J Orthop Sci (2010) 15:531–539
DOI 10.1007/s00776-010-1492-y

JOURNAL OF
ORTHOPAEDIC SCIENCE

Original article

Proposed novel unified nomenclature for range of joint motion: method for measuring and recording for the ankles, feet, and toes

Hideo Doya[1,6], Naoki Haraguchi[2,6], Hisateru Niki[3,6], Masato Takao[4,6], and Haruyasu Yamamoto[5,6]

[1] Department of Orthopaedic Surgery, Chiba University Graduate School of Medicine, Chiba, Japan
[2] Department of Orthopaedic Surgery, West Tokyo Metropolitan Police Hospital, Tokyo, Japan
[3] Department of Orthopaedic Surgery, St. Marianna University School of Medicine, Kanagawa, Japan
[4] Department of Orthopaedic Surgery, Teikyo University Graduate School of Medicine, Tokyo, Japan
[5] Department of Bone and Joint Surgery, Ehime University Graduate School of Medicine, Shitsukawa, Toon, Ehime 791-0295, Japan
[6] The Ad Hoc Committee on Terminology of the Japanese Society for Surgery of the Foot

Abstract The Ad Hoc Committee of Terminology of the Japanese Society for Surgery of the Foot (JSSF) proposes novel terminology for motion of the ankle, foot, and toe because there are some ambiguities in the current terminology. Articles were identified by searching the electronic databases of PubMed that compared definitions of American Orthopaedic Foot and Ankle Society (AOFAS), International Society of Biomechanics (ISB), and in the textbook of Kapandji as well as the American Academy of Orthopaedic Surgeons (AAOS). A total of 11 articles described the transverse (horizontal) plane motion in the hindfoot as external rotation/internal rotation and 10 as abduction/adduction. In all, 2 articles described the transverse (horizontal) plane motion in midfoot as external rotation/internal rotation and 10 as abduction/adduction. Another 4 articles described the transverse (horizontal) plane motion in the forefoot as external rotation/internal rotation and 8 as abduction/adduction. Altogether, 109 articles described the sagittal plane motion of the foot/ankle as dorsiflexion/plantarflexion and 20 as extension/flexion. In all, 99 articles described the frontal (coronal) plane motion of the foot/ankle as inversion/eversion and 4 as supination/pronation. Furthermore, 12 articles described the sagittal plane motion of toes as dorsiflexion/plantarflexion and 15 as extension/flexion. Another 16 articles described the frontal (coronal) plane motion of toes as supination/pronation and 1 as inversion/eversion. The transverse (horizontal) plane motion of the foot/ankle was defined as abduction/adduction in the hindfoot, midfoot, and forefoot; the sagittal plane motion of the foot/ankle was defined as dorsiflexion/plantarflexion; and the frontal (coronal) plane motion of the foot/ankle as inversion/eversion. The transverse (horizontal) plane motion of toes was defined as abduction/adduction; the sagittal plane motion of toes was defined as extension/flexion; and the frontal (coronal) plane motion of toes was defined as supination/pronation.

Offprint requests to: H. Yamamoto
Received: January 17, 2010 / Accepted: April 19, 2010

Introduction

It is known that the terminology used to describe motion of the foot and ankle contains a number of ambiguities.[1,2] Especially, there are two opinions about the motions inversion/eversion and supination/pronation: One is the concept defining inversion/eversion as coronal plane motion and supination/pronation as triplane motion, advocated by the American Orthopaedic Foot and Ankle Society (AOFAS)[3] and International Society of Biomechanics (ISB).[4] The other is the concept defining inversion/eversion as triplane motion and supination/pronation as coronal plane motion, advocated by Kapandji[5] and the American Academy of Orthopaedic Surgeons (AAOS)[6] (Tables 1-1, 1-2).

To solve this problem, the Ad Hoc Committee of Terminology of the Japanese Society for Surgery of the Foot (JSSF) prepared a novel proposal for terminology of motion of the ankle, foot, and toe. The purpose of this study was thus to present a novel proposal for measuring the range of joint motion (ROM) based on the terminology for motion of the ankle, foot, and toe.

