THE ETIOLOGY AND PREVENTION OF FUNCTIONAL INSTABILITY OF THE FOOT

M. A. R. FREEMAN, M. R. E. DEAN and I. W. F. HANHAM, LONDON, ENGLAND

From the Westminster Hospital, London

Functional instability of the foot (a term used in this paper to designate the disability to which patients refer when they say that their foot tends to " give way ") follows about 40 per cent of injuries to the lateral ligament of the ankle (Bosien, Staples and Russell 1955; Freeman 1964). It has been shown elsewhere (Freeman 1964, 1965) that the pathological processes to which it is usually ascribed (such as mechanical instability of the talus in the ankle mortise, or adhesion formation) are, in fact, rarely, if ever, responsible for initiating the disability (although they may well perpetuate it once it is established).

In this paper it is suggested that functional instability of the foot is usually due in the first place to motor incoordination consequent upon articular de-afferentiation, and it will be shown that this sequel can often be prevented if patients suffering sprains of the foot and ankle are treated with coordination exercises. The suggestion that the muscles are " off their guard " after articular trauma is not new (Smart 1934, Perkins 1961) but the underlying physiology has received little attention.

Many articular nerve fibres terminate in mechanoreceptors in the capsule and ligaments of joints (Freeman and Wyke 1964*c*). These endings are stimulated both by the static position and by motion of the joint in which they lie (Skoglund 1956) and it has been shown that the central effects of such stimulation include alterations in the activity of neighbouring muscles: in general these receptors subserve reflexes, the probable effect of which is to stabilise the joints in the face of passive displacements by provoking appropriate muscular activity (Freeman and Wyke 1964*a*). In particular, the mechanoreceptors in the human foot and ankle may (among other receptors) control the instantaneous and qualitatively precise contractions of the calf muscles which must occur if the foot is to remain stable on uneven ground.

Since articular nerve fibres lie in ligaments and capsules, and since these fibres have a lower tensile strength than collagen fibres, it seems inevitable that a traction injury to a ligament or capsule will lead to the rupture of nerve fibres as well as of collagen fibres. Severance of nerve fibres must be inevitable if a ligament ruptures and the chances of neural regeneration after such an injury appear slender.

Thus, ligamentous and capsular trauma may lead to partial joint de-afferentiation and this defect may be permanent. Such injuries can be expected to interfere with the reflexes which are dependent upon articular mechanoreceptors and it has, in fact, been demonstrated that surgical neurectomy of the cat's knee (a neurological lesion equivalent to traumatic articular de-afferentiation) leads to disturbances of locomotion and reflex behaviour (Freeman and Wyke 1964*b*).

It is now suggested that: 1) the afferent nerve fibres in the capsule and ligaments of the foot and ankle subserve reflexes which help to stabilise the foot during locomotion, and 2) when the foot or ankle is " sprained " partial de-afferentiation of the injured joints occurs, so that 3) reflex stabilisation of the foot is impaired and the foot tends to " give way."

In the present study proprioceptive deficits have been sought in eighty-five patients with ligamentous injuries of the foot and ankle. Selected groups of these patients have been treated by 1) immobilisation of the foot and ankle, 2) conventional physiotherapy, or 3) exercises designed to develop coordination (rather than simply strength) of the calf muscles. Proprioceptive deficits and functional instability of the foot have been sought after the completion of treatment and their incidence has been correlated with the treatment used.

MATERIAL (Tables I and II)

Eighty-five patients presenting consecutively at the Casualty Department of Westminster Hospital with recent sprains of the foot and ankle were studied. Every patient was examined radiographically to exclude bone injury.

Forty-six patients were re-examined on average nine months after injury and a further ten patients were contacted by post ten to fifteen months after injury.

METHODS

Initial examination—A detailed clinical examination of the injured foot was carried out to define the structures injured and to assess the severity of the injury.

Stress radiography was not used in this study since only a proportion of the injuries involved the ankle, and since the authors did not feel justified in subjecting patients to the minimal risks of general or local anaesthesia in order to perform an investigation which would not have affected treatment. Thus only a crude clinical estimate of mechanical instability could be made in the recently injured ankle. (A more accurate clinical estimate could, however, be made at the final follow-up examination.)

