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Kinematics of the ankle and foot

In vivo roentgen stereophotogrammetry

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Introduction

Kinematics is the science of motion alone. It is in itself fundamental in the science of biomechanics. Part of its significance relates to the understanding of other biomechanical disciplines, such as kinetics, i.e. the analysis of forces associated with motion. Knowledge of the functional relationships of the joints of the ankle/foot complex is important for the correct calculation of joint loads and torques, and for the understanding of the biomechanical background of joint disease and implant design (Kempson et al 1975, Pappas et al 1976, Samuelson et al 1983).

Most joints of the human locomotor system were originally considered to be functionally simple, but detailed analysis has often disclosed more complex mechanisms. The ankle/foot complex consists of 28 bones with more than 70 articulating surfaces. Most of the joints have been seen as either functionally simple or of little significance. Examples of the former are the talo-crural and the talo-calcaneal joints which have often been described as simple hinges (Inman 1976, Stauffer et al 1977, LaMont 1986, Seiler 1986), and examples of the latter are the tarso-metatarsal joints (Lapidus 1963). Some studies have indicated more complex relationships (Barnett and Napier 1952, Hicks 1953, van Langelaan 1983, Engsberg 1987). Detailed in vivo investigations have only been performed of the kinematics of the lateral malleolus (Kärrholm et al 1985, Ahl et al 1987).

There is at present no method available that can be used to analyse accurately all joints of the ankle and foot under dynamic conditions; existing methods all imply a choice between accuracy and dynamic assessment. This presentation is based on a static in vivo roentgen stereophotogrammetric investigation of the ankle/foot complex in different forms of input motion.

Object of study

The purpose of the investigation was to elucidate the kinematical properties of the normal ankle/foot joint complex in vivo under full body load.

Specific aims

To analyse the patterns of motion of each individual joint between the tibia and the first metatarsal in input

- plantar flexion/dorsiflexion of the foot,
- pronation/supination of the foot, and
- internal/external rotation of the leg,

To analyse the degree to which the ankle/foot joint complex can transfer leg rotation into foot pronation/supination and vice versa, and

To determine the movements of the fibula in relation to the tibia (motion at the distal tibio-fibular syndesmosis) in the above mentioned input motions of the foot and leg.

Terminology

In *this* presentation:

The *ankle* joint is synonymous with the talocrural joint.

The terms *tarsal* joints and *subtalar* joints are used where results reached by other investigators who have used these terms are discussed. These terms are both taken to refer to all joints between the talus, the calcaneus, the navicular and the cuboid bones and are only to be seen as functional terms. Whenever appropriate, the joints have been referred to by the names of the articulating bones, i.e. the talo-navicular joint, the calcaneo-cuboid joint etc.

The *joints of the arch* is a term occasionally used for the joints between the talus and the first metatarsal when these joints act together. The use of the word *arch* itself is not to be taken as a statement against the capacity of the foot to function in ways reminiscent of a truss (Lapidus 1963), a windlass (Sammarco 1980), a spring (Ker et al 1987), or any other mechanical entity, invented or found in nonliving objects.

The *cardinal planes* are named according to standard anatomical nomenclature, i.e. sagittal, frontal and horizontal.

The *axes* of the three-dimensional coordinate system used for presentations are named transverse, vertical and antero-posterior. From an anatomical point of view this is a partial concession to orthopedic usage. These terms were chosen simply because their connotations are unequivocal as long as it is kept in mind that they refer to the orientations of the axes, not the corresponding planes.

Rotation about the transverse axis is designated plantar flexion/dorsiflexion. Rotation about the antero-posterior axis is called pronation/supination and rotation about the vertical axis is called internal/external rotation. These terms are used irrespective of whether the motion described is one introduced into the system or one recorded. This distinction is instead made through use of the terms *input* rotation and *resulting* rotation wherever confusion might otherwise arise. The term input *arc* is used for the total amount of motion between the neutral position and each endpoint, i.e. 30 degrees of plantar flexion to the neutral position, neutral to 30 degrees of dorsiflexion, 20 degrees of pronation to neutral etc. Resulting rotation has in all instances been *calculated* as motion of the distal segment in relation to the proximal for each pair of segments. Data is also *presented* in this way, except for resulting rotaton of the tibia and the talus about the vertical axis in input pronation/supination of the foot. Resulting rotations and translations in relation to the axes of the coordinate system are called *component* rotations and translations, as they represent the six components of a complex three-dimensional motion.

A *segment* is in rigid body kinematics an entity, the internal structure of which is assumed not to change between different positions in time. In this presentation, the segments are the bones studied.

Joint helical axis is a term used for a calculated axis about which rotation may be assumed to have taken place between two discrete relative positions of two segments. This means that two relative positions are compared and the single axis is calculated that comes closest to satisfying the condition that the difference between the positions should be explained by rotation about that axis alone.

Abbreviations have been avoided, except in the illustrations, where the bones are denoted by the first three letters of their names (*Tib* for tibia, *Met* for metatarsal etc). *Pf* stands for plantar flexion, *df* for dorsiflexion, *pro* for pronation, *sup* for supination, *int* for internal rotation, and *ext* for external rotation.

Review of literature

Normal kinematics of the ankle and foot

Fibular motion

The significance of the difference in width between the anterior and the posterior margin of the joint surface of the talar trochlea observed in most studied anatomical specimens has been, and still is, one of the most controversial topics in the field of ankle and foot mechanics. The width difference has long been recognized (Bromfeild 1773, Sewell 1904), and its apparent demand on ankle mortise widening in dorsiflexion has been increasingly appreciated (Ashhurst and Bromer 1922, Bonnin 1950, Grath 1960, Inman 1976, Kärrholm et al 1985, Ahl et al 1987). The amount of widening found in different investigations ranges from 0 (Lauge Hansen 1942) to more than 2 mm (Ashhurst and Bromer 1922). Some investigators have found it insufficient to correspond to the observed difference in width of the edges of the talar trochlea, and additional explanations, such as rotation of the fibula about its longitudinal axis, have been postulated (Close 1956, Lederman and Cordey 1984). Inman (1976) in a study of cadaveric specimens stated that the difference in width was unimportant for joint kinematics in most of the examined specimens. Antero-posterior translation of the fibula has been noted by some investigators (Lane 1905, Alldredge 1940) while others have failed to demonstrate any significant motion of this kind (Ashhurst and Bromer 1922, Close 1956). Cranio-caudal translation of the fibula is also a matter of controversy; some investigators have found significant amounts of such motion (Lane 1905, Weinert et al 1973, Cedell 1975, Scranton et al 1976, Reimann et al 1986), others have not (Alldredge 1940, Close 1956).

The talo-crural joint

This is probably the most studied joint in the ankle/foot complex. It is also assumed to be a joint where motion can be measured by non-invasive methods. The joint axis is in early texts often assumed to be horizontal (Fick 1911), but later authors have generally agreed that the conical shape of the talar trochlea will make the joint axis tend to incline downwards laterally when projected onto the frontal plane, and postero-laterally when projected onto the horizontal plane (e.g. Isman and Inman 1969).

In an investigation of the radii of the sides of the talar trochlea Barnett and Napier (1952) found evidence of a change in orientation of the joint axis close to the neutral position between plantar flexion and dorsiflexion. This was supported by an investigation by Hicks (1953), who found the joint axis to be different in plantar flexion as compared to dorsiflexion (Figure 1). Isman and Inman (1969) could not demonstrate such a mechanism. Inman (1976) found indication of variations between individuals, but considered the talar trochlea to be part of a cone, which would not make any greater changes in joint axis inclination necessary. A line drawn through the tips of both malleoli was stated to be a good approximation of the joint axis for practical purposes. This joint axis orientation has also been found in early hominids (Latimer et al 1987).

In a roentgen stereophotogrammetric investigation of the influence of leg rotation on the tarsal joints van Langelaan (1983) found the joint axis to be inclined downwards laterally except at the start of external rotation from a position of maximum internal rotation, where the joint axis tended to incline downwards medially. Many authors still assume that the function of the talo-crural joint is that of a simple hinge (Seiler 1986, LaMont 1986)

Rotation about the vertical axis in the talo-crural joint has often only been mentioned as a side effect of the inclination of the joint axis (Inman 1976, Morris 1977). However, some authors have referred to rotation about the vertical axis as a quality of motion of its own, separate from plantar flexion /dorsiflexion. The range of rotation has been reported to be 6-15 degrees with ligaments intact (Close 1956, McCullough and Burge 1980, Rasmussen et al 1982). In these investigations, the range of rotation increased after transection of different ligaments. This finding is consistent with the observation by Stormont et al (1985) that soft tissue constraints provide approximately 70 % of the stability of the ankle in rotation.

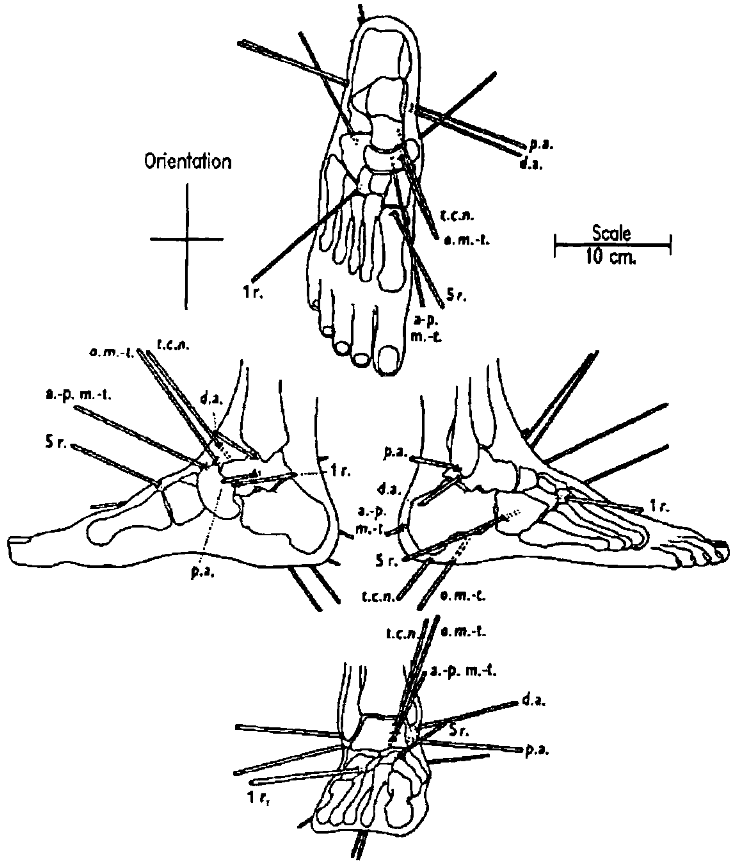

Figure 1. Joint axes of the ankle/foot complex according to Hicks (1953). Reproduced with permission. pa plantar flexion ankle; da dorsiflexion ankle; tcn talo-calcaneo-navicular, a-p mt antero-posterior midtarsal; omt oblique midtarsal.

The range of plantar flexion/dorsiflexion has been analysed by several investigators, both radiographically (Weseley et al 1969, Sammarco et al 1983), and by goniometry (Glanville and Kreezer 1937, Boone and Azen 1979, Roaas and Andersson 1982, Dick et al 1984, Lindsjö et al 1985, Sepic et al 1986). The values found range from 23 to 56 degrees of plantar flexion and from 13 to 33 degrees of dorsiflexion. Plantar flexion values were lower in the radiographic investigations. These can be assumed to be less subject to errors caused by motion below the talo-crural joint level, which also influences active, unloaded, examinations more than it does passive, loaded, assessment of plantar flexion range (Rowley et al 1986).

Investigations of dynamic ankle joint kinematics generally represent measurements of the total sagittal plane rotation occurring between foot and leg. Wright et al (1964) in an electro-goniometric investigation found approximately 10 degrees of plantar flexion and 20 degrees of dorsiflexion in normal walking. Optical methods have given values of approximately 10 degrees of dorsiflexion and 15–30 degrees of plantar flexion in normal gait (Murray et al 1964, Stauffer et al 1977, Cairns et al 1986). Racewalking (Cairns et al 1986) has been shown to substantially increase dorsiflexion, whereas an increase in cadence during normal walking tends rather to decrease the range of dorsiflexion (Zarrugh and Radcliffe 1979, Murray et al 1984). Stair walking increases both dorsiflexion and plantar flexion (Andriacchi et al 1980).

Ranges of motion in rising from a sitting position (10 degrees, Nuzik et al 1986) and from squatting (32 degrees, Ekholm et al 1984) have also been analysed.

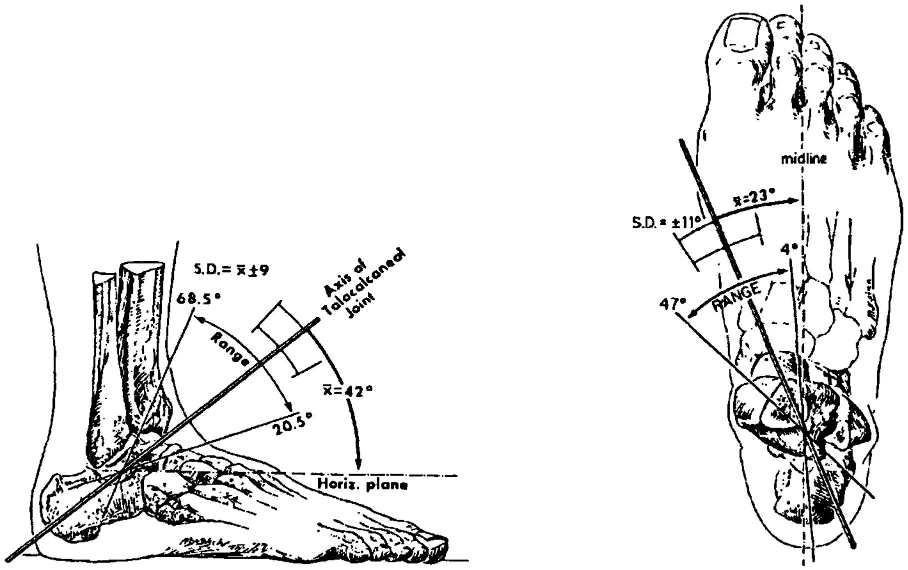

Figure 2. Subtalar joint axis according to Inman (1976). Reproduced with permission.

The subtalar or peritalar joints

Some authors use these termsas synonyms of the talo-calcaneal joint, while others have included the talo-navicular joint. Yet others have not defined the exact meaning of the term.

