# Quantitative Criteria for Prediction of the Results after Displaced Fracture of the Ankle*

BY FRANK A. PETTRONE, M.D.†, ARLINGTON, VIRGINIA, MITCHELL GAIL, M.D., PH.D.‡, DAVID PEE‡, BETHESDA, MARYLAND, THOMAS FITZPATRICK, M.D.§, AND LEO B. VAN HERPE, M.D.†, ARLINGTON, VIRGINIA

*From Arlington Hospital, Arlington*

ABSTRACT: **In a series of 146 displaced ankle fractures, the effects of age, sex, side of injury, mechanism of injury, severity as determined by the Lauge-Hansen classification, type of injury (open or closed), open or closed treatment, and internal fixation of one or both malleoli were analyzed using subjective, objective, and radiographic parameters. Statistically significant prognostic features were identified and a prognostic scale was developed using multiple linear-regression analysis.**

**The significant parameters were age, adequacy of the post-reduction positions of the medial and lateral malleoli, and completeness of the restoration of the deltoid ligament and distal tibiofibular syndesmosis. Open reduction proved superior to closed reduction, and in bimalleolar fractures open reduction of both malleoli was better than fixing only the medial side. Using the data on the first 109 fractures, a multiple linear-regression equation was formulated and used to predict the outcomes of the last thirty-seven fractures in the study. The accuracy of the predictions in them was 81 per cent.**

The frequency of unsatisfactory long-term results of treatment of displaced (bimalleolar and trimalleolar) fractures of the ankle is well known. Cedell concluded that late poor results are due to laxity of the anterior tibiofibular ligament. Most authors have stated that anatomical reduction of the displaced medial malleolus ensures correction of talar displacement and is of paramount importance in treating unstable fractures[3,11,13]. However, more recent studies have indicated that the talus is more accurately repositioned in the mortise by anatomical reduction of the lateral malleolus[18]. Joy et al. defined measurements on the radiographs made after reduction that correlated with the final clinical result and concluded that the type of fracture, the amount of displacement of the talus, and the presence of a tear of the deltoid ligament have a significant influence on the final clinical result. A major contribution of their study was the suggestion that reproducible radiographic measurements can be used to quantify the extent of injury and the clinical outcome. Our study was undertaken to extend the work of Joy et al. by identifying additional variables that may affect the clinical outcome. In addition to the factors that they studied, we analyzed the effects of spreading of the distal tibiofibular syndesmosis and of the adequacy of the reduction of the lateral malleolus. Previous studies[6,17] failed to demonstrate statistically significant different outcomes in all patients treated by open reduction compared with all those treated by closed methods. In the light of recent evidence pointing to the importance of accurate reduction of the lateral malleolus, we studied the effect of open reduction of the medial malleolus only as compared with open reduction of both malleoli after a bimalleolar fracture. Based on these investigations, we developed a mathematical model using the data collected on the first 109 patients and used this model to predict the outcomes of the thirty-seven subsequent patients.

## History

Ashhurst and Bromer, in 1922, were the first to attempt to classify ankle fractures. They divided them into abduction, adduction, and external rotation groups. This classification was subsequently modified by many authors[2,4,7,17] without notable improvement until Lauge-Hansen presented a new classification in 1948. This was an important improvement because it considered the combinations of injured ligaments and fractured bones that are associated with progressively increasing displacement. According to this classification there are five basic patterns of injury, and as the energy causing the injury increases, the damage produced progresses from ligament sprain to different combinations of fracture and of ligament rupture or avulsion of bone fragments, depending on the direction and magnitude of the applied force. In this classification, the first word identifies the position of the foot at the moment of injury; the second word, the deforming force; and the number, the structure or structures injured and hence the severity of the injury. The Lauge-Hansen classification is well accepted in Europe and has recently gained more popularity in the United States.

Wilson and Skilbred showed that objective clinical

* Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, New Orleans, Louisiana, January 25, 1982.

† 3801 North Fairfax Drive, Arlington, Virginia 22203.

‡ Biometry Branch, National Cancer Institute, Bethesda, Maryland 20205.

§ Suffern, New York.