At the time of the first examination proprioceptive deficits were sought, using a modification of Romberg's test. The patient was asked to stand first on the uninjured foot with the eyes open and then with the eyes closed, and secondly to repeat this sequence on the injured side. The patient's stability when standing on the injured foot was then compared with his stability when standing on the uninjured foot. It was argued that impaired relative stability under the conditions of this test implied a disturbance of proprioception (in the same way as does a positive Romberg's sign) provided that the performance of the test was not painful, that there was a full range of subtalar and ankle motion, and that calf muscle power was more or less normal.

When impaired stability was obvious to the examiner, the proprioceptive defect was described as " objective." In other cases the patient stated that he felt more unstable when standing on the injured leg, but no difference was obvious to the examiner. The defect in these cases was described as " subjective " and obviously less weight can be given to the sign in this group. It may, however, be noted that much sensory testing is similarly dependent upon the patient's description of his subjective state.

Treatment—The type of treatment used for each patient was chosen randomly.

Twenty-one patients were treated by immobilisation of the ankle in plaster, in which they bore weight for three weeks. Thereafter these patients wore a compression bandage but no other specific treatment was prescribed.

Thirty-two patients received on average 3 to 4 treatments in the Physiotherapy Department using ice, compression bandaging, resisted movements, stabilisation exercises and walking re-education. Treatment was designed to control swelling, to regain a full range of movement and to retain normal muscle power.

Thirty-one patients had a similar course of conventional physiotherapy, but in addition they undertook a course of exercises to develop coordination of the calf muscles. These patients received an average of 5 treatments.

The coordination exercises consisted of teaching the patient to balance upon one leg on a moving surface provided by one of two boards. The first board had a block on its under-surface curved in one plane so that the board was a see-saw. Patients were required to stand on this board with the foot placed at various angles to the axis of movement and to maintain balance with neither end of the board touching the floor. When patients had mastered this exercise they repeated the exercise on the second board, the under-surface of which was a section of a sphere. This board was, therefore, free to tip in all planes. Patients varied in their ability to stand on these boards on their uninjured foot, but all found it harder to do so on the injured

TABLE I

THE STRUCTURE OF THE STUDY

Previous symptomatic state of injured ankle	Treatment used	Number of patients initially included in the study	Number of patients finally examined	Number of patients finally contacted by post
No previous complaint or injury	Physiotherapy plus coordination exercises	20	14	2
	Physiotherapy alone	19	11	5
	Immobilisation for three weeks	13	8	3
Previous complaint or injury present	Physiotherapy plus coordination exercises	11	4	0
	Physiotherapy alone	14	5	0
	Immobilisation for three weeks	8	4	0

TABLE II

THE THREE TREATMENT GROUPS

This Table lists the points of similarity among the thirty-three patients who had previously asymptomatic ankles and who were examined at the time of the final follow-up.

Point of similarity		Treatment groups *(number of patients)*		
		Physiotherapy plus coordination exercises	Physiotherapy alone	Immobilisation for three weeks
Sex	Male	5	8	6
	Female	9	3	2
Age	Range (*years*)	14–65	17–56	20–59
	Mean (*years*)	31	32	35
Duration of clinical follow-up	Range (*months*)	6–14	6–13	5–9
	Mean (*months*)	9	10	7
Severity of bruising	Severe	7	10	4
	Moderate	1	1	2
	Mild	3	0	1
	Absent	3	0	1
Severity of swelling	Severe	7	3	2
	Moderate	1	5	0
	Mild	3	3	4
	Absent	3	0	2
Ligament injured	Lateral ligament of ankle	12	8	7
	Other and mixed	2	3	1
Initial instability standing on injured foot	Absent	3	1	1
	Subjective	0	4	1
	Objective	11	6	6

side and all appeared to be improved by treatment. Once " learnt," the ability appeared to be retained.

Coordination exercises were not started until pain had sufficiently subsided and they were continued for an average of fifty minutes in divided sessions.

