produced, followed by detachment of the ligamentum malleoli lateralis anterius with avulsion of a bony flake anterolaterally from the tibia, detachment of the ligamentum malleoli lateralis posterius and ligamentum malleoli lateralis posterius distale with very small granular bony avulsions from the dorsolateral corner and dorsal lip of the tibia and, to a small extent, detachment of periosteum from the dorsal tibial surface proximal to the posterior lip.

A third lesion, fibular fracture, occurs as in experiment 1.

Experiment 3: The foot is placed and fixed as in the two previous experiments, and a fracture running horizontally in the dorsal part of the medial malleolus is produced according to the same mechanism. The specimen is then unfastened and fixed by the femur stump in a vise. The anterior part of the foot is pronated and abducted at the heel region, and at the same time a moderate eversion pressure is exercised on the tip of the foot. By application of comparatively great force, it is noticed that the space between the tibia and the fibula is somewhat increased, so that a finger may be pressed down between the two bones in front distally. The commenced movement, i.e., abduction and some eversion of the pronated foot, is continued, and with an audible crack a fracture of the distal end of the fibula occurs 2 cm. above the distal articular surface of the tibia.

On dissection of the specimen the findings are, as in the two previous experiments, fracture of the basal part of the medial malleolus, detachment of the ligamentum malleoli lateralis posterius distale and a rather oblique-running transverse fracture of the fibula from 1 to 3 cm. above the talocrural joint. There is a small intermediate fragment laterally at the fibular fracture (fig. 8). Besides, a rupture of the membrana interossea and the anterior part of the ligamentum interosseum tibiofibulare to the extent of 2 cm. is seen. The ligamentum malleoli lateralis anterius and membrana interossea are detached from the tibia anterolaterally. The ligamenta malleoli lateralis posterius at posterius distale (transverse ligament) are found to be detached from the tibia, carrying a fragment the size of a hazelnut torn from the dorsolateral corner and dorsal lip of the tibia.

This experiment shows that if the tip of the foot is everted at the same time that the foot in its entirety is subjected to forced abduction in pronated position after the primary fracture involving the base of the medial malleolus, a lesion is produced in the distal part of the ligamentous connection between the tibia and the fibula which varies somewhat from that produced by abduction alone. The effect of the eversion of the foot is that, in addition to the detachment of the ligaments with the bony flake produced by abduction, a small detachment of the membrana interossea and ligamentum interosseum tibiofibulare occurs distally. The commencing detachment of these two interosseous structures causes the bending fracture of the fibula to take place a little more proximally in this bone, as it is no more tied tightly to the tibia just proximal to the small sac of the capsule of the talocrural joint.

*Comment.*—Fracture of the medial malleolus is produced in stage 1. Stage 2 consists in detachment of the ligamentum malleoli lateralis anterius, with a small fragment from the tibia anterolaterally, and detachment of the ligamentum malleoli lateralis posterius and ligamentum malleoli lateralis posterius distale, with a larger fragment from the dorsolateral and dorsal lip of the tibia or with a corresponding detachment of the periosteum from the tibia dorsally. Oblique fracture with a characteristic course of the fracture line and characteristic localization occurs in stage 3.

As the fracture is produced while the foot is pronated and in forced abduction, it is designated pronation-abduction fracture, stages 1, 2 and 3.

The genetic roentgenologic picture is seen in figure 9. Data on genetic reduction will be given in a later paper.

### PRONATION-EVERSION FRACTURE, STAGES 2 TO 4

*Mechanism of Fracture and Pathologic Anatomy.*—It will be remembered that in the last of the series of experiments in which stage 3 of pronation-abduction fracture was produced the anterior part of the foot was everted to a certain degree when the fracture of the foot took place by forced abduction. It was found that in addition to the usual lesions the eversion produced an incipient detachment of the membrana interossea, the ligamentum transversum cruris and the ligamentum tibiofibulare interosseum distally, causing the fibular fracture to be situated more proximally than the fibular fractures produced by forced abduction alone.

The object of the series of experiments to be described is to ascertain what lesions are produced by forced eversion of the pronated foot after the occurrence of pronation-abduction fracture, stage 1.