Subtalar joint complex as a whole (talo-calcaneo-navicular joint). The orientation of the axis of this joint system has been the subject of considerable discussion in the literature. The fact that the subtalar joint is unable to move in only one of the anatomical planes at a time has been noted by many investigators (Fick 1911, Manter 1941, Jones 1945, Hicks 1953, Isman and Inman 1969, Inman 1976), and the joint axis has been determined in pin tracing investigations on anatomical specimens to run in an oblique infero-postero-lateral to supero-antero-medial direction (Figure 2). The most widespread interpretation of this is that the function of the joint is to take up leg rotation occurring in gait (Levens et al 1948) by transferring it into pro/supination of the foot (Lovett and Cotton 1898, Hicks 1953, Inman 1969). However, as pointed out by Jones (1941), this construction does not exist in all animals, and many fast-running species are able to do without an equivalent of the oblique-axis subtalar joint seen in man.

When measuring range of motion in living subjects is attempted, the total motion between the foot and the leg induced by sideways rotation of the foot about its long axis is generally implied, as the position of the talus cannot be determined. Values found in normal subjects by goniometric techniques range from less than 30 to approximately 60 degrees (Boone and Azen 1979, Roaas and Andersson 1982, Sepic et al 1986).

One attempt to assess subtalar motion by an electro-goniometric technique involved defining the joint axis of this joint as an axis about which the foot could be freely pronated and supinated (Wright et al 1964). This would imply the talo-calcaneo-navicular joint complex, but no method of finding out whether the method in question actually measures motion in this joint complex has been offered. Average motion under dynamic conditions was 6 degrees for a normal stride in the only subject where this kind of motion was analysed.

When optical methods have been used, pro-/supinatory motion visible from behind has generally been assumed to represent subtalar joint motion. High speed filming has revealed that the amount of pronation occurring after heel strike may vary considerably between individuals (Bates et al 1979, Clarke et al 1983, Frederick 1986). This is probably not directly related to the height of the medial arch (Gould 1983) although the relationship between anatomy and mobility remains unclear.

Individual joints of the subtalar complex (talo-calcaneal joint). This joint is generally described as a hinge joint. Motion has been analysed by pin tracing and photogrammetric techniques. Close et al

(1967) studied motion in vivo by optical identification of pins drilled into the talus and the calcaneus. Mean axis deviation to the midline of the foot was found to be 16 degrees medially and mean inclination to the horizontal plane 42 degrees. Ranges of motion were 10 to 28 degrees. In the most accurate analyses hitherto performed, photogrammetric techniques have been used to study anatomical specimens (van Langelaan 1983, Engsberg 1987). In van Langelaans investigation the joint axis was found to change position for different 10 degree intervals of input tibia rotation although a tendency towards parallellity was seen. Engsberg (1987) found joint axes when motion was introduced about each of the axes of an orthogonal coordinate system to be varying in both position and orientation.

Talo-navicular joint. The talo-navicular joint itself has only been investigated in anatomical specimens (Ambagtsheer 1978, van Langelaan 1983, Benink 1985). As in the talo-calcaneal joint, different axes were seen in different input intervals. The talo-navicular joint is mostly described as being of roughly ball-and socket type, and it has been shown to be the most mobile joint in the tarsal area (van Langelaan 1983), with a range of motion often exceeding 40 degrees.

The transverse tarsal joint (mid-tarsal joint, Chopart's joint)

This term is sometimes used for the combination of the talo-navicular and the calcaneo-cuboid joints. Elftman (1960) studied the curvatures of the joint surfaces of these joints and drew the conclusion that in supination of the foot the two joints' axes of motion would intersect and decrease their motion potential. In pronation, on the other hand, the joint axes would be parallel and thus allow a greater freedom of motion, making the pronated (flat) foot more flexible and less stable. Elftman also stated that the joint axis orientation of the transverse tarsal joint was approximately midway between those of the talo-crural and talo-navicular joints.

Manter (1941) and Hicks (1953) found evidence of two different joint axes in this joint (apart from the talo-calcaneo-navicular mentioned above; Figure 2). These were both oblique, infero-postero-lateral to supero-antero-medial, in orientation. They differed in inclination, one being more horizontal than the other. Hicks stated the range of motion for the more oblique axis to be 22 degrees, and for the more horizontal as 8 degrees. These axes were possible axes of rotation (i.e. the bones proximal and distal to the joint could be made to move about only one of them at a time) but Hicks stated that both could also be used simultaneously.

The term transverse tarsal joint was not accepted by Inkster (1938) who stated that the talo-calcaneal and the talo-calcaneo-navicular joints were the only more mobile articulations between the talo-crural and the metatarso-phalangeal joints. The calcaneo-cuboid was described as "one of the joints in the more rigid middle part of the foot".

In van Langelaan's (1983) investigation of the tarsal joints the calcaneo-cuboid joint displayed a wide variation of joint axis deviations and inclinations. Variations between successive steps of external rotation were also considerable, indicating a ball and socket rather than a hinge function. Ranges of rotation from maximum internal rotation to maximum external rotation were 9 to 25 degrees.

Mobility between the navicular and the cuboid has been assumed to be small from clinical examinations and this finding has been confirmed by the few investigators who have studied it specifically (van Langelaan 1983).

The joints of the arch

This term includes the talo-navicular joint and those joints designated "the first ray joint" by Hicks (1953), i. e. the joints proximal and distal to the medial cuneiform. Hicks described the axis of this "joint" as running in a roughly antero-posterior direction with a slight medial deviation anteriorly (Figure 2) and stated that its range of motion was 22 degrees. How this amount of rotation was induced was not explicitly stated.

The only method of motion assessment used to analyse these joints to any extent in vivo is plain radiography with comparison of maximally plantar flexed and maximally dorsiflexed positions, mainly in cases of ankle fusion. This is not strictly a matter of normal kinematics even if the joints of the arch have been clinically free of disease. In cases of unilateral ankle fusion Jackson and Glasgow (1979) found an average range of motion of 19 degrees for both sides.

One interesting aspect of the kinematics of the arch is that the course of the plantar aponeurosis from the calcaneus to the toes makes plantar flexion in these joints (raising of the arch) a natural consequence of dorsiflexion of the toes (Hicks 1954, 1955). The resulting arch plantar flexion has been stated to be 10 degrees (Hicks 1954). This function has also been studied indirectly by placing strain gauges between skin attachments over the calcaneus and the first metatarsal (Kayano 1986).

The tarso-metatarsal joints (Lisfranc's joint)

These joints are generally described as relatively immobile. Lapidus (1963) stated that they "deserve to be mentioned only for the sake of history, reminding us of the days when surgeons adroitly exarticulated through the tarso-metatarsal joints without even removing their starched cuffs". In many works on foot biomechanics they have been left out altogether (Isman and Inman 1969, Morris 1977). Hicks (1953) examined the motion of "the fifth ray joint", comprising the joints between the talus/cuboid and the fifth metatarsal, and stated that the joint axis ran in an oblique inferio-postero-lateral to superio-antero-medial direction (Figure 2). The range of motion was reported to be 10 degrees.

On the whole, information concerning ankle/foot kinematics is limited for several reasons: Methods applicable in accurate analysis of complex joint systems are few. The available methods (pin tracing techniques and roentgen stereophotogrammetry) have only been used to study limited parts of the joint complex, or isolated forms of input motion. Investigators who have studied the ankle and foot have in most cases only studied anatomical preparations. The literature lacks a comprehensive in vivo analysis of the ankle/foot complex, taking different forms of input motion into consideration.

Materials and methods

Subjects

Eight healthy volunteers participated in the investigation. The subjects were 26–38 years old; six were male and two female. The study was approved by the ethical committee of the Karolinska Hospital and the subjects gave their informed consent. None of the subjects had any history of joint disease or previous foot injury.

Examined segments

Under local anesthesia, 0.8 mm tantalum markers were introduced into the tibia, fibula, talus, calcaneus, navicular, medial cuneiform and first metatarsal bones of the right foot. A spring loaded insertion device (Aronson et al 1974) was used. In two of the subjects, markers were also introduced into the cuboid bone. The number of segments marked was limited both by the demand that all segments should be identifiable on the films, and by the level of discomfort to the subjects that could be accepted. Markers were also prior to the last examinations introduced into the platform, to determine motion of the calcaneus in relation to the substratum.

No complications occurred, and any stiffness experienced by the subjects resolved within one week. Examinations were performed four to ten weeks after insertion of the markers.

Calibration of experimental setup

Two standard X-ray tubes, one stationary and one mobile, were aimed at two X-ray cassette holders mounted at right angles on a metal frame. Two plexiglass sheets containing embedded 0.8 mm tantalum markers were attached in front of the cassette holders as a reference system.

A calibration cage, also made from plexiglass and containing embedded markers was placed within the reference system (Figure 3). Two 24 x 30 cm X-ray cassettes (Kodak Hi-Mammo) were exposed at an exposure setting of 110 kV, 4.0 mAs.

Radiographic examinations

The calibration cage was removed and replaced by a platform that could be tilted about one transverse and one antero-posterior axis. The platform, which was also equipped with a removable device mounted about the proximal tibia to allow registration of leg rotation, was placed in a position of slight internal rotation to facilitate identification of the markers and to obtain true antero-posterior and lateral views of the ankle. The subject was told to stand at ease with the right foot on the platform, and to raise the left foot off the ground (Figure 4). The platform was slowly tilted into 30 degrees of plantar flexion and a pair of cassettes was exposed. New

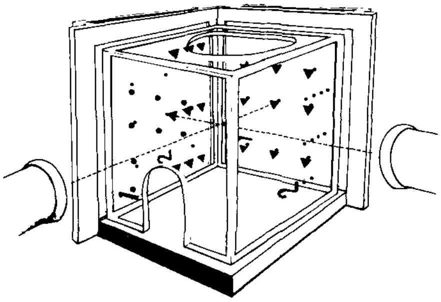

Figure 3. Calibration setup.

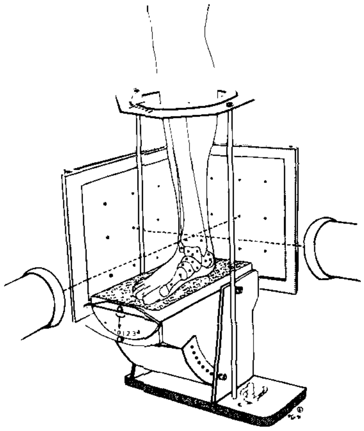

Figure 4. Experimental setup.

pairs were exposed in 20 and 10 degrees of plantar flexion and in the neutral position. The subject was then told to incline the lower leg forward, still under full body load, until a goniometer placed beside the foot read ten degrees of dorsiflexion. Additional pairs of films were exposed in this position, and in 20 and 30 degrees of dorsiflexion. All dorsiflexion positions were attained in this way as it was considered to represent a more natural form of dorsiflexion under load than that induced by tilting of the platform.

The platform was tilted into 20 degrees of pronation. New pairs of films were exposed in this position, and in ten-degree steps up to 20 degrees of supination.

The subject was then asked to rotate the leg internally to a reading of 20 degrees on the device mounted at the proximal tibia. Exposures were made in ten-degree increments up to ten degrees of external rotation.

Data processing

After developing all films, the positions of all markers on both films of each pair were identified manually. A Wild Autograph A8 photogrammetric table was used to digitize the marker positions which were fed into a Sperry 1100 computer.

Calculation procedure

From the calibration film pair the relative spatial positions of all calibration cage markers, reference markers, and both X-ray foci were calculated. The reference markers in all subsequent film pairs were used to reconstruct an imaginary copy of the calibration cage. This was utilized to calculate the positions of all segments in space. Rigid body kinematical analysis was used to calculate the relative motion of all segments that had occurred between different input foot positions, the roentgen stereophotogrammetric procedure can from earlier studies be assumed to be accurate to approximately 0.2 degrees of rotation and 0.1 mm of translation (Selvik 1974, 1983, 1989).

The calculations related to a three-dimensional coordinate system, with its origin in the center of gravity of the group of markers in the most proximal segment of each compared pair. One of the axes was parallel to the central ray of the lateral X-ray projection, one was vertical, and one was antero-posterior (Figure 5).

Motion was calculated as:

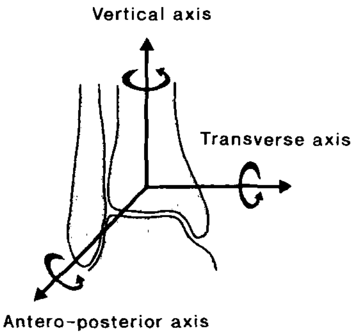

Figure 5. The coordinate system.

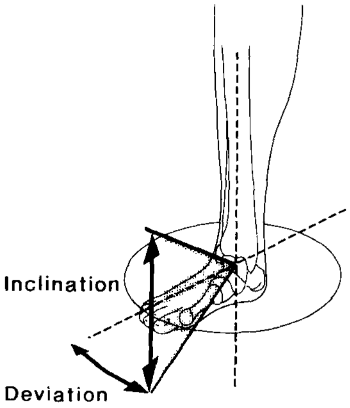

Figure 6. Illustration of the terms "deviation" and "inclination".

Component rotations and translations in relation to each axis of the three-dimensional coordinate system compared to the neutral position. This information was not corrected for differences in foot position between subjects, and its only anatomical correlate is that the transverse axis of the coordinate system is in each case approximately parallel to a frontal plane through the malleoli.