Follow-up examination—Forty-six patients were re-examined six to fourteen months (mean nine months) after injury. The symptomatic and physical state of the ankle was checked and patients were again asked to perform the proprioceptive test described above. No patient was found (clinically) to have a mechanically unstable ankle. At the time of this examination the mode of initial treatment was unknown to the examiner.

In addition ten previously asymptomatic patients completed a postal questionnaire concerning the symptomatic state of their ankle twelve to thirteen months after injury.

TABLE III

FINDINGS ON CLINICAL EXAMINATION USING A MODIFICATION OF ROMBERG'S SIGN WITHIN THREE DAYS OF INJURY

Past history of complaint, or injury to the injured foot	Diagnosis	Relative stability when standing on injured leg *(number of patients)*				
		Unimpaired	No significant pain, weakness or limitation of movement		Significant pain, weakness or limitation of movement present	
			Subjectively impaired	Objectively impaired	Subjectively impaired	Objectively impaired
Absent	Pure lateral ligament injury	6	3	8	2	21
	Mixed and other ligamentous injuries	3	3	2	1	3
Present	Pure lateral ligament injury	3	2	10	1	9
	Mixed and other ligamentous injuries	2	0	1	0	5
	Total . .	14 (16 per cent)	8 (9 per cent)	21 (25 per cent)	4 (5 per cent)	38 (45 per cent)

RESULTS

Proprioceptive deficits shortly after injury (Table III)—A proprioceptive deficit was present in 25 per cent (and possibly 34 per cent) of patients, and absent in 16 per cent. In the remainder the presence of such a deficit could not be assessed because of pain, weakness or limitation of movement.

In a small random sample of uninjured subjects no difference in stability was noted between the two legs, and in the patients described above instability could not be related to hemisphere dominance.

The outcome of treatment—The findings on re-examination and on postal follow-up are set out in Table IV. Final comparisons have been based only on the previously asymptomatic patients.

The incidence of functional instability—Among patients who were previously asymptomatic, who were treated by coordination exercises, and who finally had a full range of movement, 7 per cent (one patient) finally complained that his foot had developed a tendency to " give way." The corresponding figure for similar patients treated in other ways was 46 per cent (twelve patients) (Table IV). Coordination exercises thus led to a significant ($p=0{\cdot}0088$) reduction in the incidence of functional instability (Table V). In two further patients adhesion formation (revealed by limitation of movement) may have accounted for functional instability (Table IV).

A final proprioceptive deficit—Thirty-one previously asymptomatic patients finally had a full range of subtalar movement and of these thirteen displayed a proprioceptive deficit. Two further patients were unstable when standing on the injured leg, but since they also had a limited range of subtalar motion this instability could not confidently be taken as evidence of a proprioceptive deficit (Table IV). Of these thirteen patients only two had been treated by coordination exercises. Coordination exercises thus led to a significant ($p=0{\cdot}0132$) reduction in the incidence of a late proprioceptive deficit (Table VI).

At the time of the final examination there was a significant ($p=0{\cdot}0013$) association between the presence of a clinically detectable proprioceptive deficit and the symptom of functional instability among previously asymptomatic patients with a full range of subtalar movement (Table VII). At this time no other abnormal physical signs were detected to account for functional instability save for limitation of movement in two patients (Table IV).

TABLE IV

THE FINDINGS: 1) AT THE FINAL FOLLOW-UP EXAMINATION SIX TO FOURTEEN MONTHS AFTER INJURY IN FORTY-SIX PATIENTS, AND 2) ON POSTAL FOLLOW-UP TWELVE TO FIFTEEN MONTHS AFTER INJURY IN TEN PATIENTS

	Treatment	Findings on final examination							Findings on postal follow-up	
		Complaints		Physical findings					Complaints	
		Functional instability of the foot		Proprioceptive deficit				Limitation of movement	Functional instability of the foot	
		Absent	Present	Absent	Subjective	Objective	Test inapplicable		Absent	Present
Neither previous complaint nor injury	Physiotherapy plus co-ordination exercises	13	1*	11	1	1	1*	1	1	1
	Physiotherapy alone	6	5*	3	3	4	1*	1	2	3
	Immobilisation for three weeks	5	3	4	3	1	0	0	1	2
History of previous complaint or injury present	Physiotherapy plus co-ordination exercises	3	1	3	0	1	0	0	—	—
	Physiotherapy alone	1	4	3	0	2	0	0	—	—
	Immobilisation for three weeks	1*	3	1	0	2	1*	1	—	—

* Denotes the groups including the patients whose ankle displayed a limitation of movement.