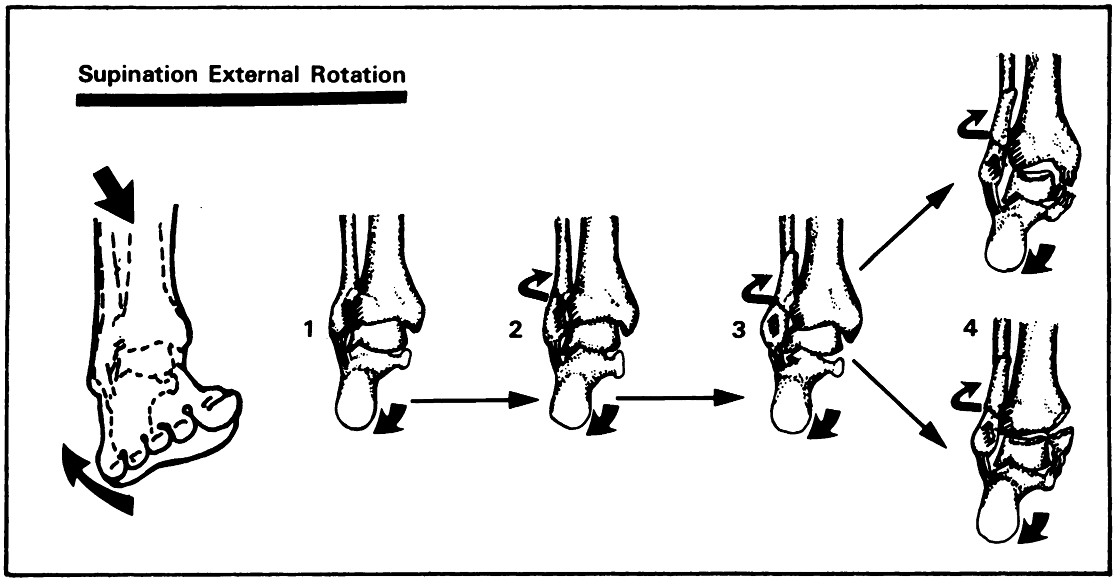


FIG. 1-A

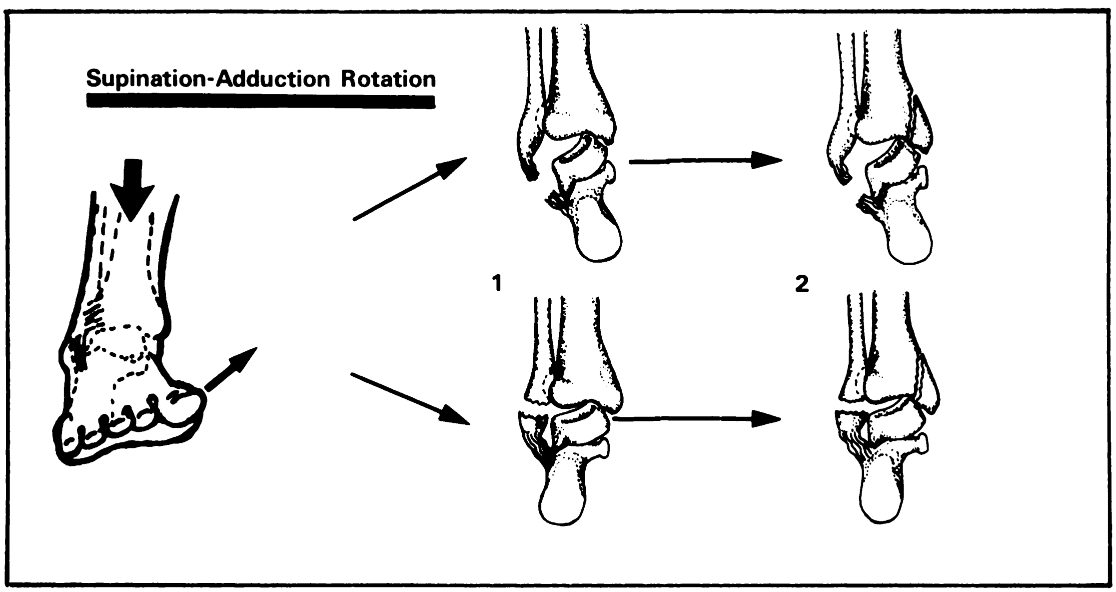


FIG. 1-B

Figs. 1-A through 1-E: The modified Lauge-Hansen classification[2,3,7,8,16]. These diagrams show the five classes of injury, the injured structures, and the classification of the severity of injury. The thick arrows indicate the direction of the injuring forces and the thin arrows indicate the progression in severity. Each listed grade of severity (1 through 4) indicates the structure or structures involved in addition to the one or more previously listed for the lower grades. For example, in a supination-external rotation grade-2 fracture (Fig. 1-A), there is rupture of the anterior tibiofibular ligament and a fracture of the lateral malleolus.

Fig. 1-A: Supination-external rotation. Severity is determined by the structures injured: (1) rupture of the anterior tibiofibular ligament, (2) spiral or oblique fracture of the lateral malleolus, (3) rupture of the posterior tibial margin, and (4) rupture of the deltoid ligament or fracture of the medial malleolus.

Fig. 1-B: Supination-adduction. Severity is determined by the structures injured: (1) traction fracture of the lateral malleolus at or below the level of the ankle joint or rupture of the talofibular ligament, and (2) nearly vertical fracture of the medial malleolus.

Fig. 1-C: Pronation-external rotation. Severity is determined by the structures injured: (1) rupture of the deltoid ligament or avulsion of the medial malleolus, (2) rupture of the anterior tibiofibular ligament and the interosseous ligament, (3) short spiral fracture of the fibula, typically located 7.6 centimeters proximal to the ankle joint but not infrequently more proximal, and (4) fracture of the posterior tibial margin or rupture of the posterior tibiofibular ligament.

Fig. 1-D: Pronation-abduction. Severity is determined by the structures injured: (1) fracture of the medial malleolus or rupture of the deltoid ligament, (2) rupture of both the anterior and the posterior tibiofibular ligament, and (3) bending fracture of the fibula, generally just proximal to the ankle joint, often associated with displacement of a triangular fragment from the lateral surface of the fibula.

Fig. 1-E: Pronation-dorsiflexion. Severity is determined by the structures injured: (1) fracture of the medial malleolus, (2) fragment fractured from the anterior articular margin of the tibia caused by the dorsiflexion of the talus, (3) supramalleolar fracture of the fibula, and (4) transverse fracture of the posterior lip of the tibial articular surface, this fragment having been avulsed by the dorsiflexion of the talus which also sheared off the anterior lip of the tibial articular surface (grade-2 severity).