Joint helical axis data for each ten-degree interval, and for each input arc. Data were calculated as resulting rotation, joint axis deviation to the midline of the foot, and joint axis inclination to the horizontal plane (Figure 6). To allow the drawing of joint axes from different subjects in the same standard set of figures, this information has been corrected for differences in foot position, and size, in the following manner:

Ankle joint

The tips of the malleoli were identified on the radiographs taken in the neutral position. The

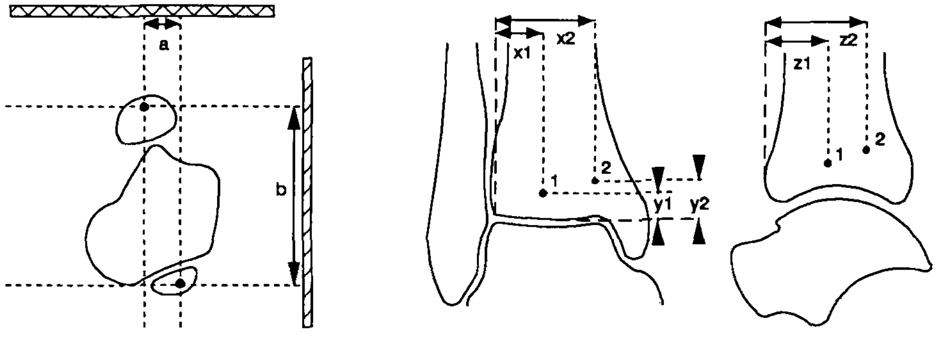

Figure 7. Correction procedure for the ankle joint. Left. Offset angle between lateral X-ray and bi-malleolar line = arctan (a/b). Right. Distances used to calcute approximate position of center of gravity of tibia segment (only two markers indicated).

distance between their projection points in the lateral view was divided by the distance between their projection points on the antero-posterior view (Figure 7). The arctangent of the resulting figure was seen as a value of the offset angle, which was subtracted from the calculated deviation values. As the horizontal plane projections of all joint axes were close to parallel and all deviations after correction were close to 90 degrees, the inclination of the frontal plane projection of each joint axis was used as a value of its true inclination to the horizontal plane. The relative position of the center of gravity of the group of markers in the tibia was also calculated. The distance of each marker from the distal lateral and distal ventral corners of the tibia, and the vertical distance from the most proximal point on the tibial joint surface were measured, as well as the total width across the malleoli (Figure 7). The distance of the center of gravity from the points mentioned was calculated, multiplied by 100 and divided by the total ankle joint width to get the position of the center of gravity in relation to a standard representation of the ankle, 100 mm wide.

Other joints

The angle between the midline of the foot and the central ray of the antero-posterior radiograph was calculated as the arctangent of the distance between a point midway between the second and third metatarsal heads and the midpoint of a line drawn between the upper medial and upper lateral corners of the trochlea tali in the antero-posterior radiograph, divided by the same distance measured on the lateral radiograph (Figure 8). The distances of all markers from tangential lines through the most ventral, medial and dorsal points on the outline of each bone were measured and used to calculate the approximate position of the center of gravity of each segment in each individual (Figure 8).

It should be noted that the points and angles calculated in this way represent approximations used to make possible the drawing of joint axes from different subjects in the same illustrations, and comparison between individuals. Differences in position and orientation of joint axes used in different input arcs of motion in each individual are derived directly from the roentgen stereophotogrammetric information and unaffected by any possible inaccuracy of the correction procedure. This is also true of the values of resulting rotation.

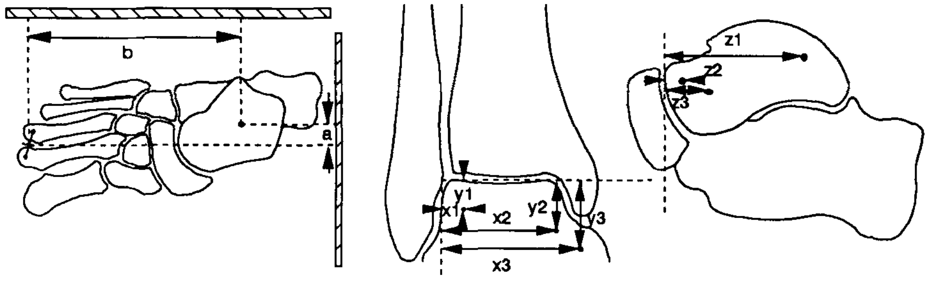

Figure 8. Correction procedure for other joints. Left. Offset angle between antero-posterior X-ray projection and midline of foot = arctan (a/b). Right. Distances used to calculate approximate position of center of gravity.

Results

For each individual articular joint, joint helical axis data (resulting rotations, joint axis deviations and inclinations) is presented. Movements of the fibula are presented as component rotations and translations in relation to the axes of the coordinate system. For analysis of interaction between joints, and presentation of motion between segments that are not adjacent, component rotations in relation to the coordinate system axes have been used.

Motion in individual joints

Talus-tibia (Table I)

All joint axis deviations in the talo-crural joint were close to 90 degrees after correction, i.e. all axes were close to parallel to the bimalleolar axis. The inclinations of the frontal plane projections have therefore been used as join axis inclination values. In the dorsiflexion arc the joint axis of the talo-crural joint showed inclination downwards laterally (Figure 9). In most input intervals, the resulting amount of rotation was close to the input, ie ten degrees. In plantar flexion the joint axis was more horizontal or inclined downwards medially. The resulting amounts of rotation were sometimes similar to the input. However, resulting amounts of rotation exceeding the input were often seen (see appendix). In internal rotation joint axis orientations were often more vertical (Figure 10). Pro-/supination and external rotation axes showed inclinations varying between horizontal and vertical. Resulting amounts of rotation varied, joint axes representing larger amounts of rotation were often more transverse (see appendix). When joint helical axes for all 10 degree intervals in each individual were superimposed, they were seen to cross within a small area, located centrally in the talar trochlea (Figure 11; Lundberg et al 1989a).

Table 1. Talus-tibia. Average resulting rotations and joint helical axis inclinations. Mean *SD*

	Resulting rotation		Joint axis inclination	
Plantarflexion	28.5	*7.5*	-2	*5*
Dorsiflexion	24.9	*3.0*	19	*3*
Pronation	3.2	*1.7*	13	*16*
Supination	4.1	*2.2*	25	*45*
Internal rotation	5.7	*2.1*	64	*16*
External rotation	6.1	*4.0*	21	*23*

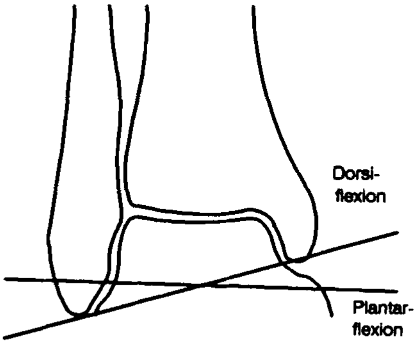

Figure 9. Average talo-crural joint axes in plantar flexion (PF) and dorsiflexion (DF).

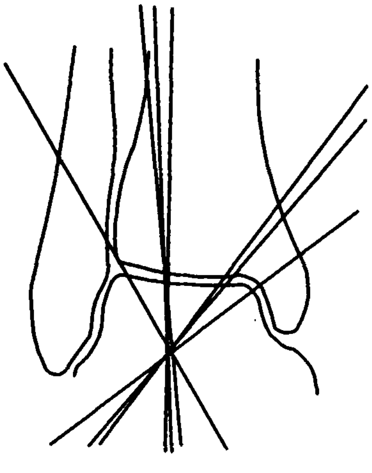

Figure 10. Individual talo-crural joint axes in internal rotation.

Navicular-talus (Table 2)

Average joint axis deviations in the talo-navicular joint varied between different inputs (Figure 12). In most instances where motion occurred in the talo-

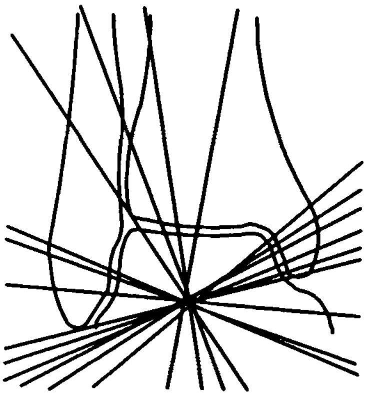

Figure 11. Talo-crural joint helical axes for all ten degree intervals in all inputs in one subject.

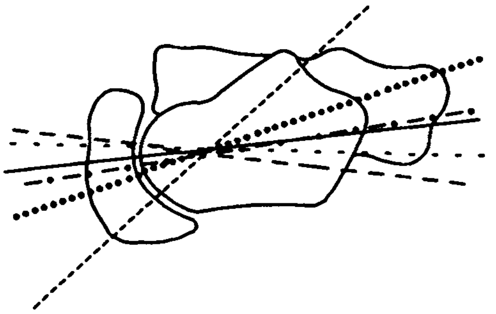

Figure 12. Average talo-navicular joint axis deviations in different inputs. —— internal, ····· external, – – – pronation, _._._ supination, ---- plantar flexion and - - - dorsiflexion.

navicular joint, the joint axis showed deviations between 0 and 90 degrees, indicating a joint axis running in an antero-medio-superior to postero-latero-inferior. However, average deviations ranged from -7 degrees (pronation) to 42 degrees (plantar flexion). Inclinations also varied between different inputs in each individual, although average values were in the range 19 to 34 degrees. Average resulting amounts of rotation ranged from less than four degrees (internal rotation) to 19 degrees (external rotation). In plantar flexion, dorsiflexion and internal rotation, resulting rotations were smaller than those observed in the talo-crural joint. In the other input qualities of motion, the talo-navicular joint showed the largest amounts of resulting rotation (Table 3).

Calcaneus-talus (Table 4)

Average deviations in the talo-calcaneal joint showed less variation than the corresponding values for the talo-navicular joint with average deviations ranging from 23 to 37 degrees (Figure 13). Individual variations were large, particularly for

Table 2. Navicular-talus. Average resulting rotations, joint helical axis deviations and inclinations. Mean *SD*

	Resulting rotation		Joint axis deviation		Joint axis inclination	
Plantarflexion	7.8	*3.2*	42	*19*	34	*12*
Dorsiflexion	5.6	*2.8*	-2	*37*	19	*10*
Pronation	8.2	*6.0*	-7	*14*	19	*11*
Supination	15.6	*3.9*	9	*9*	22	*4*
Internal rotation	3.8	*2.7*	7	*15*	27	*13*
External rotation	19.2	*6.9*	22	*7*	34	*6*

Table 4. Calcaneus-talus. Average resulting rotations, joint helical axis deviations and inclinations. Mean *SD*

	Resulting rotation		Joint axis deviation		Joint axis inclination	
Plantarflexion	4.3	*1.6*	34	*16*	32	*16*
Dorsiflexion	3.1	*1.9*	34	*19*	31	*13*
Pronation	4.5	*3.9*	33	*8*	29	*17*
Supination	9.9	*3.5*	31	*14*	33	*5*
Internal rotation	2.1	*1.4*	23	*17*	29	*15*
External rotation	11.6	*4.5*	37	*12*	38	*4*

Table 3. Average values of resulting rotation in different joints for each input. Degrees

	Talus-tibia	Navicular-talus	Calcaneus-talus	Cuboid-calcaneus	Cuboid-navicular	Medial cuneiform-navicular	First metatarsal-medial cuneiform
Plantar flexion	28.5	7.8	4.3	3.0	3.1	2.7	1.5
Dorsiflexion	24.9	5.6	3.1	2.2	1.5	2.1	1.7
Pronation	3.2	8.2	4.5	4.2	7.7	4.6	2.9
Supination	4.1	5.6	9.9	1.6	7.8	3.8	1.6
Internal rotation	5.7	3.8	2.1	0.8	3.7	0.9	2.3
External rotation	6.1	19.2	11.6	4.5	8.5	7.7	2.4

Table 5. Cuboid-calcaneus. Individual values of resulting rotation, joint helical axis deviation and inclination

	Resulting rotation		Joint axis deviation		Joint axis inclination	
Plantarflexion	3.4	2.5	-54	32	30	39
Dorsiflexion	1.4	1.6	-4	-30	42	25
Pronation	9.8	5.6	-15	-13	30	18
Supination	10.1	5.4	-10	-8	26	18
Internal rotation	2.6	4.8	-15	-14	41	13
External rotation	6.4	10.6	3	14	52	35

Table 6. Cuboid-navicular. Individual values of resulting rotation, joint helical axis deviation and inclination

	Resulting rotation		Joint axis deviation		Joint axis inclination	
Plantarflexion	2.2	3.1	-60	-73	46	24
Dorsiflexion	1.5	2.6	-37	-40	7	4
Pronation	3.7	5.5	89	-48	60	8
Supination	1.6	5.9	-47	-44	46	16
Internal rotation	1.2	0.5	-7	1	70	37
External rotation	3.9	11.5	-9	-25	16	69

Table 7. Medial cuneiform-navicular. Average resulting rotations, joint helical axis deviations and inclinations. Mean *SD*

	Resulting rotation		Joint axis deviation		Joint axis inclination	
Plantarflexion	3.0	*2.8*	21	*13*	10	*9*
Dorsiflexion	2.2	*1.3*	19	*22*	19	*15*
Pronation	4.2	*2.1*	14	*9*	15	*18*
Supination	1.6	*1.1*	30	*23*	27	*18*
Internal rotation	0.8	*0.4*	28	*22*	24	*22*
External rotation	4.5	*2.6*	16	*15*	5	*6*

Table 8. First metatarsal-medial cuneiform. Average resulting rotations, joint helical axis deviations and inclinations. Mean *SD*

	Resulting rotation		Joint axis deviation		Joint axis inclination	
Plantarflexion	1.5	*0.8*	18	*15*	21	*16*
Dorsiflexion	1.7	*0.9*	13	*46*	41	*16*
Pronation	2.9	*1.2*	4	*22*	39	*25*
Supination	1.6	*0.9*	6	*16*	32	*29*
Internal rotation	2.3	*0.9*	2	*16*	67	*11*
External rotation	2.4	*0.8*	-1	*9*	42	*13*

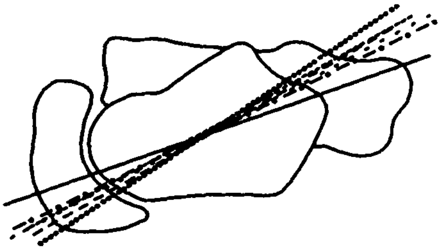

Figure 13. Average talo-calcaneal joint axes in different inputs. Symbols as in Figure 12.

joint axes associated with small amounts of resulting rotation (see appendix). Inclinations were also less varying than in the talo-navicular joint. Resulting rotations were larger in external leg rotation and in supination than in the other forms of input motion. In all inputs, the resulting average amounts of rotation were smaller than those seen in the talo- navicular joint.

Cuboid-calcaneus (Table 5)

The joint between the cuboid and the calcaneus was, as earlier stated, only analysed in two of the subjects. Joint axis deviations were generally negative, indicating supero-antero-lateral to infero-postero-medial joint axis orientation. Rotations of up to approximately ten degrees were seen.

Cuboid-navicular (Table 6)

As in the calcaneo-cuboid joint, most observed joint axes showed negative deviation.

Medial cuneiform-navicular (Table 7)

Resulting rotations were limited, except in pronation and external rotation. Joint axis deviations and inclinations varied.

First metatarsal-medial cuneiform (Table 8)

Resulting rotations were generally small. Joint axis orientations varied.