Joint motion of the foot/ankle

Planes of joint motion

As defined by the terminology of the AOFAS[3] and the ISB, we established three planes to express joint motions: transverse (horizontal), sagittal, and frontal (coronal). The neutral zero starting position was modified to the position standing with the long axis of both feet parallel each other. The transverse (horizontal) plane was defined as the plane that included the plantar surface when standing still. The sagittal plane was defined as the plane perpendicular to the transverse (horizontal) plane that included the long axis of the second metatarsal bone. The frontal (coronal) plane was defined as the

Table 1-1. Definition of joint motion of foot and ankle

Plane	AOFAS (1996)	ISB (2002)
Transverse (horizontal)	Forefoot/midfoot	Forefoot/midfoot
	Abduction	External rotation
	Adduction	Internal rotation
	Ankle/hindfoot	Ankle/hindfoot
	External rotation	External rotation
	Internal rotation	Internal rotation
Sagittal	Dorsiflexion	Dorsiflexion
	Plantarflexion	Plantarflexion
Frontal (coronal)	Eversion	Eversion
	Inversion	Inversion

AOFAS, American Orthopaedic Foot and Ankle Society; ISB, International Society of Biomechanics

Table 1-2. Definition of joint motion of foot and ankle

Plane	AAOS[6] (1965)	Kapandji[5] (1987)
Transverse (horizontal)	Abduction	Abduction
	Adduction	Adduction
Sagittal	Extension (dorsiflexion)	Flexion
	Flexion (plantarflexion)	Extension
Frontal (coronal)	Forefoot	Forefoot
	Pronation	Pronation
	Supination	Supination
	Hindfoot	Hindfoot
	Eversion	Pronation
	Inversion	Supination

AAOS, American Academy of Orthopaedic Surgeons

plane perpendicular to the transverse (horizontal) plane and the sagittal plane[2] (Fig. 1).

Joint motion of the foot/ankle

Dorsiflexion/plantarflexion is not only the motion of the ankle; the motions of the subtalar joint and Chopart/Lisfranc joint are involved in dorsiflexion/plantarflexion as well. The motions not only of the joints of the foot but also the ankle joint constitute supination/pronation or inversion/eversion. We described these motions as the unifying motion of the foot and ankle because it is difficult to separate them.

Joint motion in transverse (horizontal) plane

According to the terminology of AOFAS[3] the motion in the transverse (horizontal) plane is described as external rotation/internal rotation of the hindfoot and abduction/adduction of the forefoot, whereas the ISB terminology[4] adopts only external rotation/internal rotation and does not define abduction/adduction.

We reviewed previous articles describing the transverse (horizontal) plane motion of the foot/ankle in the hindfoot, midfoot, and forefoot. The terminology utilized in the literature was explored by examining related academic papers retrieved through a search of the PubMed medical literature database (www.pubmed.com) up to 2008. The following search terms were used in combination: ankle rotation abduction, ankle rotation adduction, foot rotation abduction, foot rotation adduction. Only articles in the English language were included. A total of 160 references were retrieved.

For the hindfoot, 11 articles described the transverse (horizontal) plane motion as external rotation/internal rotation, 10 as abduction/adduction, and 18 as both external rotation/internal rotation and abduction/adduction; 121 articles did not mention specific terms. For the midfoot, 2 articles described the transverse (horizontal) plane motion as external rotation/internal rotation and 10 as abduction/adduction; 148 articles did not mention specific terms. For the forefoot, 4 articles described the transverse (horizontal) plane motion as external rotation/internal rotation and 8 as abduction/adduction; and 148 articles did not mention specific terms (Table 2-1).

Based on the results of the current study, it seems preferable to define the transverse (horizontal) plane motion of the foot/ankle as abduction/adduction of the hindfoot, midfoot, and forefoot because abduction/adduction is somewhat commonly used to describe the