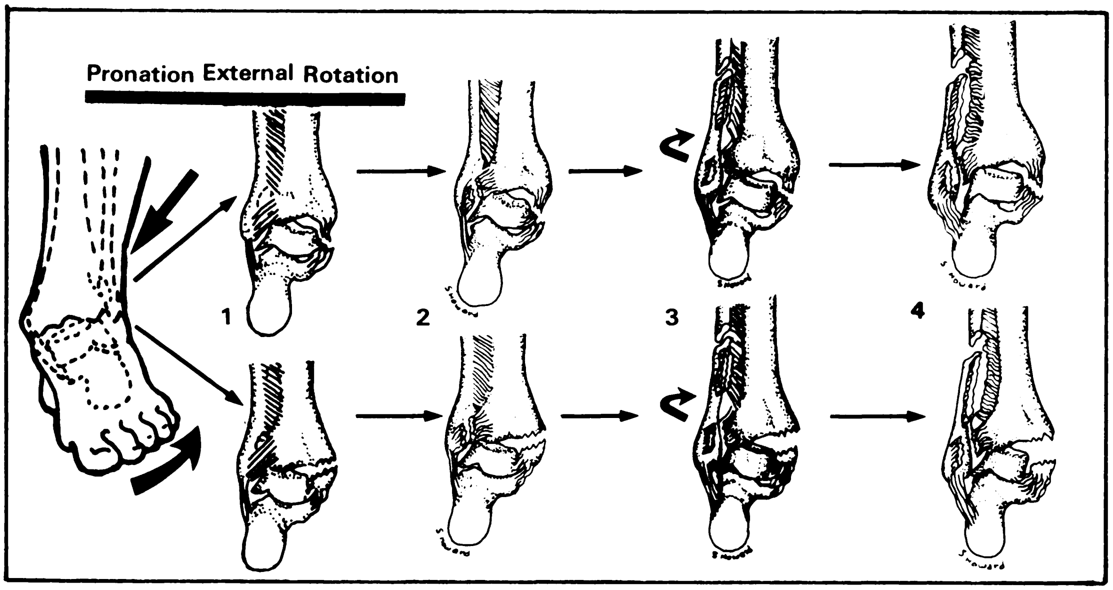


FIG. 1-C

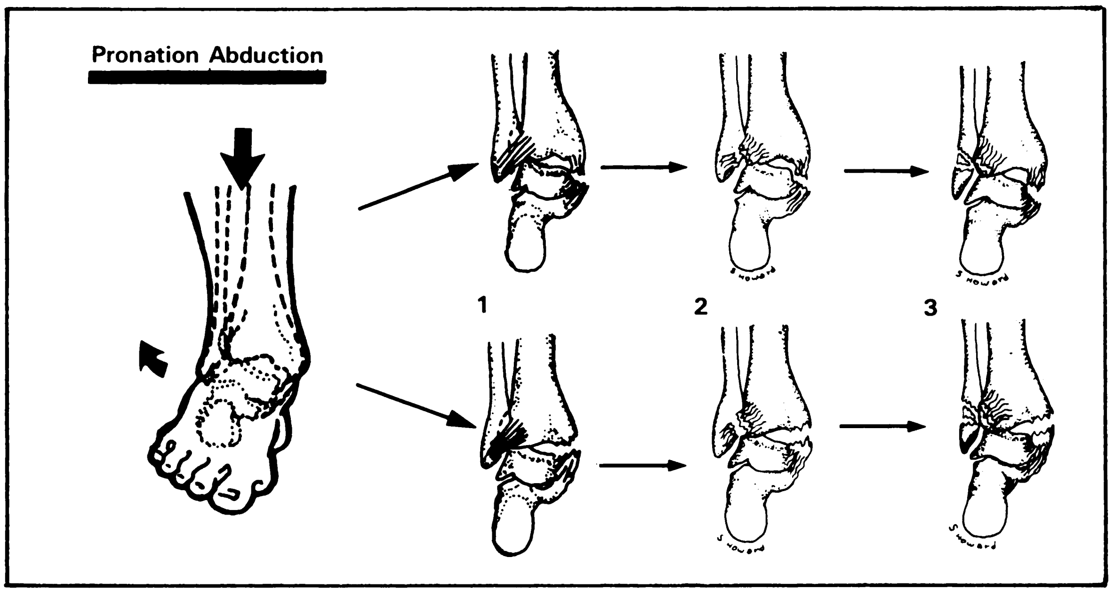


FIG. 1-D

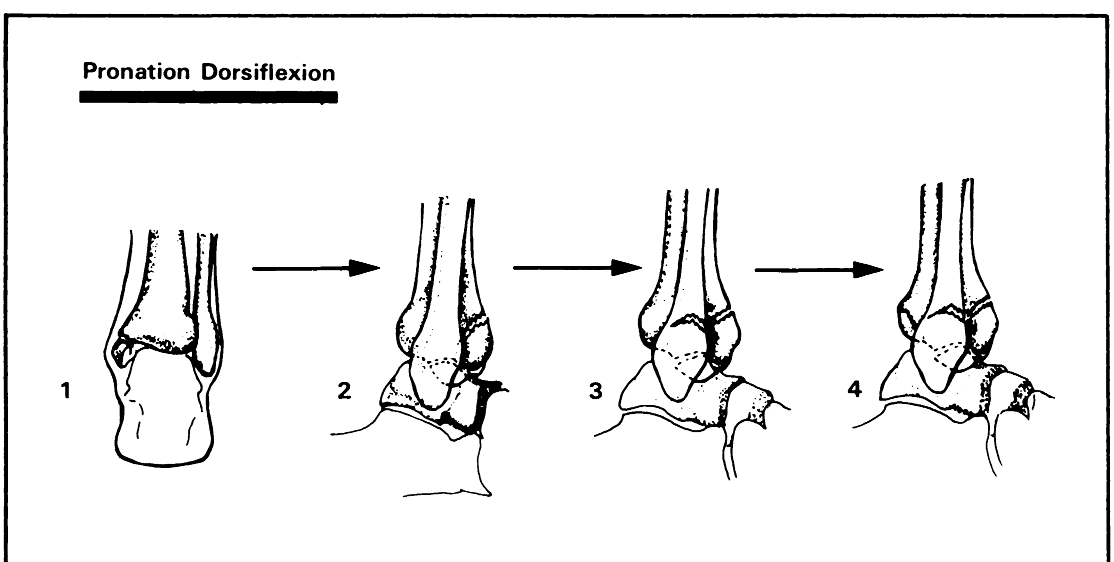


FIG. 1-E

findings usually did not change after one year from the time of injury, and that joint degeneration did not progress significantly after five years.

## Clinical Material

Diagnoses on discharge of all patients who had been admitted to Arlington Hospital during the years 1975 through 1979 were screened for cases of displaced bimalleolar and trimalleolar fractures of the ankle. One hundred and forty-six patients (146 fractures) with at least a one-year follow-up were identified and included in this study. Eleven patients were excluded because a one-year follow-up could not be obtained. Those who were excluded had either left the metropolitan area or were lost to follow-up.

The ankle fractures in this study were seen in the emergency room at Arlington Hospital, a university-associated community hospital, and were treated either by one of the twelve attending physicians or by an orthopaedic resident under the direction of an attending physician. For the closed injuries, closed reduction was attempted first. If the results were unacceptable to the physician, an open reduction was performed. All open injuries were treated by open reduction and internal fixation. The criteria that were used to judge the adequacy of reduction varied with the physicians involved. In general, if the medial malleolus was displaced less than two millimeters from the anatomical position, the syndesmosis was not widened, and the talus was not displaced, the position was accepted. Closed treatment included manipulation and immobilization in a toe-to-groin cast for four weeks, usually followed by four weeks of immobilization in a below-the-knee cast. Some ankles with disruption of the syndesmosis were held in casts for a total of twelve weeks. Ankles that were treated by open reduction had a screw placed in the medial malleolus and either a compression plate, screws, or a Rush rod for the lateral malleolus. After operation, a posterior splint was usually applied for ten days to permit range-of-motion exercises and then a short cast was worn for six weeks. Fifty-seven fractures were treated by closed reduction and eighty-nine, by open reduction.

There were eighty-five female and sixty-one male patients. Seventy-one left ankles and seventy-five right ankles were involved. The mean age of the patients was 46.8 years, with a range from eleven to eighty-nine years. Fourteen patients were less than twenty years old, forty were between twenty and thirty-nine, forty-four were between forty and fifty-nine, and forty-eight patients were sixty years old or older. Seventeen fractures were open and 129 were closed.

## Methods

We used a modified Lauge-Hansen classification (Figs. 1-A through 1-E) for these injuries. In this modification the terminology was changed in accordance with recent studies by other authors[3,5-7,10,12].

The fractures were evaluated before and after reduction to determine the influence on the results of the pre-reduction and post-reduction status of the medial malleolus, deltoid ligament, lateral malleolus, tibiofibular syndesmosis, and posterior malleolus, using the criteria described in Table II. For all patients anteroposterior, lateral, and mortise radiographs were available.

No jig was used to position the ankle because standard radiographs and radiographic techniques were used and variation was minimized[6]. The lateral radiograph was made by having the supine patient turn toward the affected side until the lateral part of the foot was parallel to the cassette. The anteroposterior radiograph was made with the leg in zero to 20 degrees of internal rotation. An attempt was made to place the long axis of the foot in a true vertical position (zero degrees of rotation). The mortise radiograph was made by turning the whole lower extremity internally 25 degrees while the patient remained supine.

The radiographs were interpreted by an observer who had no knowledge of the clinical data. There were ninety-eight supination-external rotation injuries, six supination-adduction injuries, thirty-five pronation-external rotation injuries, and four pronation-abduction injuries (Table I). Three injuries did not fit any one category. There were no pronation-dorsiflexion injuries.