The lower extremity is fixed by the amputation stump of the femur in a vise. With one hand the operator grasps the anterior part of the foot, which is pronated and then forcibly everted, while the other hand supports the heel to maintain the pronation. Pronounced tension is

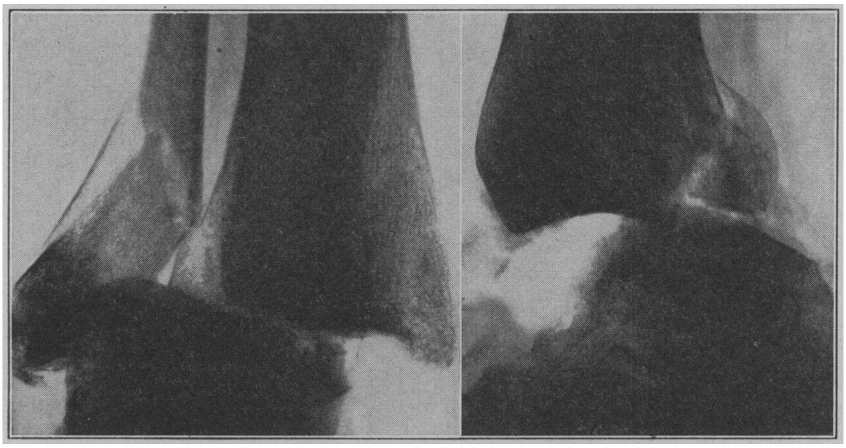

Fig. 9.—Pronation-abduction fracture, stage 3. Talus subluxated laterally and dorsally, and both malleoli dislocated with it. Note the oblique fractural surface on the proximal fibular fragment. The fibular fracture is seen indistinctly in the lateral view.

now noted in ligamentum cruciatum, ligamentum malleoli lateralis anterius, membrana interossea and ligamentum interosseum tibiofibulare.

If the eversion is gradually increased, detachment of the ligamentum malleoli lateralis anterius, ligamentum transversum cruris, membrana interossea and the greater part of the ligamentum interosseum tibiofibulare will occur when it has reached a certain value (fig. 10). The dorsal bundles of the last ligament remain intact, however, and bind the fibula to the tibia in the normal way. By the detachment of the ligamentum malleoli lateralis anterius and the membrana interossea a triangular bony flake is torn from the site of insertion on the tibia at a height of 2 to 3 cm. Above this the membrana interossea is detached with the periosteum from the anterior surface of the tibia to an extent of approximately 6 to 7 cm. The space between the tibia and the fibula is greatly increased anteriorly, so that its width is approximately 2 cm. The cause of this separation is that the talus is subluxated laterally, turning around a vertical axis and its own longitudinal axis into valgus position, whereby the lateral malleolus is moved in a fibular direction,