In summary it was found that patients treated by coordination exercises finally differed from the remainder in two respects; they displayed a lower incidence of functional instability of the foot and a lower incidence of a proprioceptive deficit. At the time of the final physical examination a proprioceptive deficit was the only abnormal finding which correlated with functional instability of the foot.

DISCUSSION

In the preface of this paper a hypothesis was advanced to account for functional instability of the foot following a foot or ankle sprain. This hypothesis leads to three predictions: 1) a proprioceptive deficit should be demonstrable immediately after some of these injuries; 2) this deficit should persist in patients developing functional instability; and 3) both the functional instability and the proprioceptive deficit might be ameliorated by treatment aimed at the re-establishment of motor coordination. This study confirms all three predictions.

Proprioceptive deficits have been sought in this study using a modification of Romberg's sign. This cannot be interpreted in the presence of a limited range of subtalar motion since this can itself cause instability when the patient stands on one leg (Hicks 1961). For obvious reasons the test is invalid if it is significantly painful to stand on one leg or if calf muscle power is markedly reduced.

TABLES V TO VII

The findings at the time of final examination in thirty-one previously asymptomatic patients. The patients included in Tables VI and VII, and those out of brackets in Table V, displayed no clinical abnormality (save for a proprioceptive deficit) at the time of the final examination. Ten additional patients (in brackets) are included in Table V who were contacted by post but not examined. Tables V and VI are extracted from Table IV.

TABLE V

THE RELATIONSHIP BETWEEN TREATMENT AND FINAL FUNCTIONAL INSTABILITY

		Treatment	
		With coordination exercises	**Without coordination exercises**
Functional instability	Present	0 (+1)=1	7 (+5)=12
	Absent	13 (+1)=14	11 (+3)=14

TABLE VI

THE RELATIONSHIP BETWEEN TREATMENT AND A FINAL PROPRIOCEPTIVE DEFICIT

		Treatment	
		With coordination exercises	**Without coordination exercises**
Proprioceptive deficit	Present	2	11
	Absent	11	7

TABLE VII

THE RELATIONSHIP BETWEEN FINAL FUNCTIONAL INSTABILITY AND A FINAL PROPRIOCEPTIVE DEFICIT

		Functional instability	
		Present	**Absent**
Proprioceptive deficit	Present	7	7
	Absent	0	17

Soon after injury an objective or subjective proprioceptive deficit was diagnosed by this test in 34 per cent of patients. No deficit was detected in 16 per cent. In the remainder pain or stiffness made interpretation of the test impossible, although the patient was unstable on the injured leg. If the significance of the clinical test used be accepted, it may, therefore, be concluded that ligamentous and capsular trauma at the foot and ankle produced a proprioceptive disturbance in at least 34 per cent and at most 84 per cent of the patients studied.

Treatment by coordination exercises was based upon the hope that some central process might compensate for articular de-afferentiation and its consequent proprioceptive deficit, and that such a process might be made more effective by deliberate " training." What neurophysiological events might underlie this " training " it is hard to say, but presumably a similar process occurs when a subject learns to ride a bicycle or walk a tight-rope.

The " training " process used in this study consisted of repeated attempts to balance on tilting boards. In everyday life functional instability is most obvious on uneven ground—that is, when the muscles of the calf are required to adapt their activity to meet passive displacements imposed on the foot. The tilting boards imposed similar passive displacements upon the patient's foot and therefore abstracted the essential ingredient from the everyday situation.

The number of patients finally compared in this study was small because several were lost to follow-up. As a consequence the statistical evaluation of the results was not as satisfactory as might have been hoped. Nevertheless, by pooling all the patients who were not treated with coordination exercises and comparing them with the remainder, sufficiently significant associations have been demonstrated to form the basis for conclusions.