TABLE I

DISTRIBUTION OF INJURIES ACCORDING TO THE LAUGE-HANSEN CLASSIFICATION*†

| Fracture Type | Severity Rating 1 | 2 | 3 | 4 | Total No. of Fractures |
|---|---|---|---|---|---|
| Supination-external rotation | 3 | 1 | 18 | 76 | 98 |
| Supination-adduction | 0 | 6 | 0 | 0 | 6 |
| Pronation-external rotation | 0 | 5 | 5 | 25 | 35 |
| Pronation-abduction | 0 | 3 | 1 | 0 | 4 |
| Pronation-dorsiflexion | 0 | 0 | 0 | 0 | 0 |
| Total | 3 | 15 | 24 | 101 | 143 |

* See Figs. 1-A through 1-E for definitions of fracture types and severity ratings.

† Three fractures were unclassifiable.

For assessment of the tibiofibular syndesmosis, three categories (A, B, and C) were established (Table II). These were based on measurements made on the anteroposterior and mortise radiographs (Fig. 2). Syndesmosis A, measured on the anteroposterior radiograph (distance A-B on Figure 2), was the width of the tibiofibular clear space. If this space was widened to five millimeters or more, the syndesmosis was assumed to be disrupted. Syndesmosis B, also measured on the anteroposterior radiograph (distance B-C on Figure 2), was the amount of overlap of the fibula and tibia. This was interpreted as showing disruption when the overlap was less than ten millimeters. Syndesmosis C, measured on the mortise radiograph (distance B-C on Figure 2), was the amount of overlap of the fibula and tibia. This was interpreted as indicating disruption when the overlap was one millimeter or less. If one or more of these measurements was abnormal, the syndesmosis was classified as disrupted.

TABLE II

CRITERIA USED TO IDENTIFY THE DISPLACEMENT OR DERANGEMENT OF EACH INJURED STRUCTURE

| Structure | Radiograph Used* | Radiographic Criteria |
|---|---|---|
| Malleolus | | |
| Medial malleolus | Anteroposterior | Fracture separation of at least 1 mm |
| Lateral malleolus | Anteroposterior and lateral | Fracture separation of at least 2 mm on the anteroposterior radiograph or at least 2 mm on the lateral radiograph |
| Posterior malleolus | Lateral | Fracture fragment includes at least 25 per cent of the tibial articular surface |
| Deltoid ligament | Anteroposterior | Medial clear space† at least 3 mm wide |
| Syndesmosis‡ | | Abnormal if syndesmosis A, B, or C is abnormal |
| Syndesmosis A | Anteroposterior | Tibiofibular clear space widened to 5 mm or more |
| Syndesmosis B | Anteroposterior | Tibiofibular overlap of less than 10 mm |
| Syndesmosis C | Mortise | Tibiofibular overlap of 1 mm or less |

* See text for definitions.
† The medial clear space was measured on the anteroposterior radiograph, as was done by Joy et al. and as is the preference at our institution.
‡ See text and Fig. 2 for definitions and measurements of the syndesmoses.

Follow-up examinations were done and radiographs were made in the attending physicians' offices at one to five years after injury. For each patient the subjective response, an objective clinical assessment of function, and the radiographic results were evaluated using the scoring tables of Joy et al. in which 4 points is assigned in each category, yielding a maximum possible over-all score of 12 points. The over-all score was used to grade the results, poor being zero to 6 points; good, 7 to 9 points; and excellent, 10 to 12 points. Therefore, considerably more weight was given to the clinical than to the anatomical result, since in the over-all score 8 points could be allotted for the subjective and objective ("clinical") results and only 4 points could be given for the radiographic (anatomical) result.

Significance levels were obtained by standard analysis of variance unless otherwise noted, and tests for trends were made using equally spaced scores[14].

A few data were missing in this study. For all 146 patients complete data were available on the subjective and objective clinical responses and on the radiographic results. All ankles were evaluated after reduction for derangements of the medial and lateral malleoli, the deltoid ligament, and the posterior malleolus according to the criteria shown in Table II. Information on the structural derangements prior to reduction was available for the posterior malleolus in all 146 ankles and for the medial malleolus, lateral malleolus, and deltoid ligament for 145 ankles. Measurements of syndesmosis A were available for 144 ankles before reduction and for 145 after reduction.

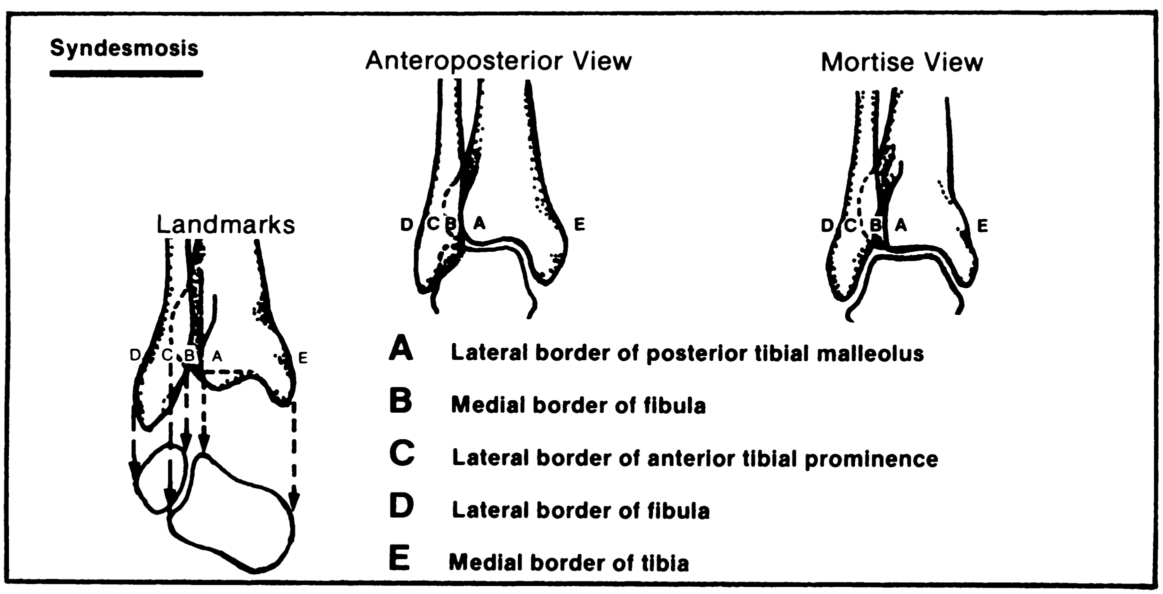


FIG. 2

Diagrams showing the landmarks (A through E) on the radiographs used to make the measurements that defined the three syndesmoses and the status of the tibiofibular syndesmosis (see text and Table II). Syndesmosis A: distance between A and B on the anteroposterior radiograph — tibiofibular clear space. Syndesmosis B: distance between C and B on the anteroposterior radiograph — tibiofibular overlap. Syndesmosis C: distance between C and B on the mortise radiograph — tibiofibular overlap.