Comments

The talo-crural joint displayed the highest values of resulting rotation in plantar flexion, dorsiflexion and internal rotation. In all other inputs, the greatest amounts of resulting rotation were seen in the talo-navicular joint. In this joint, resulting rotation was greatest in input external leg rotation and smallest in internal leg rotation. The same pattern was seen in the talo-calcaneal joint, where the differences between different inputs were even more marked. Most of the joint axes in the talo-calcaneal joint and the joints of the arch showed infero-postero-lateral to supero-antero-medial orientation. Average deviations were smaller in the talo-navicular and cuneiformo-metatarsal, than in the talo-calcaneal and naviculo-cuneiform joints.

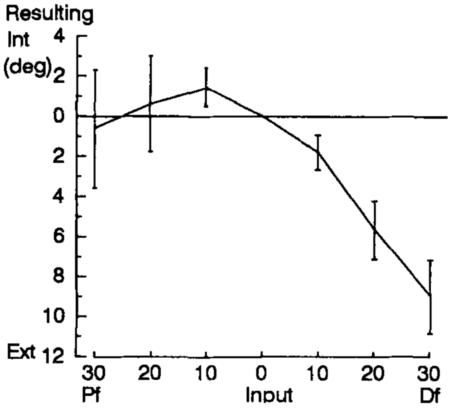

Figure 14. Resulting horizontal plane rotation in the talo-crural joint in input plantar flexion/dorsiflexion.

Joint interaction and transferral of rotation

Plantar flexion/dorsiflexion

Resulting rotation about the transverse axis between the talus and the first metatarsal ranged from 0.8 to 12.2 degrees of dorsiflexion (average 7.1 degrees) from 30 degrees of plantar flexion to the neutral position and from 2 degrees of plantar flexion to 3.8 degrees of dorsiflexion in the dorsiflexion arc (average 1.3 degrees dorsiflexion; Lundberg et al 1989b). Total rotation between the tibia and the first metatarsal averaged 36 degrees in plantar flexion and 24 degrees in dorsiflexion. Thus, the average contribution from the joints of the arch was approximately 20 percent in plantar flexion and 5 percent in dorsiflexion. Motion registered in the joints of the arch mainly occurred in the talo-navicular and naviculo-cuneiform joints (average 72 percent and 23 percent respectively in plantar flexion).

From 30 degrees of plantar flexion to the neutral position, slight internal rotation of the talus in relation to the tibia was seen (Figure 14). This motion was in the arc from the neutral position to 30 degrees of dorsiflexion followed by external rotation (Lundberg et al 1989b).

Comments

Plantar flexion induced more motion in the joints of the arch than dorsiflexion did. This difference was in most subjects not coupled to a smaller amount of talo-crural joint rotation in plantar flexion. The fact that total resulting rotation in plantar flexion was greater than the input difference in platform inclination and greater than the rotation seen in dorsiflexion may have several explanations. Possible causes are differences in actual amount of input motion due to the absence of rigid fixation of the foot and the leg allowing small differences in actual input, and an elevation of the talus. The latter explanation would demand plantar flexion in the talo-calcaneal joint. However, this motion only averaged 2.2 degrees and never exceeded 4.5 degrees.

The joints of the arch provided approximately 20 percent of the total transverse axis rotation in plantar flexion. In dorsiflexion, the joints of the arch showed transverse axis rotation in the opposite direction to the input and to the resulting talo-crural joint rotation in two of the subjects. Among the six subjects where the talo-crural joint and the joints of the arch acted together the joints of the arch provided approximately 10 percent of the total transverse axis rotation.

Pronation/supination

Average antero-posterior axis rotation (resulting pronation/supination) between the first metatarsal and the talus was 13 degrees from 20 degrees of pronation to the neutral position and 15 degrees from the neutral position to 20 degrees of supination (Lundberg et al 1989c). This means that approximately 70 percent of the pro-/supinatory motion was accounted for in the joints of the arch.

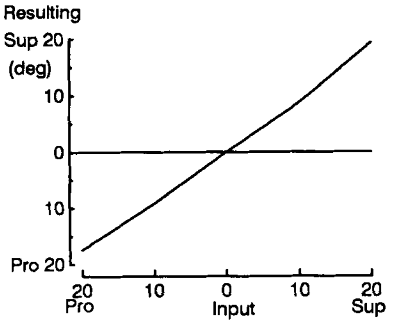

Figure 15. Resulting pronation/supination between the calcaneus and the platform in input pronation/supination of the foot.

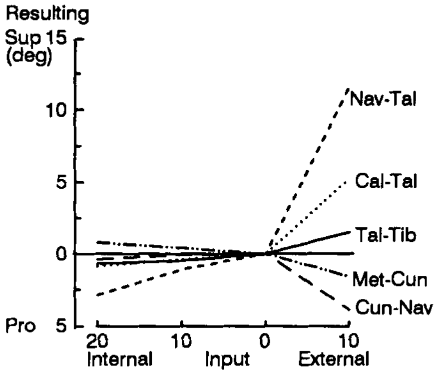

Figure 16. Resulting pronation/supination in input internal/ external rotation of the leg.

In the talo-calcaneal joint, average antero-posterior axis rotation was 2.7 degrees in the pronation arc and 5.5 degrees in the supination arc.

Vertical axis rotation of the talus in relation to the first metatarsal averaged 3.9 degrees in the pronation arc and 6.6 degrees in the supination arc (total average 11 degrees).

Vertical axis rotation of the tibia in relation to the first metatarsal averaged 3.3 degrees in the pronation arc and 4.8 degrees in the supination arc (total average 8.1 degrees).

The resulting antero-posterior axis rotation between the calcaneus and the platform was close to the input in the only subject where the platform markers could be identified (Figure 15; Lundberg et al 1989c).

Comments

Pronatory/supinatory motion was distributed throughout the whole arc with the talo-navicular and talo-calcaneal joints playing the greatest part. Both these joints showed less resulting rotation in pronation than in supination with the greatest difference observed in the talo-calcaneal joint. A different pattern was often seen in the joints proximal and distal to the medial cuneiform which both displayed greater resulting rotations in the pronation part of the arc.

Moving the foot from pronation to supination induced some vertical axis rotation of the lower leg, indicating the existence of a rotation transferring mechanism. Rotation of the tibia in relation to the first metatarsal was of smaller magnitude than rotation of the talus in relation to the first metatarsal. This indicates that the talo-crural joint may to some degree counteract the vertical axis rotation induced distal to the talus.

The theory that the joint axes of the calcaneo-cuboid and talo-navicular joints should become more parallel in pronation than in supination could only be tried in two of the subjects. In these no obvious differences in joint axis deviation or inclination could be seen.

Leg rotation

In the internal rotation arc, resulting rotations were comparatively small (Lundberg et al 1989d). The greatest component rotation seen was talo-crural joint rotation about the vertical axis (average 5.0 degrees). In the external rotation part of the arc, the greatest component rotation was talo-navicular joint rotation about the vertical axis (average 12 degrees).

Antero-posterior axis rotation between the tibia and the first metatarsal induced by leg rotation averaged 3.4 degrees supination from 20 degrees internal rotation to the neutral position and a further 7.8 degrees supination from the neutral to 10 degrees of external rotation. The corresponding average values between the talus and the first metatarsal were 2.5 degrees of supination from 20 degrees of internal rotation to the neutral position and 5.4 degrees of supination from the neutral position to 10 degrees of external rotation.

Through the whole arc from 20 degrees of internal rotation to 10 degrees of external rotation, the talo-crural, talo-navicular and talo- calcaneal joints showed supination while the cuneiformo-metatarsal joint showed pronation. The naviculo-cuneiform joint showed initial average supination up to the neutral position, followed by pronation (Figure 16; Lundberg et al 1989d).

Comments

The joints showing the largest amounts of resulting rotations in leg rotation were the talo-navicular and the talo-calcaneal. Of these, the talo-navicular joint was the one associated with the greatest amounts of rotation. This was most pronounced in external rotation, where resulting talo-navicular supination invariably exceeded the input leg rotation as recorded at the proximal tibia, indicating a transferral of external leg rotation to supination of the navicular. The joints between the navicular and the medial cuneiform and between the cuboid and the navicular also showed greater values of resulting rotation in external rotation than in internal rotation. This resulting rotation was such as to partly counteract the rotation occurring in the talo-navicular joint. In internal rotation the largest average rotation was seen in the talo-crural joint. The total amounts of rotation between tibia and metatarsal induced in the internal rotation arc were considerably lower than the readings at the proximal tibia.

Fibular motion

In plantar flexion/dorsiflexion, there were consistent patterns of lateral (Figure 17) and posterior (Figure 18) translation of the fibula (Svensson et al 1989). Average translation along the vetrical axis was less than 0.1 mm in all input arcs. Rotation about the vertical axis approached 3 degrees in two of the subjects. Average rotation did not exceed one degree about any of the coordinate system axes in any input arc. Pronation/supination and internal/external rotation did not induce any consistent pattern of motion between the tibia and the fibula (Svensson et al. 1989).

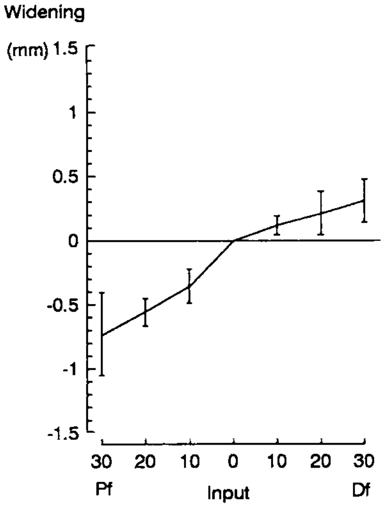

Figure 17. Transverse axis translation of the fibula in relation to the tibia in input plantar flexion/dorsiflexion.

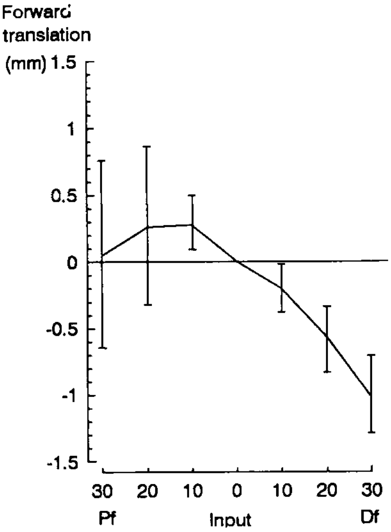

Figure 18. Antero-posterior translation of the fibula in relation to the tibia in input plantar flexion/dorsiflexion.

Discussion

Methodological aspects

Roentgen stereophotogrammetric analysis is a highly accurate method. The main restrictions of this technique are caused by its invasive nature and the need for high quality x-ray film with a rigid reference system exposed onto the film.

In the present investigation, the following basic considerations were made:

1. As roentgen stereophotogrammetric analysis was considered to be the only method that met the demands of accuracy and in vivo applicability, and this method is very difficult to apply under dynamic conditions, a static setup was accepted.

2. As the ankle/foot complex was seen as a spatial framework where the initial position of each member was considered unknown, the input positions were not defined as positions of the foot in relation to the leg, but as positions of the platform. These do not have any obvious fixed relationship to the positions of the examined bones and should not be seen as exact in any other sense than that the positions of the platform were the same for the examinations of all subjects.

3. The aim was strictly to analyse normal motion; no attempts to define laxity tests etc. were made.

4. As no particular kind of input motion was a priori considered more interesting than any other, the investigation was primarily planned as three different studies. In one of these the input was plantar flexion/dorsiflexion, in another it was pronation/supination and the third concerned rotation of the leg. In plantar flexion and pronation/supination input motion was provided as tilting of the platform. Dorsiflexion was introduced as forward inclination of the lower leg.

5. Smaller input intervals than ten degrees of rotation were not considered to offer additional information in proportion to the increased x-ray dosage.

6. The number of segments marked was limited by the demand that all markers must be visible on all films. Initially seven segments were used (tibia, fibula, talus, calcaneus, navicular, medial cuneiform and first metatarsal). As no complications occurred and no unsolvable marker identification problems were encountered markers in the cuboid bone were added in the last two subjects marked. Markers were also introduced into the platform, these, however, could only be identified in one series of pronation/supination examinations.

In this presentation the joints between the lower leg and the forefoot are seen as parts of one joint complex. The reason for this is not strictly anatomical, or even physiological; all the joints of this area have the prerequisites for functioning either on their own, or as parts of smaller joint complexes. However, it has not been considered proper to assume that any joints can be excluded a priori from the joint complex under study.

In each subject, the relationship between the joint axes registered for each input interval of motion is derived directly from the roentgen stereophotogrammetric data and only subject to the method error of the measurement procedure. The position of the origin and the orientation of the coordinate system, however, are affected by differences in the placing of the markers and the position of the foot on the platform, as well as the degree of internal rotation of the platform. To make it possible to draw the joint axes of all subjects in the same standard figure, it was necessary to correct for these factors.

The talo-crural joint

The main function of the talo-crural joint has been assumed to be the accomodation of plantar flexion/dorsiflexion motion. Few attempts have been made to analyse the function of the talo-crural joint in leg rotation. In the present investigation, the greatest amounts of resulting rotation were seen in plantar flexion and dorsiflexion. There was a general tendency towards joint axis inclination downwards laterally in dorsiflexion and inclination downwards medially in plantar flexion. However, in pronation/supination and leg rotation, substantial amounts of rotation occurred about axes with a more vertical orientation (Lundberg et al 1989a). The ranges of rotation were within the range given by earlier authors (Close 1956, McCullough and Burge 1980, Rasmussen et al 1982). The presented results indicate that the differences in inclination between plantar flexion and dorsiflexion joint axes as well as the rotation registered may relate to a pattern of joint function with two degrees of freedom of rotation. All observed joint helical axes in each examined individual crossed within a small central area in the talar trochlea. This may indicate the existence of a center of rotation in the talo-crural joint, located close to the midpoint of a line through the tips of the malleoli.

The talo-calcaneal joint

The talo-calcaneal joint has been seen as a simple hinge by most authors (Manter 1941, Isman and Inman 1969). In the present investigation the talo-calcaneal joint axes in most subjects tended to be parallel, but not coinciding, indicating a polyaxial hinge pattern. The amounts of resulting rotation were smaller in internal leg rotation and pronation than in external rotation and supination.