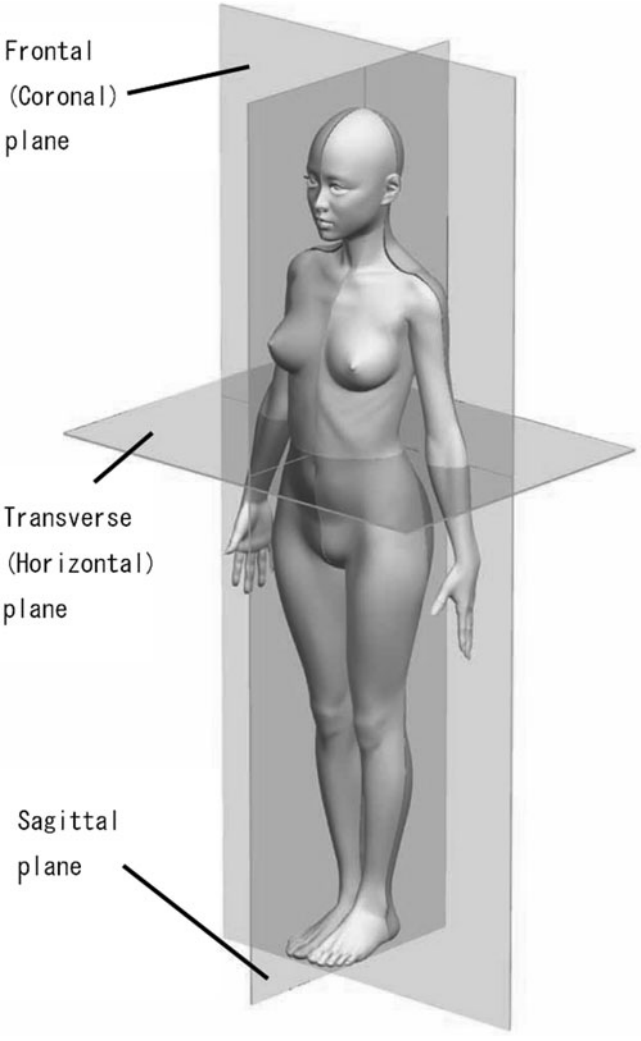


Fig. 1. Three-dimensional view of planes of joint motion at a modified neutral zero starting position

Table 2-1. Results of searching electronic databases for foot/ankle motion in the transverse (horizontal) plane

Condition	Hindfoot	Midfoot	Forefoot
External/internal rotation	11	2	4
Abduction/adduction	10	10	8
Both	18	0	0
Not specified	121	148	148
Total	160	160	160

transverse (horizontal) plane motion of the midfoot and forefoot, although external rotation/internal rotation and abduction/adduction are equally used for the hindfoot (Fig. 2).

Joint motion in the sagittal plane

There are some ambiguities describing the joint motion in sagittal plane, it was defined as extension/flexion

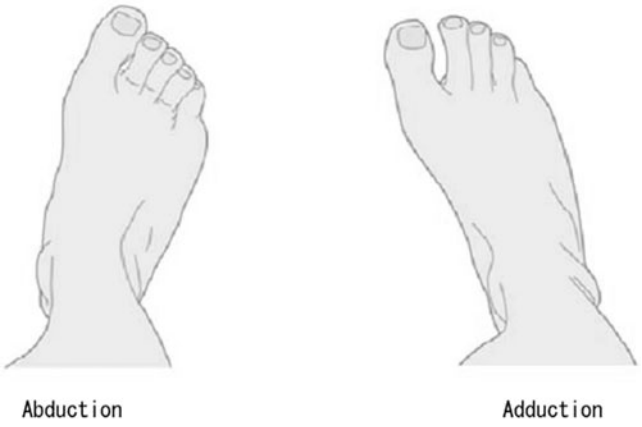


Fig. 2. Joint motion of the foot/ankle in the transverse (horizontal) plane

Table 2-2. Results of searching electronic databases for foot/ankle motion in the sagittal plane

Dorsiflexion/plantarflexion	109
Extension/flexion	20
Both	5
Dorsal extension/plantar flexion	3
Not specified	53
Total	190

(dorsiflexion/plantarflexion) in the terminology of AAOS,[6] however extension/flexion is defined to the reverse motion by Kapandji.[5] In the textbook of Kapandji, he describes that flexion of the ankle is the movement, which approximates the dorsum of the foot and anterior surface of the leg, and extension of the ankle is the movement of the dorsum of the foot away from the anterior surface of the leg. He also mentioned to the term dorsiflexion, which is incorrect because flexion always correspond to the movement of approximation of the segments of a limb and the trunk.

We reviewed the previous papers describing the sagittal plane motion of foot/ankle. The terminology utilized in the literature was explored by examining related academic papers retrieved through a search of the PubMed up to 2008. The following search terms were used in combination: ankle, foot, flexion, extension. Only papers in the English language were included. A total of 190 references were retrieved.

There were 109 papers describing the sagittal plane motion as dorsiflexion/plantarflexion, 20 papers describing the sagittal plane motion as extension/flexion, 5 papers describing the sagittal plane motion as both dorsiflexion/plantarflexion and extension/flexion and 3 papers describing the sagittal plane motion as dorsal extension/plantar flexion, and 53 papers not describing specific terms (Table 2-2). In the 20 papers describing