TABLE III

EFFECT ON OVER-ALL RESULT OF FACTORS DETERMINED BEFORE REDUCTION

| | Mean Result (Points) | No. of Ankles | Differences in Mean Results (Points) | Statistical Significance of Differences* |
|---|---|---|---|---|
| Age | | | | |
| 1 to 19 years | 10.14 | 14 | | |
| 20 to 39 years | 9.07 | 40 | 1.07 | |
| 40 to 59 years | 8.50 | 44 | 1.64 | $p < 0.001$ (3 d.f.) |
| >60 years | 7.66 | 48 | 2.48 | $p < 0.001$ (trend) |
| Sex | | | | |
| Male | 8.86 | 61 | | |
| Female | 8.25 | 85 | 0.61 | ns |
| Side of injury | | | | |
| Left | 8.80 | 71 | | |
| Right | 8.24 | 75 | 0.56 | ns |
| Injury | | | | |
| Closed | 8.66 | 129 | | |
| Open | 7.35 | 17 | 1.31 | $p = 0.019$ |
| Lauge-Hansen classification | | | | |
| Supination-external rotation | 8.42 | 98 | | |
| Pronation-external rotation | 8.37 | 35 | 0.05 | ns |
| Lauge-Hansen severity rating (supination-external rotation and pronation-external rotation fractures only) | | | | |
| 1 | 11.00 | 3 | | |
| 2 | 8.33 | 6 | 2.67 | |
| 3 | 8.61 | 23 | 2.39 | ns (3 d.f.) |
| 4 | 8.25 | 101 | 2.75 | $p = 0.038$ (trend) |

* ns means that the observed two-sided significance level exceeds 0.05 ($p > 0.05$).

The corresponding numbers for syndesmosis B were 143 and 145 ankles; for syndesmosis C, 124 and 125 ankles; and for involvement of any one of the three syndesmoses, 140 and 132 ankles. The numbers for involvement of any syndesmosis were intermediate because a definitive diagnosis of involvement of the syndesmosis in any one ankle required only that one of the three be involved, whereas a definitive diagnosis that a syndesmosis was not involved required negative measurements for all three syndesmoses (A, B, and C). For purposes of analysis, when a required measurement was unavailable that ankle was omitted from the analysis, as is indicated by the numbers of ankles shown in Tables IV through IX.

## Results

The subjective, objective, and radiographic scores at final follow-up showed high correlations in the following comparisons: subjective versus objective, 0.78; radiographic versus subjective, 0.68; and radiographic versus objective, 0.68. The mean point scores in each of these categories were: subjective, 2.79 (±0.77); objective, 2.80 (±0.77); and radiographic, 2.92 (±0.90). The radiographic scores tended to be slightly higher than the subjective and objective scores, but all three scores tended to rise and fall together.

Of the over-all result scores, 19.9 per cent were 6 points or less (poor); 45.9 per cent were 7, 8, or 9 points (good); and 34.2 per cent were 10, 11, or 12 points (excellent). The mean over-all result score was 8.51 points.

Several factors that were determined before reduction were studied to see if they were related to the over-all results (Table III). The age of the patient showed a statistically significant ($p < 0.001$) relationship to the over-all result, the result rating declining significantly with advanc-

TABLE IV

PRE-REDUCTION FACTORS AS INDICATORS OF THE OVER-ALL RESULTS

| | Mean Result (Points) | No. of Ankles* | Differences in Mean Results (Points) | Statistical Significance of Differences† |
|---|---|---|---|---|
| Medial malleolus | | | | |
| Not involved | 8.60 | 40 | | |
| Involved | 8.49 | 105 | 0.11 | ns |
| Deltoid ligament | | | | |
| Not involved | 8.56 | 115 | | |
| Involved | 8.33 | 30 | 0.23 | ns |
| Lateral malleolus | | | | |
| Not involved | 9.55 | 27 | | |
| Involved | 8.28 | 118 | 1.28 | $p = 0.006$ |
| Syndesmosis | | | | |
| Not involved | 8.96 | 23 | | |
| Involved | 8.38 | 117 | 0.58 | ns |
| Posterior malleolus | | | | |
| Not involved | 8.53 | 134 | | |
| Involved | 8.33 | 12 | 0.20 | ns |

* Only ankles with available measurements were analyzed.

† ns means that the observed two-sided significance level exceeds 0.05 ($p > 0.05$).

TABLE V

POST-REDUCTION FACTORS AS INDICATORS OF THE OVER-ALL RESULTS

| | Mean Result *(Points)* | No. of Ankles* | Differences in Mean Results *(Points)* | Statistical Significance of Differences† |
|---|---|---|---|---|
| Medial malleolus | | | | |
| Not involved | 8.76 | 120 | | |
| Involved | 7.38 | 26 | 1.38 | p = 0.003 |
| Deltoid ligament | | | | |
| Not involved | 8.59 | 136 | | |
| Involved | 7.40 | 10 | 1.19 | ns |
| Lateral malleolus | | | | |
| Not involved | 9.30 | 83 | | |
| Involved | 7.48 | 63 | 1.82 | p < 0.001 |
| Syndesmosis | | | | |
| Not involved | 8.96 | 54 | | |
| Involved | 8.11 | 78 | 0.85 | p = 0.030 |
| Posterior malleolus | | | | |
| Not involved | 8.53 | 134 | | |
| Involved | 8.33 | 12 | 0.20 | ns |

* Only ankles with available measurements were analyzed.

† ns means that the observed two-sided significance level exceeds 0.05 ($p > 0.05$).

ing age. Sex and side of injury were not significantly associated with the final outcome. The outcomes of open injuries were significantly worse than those of closed injuries.

The Lauge-Hansen classification of anatomical type comparing supination-external rotation with pronation-external rotation injuries was not of prognostic value. However, the Lauge-Hansen grading of severity of these two injuries (Figs. 1-A through 1-E) showed a weak correlation with the outcome (Table III). Assessment of the prognostic importance of the preoperative (Table IV) and postoperative (Table V) conditions of the medial malleolus, deltoid ligament, lateral malleolus, syndesmosis, and posterior malleolus showed that before reduction only the status of the lateral malleolus appeared to be important, but after reduction the conditions of all structures except the posterior malleolus and deltoid ligament were demonstrably important. The lack of statistical significance of restoration of the deltoid ligament after reduction was due to the small number of patients with residual abnormalities. The importance of residual derangement of this ligament for prognosis, however, is indicated by the relatively large difference (1.19 points) between the mean results in the ankles with and without restoration of a normal medial clear space. The difference between the mean results in ankles with and without restoration of the posterior malleolus, by contrast, was only 0.20 point. To judge from this series, the relative importance of the structures to be restored in the treatment of displaced fractures of the ankle (progressing from the most to the least important) seem to be the lateral malleolus, the medial malleolus, the deltoid ligament, the syndesmosis, and the posterior malleolus. These findings suggest that the lateral malleolus should receive more attention than it has in the past.