The talo-navicular joint

Previous investigations of the talo-navicular joint have shown large amounts of resulting motion (van Langelaan 1983). This was confirmed by the present investigation: resulting rotation in all input arcs was greater than that seen in the talo-calcaneal joint, and talo-navicular joint motion induced by external leg rotation consistently exceeded the input. The talo-navicular joint was also the joint that showed the largest amounts of resulting rotation in pronation/supination and it participated, although to a lesser extent, in plantar flexion. Talo-navicular joint rotations exceeding input have also been noted in investigations where the tibia was rigidly attached to the equipment providing input motion (van Langelaan 1983, Benink 1985). As indicated by Manter (1941) the plantar flexion axes of the talo-navicular joint were more transverse than the axes seen in other qualities of motion. The pattern of talo-navicular joint motion is also consistent with the observation by Katoh et al (1983) that isolated talo-navicular fusion influenced walking on a sideslope (pro-/supination) and push-off (external leg rotation and plantar flexion) more than other elements of gait.

Other joints

Other joints of the ankle/foot complex have been assumed to take only a limited part in motion of the foot. Nonetheless an investigation by Hicks (1953) revealed that "the first ray joint" had a range of motion exceeding 20 degrees. The joint between the cuboid and the navicular has traditionally been seen as relatively immobile. In the present investigation this joint was only examined in two subjects. In these, substantial amounts of rotation were seen, particularly in pro-/supination and external leg rotation. The joints proximal and distal to the medial cuneiform showed comparatively limited amounts of rotation under the conditions of the investigation. In some subjects the joint between the navicular and the medial cuneiform participated in plantar flexion, otherwise they primarily took part in pronation/supination of the foot. The total rotation of 22 degrees seen by Hicks (1953) was not approached by the subjects in this investigation. Hicks studied anatomical specimens and did not state explicitely how motion was induced. In the present investigation the input pronation/supination (which was the input inducing the largest amounts of rotation in these joints) was limited by the fact that it was impossible to remain standing on the platform when the pro-/supination tilt exceeded approximately 20 degrees. Although total rotation was limited these joints participated in pro-/supination and also performed a compensatory pronation when the navicular was supinated by input external leg rotation.

Joint interaction

Joint interaction in plantar flexion/dorsiflexion has mainly been studied in cases of unilateral ankle fusion (Jackson and Glasgow 1979, Buck et al 1987). The total motility of the joints of the arch has been found to be considerable, especially when active motion is analyzed (Jackson and Glasgow 1979). This is also in accordance with the statement of Rowley et al (1986) that more motion in plantar flexion/dorsiflexion normally occurs under non-weight-bearing conditions. Pro-/supinatory motion has generally been assumed to take place in the talo-calcaneal, and to some extent the talo-navicular, joints. The interaction of the tarsal joints in input leg rotation has been analysed by Huson (1982, 1985), van Langelaan (1983) and Benink (1985). These authors considered the tarsal bones to be parts of a closed kinematic chain where motion of one member would invariably affect all the others. In the present investigation, all inputs affected all the examined joints. However, the patterns of interaction varied, and the following points were most apparent:

- In the present investigation, only weight-bearing examinations were made, and plantar flexion/ dorsiflexion induced motion mainly in the talocrural joint. However, in the plantar flexion arc, motion also occurred in the talo-navicular joint, and in some subjects in the distal joints of the arch (Lundberg et al 1989b). In dorsiflexion only small amounts of rotation occurred in the joints of the arch.

- Motion in pronation/supination occurred through the whole joint complex, in the form of a torsion motion of the foot (Lundberg et al 1989c). As the resulting talo-calcaneal was more limited than expected, an attempt to analyse motion between the calcaneus and the substratum was made. Motion could only be measured in one of the subjects, and indicated a sideways rolling motion of the calcaneus that approached the input in magnitude.

- Leg rotation in the internal rotation arc induced very limited rotation throughout the joint complex. This throws some doubt on the registration of input internal rotation at the proximal tibia. In the external rotation arc, large amounts of resulting rotation about all axes of the coordinate system were induced in the talo-navicular and talo-calcaneal joints, while the joints proximal and distal to the medial cuneiform displayed compensatory counterrotation (Lundberg et al 1989d).

Transferral of rotation through the "hindfoot" is thought to account for the ability of the joint complex to accomodate rotation of the proximal segments of the lower extremity without excessive shear loads at the skin/substratum interface (Inman 1976). In the present investigation, most of the pro/supinatory rotation induced by sideways tilting of the platform has been taken up in the joints of the medial arch, while internal leg rotation has induced only small amounts of motion in the joint complex (Lundberg et al 1989c, d). Only in external leg rotation has a clear-cut pattern of transformation into supinatory rotation of the foot been observed. In this context it should be kept in mind that external rotation of the leg occurs through the greater part of the stance phase of walking. The presented results are not inconsistent with a closed kinematic chain function of the tarsus (Huson 1982, 1985). However, all motions introduced into the system do not necessarily affect this chain to the same extent. From this investigation, external leg rotation (as studied by van Langelaan 1983 and Benink 1985) seems to be the most powerful inducer of tarsal joint motion.

Motion of the fibula

Motion of the fibula has been analysed by several investigators (Close 1956, Grath 1960, Kärrholm et al 1985, Ahl et al 1987). The most consistent finding has been widening of the ankle mortise in dorsiflexion, while other qualities of motion have been controversial. In the present investigation, lateral (mortise widening) and posterior translation of the fibula were seen in input dorsiflexion from a plantar flexed position. Rotations, and vertical axis translations, were small and inconsistent. Pro-/supination and leg rotation did not induce any consistent patterns of fibular motion (Svensson et al 1989).

Summary

Roentgen stereophotogrammetric analysis has been used to study ankle/foot kinematics in eight healthy volunteers. *All the joints between the tibia and the* first metatarsal as well as the talo-calcaneal and tibio-fibular joints were analysed in input plantar flexion/dorsiflexion and pronation/supination of the foot as well as internal/external rotation of the leg. The findings included the following:

Individual joints

1. The joint axis of the talo-crural joint varied with varying kinds of input motion. Substantial amounts of rotation occurred about axes close to the vertical; this occurred particularly when the input motion was in the internal rotation part of the arc of leg rotation and in pro-/supination of the foot.

2. The total amount of rotation in the talo-calcaneal joint was small in internal rotation of the leg and in pronation of the foot compared to external rotation of the leg and supination of the foot.

3. The talo-navicular joint showed a limited ball-and-socket joint pattern in all subjects. The total amounts of rotation were larger than in the talo-calcaneal joint in all subjects. Plantar flexion axes were more transverse than the axes seen in other kinds of input motion.

4. The talo-calcaneal and talo-navicular joint axes were seldom parallel, indicating that these joints do not necessarily behave as a simple hinge.

Joint interaction

Joint interaction varied in different qualities of input motion. Plantar flexion induced rotation in the talo-crural joint, and to some extent in the joints of the arch. Dorsiflexion mainly induced talo-crural joint motion. Pronation/supination induced motion in all joints. The distal joints of the arch displayed more rotation in pronation than in supination, while the talo-calcaneal joint showed less motion in pronation than in supination. Internal leg rotation induced little rotation in the joints of the ankle/foot complex. External rotation induced external rotation, dorsiflexion, and supination in the talo-navicular and talo-calcaneal joints. The distal joints of the arch displayed compensatory plantar flexion and pronation.

Transferral of rotation

The ankle/foot complex showed ability to transform leg rotation into pro-/supination and vice versa. This function was most pronounced in external leg rotation.

Motions of the fibula

The fibula showed consistent lateral and posterior translation from input plantar flexion to dorsiflexion of the foot.

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Appendix

Key to data

A	Moving segment		
		Tib	tibia
		Tal	talus
		Nav	navicular
		Cal	calcaneus
		Cun	medial cuneiform
		Met	first metatarsal
B	Reference segment (see above)		
C	Input position, in degrees		
		Int	internal rotation
		Ext	external rotation
		Pro	pronation
		Sup	supination
		PF	plantarflexion
		DF	dorsiflexion
D	Measured entity		
		Rot	resulting rotation
		Dev	joint axis deviation
		Inc	joint axis inclination
		RX	transverse axis rotation
		RY	vertical axis rotation
		RZ	antero-posterior axis rotation
E-L	Individual subjects. Values in degrees in relation to neutral position		
M	Mean		
N	SD		

Bullet (•) denotes missing value

A	B	C	D	E	F	G	H	I	J	K	L	M	N
Tal	Tib	Int 20	Rot	4.6	4.3	2.0	9.7	6.0	6.3	6.2	6.2	5.7	2.1
Tal	Tib	Int 20	Inc	43	73	43	56	71	79	60	68	64	16
Tal	Tib	Ext 10	Rot	3.4	8.5	6.6	14.6	2.6	1.9	4.5	4.6	6.1	4.0
Tal	Tib	Ext 10	Inc	61	15	7	22	2	50	-7	-1	19	23
Tal	Tib	Pro 20	Rot	4.5	3.3	0.7	1.9	6.3	1.7	3.2	4.0	3.2	1.7
Tal	Tib	Pro 20	Inc	-2	-8	47	7	24	21	6	7	13	16
Tal	Tib	Sup 20	Rot	3.7	1.6	3.0	1.8	3.4	4.2	8.5	6.8	4.1	2.2
Tal	Tib	Sup 20	Inc	6	86	37	-25	-59	67	44	42	25	45
Tal	Tib	PF 30	Rot	17.8	25.3	20.2	28.4	38.4	30.9	26.6	40.7	28.5	7.5
Tal	Tib	PF 30	Inc	-9	-6	-2	7	0	-6	3	-3	-2	5
Tal	Tib	DF 30	Rot	25.0	24.4	24.3	28.4	23.5	22.5	30.4	20.3	24.9	3.0
Tal	Tib	DF 30	Inc	15	18	23	20	19	22	18	15	19	3
Cal	Tal	Int 20	Rot	0.2	3.1	1.5	1.3	4.5	1.4	0.9	3.8	2.1	1.4
Cal	Tal	Int 20	Dev	28	42	-14	31	28	34	4	32	23	17
Cal	Tal	Int 20	Inc	5	36	5	41	35	41	27	44	29	15
Cal	Tal	Ext 10	Rot	9.2	18.4	9.6	16.3	7.0	4.4	12.9	15.0	11.6	4.5
Cal	Tal	Ext 10	Dev	42	39	65	31	37	31	34	20	37	12
Cal	Tal	Ext 10	Inc	35	44	35	37	38	43	32	37	38	4
Cal	Tal	Pro 20	Rot	0.5	3.1	2.1	1.9	12.6	3.1	3.4	9.3	4.5	3.9
Cal	Tal	Pro 20	Dev	46	41	41	28	23	25	30	31	33	8
Cal	Tal	Pro 20	Inc	66	33	6	19	25	20	23	35	26	17
Cal	Tal	Sup 20	Rot	5.9	8.5	10.1	8.2	8.9	8.1	18.3	10.8	6.9	3.5
Cal	Tal	Sup 20	Dev	34	39	59	29	7	28	28	26	31	14
Cal	Tal	Sup 20	Inc	24	40	32	31	32	32	31	39	33	5
Cal	Tal	PF 30	Rot	7.1	4.3	1.7	3.3	4.5	6.1	4.0	3.3	4.3	1.6
Cal	Tal	PF 30	Dev	45	46	25	51	2	46	35	24	34	15
Cal	Tal	PF 30	Inc	35	48	2	39	10	40	35	45	32	16
Cal	Tal	DF 30	Rot	1.0	6.2	2.1	5.4	1.9	1.8	1.9	4.8	3.1	1.9
Cal	Tal	DF 30	Dev	70	45	15	29	11	21	53	23	34	19
Cal	Tal	DF 30	Inc	56	38	4	29	34	28	28	28	31	13
Nav	Tal	Int 20	Rot	1.6	6.4	0.4	3.6	6.5	2.6	0.8	6.0	3.6	2.7
Nav	Tal	Int 20	Dev	-26	13	-3	17	11	20	24	2	7	15
Nav	Tal	Int 20	Inc	44	36	0	30	30	34	19	26	27	12
Nav	Tal	Ext 10	Rot	16.1	31.0	17.5	26.6	16.2	7.1	18.4	22.4	19.2	6.9
Nav	Tal	Ext 10	Dev	36	22	19	14	14	19	23	29	22	7
Nav	Tal	Ext 10	Inc	26	45	31	32	39	38	26	36	34	8
Nav	Tal	Pro 20	Rot	4.7	7.0	2.7	2.7	19.8	6.5	5.3	16.6	8.2	6.0
Nav	Tal	Pro 20	Dev	-38	5	7	-15	-0	-9	2	-7	-7	14
Nav	Tal	Pro 20	Inc	25	20	14	38	24	4	4	25	19	11
Nav	Tal	Sup 20	Rot	10.2	11.7	18.3	11.7	19.0	14.9	21.4	19.4	15.6	3.9
Nav	Tal	Sup 20	Dev	20	12	15	9	-4	4	20	-2	9	9
Nav	Tal	Sup 20	Inc	16	24	24	22	24	15	23	29	22	4
Nav	Tal	PF 30	Rot	12.8	6.6	1.9	10.2	7.8	10.3	5.3	7.5	7.8	3.2
Nav	Tal	PF 30	Dev	52	64	30	32	2	58	36	58	41	19
Nav	Tal	PF 30	Inc	29	45	28	46	8	40	32	44	34	12
Nav	Tal	DF 30	Rot	3.8	10.0	1.3	8.8	4.3	6.0	3.0	7.7	5.6	2.8
Nav	Tal	DF 30	Dev	-60	1	80	-1	-10	-22	-3	-5	-2	37
Nav	Tal	DF 30	Inc	31	19	25	19	29	2	4	20	19	10
Cun	Nav	Int 20	Rot	0.4	0.3	0.7	1.4	1.0	1.4	0.8	0.6	0.8	0.4
Cun	Nav	Int 20	Dev	74	50	16	13	14	11	13	29	28	22
Cun	Nav	Int 20	Inc	7	36	1	8	47	23	1	66	24	22
Cun	Nav	Ext 10	Rot	3.0	7.8	3.5	9.1	4.7	2.0	0.9	4.9	4.5	2.6
Cun	Nav	Ext 10	Dev	40	10	16	17	12	6	38	-6	16	15
Cun	Nav	Ext 10	Inc	19	4	4	1	1	1	3	6	5	8
Cun	Nav	Pro 20	Rot	4.0	2.6	3.9	9.1	3.4	5.0	4.0	1.7	4.2	2.1
Cun	Nav	Pro 20	Dev	9	0	7	19	7	27	27	20	14	9
Cun	Nav	Pro 20	Inc	35	3	6	3	8	13	2	53	15	18
Cun	Nav	Sup 20	Rot	3.8	2.0	2.2	0.6	0.4	0.6	1.0	2.1	1.6	1.1
Cun	Nav	Sup 20	Dev	2	7	6	36	56	16	52	64	30	23
Cun	Nav	Sup 20	Inc	11	8	7	47	57	18	26	44	27	18
Cun	Nav	PF 30	Rot	3.9	1.9	1.5	10.0	2.1	2.3	0.7	2.0	3.0	2.8
Cun	Nav	PF 30	Dev	23	12	9	22	18	26	50	7	21	13
Cun	Nav	PF 30	Inc	19	26	5	2	5	15	2	2	10	9
Cun	Nav	DF 30	Rot	1.5	1.7	2.8	5.2	2.3	1.4	0.5	2.3	2.2	1.3
Cun	Nav	DF 30	Dev	12	5	28	3	17	-1	72	17	19	22
Cun	Nav	DF 30	Inc	30	49	19	4	0	25	16	11	19	15
Met	Cun	Int 20	Rot	2.3	3.2	1.1	2.9	1.5	2.9	1.1	3.4	2.3	0.9
Met	Cun	Int 20	Dev	-26	6	-13	-1	14	12	28	-6	2	16
Met	Cun	Int 20	Inc	81	70	56	77	44	72	70	64	67	11
Met	Cun	Ext 10	Rot	3.4	2.1	3.7	1.9	3.1	1.3	1.6	2.6	2.4	0.8
Met	Cun	Ext 10	Dev	8	10	-15	-9	-7	-3	-3	9	-1	9
Met	Cun	Ext 10	Inc	61	56	43	37	24	28	54	38	42	13
Met	Cun	Pro 20	Rot	4.5	1.5	2.9	3.4	0.9	3.4	4.3	2.5	2.9	1.2
Met	Cun	Pro 20	Dev	-38	-6	3	0	49	7	5	15	4	22
Met	Cun	Pro 20	Inc	26	17	15	49	63	59	6	77	39	26
Met	Cun	Sup 20	Rot	2.1	3.3	1.9	1.8	0.3	1.8	0.7	1.1	1.6	0.9
Met	Cun	Sup 20	Dev	-7	-4	-0	-7	21	12	41	-7	6	16
Met	Cun	Sup 20	Inc	34	1	6	79	24	28	78	4	32	29
Met	Cun	PF 30	Rot	3.0	●	0.4	1.3	1.0	1.7	1.8	1.2	1.5	0.8
Met	Cun	PF 30	Dev	29	●	38	1	33	21	-6	9	18	15
Met	Cun	PF 30	Inc	53	●	15	16	29	31	5	3	21	18
Met	Cun	DF 30	Rot	1.2	3.9	1.2	2.0	1.1	1.6	0.7	1.7	1.7	0.9
Met	Cun	DF 30	Dev	-60	64	83	-4	-4	-22	53	-5	13	46
Met	Cun	DF 30	Inc	49	60	22	58	17	32	57	34	41	16