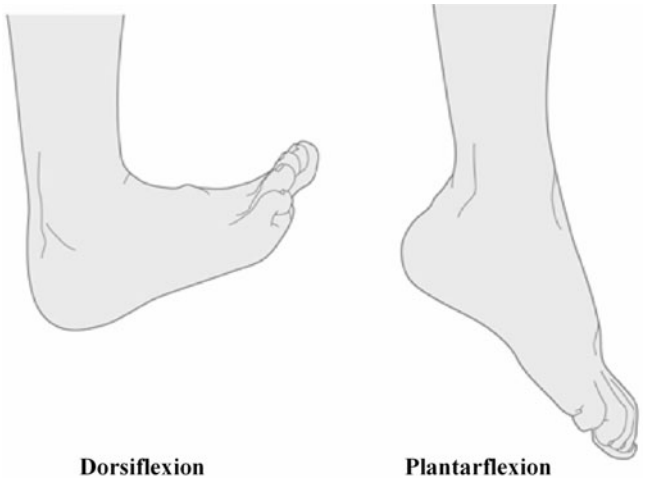


Fig. 3. Joint motion of the foot/ankle in the sagittal plane

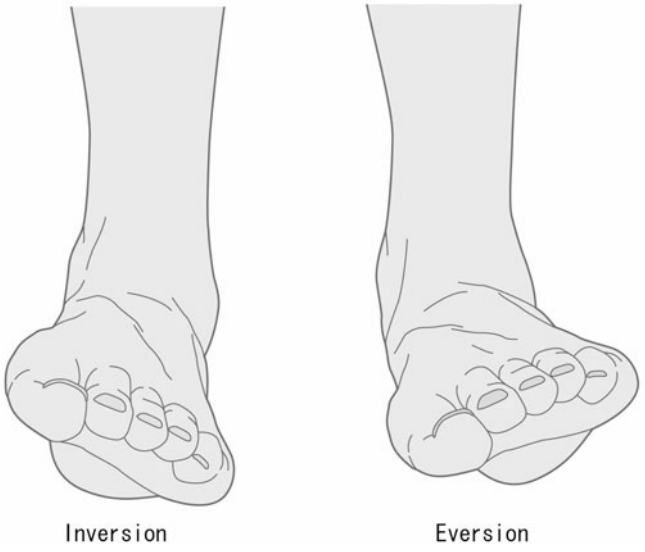


Fig. 4. Joint motion of the foot/ankle in the frontal (coronal) plane

the sagittal plane motion as extension/flexion, the direction of the motion was corresponding to the definition of Kapandji[5] and we could not find any paper describing the dorsiflexion for the upward motion of the ankle and plantarflexion for the downward motion of the ankle as described by AAOS.[6]

In the novel proposition, we eliminated extension/flexion, and defined the sagittal plane motion of foot/ankle as dorsiflexion/plantarflexion, because dorsiflexion/plantarflexion is commonly used to describe the sagittal plane motion of foot/ankle (Fig. 3).

Joint motion in frontal (coronal) plane

In some textbooks, coronal plane motion of foot/ankle is defined as inversion/eversion,[1,2,7,8] but it is also defined as supination/pronation in other textbooks.[5,9–11]

Doya et al reviewed the previous papers describing the frontal (coronal) plane motion of foot/ankle.[12] They explored the terminology utilized in the literature examining related academic papers retrieved through a search of the PubMed up to 2006. The following search terms were used in combination: ankle, foot, inversion, eversion. Only papers in the English language were included. A total of 141 references were retrieved. They reported that there were 92 papers describing the frontal (coronal) plane motion as inversion/eversion, 4 papers describing the frontal (coronal) plane motion as supination/pronation, and 45 papers not describing specific terms (Table 2-3).

According to the results of the current study, it may be preferable to define the frontal (coronal) plane motion of foot/ankle as inversion/eversion, because inversion/eversion is commonly used to describe the coronal plane motion of foot/ankle (Fig. 4).

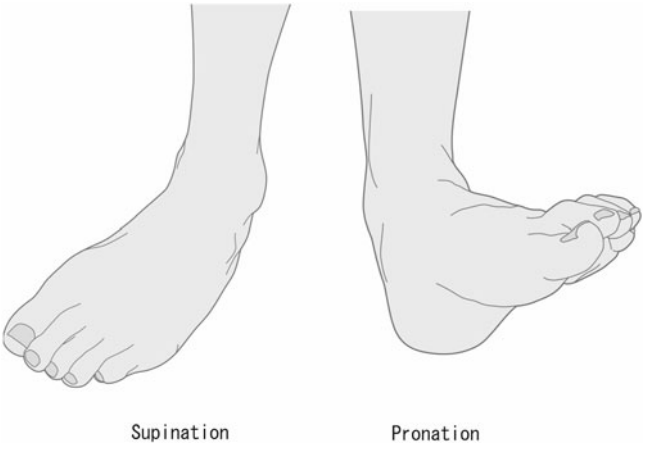


Fig. 5. Combined joint motion of the foot/ankle in a triplane view

Table 2-3. Results of searching electronic databases for foot/ankle motion in the frontal (coronal) plane