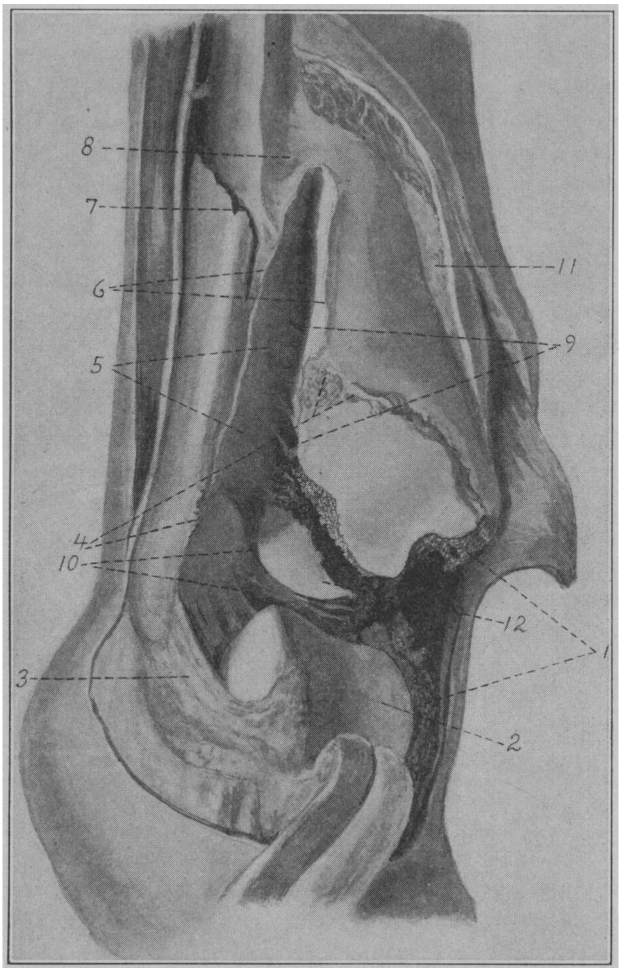


Fig. 10.—Pronation-eversion fracture, stage 4. *1,* fracture in the medial malleolus. *2,* talus. *3,* ligamentum talofibulare anterius intact. *4,* ligamentum malleoli lateralis anterius detached with a bony avulsion from tuberculum anterius tibae. *5,* detachment of ligamentum interosseum tibiofibulare. *6,* rupture of distal part of interosseous membrane. *7,* fracture of fibula. *8,* membrana interossea. *9,* dorsal intact part of ligamentum interosseum tibiofibulare. *10,* ligamenta malleoli lateralis posterius et posterius distale intact. *11,* ruptured part of ligamentum transversum cruris partly dissected and retracted. *12,* fragment of dorsal lip of tibia.

so that it is dislocated laterally and rotated outward. As the ligaments from the posterior surface of the lateral malleolus to the dorsal-distal part of the tibia and the dorsal bundles of the ligamentum interosseum tibiofibulare are still intact and anchor the fibula to the tibia dorsally in the incisura fibularis tibiae, the outward rotation of the lateral malleolus and the distal end of the fibula will take place around these intact ligaments as a hinge. The syndesmosis may be compared with a door which is widely open in front and has only a slit behind. The membrana interossea keeps the fibula in normal relationship to the tibia from approximately 7 cm. to the distal articular surface of the latter.

The medial malleolar fragment will, owing to its taut, intact ligamentous attachment, follow the movement of the talus, when the latter is subluxated laterally and rotated outward, and will therefore be dislocated distally and fibularly under the distal articular surface of the tibia.

If the eversion is continued after this, while the pronation of the foot is still maintained merely by supporting the medial surface of the heel region, the talus will exercise an increasing pressure against the lateral malleolus in fibular and proximal directions. As already mentioned in the section describing the last experiment of production of pronation-abduction fracture, the fact that the pressure will be exercised in these directions is due to the shape of the articular surface on the lateral side of the trochlea and the lateral malleolus. As the lateral malleolus and the distal part of the fibula are completely loosened from the tibia anteriorly by detachment of the said ligaments and as a certain rotation has taken place, because the anterior part of these bony parts are no longer attached to each other by the ligaments, the talus reaction will, when the eversion of the foot is continued, especially increase the torsion of the fibula around its longitudinal axis. However, this torsion will be unimpeded only to a certain point, as the membrana interossea and all the other components which try to keep the fibula in normal relationship to the tibia will prevent further rotation of the fibula.

However, if the outward rotation of the foot is continued, the talus pressure will, when it has reached a certain value, cause the torsional tension in the fibula to be exceeded, so that this bone is fractured 8 to 9 cm. above the tip of the lateral malleolus. The fracture of the fibula is found in the borderland between the "surgical neck" and the shaft of the fibula; the fracture line is somewhat oblique and twisted (fig. 10), slightly left handed and curved, but the fracture is short, only 1 cm. in length. It should be noted that the fracture occurs at the level at which rupture of the membrana interossea and ligamentum interosseum tibiofibulare ceases and at which the septum for the musculus tibialis posticus passes from the medial crest to the dorsal surface of the membrana interossea. Furthermore, the fracture is found between the ellipsoidal "surgical neck" and the more cristate shaft. Although the fracture is produced by torsion, its line is only slightly helical, which must be supposed to be due to the anatomic structure of the bone in the borderland between the "neck" and the shaft and to the insertion of the membrana interossea, fasciae and septums. In view of the observations on the course of the spiral fracture of the tibia recorded by Zuppinger, it seems to be reasonable to suppose that such factors may influence the spiral form and extent of a torsion fracture. Zuppinger showed that the vertical part of a spiral fracture produced by external rotation of the distal end of the tibia according to the structure of the bone would occur medially and anteriorly in the bone, as it also did in experiments with isolated tibias, and he showed that the clinical spiral fracture of the tibia produced by external rotation of the foot had a longitudinal fracture line dorsally in the bone, the explanation of which was that the insertion of powerful supporting bands laterally and dorsally on the tibia caused its rotation axis to shift.