A	B	C	D	E	F	G	H	I	J	K	L	M	N
Fib	Tib	DF 30	RX	-0.1	-0.1	0.2	-0.1	-0.1	-0.1	0.2	●	-0.0	0.1
Fib	Tib	DF 20	RX	-0.4	-0.0	0.0	-0.2	0.1	-0.1	0.1	0.4	-0.0	0.2
Fib	Tib	DF 10	RX	-0.3	-0.0	-0.1	0.0	0.1	-0.3	-0.1	-0.0	-0.1	0.1
Fib	Tib	PF 10	RX	-0.1	0.1	-0.1	0.2	-0.0	0.1	0.0	-0.0	0.0	0.1
Fib	Tib	PF 20	RX	0.1	0.1	0.4	-0.4	-0.3	0.1	0.1	0.1	0.0	0.2
Fib	Tib	PF 30	RX	0.4	-0.1	0.5	0.1	-0.0	0.7	0.4	0.7	0.3	0.3
Tal	Tib	DF 30	RX	-23.5	-21.2	-21.4	-26.0	-20.7	-20.5	-28.6	-19.4	-22.7	3.0
Tal	Tib	DF 20	RX	-16.9	-13.3	-13.0	-15.0	-13.1	-12.9	-25.7	-14.8	-15.6	4.0
Tal	Tib	DF 10	RX	-9.3	-4.3	-7.3	-6.5	-1.8	-4.1	-8.7	-6.2	-5.9	2.3
Tal	Tib	PF 10	RX	10.9	9.9	11.9	10.8	13.0	12.0	11.2	9.4	11.1	1.1
Tal	Tib	PF 20	RX	13.6	19.0	15.7	24.4	25.4	21.0	22.8	24.8	20.8	4.1
Tal	Tib	PF 30	RX	17.5	23.2	19.4	28.1	38.3	30.3	26.4	40.1	27.9	7.7
Nav	Tal	DF 30	RX	-2.5	3.5	-1.2	1.9	0.8	-1.3	0.3	0.8	0.3	1.8
Nav	Tal	DF 20	RX	0.2	1.3	-1.1	-0.2	1.4	-1.5	3.5	●	0.5	1.6
Nav	Tal	DF 10	RX	0.5	-1.9	-1.1	-0.4	0.8	-1.5	-2.1	-0.7	-0.8	1.0
Nav	Tal	PF 10	RX	3.7	2.2	0.7	0.9	0.3	2.5	0.6	0.4	1.4	1.1
Nav	Tal	PF 20	RX	5.8	1.5	0.4	2.2	0.4	4.4	2.7	2.1	2.4	1.8
Nav	Tal	PF 30	RX	9.4	4.6	1.2	5.3	3.9	7.2	3.1	5.1	5.0	2.4
Cun	Nav	DF 30	RX	-0.4	-0.6	-1.8	0.7	1.3	-0.2	-0.5	1.1	-0.0	1.0
Cun	Nav	DF 20	RX	0.0	-0.8	-1.4	-0.1	1.0	-0.2	0.7	●	-0.1	0.7
Cun	Nav	DF 10	RX	-0.0	-1.2	-1.1	0.3	2.0	-0.5	-0.5	0.9	-0.0	1.0
Cun	Nav	PF 10	RX	0.0	0.5	-0.1	2.5	-0.0	0.3	0.3	-0.1	0.4	0.8
Cun	Nav	PF 20	RX	0.9	0.3	0.3	5.1	1.1	0.7	0.8	-0.1	1.1	1.5
Cun	Nav	PF 30	RX	1.9	0.9	0.6	7.2	2.1	1.3	0.6	0.7	1.9	2.1
Met	Cun	DF 30	RX	-0.6	-1.9	-0.4	-0.2	-0.2	-0.8	-0.3	-0.2	-0.6	0.6
Met	Cun	DF 20	RX	-0.2	-1.3	-0.2	-0.1	-0.1	-0.6	-0.3	-0.1	-0.4	0.4
Met	Cun	DF 10	RX	0.2	-1.0	-0.1	0.2	-0.2	-0.4	-0.2	0.0	-0.2	0.4
Met	Cun	PF 10	RX	0.0	-1.4	0.1	0.5	-0.1	0.4	-0.1	-0.0	-0.1	0.5
Met	Cun	PF 20	RX	0.3	●	0.1	0.7	0.1	0.2	0.0	0.2	0.2	0.2
Met	Cun	PF 30	RX	1.1	●	0.3	0.6	1.5	0.7	-0.1	0.4	0.6	0.5
Cal	Tal	DF 30	RX	-0.6	4.4	1.1	3.1	1.3	0.8	1.4	2.4	1.8	1.4
Cal	Tal	DF 20	RX	0.1	3.7	-0.2	0.6	1.8	-0.2	3.9	1.2	1.4	1.5
Cal	Tal	DF 10	RX	-0.1	1.2	-0.7	-0.4	0.4	-0.4	-1.1	0.6	-0.1	0.7
Cal	Tal	PF 10	RX	1.2	1.7	0.7	-0.8	-1.4	1.1	0.4	-0.4	0.3	1.0
Cal	Tal	PF 20	RX	2.2	0.3	0.8	-0.4	-1.8	1.9	1.6	-0.3	0.5	1.3
Cal	Tal	PF 30	RX	4.5	2.5	1.1	2.1	0.4	3.8	2.2	1.3	2.2	1.3
Met	Tal	DF 30	RX	-3.8	-2.9	-3.3	1.9	2.0	-2.3	-0.8	●	-1.3	2.3
Met	Tal	DF 20	RX	0.0	-0.3	-2.7	-0.8	2.3	-2.3	3.8	-1.0	-0.1	2.0
Met	Tal	DF 10	RX	0.7	0.2	-2.2	-0.4	2.7	-2.4	-0.6	0.2	-0.2	1.5
Met	Tal	PF 10	RX	3.7	0.7	1.0	1.5	0.3	3.2	0.9	0.3	1.4	1.2
Met	Tal	PF 20	RX	7.0	1.6	0.2	4.8	1.6	5.3	3.3	2.2	3.3	2.1
Met	Tal	PF 30	RX	12.2	6.5	0.8	12.1	7.4	9.3	3.6	6.2	7.1	3.7
Fib	Tib	Sup 20	RX	0.2	-0.1	-0.2	0.2	-0.3	-0.2	0.4	-0.3	-0.0	0.2
Fib	Tib	Sup 10	RX	0.2	-0.1	-0.3	0.2	-0.2	-0.3	0.1	-0.1	-0.1	0.2
Fib	Tib	Pro 10	RX	-0.1	0.0	-0.0	0.1	-0.2	-0.1	-0.1	-0.0	-0.1	0.1
Fib	Tib	Pro 20	RX	-0.3	-0.1	0.0	-0.1	-0.4	-0.3	-0.1	-0.2	-0.2	0.1
Tal	Tib	Sup 20	RX	3.6	-0.1	-2.2	5.2	-2.9	-1.5	-5.9	-4.9	-1.1	3.6
Tal	Tib	Sup 10	RX	3.7	-2.6	-3.9	3.7	-1.5	-1.3	-1.7	0.3	-0.4	2.6
Tal	Tib	Pro 10	RX	1.7	0.1	-2.5	0.8	1.3	0.6	0.5	2.6	0.6	1.4
Tal	Tib	Pro 20	RX	4.2	3.0	-0.3	3.7	2.5	1.4	3.1	3.8	2.7	1.4
Nav	Tal	Sup 20	RX	4.3	5.0	6.8	4.1	1.6	3.2	8.0	1.8	4.4	2.1
Nav	Tal	Sup 10	RX	1.7	3.7	3.4	1.0	1.2	2.1	3.2	2.0	2.3	1.0
Nav	Tal	Pro 10	RX	1.7	-0.1	-0.5	-1.0	-0.5	-0.4	-0.8	-1.7	-0.4	0.9
Nav	Tal	Pro 20	RX	2.1	-2.7	-1.0	-0.0	-5.1	-0.1	-1.0	-2.4	-1.3	2.0
Cun	Nav	Sup 20	RX	-0.7	-0.9	-0.8	0.1	-0.2	-0.3	-0.8	1.5	-0.2	0.7
Cun	Nav	Sup 10	RX	0.1	-0.4	-0.8	-0.8	0.0	-0.3	-1.1	0.6	-0.3	0.6
Cun	Nav	Pro 10	RX	0.1	0.7	0.2	2.6	1.4	1.1	2.3	-0.9	0.9	1.1
Cun	Nav	Pro 20	RX	1.0	0.8	1.5	6.2	1.2	3.0	1.2	-0.5	1.8	1.9
Met	Cun	Sup 20	RX	-0.0	0.8	0.5	0.1	-0.2	0.6	0.1	-0.1	0.2	0.3
Met	Cun	Sup 10	RX	0.0	0.3	0.3	-0.1	-0.1	0.1	-0.3	-0.1	0.0	0.2
Met	Cun	Pro 10	RX	0.3	-0.6	-6.0	0.1	0.1	0.3	0.4	0.3	-0.6	2.0
Met	Cun	Pro 20	RX	1.2	-0.3	0.9	0.7	0.4	0.5	0.9	0.3	0.6	0.4
Cal	Tal	Sup 20	RX	3.6	5.4	8.2	4.7	2.3	3.9	8.2	4.9	5.1	2.0
Cal	Tal	Sup 10	RX	1.3	4.1	4.5	1.8	1.5	3.2	3.8	3.0	2.9	1.2
Cal	Tal	Pro 10	RX	0.0	-0.0	-1.0	-1.5	-1.5	-1.3	-1.4	-4.3	-1.4	1.3
Cal	Tal	Pro 20	RX	0.2	-2.3	-1.7	-1.6	-7.0	-1.7	-2.0	-6.5	-2.7	2.2
Met	Tal	Sup 20	RX	3.3	5.0	6.6	4.2	1.4	3.4	7.3	3.6	4.3	1.8
Met	Tal	Sup 10	RX	1.8	3.5	3.0	0.2	1.1	3.6	1.9	2.8	2.2	1.1
Met	Tal	Pro 10	RX	2.2	0.1	-0.3	1.4	1.0	0.9	0.8	-2.5	0.4	1.3
Met	Tal	Pro 20	RX	4.2	-2.3	1.2	6.1	-3.9	2.6	2.2	-3.0	0.9	3.4
Fib	Tib	In 20	RX	0.5	0.3	-0.0	0.5	0.6	0.6	0.8	0.4	0.4	0.2
Fib	Tib	In 10	RX	0.4	-0.1	-0.3	0.1	0.2	0.4	1.2	0.2	0.2	0.4
Fib	Tib	Ut 10	RX	-0.6	-0.0	-0.1	-0.2	-0.2	-0.3	-0.0	0.1	-0.2	0.2
Tal	Tib	In 20	RX	3.4	1.4	-1.4	0.0	1.9	-1.1	-3.0	-0.2	0.1	1.9
Tal	Tib	In 10	RX	2.0	1.7	-1.2	0.9	-0.3	-0.7	-0.9	-0.3	0.2	1.1
Tal	Tib	Ut 10	RX	-1.6	-7.5	-8.3	-8.1	-2.6	2.5	-4.5	-4.5	-4.3	3.5
Nav	Tal	In 20	RX	0.4	-2.8	0.1	-2.1	-2.5	-1.1	-0.4	-2.0	-1.3	1.1
Nav	Tal	In 10	RX	1.7	-2.1	1.0	-1.8	0.1	-0.7	-0.1	-0.8	-0.3	1.2
Nav	Tal	Ut 10	RX	9.2	11.5	7.4	9.2	4.7	2.5	6.9	10.7	7.8	2.6
Cun	Nav	In 20	RX	-0.4	-0.2	-0.3	1.2	0.3	0.6	0.3	0.2	0.2	0.6
Cun	Nav	In 10	RX	0.1	-0.2	-0.4	-0.2	0.5	0.1	0.6	-0.2	0.0	0.3
Cun	Nav	Ut 10	RX	2.1	3.6	1.8	5.9	2.0	0.8	0.6	-0.4	2.0	1.9
Met	Cun	In 20	RX	0.2	-0.4	0.0	-0.2	-0.1	0.4	0.2	0.2	0.0	0.3
Met	Cun	In 10	RX	0.5	0.1	-0.4	-0.3	0.5	0.3	0.2	0.1	0.1	0.3
Met	Cun	Ut 10	RX	-0.4	0.6	0.1	-0.1	-0.2	0.2	0.1	0.7	0.1	0.4
Cal	Tal	In 20	RX	0.1	-2.2	0.0	●	-2.5	-0.7	-0.2	-2.0	-1.1	1.0
Cal	Tal	In 10	RX	0.4	-1.4	1.2	-1.0	-0.6	-0.6	-0.3	-0.9	-0.4	0.8
Cal	Tal	Ut 10	RX	5.5	10.4	7.7	9.1	4.0	2.1	6.8	5.6	6.4	2.5
Met	Tal	In 20	RX	0.1	-3.7	-0.2	-1.4	-1.8	-0.4	0.1	-2.1	-1.2	1.2
Met	Tal	In 10	RX	2.3	-2.3	0.3	-2.3	0.6	-0.4	0.6	-1.0	-0.3	1.5
Met	Tal	Ut 10	RX	10.4	16.3	8.9	15.5	6.3	3.3	7.3	11.2	8.9	4.2