Inversion/eversion	92
Supination/pronation	4
Not specified	45
Total	141

Complex motion

We defined the complex motion in two or three planes as a combination of the motions. Especially, the triplane motion — composed of plantarflexion, adduction, and inversion of the foot/ankle — is defined as supination; and the motion composed of dorsiflexion, abduction, and eversion is defined as pronation (Fig. 5) This is

Table 2-4. Results of searching electronic databases for proposition of terminology of foot/ankle motion

Plane	Ankle joint	Subtalar joint	Chopart/Lisfranc joints
Transverse (horizontal)	Abduction Adduction	Abduction Adduction	Abduction Adduction
Sagittal	Dorsiflexion Plantarflexion	Dorsiflexion Plantarflexion	Dorsiflexion Plantarflexion
Frontal (coronal)	Eversion Inversion	Eversion Inversion	Eversion Inversion

because "supination" originates from *supino* in Latin (to bend backward), and pronation originates from *prono* in Latin (to bend forward).[13] In the forearm, the motion of rotating outward around the axis of the forearm from the neutral zero starting position results in the hand turning upward is called supination, and the motion of rotating it inward around the axis of the forearm from the neutral zero starting position results in the hand turning downward is called pronation. In the modified neutral zero position of the foot/ankle, the foot is already rotated inward around the axis of the leg, and the ankle is dorsiflexed corresponding to the neutral zero position of the forearm. The motion of making the foot/ankle bend backward consists of rotating outward around the leg axis, thereby plantarflexing the ankle and adducting the foot; and the motion of making the foot/ankle bend forward consists of rotating inward around the leg axis, thereby dorsiflexing the ankle and abducting the foot. From the etymological point of view, this indicates that supination is a complex motion of plantarflexion, adduction, and inversion; and pronation is a complex motion of dorsiflexion, abduction, and eversion.

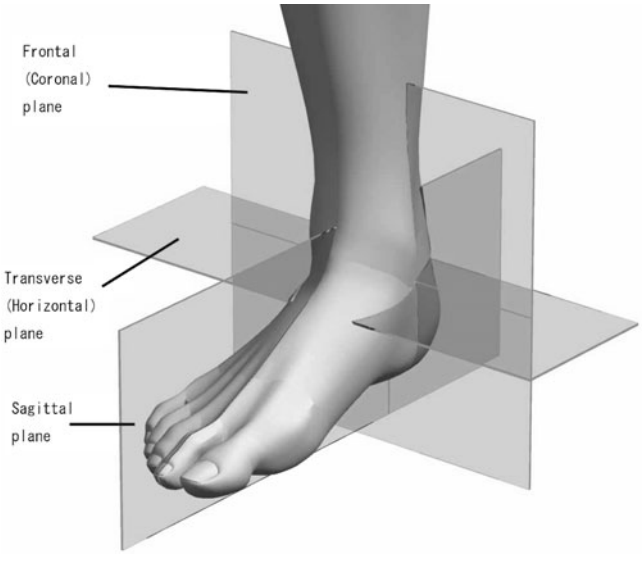


Fig. 6. Three-dimensional view of planes of joint motion of the foot/ankle

Table 2-5. Results of searching electronic databases for supination/pronation of the foot/ankle

Plane	Supination	Pronation
Transverse (horizontal)	Adduction	Abduction
Sagittal	Plantarflexion	Dorsiflexion
Frontal (coronal)	Inversion	Eversion

Proposed terminology for joint motion of the foot/ankle

See Fig. 6 for reference.

- *Abduction/adduction* (Table 2-4): Abduction/adduction comprises motion of the ankle joint, subtalar joint, and Chopart/Lisfranc joint in the transverse (horizontal) plane.
- *Dorsiflexion/plantarflexion* (Table 2-4): Dorsiflexion/plantarflexion comprises motion of the ankle joint, subtalar joint, and Chopart/Lisfranc joint in the sagittal plane.
- *Inversion/eversion* (Table 2-4): Inversion/eversion comprises motion of the ankle joint, subtalar joint, and Chopart/Lisfranc joint in the frontal (coronal) plane.
- *Supination/pronation* (Table 2-5): Supination/pronation is complex joint motion in the triplane. *Supination* is the complex motion of plantarflexion, adduction, and inversion comprised of motion of the ankle joint, subtalar joint, and Chopart/Lisfranc joint. *Pronation* is the complex motion of dorsiflexion, abduction, and eversion comprised of motion of the ankle joint, subtalar joint, and Chopart/Lisfranc joint.