As can be seen in Table VI, the post-reduction measurements of syndesmosis A and syndesmosis B were the most sensitive indicators of persistent disruption of the tibiofibular syndesmosis and were the only ones that were

TABLE VI

PRE-REDUCTION AND POST-REDUCTION MEASUREMENTS OF THE SYNDESMOSIS AS INDICATORS OF THE OVER-ALL RESULTS*

| | Mean Over-All Results *(Points)* | Difference in Mean Results *(Points)* | No.† | Statistical Significance of Differences‡ |
|---|---|---|---|---|
| Before reduction | | | | |
| Syndesmosis A | | | | |
| Tibiofibular clear space < 5 mm | 8.77 | | 75 | |
| Tibiofibular clear space ≥ 5 mm | 8.21 | 0.56 | 69 | ns |
| Syndesmosis B | | | | |
| Tibiofibular overlap ≥ 10 mm | 8.94 | | 36 | |
| Tibiofibular overlap < 10 mm | 8.33 | 0.61 | 107 | ns |
| Syndesmosis C | | | | |
| Tibiofibular overlap > 1 mm | 8.74 | | 46 | |
| Tibiofibular overlap ≤ 1 mm | 8.40 | 0.34 | 78 | ns |
| After reduction | | | | |
| Syndesmosis A | | | | |
| Tibiofibular clear space < 5 mm | 8.74 | | 118 | |
| Tibiofibular clear space ≥ 5 mm | 7.48 | 1.26 | 27 | p = 0.007 |
| Syndesmosis B | | | | |
| Tibiofibular overlap ≥ 10 mm | 8.90 | | 82 | |
| Tibiofibular overlap < 10 mm | 7.98 | 0.92 | 63 | p = 0.012 |
| Syndesmosis C | | | | |
| Tibiofibular overlap > 1 mm | 8.64 | | 86 | |
| Tibiofibular overlap ≤ 1 mm | 8.25 | 0.39 | 39 | ns |

* For definitions of syndesmoses A, B, and C, see Table II.

† Only ankles with available measurements were analyzed.

‡ ns means that the observed two-sided significance level exceeds 0.05 ($p > 0.05$).

TABLE VII

EFFECT OF THE NUMBER AND PATTERN OF ABNORMAL POST-REDUCTION FACTORS ON THE OVER-ALL RESULT

| No. of Abnormalities | Pattern of Involvement after Reduction* Medial Malleolus | Deltoid Ligament | Lateral Malleolus | Syndesmosis | Posterior Malleolus | Mean Over-All Result (*Points*) | No. of Ankles† |
|---|---|---|---|---|---|---|---|
| 0 | − | − | − | − | − | 9.50 | 32 |
| 1 | − | − | − | − | + | 9.50 | 2 |
| | − | − | − | + | − | 9.67 | 24 |
| | − | − | + | − | − | 7.70 | 10 |
| | + | − | − | − | − | 8.67 | 6 |
| 2 | − | − | − | + | + | 8.40 | 5 |
| | − | − | + | − | + | 12.00 | 1 |
| | − | − | + | + | − | 7.81 | 26 |
| | − | + | − | + | − | 5.50 | 2 |
| | + | − | − | + | − | 10.00 | 4 |
| | + | − | + | − | − | 6.67 | 3 |
| 3 | − | − | + | + | + | 7.50 | 2 |
| | − | + | + | + | − | 5.67 | 3 |
| | + | − | + | + | − | 6.20 | 10 |
| 4 | + | − | + | + | + | 5.00 | 1 |
| | + | + | + | + | − | 6.00 | 1 |

* A plus sign means that the structure was still deranged and a minus sign indicates that it was not.

† This table lists results for only 132 ankle injuries because complete data on all structures, including the syndesmosis, was required for inclusion.

significant. There was no reason to suspect that the missing measurements for syndesmosis C would alter the conclusions, because the differences in the mean over-all results were small and there was no identifiable bias in the process that was used to collect the data.

Having established the prognostic significance of derangements of the individual structures, we attempted to determine whether the number and pattern of derangements remaining after reduction had prognostic significance. As is shown in Table VII, the number of abnormal structures remaining after reduction was an excellent predictor of the over-all result. The more structures that were abnormal, the worse the over-all result. On the other hand, for any given number of abnormal structures remaining after reduction, no particular pattern of the abnormal structures appeared to influence the over-all result.

Patients treated by open reduction had an average of 2.84 deranged structures initially, compared with an average of 2.39 for patients treated by closed reduction ($p < 0.001$). Thus, ankles treated with open reduction tended to be more severely injured. Although both open and closed treatment reduced the total number of deranged structures, open reduction was more effective in doing so ($p = 0.020$). The effectiveness of the reduction of each of the

TABLE VIII

COMPARISON OF THE EFFECTIVENESS OF OPEN AND CLOSED REDUCTION IN CORRECTING STRUCTURAL ABNORMALITIES AND PER CENT IMPROVED*

| | − Before, + After (*No.*) | − Before, + After (*No.*) | + Before, − After (*No.*) | + Before, + After (*No.*) | Per Cent Improved† |
|---|---|---|---|---|---|
| Open reduction (89 ankles)‡ | | | | | |
| Medial malleolus | 17 | 0 | 60 | 11 | 85 |
| Deltoid ligament | 71 | 1 | 13 | 3 | 81 |
| Lateral malleolus | 14 | 0 | 47 | 27 | 64 |
| Syndesmosis | 10 | 0 | 24 | 48 | 33 |
| Posterior malleolus | 80 | 0 | 0 | 9 | 0 |
| Closed reduction (57 ankles)‡ | | | | | |
| Medial malleolus | 23 | 0 | 19 | 15 | 56 |
| Deltoid ligament | 42 | 1 | 9 | 5 | 64 |
| Lateral malleolus | 13 | 0 | 9 | 35 | 20 |
| Syndesmosis | 11 | 2 | 8 | 28 | 22 |
| Posterior malleolus | 54 | 0 | 0 | 3 | 0 |

* A plus sign indicates an abnormality and a minus sign, no abnormality. The abnormalities are defined in Table II.

† Per cent improved applies only to the structures that were abnormal before reduction. Each percentage was computed by dividing the appropriate number under "+ before, − after" by the sum of the corresponding numbers under "+ before, − after" and "+ before, + after" and then multiplying the resulting quotient by 100.