A	B	C	D	E	F	G	H	I	J	K	L	M	N
Fib	Tib	DF 30	RY	-0.7	-0.6	-0.1	-2.0	0.2	-2.0	0.5	●	-0.6	0.9
Fib	Tib	DF 20	RY	-0.1	-0.0	0.0	-0.7	-0.1	-0.9	0.5	0.8	-0.1	0.5
Fib	Tib	DF 10	RY	0.3	-0.0	-0.0	0.1	-1.0	-0.5	-0.2	0.3	-0.1	0.4
Fib	Tib	PF 10	RY	0.6	-0.2	-0.1	0.3	0.5	0.4	1.2	-0.2	0.3	0.4
Fib	Tib	PF 20	RY	0.1	-0.5	-0.3	-0.2	1.5	0.6	3.3	-0.5	0.5	1.2
Fib	Tib	PF 30	RY	-0.0	-1.4	-0.9	0.2	2.7	-0.8	2.4	-0.1	0.3	1.4
Tal	Tib	DF 30	RY	-8.1	-9.3	-10.7	-11.4	-7.0	-9.3	-10.4	-5.5	-8.9	1.9
Tal	Tib	DF 20	RY	-4.8	-5.2	-5.7	-6.4	-4.2	-6.5	-9.0	-4.1	-5.6	1.5
Tal	Tib	DF 10	RY	-2.2	-1.4	-3.1	-2.2	-0.4	-1.0	-3.0	-1.4	-1.8	0.9
Tal	Tib	PF 10	RY	1.0	0.1	2.3	2.2	2.9	0.6	1.8	0.7	1.4	0.9
Tal	Tib	PF 20	RY	-0.8	-2.4	-0.9	3.6	3.9	-0.9	3.2	-1.4	0.6	2.4
Tal	Tib	PF 30	RY	-2.2	-3.7	-1.0	3.6	3.8	-3.4	1.5	-3.8	-0.6	3.0
Nav	Tal	DF 30	RY	-2.0	3.5	-0.6	3.8	4.0	0.2	-0.2	2.7	1.4	2.2
Nav	Tal	DF 20	RY	-1.5	1.3	-0.7	-0.1	4.1	-0.8	3.6	●	0.8	2.0
Nav	Tal	DF 10	RY	-0.7	-1.9	-0.8	-0.2	2.5	-1.4	-1.8	1.1	-0.4	1.4
Nav	Tal	PF 10	RY	1.1	2.2	0.8	1.4	-1.6	2.4	0.7	-0.2	0.9	1.2
Nav	Tal	PF 20	RY	3.4	1.5	0.6	4.5	0.2	4.0	2.6	1.3	2.2	1.5
Nav	Tal	PF 30	RY	6.5	4.7	0.8	7.6	4.3	6.8	2.9	5.3	4.9	2.1
Cun	Nav	DF 30	RY	-0.8	-1.3	-0.9	-0.5	-0.7	-0.6	0.1	-0.5	-0.6	0.4
Cun	Nav	DF 20	RY	0.1	-0.8	-0.7	-0.2	-0.4	-0.5	0.2	●	-0.3	0.3
Cun	Nav	DF 10	RY	0.3	-0.3	-0.3	0.0	-0.4	-0.5	-0.3	-0.6	-0.3	0.3
Cun	Nav	PF 10	RY	1.1	-0.8	-0.4	-0.1	0.9	0.0	0.0	0.3	0.1	0.6
Cun	Nav	PF 20	RY	0.8	-0.3	-0.4	-6.1	-0.1	0.0	0.1	0.5	-0.7	2.1
Cun	Nav	PF 30	RY	1.2	-0.9	-0.1	-1.1	-0.5	-0.6	0.0	-0.1	-0.2	0.7
Met	Cun	DF 30	RY	0.9	3.4	-0.4	1.2	0.3	0.8	0.6	1.0	1.0	1.0
Met	Cun	DF 20	RY	0.7	2.8	-0.6	0.6	0.4	0.0	0.5	0.3	0.6	0.9
Met	Cun	DF 10	RY	0.4	1.3	-0.9	0.3	0.3	-0.2	0.0	0.8	0.2	0.6
Met	Cun	PF 10	RY	1.5	2.7	0.6	-0.3	0.2	-0.3	-0.2	0.3	0.6	1.0
Met	Cun	PF 20	RY	2.2	●	0.0	-0.1	0.4	-0.6	0.1	0.5	0.4	0.8
Met	Cun	PF 30	RY	2.4	●	0.1	-0.6	-0.6	-0.9	-0.1	-0.1	0.0	1.0
Cal	Tal	DF 30	RY	-0.8	3.9	-0.2	2.8	1.6	0.9	0.9	2.4	1.4	1.5
Cal	Tal	DF 20	RY	-0.3	2.8	-0.1	0.2	2.0	-0.4	3.8	0.6	1.1	1.5
Cal	Tal	DF 10	RY	-0.1	0.5	-0.2	-0.3	0.4	-0.9	-1.2	0.5	-0.2	0.6
Cal	Tal	PF 10	RY	1.8	1.5	0.2	-0.5	-1.0	1.4	0.6	-0.2	0.5	0.9
Cal	Tal	PF 20	RY	2.4	0.7	-0.3	-0.1	-1.0	2.4	2.0	0.1	0.8	1.2
Cal	Tal	PF 30	RY	4.2	3.2	-0.1	1.9	1.4	4.1	2.3	2.4	2.4	1.3
Met	Tal	DF 30	RY	-1.9	5.2	-1.9	4.6	3.7	0.3	0.5	●	1.5	2.8
Met	Tal	DF 20	RY	-0.7	3.1	-2.0	0.4	4.3	-1.2	4.3	-0.0	1.0	2.3
Met	Tal	DF 10	RY	-0.1	-1.0	-2.0	0.1	2.4	-2.0	-2.0	1.1	-0.4	1.5
Met	Tal	PF 10	RY	3.7	4.1	1.0	0.3	-0.5	2.1	0.6	0.4	1.5	1.6
Met	Tal	PF 20	RY	6.5	1.2	0.2	1.8	0.3	3.4	2.9	2.3	2.3	1.9
Met	Tal	PF 30	RY	10.2	3.9	0.8	6.3	3.0	5.4	2.8	5.2	4.7	2.7
Fib	Tib	Sup 20	RY	1.1	-0.2	0.6	0.2	-0.2	-0.1	0.3	-0.4	0.2	0.5
Fib	Tib	Sup 10	RY	0.9	0.3	0.2	0.0	0.4	-0.1	0.2	-0.2	0.2	0.3
Fib	Tib	Pro 10	RY	0.3	-0.0	-0.3	0.0	0.2	-0.2	-0.5	-0.1	-0.1	0.2
Fib	Tib	Pro 20	RY	0.3	-0.5	-0.5	-0.8	-0.5	-0.4	-0.3	-0.3	-0.4	0.3
Tal	Tib	Sup 20	RY	0.6	-1.5	-1.8	1.1	-2.9	-3.9	-6.1	-4.6	-2.4	2.3
Tal	Tib	Sup 10	RY	1.0	-0.6	-1.9	1.0	-1.5	-1.1	-1.1	-2.2	-0.8	1.1
Tal	Tib	Pro 10	RY	-0.1	-0.2	-0.5	2.1	1.3	0.2	0.3	0.5	0.4	0.8
Tal	Tib	Pro 20	RY	0.0	-0.4	-0.4	1.7	2.5	0.6	0.4	0.4	0.6	0.9
Nav	Tal	Sup 20	RY	3.2	5.2	7.4	5.6	8.0	4.3	9.6	9.6	6.6	2.3
Nav	Tal	Sup 10	RY	2.6	4.1	3.4	0.6	3.6	3.0	2.4	5.7	3.2	1.4
Nav	Tal	Pro 10	RY	-1.9	0.4	-0.2	-0.3	-1.1	-0.2	0.0	-5.1	-1.0	1.7
Nav	Tal	Pro 20	RY	-2.1	-2.3	-0.6	1.4	-7.2	0.5	-0.3	-8.8	-2.2	3.0
Cun	Nav	Sup 20	RY	0.7	-0.3	-0.3	-0.2	-0.4	-0.2	-0.4	-1.5	-0.3	0.5
Cun	Nav	Sup 10	RY	-0.5	-0.2	-0.7	-0.0	-0.6	0.0	-0.1	-0.9	-0.4	0.3
Cun	Nav	Pro 10	RY	1.7	0.4	-0.5	-0.3	0.2	-0.3	-0.1	1.1	0.3	0.7
Cun	Nav	Pro 20	RY	2.3	0.1	-0.4	-0.8	0.4	-1.3	0.1	1.4	0.2	1.1
Met	Cun	Sup 20	RY	1.2	0.1	-0.2	1.1	0.1	-0.9	0.7	0.1	0.3	0.6
Met	Cun	Sup 10	RY	0.4	0.7	0.6	-0.3	0.2	0.6	0.8	0.2	0.4	0.3
Met	Cun	Pro 10	RY	0.3	0.7	0.1	-2.0	-0.4	-1.1	-0.2	-1.5	-0.5	0.9
Met	Cun	Pro 20	RY	-2.0	-0.4	-0.8	-3.6	-0.8	-2.9	-0.6	-2.4	-1.7	1.1
Cal	Tal	Sup 20	RY	2.6	5.6	5.5	4.6	4.9	4.5	10.3	7.0	5.6	2.1
Cal	Tal	Sup 10	RY	1.4	4.1	1.8	1.3	2.2	3.3	6.3	3.6	2.9	1.3
Cal	Tal	Pro 10	RY	0.5	-0.1	0.1	-0.9	-1.1	-1.0	-1.0	-4.0	-0.9	1.3
Cal	Tal	Pro 20	RY	0.4	-1.7	-0.2	-0.8	-4.6	-1.0	-1.3	-6.0	-1.8	1.9
Met	Tal	Sup 20	RY	4.9	6.0	6.9	6.4	7.7	3.4	9.7	8.7	6.6	2.0
Met	Tal	Sup 10	RY	2.6	4.6	3.2	0.2	3.1	3.5	3.0	5.2	3.2	1.4
Met	Tal	Pro 10	RY	0.1	1.5	-0.6	-2.7	-1.5	-1.7	-0.3	-5.4	-1.3	1.9
Met	Tal	Pro 20	RY	-2.0	-2.7	-2.0	-3.4	-6.1	-4.1	-1.1	-7.7	-3.9	2.5
Fib	Tib	Int 20	RY	0.1	-0.4	-0.3	-1.5	-0.1	-0.4	-0.2	-0.2	-0.4	0.5
Fib	Tib	Int 10	RY	0.6	-0.6	-0.3	-0.1	0.3	0.1	0.3	-0.1	0.0	0.4
Fib	Tib	Ext 10	RY	0.4	-0.0	-0.1	-0.6	0.1	0.3	0.2	0.4	0.1	0.3
Tal	Tib	Int 20	RY	-2.9	-4.0	-1.4	-8.2	-6.7	-6.1	-6.4	-6.1	-5.0	2.0
Tal	Tib	Int 10	RY	-1.9	-1.2	-1.2	-3.7	-2.8	-3.2	-6.3	-1.6	-2.7	1.6
Tal	Tib	Ext 10	RY	2.5	-2.5	-1.4	-6.1	-0.1	1.4	0.4	0.0	-0.7	2.5
Nav	Tal	Int 20	RY	-1.1	-3.6	0.0	-2.1	-3.1	-1.5	-0.3	-3.4	-1.9	1.3
Nav	Tal	Int 10	RY	1.0	-2.7	1.5	-1.9	-0.7	-1.2	0.0	-1.9	-0.7	1.4
Nav	Tal	Ext 10	RY	8.3	23.7	9.8	17.1	10.7	4.3	7.9	14.4	12.0	5.7
Cun	Nav	Int 20	RY	0.1	-0.2	0.0	-0.2	-0.7	-0.6	-0.0	-0.5	-0.3	0.3
Cun	Nav	Int 10	RY	0.6	-0.2	-0.8	-0.3	-0.0	-0.1	-0.2	0.1	-0.1	0.4
Cun	Nav	Ext 10	RY	1.0	-0.7	-0.3	-1.4	-0.2	-0.1	0.0	0.6	-0.1	0.7
Met	Cun	Int 20	RY	-2.3	-3.0	-0.9	-3.5	-1.0	-2.8	-1.0	-3.0	-2.2	1.0
Met	Cun	Int 10	RY	-0.7	-1.2	0.2	-1.0	-0.0	-1.3	-0.6	-1.1	-0.7	0.5
Met	Cun	Ext 10	RY	2.9	-1.7	2.5	0.2	1.3	0.6	1.3	-1.6	0.7	1.6
Cal	Tal	Int 20	RY	0.0	-1.6	0.1	●	-2.5	-0.9	-0.4	-2.6	-1.2	1.1
Cal	Tal	Int 10	RY	0.6	-1.4	0.8	-1.0	-0.7	-0.8	-0.3	-1.4	-0.5	0.8
Cal	Tal	Ext 10	RY	5.5	13.4	5.5	10.7	4.4	3.0	7.4	9.5	7.4	3.3
Met	Tal	Int 20	RY	-3.3	-6.7	-0.9	-5.8	-4.9	-4.8	-1.3	-7.0	-4.3	2.1
Met	Tal	Int 10	RY	0.8	-4.1	0.6	-3.3	-0.6	-2.6	-0.7	-3.0	-1.6	1.6
Met	Tal	Ext 10	RY	12.6	22.2	12.3	17.6	12.1	4.9	9.3	13.4	13.0	4.8