Joint motion of toes

We defined the joint motion of toes with three planes, as described for the foot/ankle. Motion in the transverse (horizontal) plane was defined as abduction/adduction according to the motion of forefoot.

We reviewed previous articles that described the sagittal plane motion of toes. The terminology utilized in the literature was explored by examining related academic articles retrieved through a search of the PubMed up to 2008. The following search terms were used in combination: hallux, toe, flexion, extension. Only articles in the English language were included. A total of 112 references were retrieved. A total of 12 articles described the sagittal plane motion as dorsiflexion/plantarflexion and 15 as extension/flexion; 85 articles did not mention specific terms (Table 3-1). We defined the sagittal plane motion of toes as extension/flexion as it was described in the conventional terminology of the Japanese Orthopaedic Association (JOA) because both of them were used equally.

Articles describing the frontal (coronal) plane motion of toes were also reviewed. The terminology was explored by examining papers retrieved through a search of the PubMed up to 2008. The following search terms were used in combination: hallux, toe, supination, pronation, inversion, eversion. Only English-language articles were included. A total of 145 references were retrieved. Altogether, 16 papers described the frontal (coronal) plane motion as supination/pronation and 1 as inversion/eversion; 128 papers did not mention specific terms (Table 3-2). In the preparation of the novel proposal for the terminology motion of toes, we defined the frontal (coronal) plane motion as supination/pronation. Care must be taken because the definitions are different from those of supination/pronation of the foot/ankle.

Based on the results of the current study, it is preferable to define motion of the toes as motion in the MTP joint and the IP (PIP and DIP) joint, respectively, because it is difficult to determine the basic axis and moved axis as the whole motion of the toes.

Table 3-1. Results of searching the electronic databases for toe motion in the sagittal plane

Dorsiflexion/plantarflexion	12
Extension/flexion	15
Not specified	85
Total	112

Table 3-2. Results of searching the electronic databases for toe motion in the frontal (coronal) plane

Supination/pronation	16
Inversion/eversion	1
Not specified	128
Total	145

Proposed terminology for joint motion of toes

See Fig. 7 for reference.

- *Abduction/adduction* (Table 3-3): Abduction/adduction is composed by the motion of MTP joint, IP joint of great toe and PIP and DIP joints of toes in transverse (horizontal) plane.

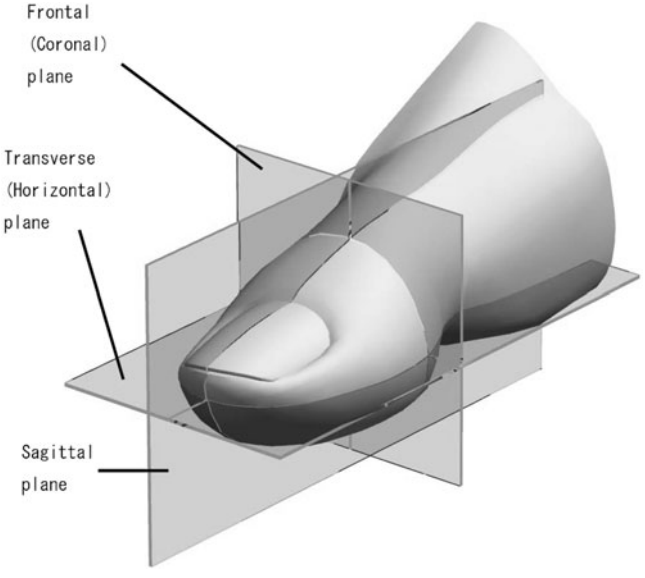


Fig. 7. Three-dimensional view of planes of joint motion of the toes

Table 3-3. Results of searching the electronic databases for proposition of terminology of the motion of toes

Plane	MTP joint	IP joint of great toe	PIP and DIP joints of toes
Transverse (horizontal)	Abduction Adduction	Abduction Adduction	Abduction Adduction
Sagittal	Extension Flexion	Extension Flexion	Extension Flexion
Frontal (coronal)	Supination Pronation	Supination Pronation	Supination Pronation

MTP, metatarsophalangeal; IP, interphalangeal; PIP, proximal interphalangeal; DIP, distal interphalangeal

- *Extension/flexion* (Table 3-3): Extension/flexion is composed by the motion of MTP joint, IP joint of great toe and PIP and DIP joints of toes in sagittal plane.
- *Supination/pronation* (Table 3-3): Supination/pronation is composed by the motion of MTP joint, IP joint of great toe and PIP and DIP joints of toes in frontal (coronal) plane.