At the time of the final examination no presently recognised pathology was detected which might have accounted for functional instability of the foot save for adhesion formation in two patients. Stress radiography was not used in this study, but a talar tilt was never detected clinically. This finding supports the previously reported conclusion that the pathological processes to which functional instability of the foot is at present ascribed rarely, in fact, initiate the disability (Freeman 1964, 1965).

The three associations demonstrated at the time of the final examination (Table V) allow the following conclusions to be drawn: 1) treatment by coordination exercises virtually eliminates the symptom of late functional instability; 2) this treatment diminishes the incidence of a persistent, detectable proprioceptive deficit; and 3) such a deficit is associated with the late symptom of functional instability.

These conclusions are strengthened by the facts: 1) that selection for a particular form of treatment was random; 2) that, probably as a consequence, the three treatment groups were closely similar with respect to many of the variables to which the differences in the final outcome might otherwise have been attributed (Table II); 3) that only previously asymptomatic patients have been finally compared, so that patients' final complaints and physical signs must have been due to the injury described in this study; and 4) that the follow-up was partly " blind."

These findings, together with the observation that a proprioceptive deficit is frequently demonstrable soon after injury, strongly support the hypothesis that the patho-physiology of capsular and ligamentous trauma includes a neurological lesion and that, at the foot and ankle, this lesion often accounts for the symptom of " giving way " of the foot.

SUMMARY

1. Eighty-five patients have been studied soon after a ligamentous injury at the foot or ankle. These patients were treated in one of three ways, and in fifty-six patients the results were evaluated six to fifteen months after injury.

2. It is concluded: *a*) that ligamentous injuries at the foot and ankle frequently produce a proprioceptive deficit affecting the muscles of the injured leg; *b*) that such a deficit is responsible for the symptom of " giving way " of the foot; and *c*) that the incidence of both the proprioceptive deficit and the symptom of " giving way " can substantially be reduced by treatment after injury with the coordination exercises described in this study.

3. The mechanism of production of the proprioceptive defect is discussed.

We wish to express our gratitude to Mr D. L. Evans for permission to study his patients and to Dr D. A. Brewerton and the staff of the Physiotherapy Department of Westminster Hospital for treating the patients on our behalf.

REFERENCES

BOSIEN, W. R., STAPLES, O. S., and RUSSELL, S. W. (1955): Residual Disability Following Acute Ankle Sprains. *Journal of Bone and Joint Surgery*, **37-A,** 1237.

FREEMAN, M. A. R. (1964): Ligamentous Injury: A Study of Injuries to the Lateral Ligament of the Ankle. *M.D. Thesis Cambridge University*.

FREEMAN, M. A. R. (1965): Instability of the Foot after Injuries to the Lateral Ligament of the Ankle. *Journal of Bone and Joint Surgery*, **47-B,** 669.

FREEMAN, M. A. R., and WYKE, B. D. (1964*a*): Articular Contributions to Limb Muscle Reflexes (1). *Journal of Physiology*, **171,** 21P.

FREEMAN, M. A. R., and WYKE, B. D. (1964*b*): Articular Contributions to Limb Muscle Reflexes (2). *Journal of Physiology*, **171,** 56P.

FREEMAN, M. A. R., and WYKE, B. D. (1964*c*): The Innervation of the Cat's Knee Joint. *Journal of Anatomy*, **98,** 299.

HICKS, J. H. (1961): The Three Weight-bearing Mechanisms of the Foot. In *Studies of the Musculo-skeletal System*, p. 172. Editor: F. Gaynor Evans. Springfield, Illinois: Charles C. Thomas.

PERKINS, G. (1961): *Orthopaedics*, p. 607. London: The Athlone Press.

SKOGLUND, S. (1956): Anatomical and Physiological Studies of Knee Joint Innervation in the Cat. *Acta Physiologica Scandinavica*, **36,** Supplementum 124, 7.

SMART, Sir M. (1934): Pathology and Treatment of Sprains. *British Medical Journal*, **ii,** 673.