By continuation of the experiment it was found that after the occurrence of the fibular fracture the foot may unresistingly be further everted. The talus is rotated outward and placed more in a valgus position and further subluxated. The malleolar fragment will also, to an increasing extent, be rotated outward, so that the space between the tibia and the fibula is increased until there is a considerable diastasis between the anterior borders of the tibia and the fibula.

In this position the dorsolateral corner and the dorsal lip of the tibia will be the only parts of the distal articular surface which rest on the superior surface of the talus, which is now rotated considerably as compared with its normal position in the malleolar fork.

If at that stage the eversion pressure is increased simultaneously with the application of pressure in a proximal direction against the planta in the heel region, a marked tension is noticed in the ligaments between the posterior part of the lateral malleolus and the dorsolateral corner and dorsal lip of the tibia. When the force has reached a certain degree, the ligamenta malleoli lateralis posterius et posterius distale (transverse ligament) are detached together with a small granular fragment corresponding to their insertion on the dorsolateral corner and the lateral half of the posterior lip of the tibia, and there is detachment of the periosteum of the posterior tibial surface corresponding to the insertion of the ligamentum malleoli lateralis posterius proximal to the posterior tibial lip (fig. 10).

A lesion of the tibia is thus produced partly by pressure from the talus against the dorsolateral corner and the posterior lip of the tibia and partly by the pull exercised on the bony region by the ligaments attached to it.

Subsequent to the production of this lesion, further subluxation of the talus will appear laterally and, in turn, dorsal luxation of this bone, during which the lateral luxation will recede somewhat. The distal part of the lateral malleolar fragment will be dislocated laterally, dorsally and proximally, while the proximal end of the distal fibular fragment, by which it approaches the tibia, will be dislocated somewhat medially and anteriorly. In this position the distal and proximal fibular fragments will form an angle with each other opening backward and laterally.

The dorsal bundles of the ligamentum interosseum tibiofibulare are still intact and act as a hinge, around which the malleolar fragment is turned and to some degree kept in contact with the tibia. The capsule of the ankle joint is almost entirely lacerated.

After the occurrence of the fourth lesion the connection between the foot and the crural bones is loose, and the crus and foot are attached to each other only by the skin, fasciae, muscles, tendons, vessels, nerves and interstitial tissue.

Experiments 2 and 3: These were carried out as described in the preceding paragraphs. Oblique fracture of the fibula occurred 7 to 9.5 cm. and 8 to 11.5 cm. respectively above the tip of the malleolus.

The fourth lesion was avulsion of a fragment the size of a hazelnut from the dorsolateral corner of the tibia and of a narrow bony rim along the posterior tibial lip. The periosteum was loosened to a small extent on the dorsal surface of the tibia proximal to the posterior lip, but it did not rupture.

Experiment 4: The two first lesions were produced as in experiments 1 and 3. In this experiment the detachment of the membrana interossea tibiofibulare goes farther proximally than in the three preceding ones, i.e., proximal to the borderland between the "surgical neck" and the shaft of the fibula and proximal to the strengthening of the septum dorsally in the membrana interossea.

After these two lesions occurred the eversion pressure against the tip of the foot produced (when the distal part of the fibula was rotated outwardly) a rather oblique, slightly spiral fracture of the shaft of the fibula from 18 to 21 cm. above the tip of the malleolus and 20 cm. below the head of the fibula, i.e., almost at the middle of the bone (fig. 11).