‡ The total numbers of injuries represented in this table are: 146 for the posterior malleolus, 145 each for the medial and lateral malleoli and the deltoid ligament, and 131 for the syndesmosis. This variation reflects a small number of injuries with incomplete pre-reduction and post-reduction data.

TABLE IX

OVER-ALL RESULTS COMPARING OPEN AND CLOSED REDUCTION

| Fractures | Mean (*Points*) | Standard Error (*Points*) | No. | Statistical Significance* |
|---|---|---|---|---|
| All | | | | |
| Open | 8.64 | 0.23 | 89 | |
| Closed | 8.32 | 0.29 | 57 | ns |
| Supination-external rotation grades 1, 2, and 3 | | | | |
| Open | 9.36 | 0.47 | 11 | |
| Closed | 8.54 | 0.81 | 11 | ns |
| Supination-external rotation grade 4 | | | | |
| Open | 8.65 | 0.30 | 46 | |
| Closed | 7.67 | 0.34 | 30 | $p = 0.036$ |
| Pronation-external rotation grades 1, 2, and 3 | | | | |
| Open | 8.57 | 1.15 | 7 | |
| Closed | 9.00 | 0.58 | 3 | ns |
| Pronation-external rotation grade 4 | | | | |
| Open | 8.12 | 0.52 | 16 | |
| Closed | 8.44 | 0.60 | 9 | ns |
| Supination-external rotation and pronation-external rotation grades 3 and 4 | | | | |
| Open | 8.52 | 0.24 | 75 | |
| Closed | 8.02 | 0.28 | 49 | ns |
| Supination-external rotation and pronation-external rotation grades 3 and 4 | | | | |
| Closed | 8.02 | 0.28 | 49 | |
| Open, both malleoli fixed | 9.33 | 0.26 | 43 | $p < 0.001$ (1 d.f.) |
| Open, only medial malleolus fixed | 7.66 | 0.35 | 29 | $p < 0.001$ (1 d.f.) |
| Open débridement | 5.33 | 1.45 | 3 | |

* ns means that the observed two-sided significance level exceeds 0.05 ($p > 0.05$).

deranged structures that were analyzed is expressed as "per cent improved" in Table VIII. This was calculated by dividing the number of derangements of the structure in question that were corrected by reduction by the total number of derangements of that same structure that were present initially and multiplying the resulting ratio by 100. The differences between the per cent improved after open and closed reduction were highly statistically significant for the medial malleolus ($p = 0.003$) and for the lateral malleolus ($p < 0.001$) but not for the other structures, based on the one-degree-of-freedom chi-square test for a difference in proportions[15].

The over-all results for all 146 patients (Table IX) suggest that open reduction and internal fixation leads to marginally better results than does closed reduction, but the difference was not statistically significant. This comparison did not take into account the difference in the severity of the injuries in the open-reduction and closed-reduction groups. Similar analyses of the results in the subgroups defined by the Lauge-Hansen classification of severity (Table IX) showed no statistically significant superiority of open reduction over closed reduction except in the case of supination-external rotation grade-4 fractures ($p = 0.036$). However, when we analyzed the 124 supination-external rotation grade-3 and 4 injuries and pronation-external rotation grade-3 and 4 injuries, all of which were bimalleolar fractures, we found that the results were better after open reduction and internal fixation of both the medial and the lateral malleolus than after closed reduction ($p < 0.001$). Furthermore, we found that the results after open reduction with internal fixation of both of the malleoli were better than those after open reduction with internal fixation of only the medial malleolus ($p < 0.001$). The results after open reduction and internal fixation of just the medial malleolus were slightly worse than the results after closed reduction, but this difference was not statistically significant.

### Prediction of Over-All Result

After we had analyzed the data on the first 109 patients in our series, we attempted to derive an equation that would predict the over-all results and also identify the predictors of poor and of excellent results. Several mathematical models were fitted to the data using conventional techniques of multiple linear regression as implemented by computer programs in the Statistical Package for the Social Sciences (SPSS) system. The most promising predictive equation, which was based on post-reduction anatomical derangements as defined in Table II, was: over-all result score = 10.454 minus (1.701 if the medial malleolus is displaced, 1.325 if the lateral malleolus is displaced, 2.110 if the deltoid ligament is deranged, and 0.524 if the posterior malleolus is displaced), minus 0.02659 multiplied by the patient's age in years.

This equation was tested on the thirty-seven patients who subsequently entered our study. It correctly divided thirty (81.1 per cent) of these thirty-seven patients into those with result scores of 8 points or less and those with result scores of more than 8 points. By chance alone, only 61.3 per cent correct predictions would have been accepted. The association between predicted outcome and actual outcome was statistically significant ($p = 0.002$).

## Discussion

Our study, like that of Joy et al., demonstrated that the findings by measurements on the post-reduction radiographs have statistically significant relationships with the final clinical results. In the study of Joy et al., the variables that correlated significantly with the final clinical result were the type of fracture, the amount of displacement of the talus, and the width of the medial clear space as measured on the anteroposterior radiograph (showing a tear of the deltoid ligament). In our study we found a statistically significant relationship between the over-all result and the amount of displacement of the medial and lateral malleoli, the presence or absence of disruption of the syndesmosis, and the patient's age. The width of the medial clear space also appeared important, but because only ten ankles had an abnormal clear space postoperatively our results were not statistically significant. These findings confirm the traditional precept of fracture care, that exact anatomical repositioning of the fracture should be the goal of reduction. We endeavored to identify specific radiographic measurements that might serve as objective guides in the evaluation of the adequacy of reduction. Measurements that indicate an inadequate reduction of the medial malleolus and medial clear space have been described[6,9]. Yablon et al. emphasized the importance of adequate reduction of the lateral malleolus and syndesmosis. Our study reaffirms the importance of correcting any displacement of the lateral malleolus and any disruption of the syndesmosis. Our data also showed that the number of structures that still were deranged after reduction was of prognostic significance: the more structures showing residual displacement, the poorer the outcome. Although orthopaedists traditionally make judgments of the adequacy of reduction, there have been no objective measurements to verify the soundness of these judgments. This study attempted to provide objective radiographic measurements.