A	B	C	D	E	F	G	H	I	J	K	L	M	N
Fib	Tib	DF 30	RZ	-0.6	-0.8	-0.7	-0.8	0.2	-0.7	-1.0	●	-0.8	0.3
Fib	Tib	DF 20	RZ	-0.6	-0.8	-0.4	-0.6	-0.1	-0.7	-1.2	-0.2	-0.6	0.3
Fib	Tib	DF 10	RZ	-0.2	-0.6	-0.2	-0.4	-0.2	-0.5	-0.6	-0.1	-0.4	0.2
Fib	Tib	PF 10	RZ	0.7	-0.2	0.1	0.1	0.5	0.5	0.3	-0.1	0.2	0.3
Fib	Tib	PF 20	RZ	0.6	-0.5	-0.1	0.4	0.7	0.2	0.5	0.2	0.3	0.4
Fib	Tib	PF 30	RZ	0.8	-0.7	-0.0	0.3	1.3	0.4	0.3	0.9	0.4	0.6
Tal	Tib	DF 30	RZ	1.5	6.3	3.0	0.7	0.2	-0.1	-0.3	1.3	1.6	2.0
Tal	Tib	DF 20	RZ	1.6	4.6	2.2	0.6	0.7	0.6	0.2	1.1	1.4	1.3
Tal	Tib	DF 10	RZ	1.1	1.9	1.2	0.0	0.6	0.3	0.5	0.8	0.8	0.6
Tal	Tib	PF 10	RZ	-2.0	-3.8	-3.2	-1.8	-1.5	-2.2	-1.2	-1.6	-2.2	0.9
Tal	Tib	PF 20	RZ	-2.4	-7.3	-4.2	-1.7	-3.4	-3.6	-3.1	-3.5	-3.7	1.6
Tal	Tib	PF 30	RZ	-2.4	-8.9	-5.3	-3.5	-3.3	-3.9	-2.8	-4.8	-4.3	1.9
Nav	Tal	DF 30	RZ	1.9	8.9	0.2	7.1	5.1	5.8	3.0	7.1	4.9	2.8
Nav	Tal	DF 20	RZ	1.3	5.8	-0.4	0.7	5.8	0.4	6.2	●	2.8	2.7
Nav	Tal	DF 10	RZ	1.1	1.0	-1.1	-0.8	1.4	-1.4	-1.6	2.2	0.1	1.4
Nav	Tal	PF 10	RZ	0.4	2.6	1.1	-1.1	-3.4	0.8	0.7	-0.8	0.0	1.7
Nav	Tal	PF 20	RZ	2.7	-1.2	0.3	0.1	-4.1	0.3	1.9	0.2	0.0	1.9
Nav	Tal	PF 30	RZ	5.2	0.6	1.2	3.1	-2.3	2.5	3.1	1.5	1.9	2.1
Cun	Nav	DF 30	RZ	1.2	-1.0	1.9	-1.7	-2.2	-1.3	-0.1	-1.9	-0.6	1.4
Cun	Nav	DF 20	RZ	1.7	0.4	1.4	-0.5	-1.9	-0.4	-1.5	●	-0.1	1.3
Cun	Nav	DF 10	RZ	1.0	1.9	0.6	-0.8	-3.0	-0.1	0.4	-0.9	-0.1	1.4
Cun	Nav	PF 10	RZ	-1.9	-2.3	-0.2	-2.3	-0.0	-0.2	-0.1	0.1	-0.8	1.0
Cun	Nav	PF 20	RZ	-3.2	-1.5	-1.1	-2.6	-1.9	-0.3	-0.9	-0.0	-1.4	1.0
Cun	Nav	PF 30	RZ	-6.6	-1.5	-1.3	-7.8	-3.2	-1.8	-0.4	-1.9	-3.0	2.6
Met	Cun	DF 30	RZ	0.2	-0.2	1.0	-0.4	-0.2	-1.1	0.2	-1.4	-0.2	0.7
Met	Cun	DF 20	RZ	0.2	0.7	0.8	-0.1	-0.4	-0.3	-0.6	-0.1	0.0	0.5
Met	Cun	DF 10	RZ	0.3	0.6	0.6	-0.5	-0.8	0.3	0.6	-0.7	0.0	0.6
Met	Cun	PF 10	RZ	-1.3	-0.3	-0.5	-0.7	-0.4	-0.0	0.2	-0.3	-0.4	0.4
Met	Cun	PF 20	RZ	-1.4	●	-0.2	-0.8	-1.8	-0.9	-2.1	-1.0	-1.2	0.8
Met	Cun	PF 30	RZ	-1.5	●	-0.2	-0.8	-1.2	-1.2	-1.8	-1.1	-1.1	0.5
Cal	Tal	DF 30	RZ	-0.1	2.0	-1.8	2.8	1.7	1.4	0.8	3.4	1.3	1.6
Cal	Tal	DF 20	RZ	0.3	1.8	1.0	0.5	2.3	-0.3	3.5	1.2	1.3	1.1
Cal	Tal	DF 10	RZ	0.0	0.4	1.2	-0.2	-0.0	-0.8	-1.4	0.6	0.0	0.8
Cal	Tal	PF 10	RZ	1.4	1.0	2.0	-0.5	-1.8	1.1	0.4	-0.0	0.4	1.1
Cal	Tal	PF 20	RZ	1.9	0.4	2.2	-0.3	-2.8	1.1	1.7	0.3	0.6	1.5
Cal	Tal	PF 30	RZ	3.4	1.1	1.2	0.6	-2.6	2.4	2.3	1.8	1.3	1.7
Met	Tal	DF 30	RZ	3.3	7.8	3.1	4.9	2.7	3.5	3.1	●	4.0	1.7
Met	Tal	DF 20	RZ	3.2	7.0	1.9	0.1	3.5	-0.3	4.1	1.8	2.7	2.2
Met	Tal	DF 10	RZ	2.4	3.5	0.3	-2.2	-2.5	-1.2	-0.6	0.5	0.0	2.0
Met	Tal	PF 10	RZ	-1.3	-0.0	0.5	-4.1	-3.7	0.6	0.8	-1.0	-1.0	1.8
Met	Tal	PF 20	RZ	-0.6	-2.7	-1.0	-6.3	-7.7	-1.0	-1.1	-0.8	-2.7	2.6
Met	Tal	PF 30	RZ	0.3	-1.1	-0.4	-6.3	-6.9	-0.7	0.9	-1.5	-2.0	2.8
Fib	Tib	Sup 20	RZ	0.0	-0.4	0.0	-0.3	0.0	-0.3	-0.2	-0.4	-0.2	0.2
Fib	Tib	Sup 10	RZ	0.1	-0.3	-0.3	-0.2	0.1	-0.4	-0.3	-0.3	-0.2	0.2
Fib	Tib	Pro 10	RZ	0.0	-0.2	-0.1	-0.1	-0.0	0.1	0.1	0.1	-0.0	0.1
Fib	Tib	Pro 20	RZ	0.0	-0.1	0.1	-0.3	0.1	0.1	0.1	-0.1	-0.0	0.1
Tal	Tib	Sup 20	RZ	0.5	0.5	1.0	-0.5	0.2	0.7	0.2	0.6	0.4	0.4
Tal	Tib	Sup 10	RZ	-0.1	1.2	1.4	-0.4	0.1	0.3	0.2	-0.2	0.3	0.6
Tal	Tib	Pro 10	RZ	-0.6	0.2	0.4	-0.9	-0.1	-0.4	-0.4	-0.7	-0.3	0.4
Tal	Tib	Pro 20	RZ	-1.5	-1.3	-0.5	-0.7	-0.3	-0.9	-0.6	-1.2	-0.9	0.4
Nav	Tal	Sup 20	RZ	8.6	9.0	12.5	8.6	17.0	13.7	16.7	16.7	12.8	3.5
Nav	Tal	Sup 10	RZ	4.9	6.4	6.7	3.0	8.0	9.9	7.3	8.5	6.9	2.0
Nav	Tal	Pro 10	RZ	-2.1	-1.2	-1.1	-2.8	-5.7	-4.7	-3.6	-11.2	-4.0	3.1
Nav	Tal	Pro 20	RZ	-3.6	-6.1	-2.5	-2.9	-18.0	-6.5	-6.2	-15.1	-7.5	5.6
Cun	Nav	Sup 20	RZ	3.7	1.8	2.0	-0.3	0.1	0.6	0.4	-0.3	1.0	1.3
Cun	Nav	Sup 10	RZ	1.6	0.4	0.7	1.1	0.1	0.3	1.3	-0.8	0.6	0.7
Cun	Nav	Pro 10	RZ	-2.0	-1.0	-1.4	-3.1	-2.1	-1.5	-1.5	0.2	-1.5	0.9
Cun	Nav	Pro 20	RZ	-3.2	-2.5	-3.6	-7.5	-3.2	-3.8	-3.3	-0.8	-3.5	1.8
Met	Cun	Sup 20	RZ	1.7	3.2	1.8	0.7	0.2	1.6	-0.1	1.1	1.3	1.0
Met	Cun	Sup 10	RZ	0.6	1.3	1.1	1.0	0.1	0.2	0.1	0.0	0.5	0.5
Met	Cun	Pro 10	RZ	-2.0	-2.1	-0.8	0.2	0.2	-0.2	-1.8	0.9	-0.7	1.1
Met	Cun	Pro 20	RZ	-3.8	-1.4	-2.7	-1.1	-0.2	-1.7	-4.1	0.5	-1.8	1.5
Cal	Tal	Sup 20	RZ	3.9	3.2	2.0	4.2	7.0	5.4	12.1	6.3	5.5	2.9
Cal	Tal	Sup 10	RZ	1.6	2.5	-1.2	1.6	3.4	4.2	5.3	3.6	2.6	1.9
Cal	Tal	Pro 10	RZ	0.0	-0.1	2.2	-1.2	-2.9	-1.7	-1.7	-4.5	-1.2	1.9
Cal	Tal	Pro 20	RZ	0.1	-1.4	1.2	-1.4	-9.5	-2.4	-2.5	-5.8	-2.7	3.2
Met	Tal	Sup 20	RZ	14.1	14.0	16.3	9.0	17.4	15.6	17.2	17.2	15.1	2.6
Met	Tal	Sup 10	RZ	7.1	8.1	8.6	5.1	8.2	10.4	8.8	7.9	8.0	1.4
Met	Tal	Pro 10	RZ	-6.0	-4.3	-3.3	-6.7	-7.6	-6.5	-6.8	-10.1	-6.3	1.9
Met	Tal	Pro 20	RZ	-10.6	-9.9	-8.7	-11.7	-21.2	-11.9	-12.6	-15.5	-12.8	3.7
Fib	Tib	Int 20	RZ	0.1	-0.3	-0.3	0.1	0.5	-0.2	-0.1	-0.2	-0.0	0.3
Fib	Tib	Int 10	RZ	0.1	-0.2	-0.1	-0.2	0.2	-0.2	0.1	-0.2	-0.1	0.2
Fib	Tib	Ext 10	RZ	-0.2	-0.3	0.1	-0.5	-0.2	0.1	-0.1	-0.3	-0.2	0.2
Tal	Tib	Int 20	RZ	-1.1	-0.7	-0.1	-0.8	-0.5	-1.9	-0.4	-0.5	-0.7	0.5
Tal	Tib	Int 10	RZ	-0.6	-0.8	-0.1	-0.2	-0.0	-1.6	-0.4	-0.2	-0.5	0.5
Tal	Tib	Ext 10	RZ	1.6	3.1	1.7	0.4	0.1	4.9	0.1	0.5	1.5	1.6
Nav	Tal	Int 20	RZ	-1.1	-4.8	0.4	-3.2	-5.2	-1.9	-0.7	-7.0	-2.9	2.4
Nav	Tal	Int 10	RZ	1.3	-3.3	2.1	-2.1	-0.9	-1.6	-0.8	-3.3	-1.1	1.6
Nav	Tal	Ext 10	RZ	9.7	14.4	12.0	16.3	10.8	4.9	12.2	12.2	11.5	3.1
Cun	Nav	Int 20	RZ	0.1	-0.1	0.6	-1.6	-0.6	-1.2	-0.7	0.2	-0.4	0.7
Cun	Nav	Int 10	RZ	0.7	0.0	-0.2	-0.1	-0.8	-0.4	-0.7	0.6	-0.1	0.5
Cun	Nav	Ext 10	RZ	-1.9	-6.9	-3.0	-7.5	-4.2	-1.9	-0.6	-4.9	-3.9	2.3
Met	Cun	Int 20	RZ	0.3	1.0	0.6	1.6	1.0	0.9	-0.3	1.5	0.8	0.6
Met	Cun	Int 10	RZ	-0.0	1.3	0.2	1.3	-0.4	0.6	-0.6	0.5	0.4	0.7
Met	Cun	Ext 10	RZ	-1.6	-1.0	-2.7	-1.0	-2.8	-1.2	-0.9	-2.0	-1.6	0.7
Cal	Tal	Int 20	RZ	0.2	-1.3	1.5	●	-2.6	-0.7	-0.8	-2.0	-0.9	1.3
Cal	Tal	Int 10	RZ	0.6	-1.0	1.3	-0.8	-0.5	-0.7	-0.7	-1.2	-0.4	0.8
Cal	Tal	Ext 10	RZ	4.7	6.0	1.0	6.8	3.4	2.4	7.7	9.7	5.2	2.7
Met	Tal	Int 20	RZ	-0.7	-3.7	1.6	-3.2	-4.8	-2.2	-1.7	-6.4	-2.5	2.1
Met	Tal	Int 10	RZ	1.9	-2.0	2.1	-1.0	-2.1	-1.4	-2.1	-2.2	-0.6	1.7
Met	Tal	Ext 10	RZ	8.1	4.5	8.0	5.8	3.5	1.8	10.6	5.3	5.4	2.4