When the eversion pressure is increased, the lateral malleolus is dislocated and rotated outward dorsally and laterally, while the proximal end of the malleolar fragment is dislocated medially and anteriorly. The anterior diastasis between the tibia and the fibula becomes marked, and the talus is subluxated laterally to an increasing extent until the medial surface of the talus is just lateral to the fibular margin of the distal articular surface of the tibia. At this time the talus is luxated, while being displaced forward and upward into the space between the tibia and the fibula, so that its superior surface is 1.5 cm. proximal to the distal articular surface of the tibia (fig. 11).

This slight forward displacement of the talus must necessarily take place from central luxation upward between the tibia and the fibula, as the ligaments from the dorsal part of the lateral malleolus to the

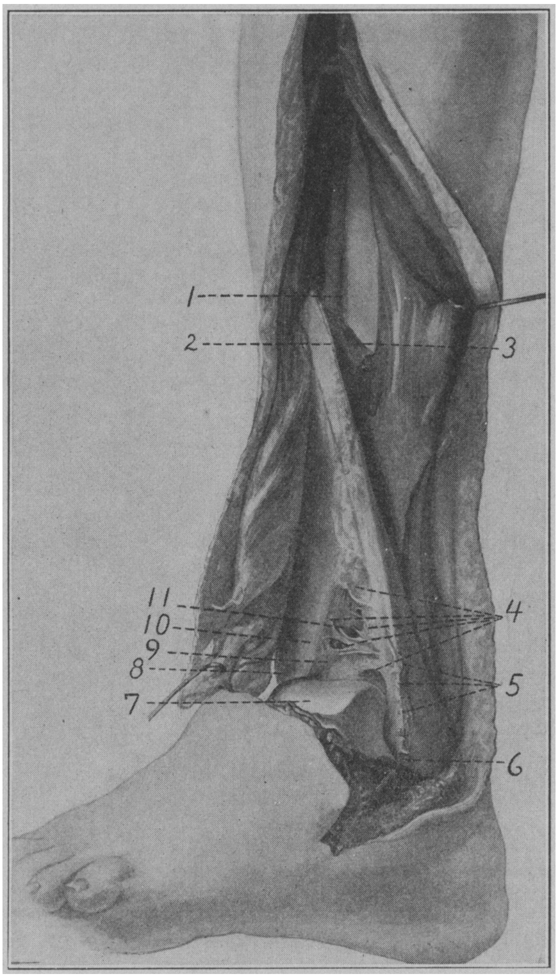


Fig. 11.—Pronation-eversion fracture, stage 3, with central luxation of talus. (Distal part of the interosseous membrane and ligamentum transversum cruris removed. They were ruptured distally to an extent of 6 to 7 cm.) *1,* anterior crest of fibula on proximal fragment. *2,* anterior crest of fibula on distal fragment. *3,* rather oblique fracture a little below the middle of the fibula. *4,* avulsion of the anterior and mesial part of ligamentum interosseum tibiofibulare. *5,* detachment of interosseous membrance. *6,* rupture of interosseous membrane. *7,* oblique spiral fracture of fibula. *8,* end of tibia which is somewhat distal to the superior surface of the talus. *9,* space for the sac from the talocrural joint up between the tibia and the fibula. *10,* anterior surface of tibia. *11,* incisura fibularis tibiae.

dorsal distal part of the tibia and the dorsal bundles of the ligamentum interosseum tibiofibulare remain intact.

A necessary condition of the central luxation of the talus is that detachment of the membrana interossea occurs to a sufficiently great extent proximally so that the rotation and lateral displacement of the distal fibular fragment may take place to such a degree that a sufficient diastasis appears distally between the tibia and the fibula. Experimental production of the fracture clinically described by Dupuytren has taken place.