Range of joint motion; method of measuring and recording for ankle, foot, and toe

In consideration of the above, we established a novel joint motion of the foot/ankle and toe as well as the range of joint motion. Refer to Tables 4–7 for details.

Notes

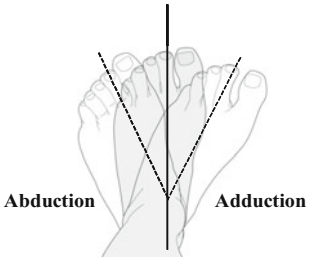
1. Valgus/varus is not used for motion of the forefoot and toes but as the term describing motion in the transverse (horizontal) plane for the foot/ankle and toe. For instance, hallux valgus is the deformity of

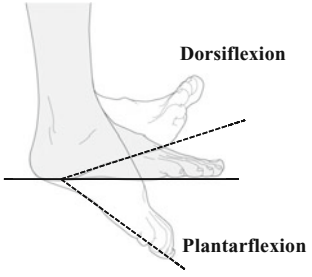
Table 4. Proposition of joint motion of foot/ankle and toe

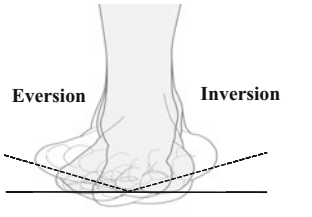
Plane	Foot/ankle	Toe
Transverse (horizontal)	Abduction	Abduction
	Adduction	Adduction
Sagittal	Dorsiflexion	Extension
	Plantarflexion	Flexion
Frontal (coronal)	Inversion	Supination
	Eversion	Pronation

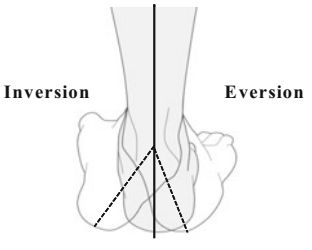
Table 5. Range of joint motion: method of measuring and recording for foot/ankle

		Measuring			
Joint motion	ROM	Plane	Basic axis[a]	Moved axis[a]	Figure[a]
Abduction	0–10	Transverse (horizontal)	Long axis of second metatarsal bone	Long axis of second metatarsal bone	
Adduction	0–20	Transverse (horizontal)	Long axis of second metatarsal bone	Long axis of second metatarsal bone	
Dorsiflexion	0–20	Sagittal	Perpendicular to axis of leg	Plantar surface	
Plantarflexion	0–60	Sagittal	Perpendicular to axis of leg	Plantar surface	
Inversion (midfoot and forefoot)	0–20	Frontal (coronal)	Plantar surface	Plantar surface	
Eversion (midfoot and forefoot)	0–20	Frontal (coronal)	Plantar surface	Plantar surface	
Inversion (hindfoot)	0–30	Frontal (coronal)	Axis of leg	Axis of calcareous	
Eversion (hindfoot)	0–30	Frontal (coronal)	Axis of leg	Axis of calcareous	





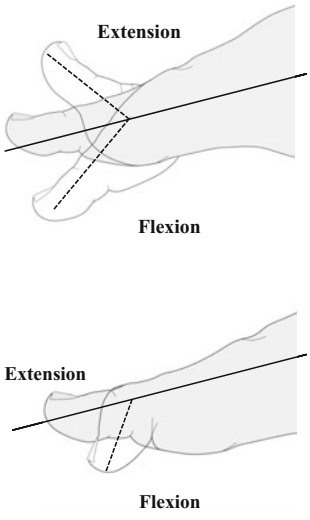




ROM, range of motion
[a] Basic axis, solid line; moved axis, broken line

Table 6. Range of joint motion: method of measuring and recording for the great toe

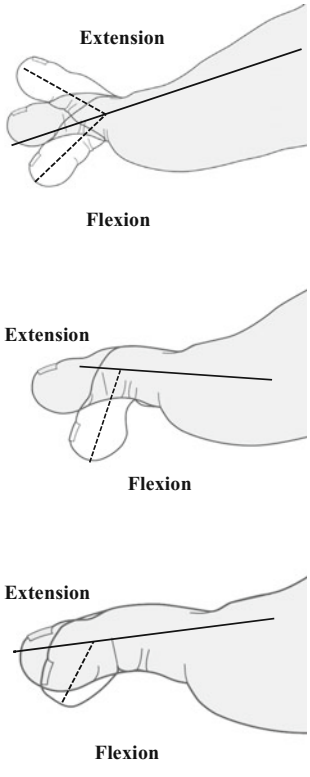
Joint motion	ROM	Measuring (in the sagittal plane)		Figure[a]
		Basic axis[a]	Moved axis[a]	
MP joint				
Extension	0–60	Long axis of first metatarsal bone	Long axis of first basal phalanx	
Flexion	0–35	Long axis of first metatarsal bone	Long axis of first basal phalanx	
IP joint				
Extension	0	Long axis of first basal phalanx	Long axis of first distal phalanx	
Flexion	0–60	Long axis of first basal phalanx	Long axis of first distal phalanx	