Few studies of displaced ankle fractures have compared the results of open and closed treatment of similar groups of fractures. The findings in the series of 350 operatively treated ankles of Solonen and Lauttamus are difficult to compare with ours because they included all Lauge-Hansen stages. The indication for operation in their series was any fracture-dislocation, since they believed that the results of conservative treatment of these injuries were less satisfactory than those after open reduction. In the studies of Wilson and Skilbred and of Joy et al. there were only 118 fractures (forty-six treated open and seventy-two treated closed), and these authors concluded independently that no statistically valid analysis of the results of open and closed treatment was possible. The indications for surgery in the series of Wilson and Skilbred were failure of closed reduction (criteria not specified), rupture of the syndesmosis, and fracture of the medial malleolus at the level of the plafond. When we analyzed all of our fracture combinations, no statistically significant differences were detected between patients treated by open reduction and those treated by closed reduction. However, more meaningful comparisons of treatment were made within subgroups of similar fractures defined by the Lauge-Hansen classification. This classification allows one to compare methods of treatment in subgroups of fractures of similar severity and type. When the most severe injuries (supination-external rotation grades 3 and 4 and pronation-external rotation grades 3 and 4) were grouped together, the data showed that the results after open reduction and internal fixation of both malleoli were superior ($p < 0.001$) to those after closed treatment (Table IX). Forty-nine of these severe fractures were treated by closed reduction; twenty-nine, by open reduction of the medial malleolus only; and forty-three, by open reduction of both the medial and the lateral malleolus. Open reduction of both malleoli proved superior to closed reduction ($p < 0.001$), and the results following open reduction of both malleoli were superior to those following open reduction of the medial malleolus alone ($p < 0.001$). Indeed, open reduction of the medial malleolus only was associated with results that were worse than those after closed reduction, but this difference was not statistically significant. It should be recalled that these data were not obtained in a randomized trial, which leaves open the possibility that the apparent benefit of bimalleolar fixation is due to an unidentified selection bias favoring the ankles treated in this manner. Nonetheless, our observations support the contention of Yablon et al. that anatomical reduction of the lateral malleolus is clinically important.

In our series, age was a significant predictor of outcome. An increase of twenty years in age was associated with a 0.5-point decrease in the over-all final score. The age data of Joy et al. support our finding, but they did not demonstrate a statistically significant effect of age.

The described predictor equation based on age and on the post-reduction anatomical assessment may be of practical value to orthopaedists who must decide whether to accept the reduction shown by the radiograph made after reduction. We plan to test this equation further in a prospective study.

## Conclusions

In a retrospective analysis of 146 displaced ankle fractures, objective radiographic criteria for assessing the adequacy of the reduction were identified and a significant relationship was demonstrated between the adequacy of the anatomical reduction and the final over-all result which was based on subjective, objective, and radiographic criteria. When predicting the results, the following factors were most significant: age, displacement of the medial or lateral malleolus, widening of the syndesmosis, and widening of the medial clear space. The prognosis worsened as the number of deranged structures increased. A simple linear-regression model that uses this information enabled prediction of the final result with an accuracy rate of more than 80 per cent.

After closed reduction, if the lateral and medial malleoli are reduced anatomically, the syndesmosis shows no widening, and the medial clear space is normal, then one can predict a good result, especially in patients who are less than forty years old. If, however, any three of these structures are deranged according to the criteria in Table II, then one can predict an unsatisfactory result, and repeat reduction, open or closed, should be considered. Our observations suggest that open bimalleolar reduction is preferable to closed reduction in patients with a supination-external rotation grade-3 or 4 or pronation-external rotation grade-3 or 4 injury. In addition, our data suggest that when open reduction of a bimalleolar fracture is indicated, fixation of both the medial and the lateral malleolus will give a better result than fixation of the medial malleolus only. To verify these hypotheses, it would be desirable to carry out a randomized prospective trial with stratification by pattern of initial injury. We are continuing our present study to determine whether these trends are borne out when larger numbers of fractures are studied.

## References


1. Ashhurst, A. P. C., and Bromer, R. S.: Classification and Mechanism of Fractures of Leg Bones Involving the Ankle. Arch. Surg., **4:** 51-129, 1922.
2. Burwell, H. N., and Charnley, A. D.: The Treatment of Displaced Fractures of the Ankle by Rigid Internal Fixation and Early Joint Movement. J. Bone and Joint Surg., **47-B(4):** 634-660, 1965.
3. Campbell's Operative Orthopaedics: Ed. 5, edited by A. H. Crenshaw. St. Louis, C. V. Mosby, 1971.
4. Cedell, C.-A.: Supination-Outward Rotation Injuries of the Ankle. A Clinical and Roentgenological Study with Specific Reference to the Operative Treatment. Acta Orthop. Scandinavica, Supplementum 110, 1967.
5. Close, J. R.: Some Applications of the Functional Anatomy of the Ankle Joint. J. Bone and Joint Surg., **38-A:** 761-781, July 1956.
6. Joy, Gregory; Patzakis, M. J.; and Harvey, J. P., Jr.: Precise Evaluation of the Reduction of Severe Ankle Fractures. Technique and Correlation with End Results. J. Bone and Joint Surg., **56-A:** 979-993, July 1974.
7. Klossner, Olli: Late Results of Operative and Non-Operative Treatment of Severe Ankle Fractures. A Clinical Study. Acta Chir. Scandinavica, Supplementum 293, 1962.
8. Lauge-Hansen, N.: Fractures of the Ankle. IV. Clinical Use of Genetic Roentgen Diagnosis and Genetic Reduction. Arch. Surg., **64:** 488-500, 1952.
9. McDade, W. C.: Treatment of Ankle Fractures. Diagnosis and Treatment of Ankle Injuries. *In* Instructional Course Lectures, The American Academy of Orthopaedic Surgeons. Vol. 24, pp. 251-293. St. Louis, C. V. Mosby, 1975.
10. Malka, J. S., and Taillard, W.: Results of Nonoperative and Operative Treatment of Fractures of the Ankle. Clin. Orthop., **67:** 159-168, 1969.
11. Pettrone, F., and Van Herpe, L. B.: Displaced Ankle Fractures. Read at the Virginia Orthopaedic Meeting, Williamsburg, Virginia, 1979.
12. Quigley, T. B.: Analysis and Treatment of Ankle Injuries Produced by Rotatory, Abduction, and Adduction Forces. *In* Instructional Course Lectures, The American Academy of Orthopaedic Surgeons. Vol. 19, pp. 172-182. St. Louis, C. V. Mosby, 1970.
13. Rockwood, C. A., Jr., and Green, D. P.: Fractures. Philadelphia, J. B. Lippincott, 1975.
14. Snedecor, G. W., and Cochran, W. G.: Statistical Methods. Ed. 6. Ames, Iowa, Iowa State University Press, 1967.
15. Solonen, K. A., and Lauttamus, Leo: Operative Treatment of Ankle Fractures. Acta Orthop. Scandinavica, **39:** 223-237, 1968.
16. Vasli, Sverre: Operative Treatment of Ankle Fractures. Acta Chir. Scandinavica, Supplementum 226, 1957.
17. Wilson, F. C., Jr., and Skilbred, L. A.: Long-Term Results in the Treatment of Displaced Bimalleolar Fractures. J. Bone and Joint Surg., **48-A:** 1065-1078, Sept. 1966.
18. Yablon, I. G.; Heller, F. G.; and Shouse, LeRoy: The Key Role of the Lateral Malleolus in Displaced Fractures of the Ankle. J. Bone and Joint Surg., **59-A:** 169-173, March 1977.