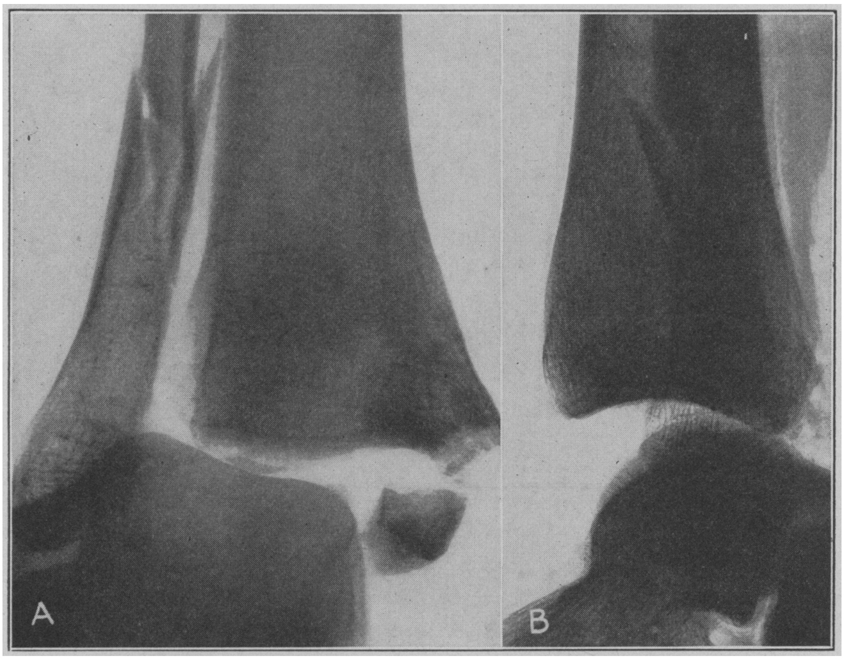


Fig. 12.—*A*, pronation-eversion fracture, stage 4. Lateral subluxation and valgus position of talus. Fragment of the medial malleolus dislocated laterally and distally. Widening of the syndesmotic space (pathologicoanatomically, 1.5 cm.). Fracture of the fibula 7 to 8 cm. above the point of the medial malleolus. *B*, dorsal subluxation of talus and small fragment torn from posterior lip of tibia. Fibular fracture is seen distinctly.

*Comment.*—From these experiments it appears that the mechanism of fracture applied will produce four lesions in the ankle region and the fibula in a certain sequence. The first lesion is pronation-abduction fracture. The second lesion is detachment of the entire ligamentum malleoli lateralis anterius, rupture of the ligamentum transversum cruris and the membrana interossea to a considerable extent and detachment of the ligamentum interosseum tibiofibulare with the exception of its dorsal bundles. The third lesion is a more or less oblique or spiral fracture of the fibula from more than 8 to 9 cm. above the tip of the malleolus. The localization of the fibular fracture depends on how far proximally the tibiofibular ligamentous attachments rupture and on how great the elasticity of these ligamentous systems is. If they are weak and rupture easily or if they possess an essential degree of elasticity, the fibula may rotate more freely and to a greater extent, so that in the end it is chiefly the ligamentous system at the proximal tibiofibular articulation which prevents further rotation. The consequence of this is that the site of the torsion fracture is as proximal as in the "anatomic neck" of the fibula, the bony resistance of which is less and which is nearest to the point of fixation (the proximal tibiofibular articulation). If the fracture is at about the middle of the bone or proximal to it, the distal fibular fragment may rotate and be dislocated so much that the separation between the tibia and the fibula may be large enough to give space to the talus, so that a central luxation takes place without rupture of the dorsal ligaments of the lateral malleolus and the dorsal bundles of the ligamentum interosseum tibiofibulare. The fourth lesion is detachment of the ligamentum malleoli lateralis posterius distale with a smaller or larger avulsion from the dorsolateral corner and the posterior lip of the tibia. As the pronation position of the foot and the forced eversion are the two main factors to which the occurrence of the three lesions is due, these fractures are designated pronation-eversion fractures, stages 2, 3 and 4.

The genetic roentgenologic picture is seen in figure 12. Data on genetic reduction will be given in a later paper. In this paper it will be seen that fractures produced by experimental-surgical means and pathologically and roentgenologically classified correspond to the clinical fractures of the ankle, that the genetic roentgenologic diagnosis can be successfully made and that reduction can be performed so that the position of all the fragments will be anatomically correct.