[a] Basic axis, solid line; moved axis, broken line

Table 7. Range of joint motion: method of measuring and recording for toes

Joint motion	ROM	Measuring (in the sagittal plane)		Figure[a]
		Basic axis[a]	Moved axis[a]	
MP joint				
Extension	0–60	Long axis of 2nd–5th metatarsal bone	Long axis of 2nd–5th basal phalanx	
Flexion	0–35	Long axis of 2nd–5th metatarsal bone	Long axis of 2nd–5th basal phalanx	
PIP joint				
Extension	0	Long axis of 2nd–5th basal phalanx	Long axis of 2nd–5th mid-phalanx	
Flexion	0–60	Long axis of 2nd–5th basal phalanx	Long axis of 2nd–5th mid-phalanx	
DIP joint				
Extension	0	Long axis of 2nd–5th mid phalanx	Long axis of 2nd–5th distal phalanx	
Flexion	0–60	Long axis of 2nd–5th mid phalanx	Long axis of 2nd–5th distal phalanx	



[a] Basic axis, solid line; moved axis, broken line

first MTP joint; however, concerning the direction of the movement, it corresponds to abduction and actually pronation of the great toe.
2. Two methods for measuring inversion/eversion of the foot/ankle are described because the implications of inversion/eversion of the hindfoot and mid-forefoot are clinically different.
3. Complex motions composed of two or three motions are described as the combination of the motions (e.g., dorsiflexion + abduction, dorsiflexion + abduction + inversion).
4. Supination/pronation of the foot/ankle is a particularly complex motion. Supination requires plantarflexion + adduction + inversion; and pronation requires dorsiflexion + abduction + eversion. However, supination/pronation of the toes is defined as the frontal (coronal) plane motion.
5. Measuring the motions of toes was defined only in the sagittal plane because motion in the transverse (horizontal) plane or frontal (coronal) plane is less frequently seen in clinical practice.

References

1. Reese NB, Bandy WD. Joint range of motion and muscle length testing. Philadelphia: Saunders; 2002.
2. Resch S. Functional anatomy and topography of the foot and ankle. In: Myerson MS, editor. Foot and ankle disorders. Philadelphia: Saunders; 1999. p. 25–9.
3. Saltzman C, Alexander I, Kitaoka H, Trevino S. Orthopaedic Foot and Ankle Society Ad Hoc Committee report, January 1996. Foot Ankle Int 1997;18:310–1.
4. Wu G, Siegler S, Allard P, Kirtley C, Leardini A, Rosenbaum D, et al. ISB recommendation on definitions of joint coordinate system of various joints for the reporting of human joint motion. Part 1. Ankle, hip, and spine. J Biomech 2002;35:543–8.
5. Kapandji IA. The physiology of the joints. Vol 2, 5th edn. London: Churchill Livingstone; 1987.
6. American Academy of Orthopaedic Surgeons. Joint motion: method of measuring and recording. Rosemont, IL: AAOS; 1965.
7. Valmassy RL. Clinical biomechanics of the lower extremities. St. Louis: Mosby; 1996.
8. Clarkson HM. Joint motion and function assessment. Philadelphia: Lippincott Williams & Wilkins; 2005.
9. Norkin CC, White DJ. Measurement of joint motion a guide to goniometry. 3rd edn. Philadelphia: FA Davis; 2003.
10. Soames R. Joint motion clinical measurement and evaluation. London: Churchill Livingstone; 2003.
11. Smith LK, Weiss EL, Lehmkuhl LD. Brunnstrom's clinical kinesiology. 5th edn. Philadelphia: FA Davis; 1996.
12. Doya H, Murata A, Asano Y, Moriya H, Yoshinaga K. Defining inversion/eversion of the foot; is it a triplane motion or a coronal plane motion? Jpn J Rehabil Med 2007;44:286–92 (in Japanese).
13. Lewis CT, Short C. A Latin dictionary. Oxford: Oxford University Press; 1969.