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COMPREHENSIVE REVIEW OF FOOT MEASUREMENTS TERMINOLOGY IN USE

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COMPREHENSIVE REVIEW OF FOOT MEASUREMENTS TERMINOLOGY IN USE

ABSTRACT

Digital foot measurements are typically obtained from foot scanners or digital measuring software providers and they are consumed (or used) by footwear brands, orthotic workshops, size recommendation platforms, or even directly by footwear and orthotics users. IEEE SA Industry Connections (IC) 3D Body Processing (3DBP) Footwear Subgroup recommends that each digital foot measurement provider make measurement definitions publicly available for foot measurement data consumers. Foot scanning companies are providing measuring software that follow different definitions. This is particularly problematic in the case of key references, such as the foot axis. Many measurements are dependent upon the definition of the foot axis, giving rise to different values assigned to the same designation. This compilation will facilitate the comparison across definitions for measurement data consumers and help them make informed decisions.

1. RECOMMENDATION

Digital foot measurements are typically obtained from foot scanners or digital measuring software providers and they are consumed (or used) by footwear brands, orthotic workshops, size recommendation platforms or even directly by footwear and orthotics users. The recent large-scale installations of foot scanners into footwear retail makes it possible to collect large data sets of customer foot data. These data sets provide new opportunities for footwear brands to use the data when designing and grading footwear.

IEEE SA Industry Connections (IC) 3D Body Processing (3DBP) Footwear Subgroup recommends that each digital foot measurement provider make measurement definitions publicly available for foot measurement data consumers.

Why is it important that foot measurement definitions be publicly available? Mainly, it is to help data consumers make informed decisions. For instance:

- Brands need to understand the process used to obtain measurements if the brand is tying their process to a particular measurement input technology.
- Shoe-size recommendation platforms utilizing more than one input device (e.g., scanner smartphone app, or traditional manual approaches) need to understand the definitions underlying the methods or risk misinterpreting the output.
- A user may wish to use his/her acquired measurements with a specific device/technology and use them in different contexts, such as selecting footwear by stated size online or selecting foot orthotics.
- A researcher wishing to compare results between different foot scanning projects needs to understand the process used to obtain those measurements.

2. INTRODUCTION

Measurements of the human body based on manual methods have a long history and were standardized long before whole body scanners were developed. Manual measurements and scan-derived measurements are based on common definitions. Both methods use the same body-oriented coordinate system based on mid-sagittal plane, vertical direction, and bilateral direction. Several different foot-oriented coordinate systems (or foot axis) have been used.

The relative symmetry of the human body made this possible. However, human feet are asymmetrical to a degree that is important for proper fitting footwear and, unlike the body, standardized foot measurement definitions for shoe sizing are scarce, and just few standardization bodies addressed them (e.g., JIS S 5037:1998 [1]). Three-dimensional (3D) foot scanners have been available since the late nineties while the first international ISO standard was released in 2015 (ISO/TS 19408:2015 [2]). Existing standards of foot measurements are intended for manual measurements. Scan-derived foot measurements can be defined using a coordinate system (or foot axis) based on landmarks that are not practical for manual measurements.

These facts resulted in several foot scanning companies providing measuring software that follow different definitions. This is particularly problematic in the case of key references, such as the foot axis. Many

measurements are dependent upon the definition of the foot axis, giving rise to different values assigned to the same designation.

This paper will not be presenting a comparison between manual and scanned measurements or about the reliability of traditional or digital methods, since there is extensive literature addressing these topics (Ballester et al., 2017 [3], [4]; Butler, R. J. et al., 2008 [5]; De Mits, S. et al., 2010 and 2011 [6], [7]; Gordon C. C. et al., 1989 [8]; ISO 20685-1:2018 [9], Kouchi, M. et al., 1996 [10], 1999 [11] and 2014 [12]; Kouchi, M., and Mochimaru, M., 2006 [13] and 2011 [14]; Laughton, C. et al., 2002 [15]; Lee, Y. C. et al., 2014 [16]; Liu, W. et al., 1999 [17]; Mall, N. A. et al., 2005 [18] and 2007 [19]; Pohl, M. B. and Farr, L., 2010 [20]; Telfer, S., and Woodburn, J., 2010 [21]; Williams, D. S., and McClay, I. S., 2000 [22]; Witana, C. P. et al., 2006 [23]).

This paper gathers a compilation of foot measurement definitions and related terminology made by the IEEE IC 3DBP Footwear Subgroup. This compilation includes terms and definitions from standards (i.e., ISO/TS 19408:2015 [2], JIS S 5037:1998 [1]) and from the main foot measurement suppliers: SATRA [24], I-Ware Laboratory Co., Ltd. (I-Ware) [25], Volumental [26] [27], Instituto de Biomecánica de Valencia (IBV) [28], TryFit [29], TechMed 3D [30], Bodyform3D [31], and Aetrex [32], [33], [34], [35]. Measurements from ISO 8559-1:2017 [36], ISO 7250-1:2017 [37], and ASTM D5219-15 [38] are deliberately excluded because they are focused on full body dimensions and the foot definitions are either included in ISO/TS 19408:2015 [2] or are too vaguely defined. This compilation will facilitate the comparison across definitions for measurement data consumers. If other companies or standards organizations would like to be included in a future paper, please contact the authors.

This document focuses on static foot measurements. Dynamic foot measurements are not covered. Shoe last measurements, even those similar in names to foot measurements are not covered.

This paper is organized into two sections: Section 3 includes a review of terms related to foot measurements; Section 4 identifies gaps in current standards and industry practices and concludes with possible future work.

3. TERMS AND DEFINITIONS

This section is structured into three subsections:

- Section 3.1 includes the definition of measuring or scanning conditions that have an important impact on foot shape, and therefore on measurement definitions.
- Section 3.2 provides key anatomical references, features, planes, and lines that are used to define foot measurements.
- Section 3.3 includes foot measurement definitions found in standards and/or utilized by foot scanner and digital foot processing technologies.

For clarity and to facilitate comparisons, original definitions with images provided by each measurement provider have been rewritten and grouped to show the differences between them.

3.1. FOOT SCANNING CONDITIONS AFFECTING FOOT SHAPE

3.1.1. ATTIRE

When being measured or scanned, the foot can be barefoot, wearing a sock, a thin hose or a compression stocking. Foot attire thickness will affect measurements. Moreover, compression can induce shape changes, especially in the forefoot. Note that even with thin hose, toes are compressed with the result that toe angle measurements and sometimes foot length are affected. Some scanning solutions require the user to wear a patterned sock to digitize it.

It is recommended that each scanning or foot measuring technology state if the use of socks is supported or required. TABLE 1 summarizes the requirements and recommendations made by different measurement providers in this regard.

TABLE 1 Requirements and recommendations for attire made by different measurement providers

Provider	Requirements/recommendations	Other conditions supported
ISO/TS 19408:2015	Barefoot required	Thin hose that does not significantly affect the dimensions of the foot.
Aetrex	Barefoot recommended	Any type of hose or sock is supported. For any thickness beyond a thin hose, the person should be informed hose or sock choices will impact final dimensions of foot measurement.
Bodyform3D	Barefoot recommended	Very thin hose that is not shiny and does not affect the dimensions of the foot.
IBV, SATRA, I-Ware, and TechMed 3D	Barefoot recommended	Thin hose that does not significantly affect the dimensions of the foot.
TryFit	Any color thin socks recommended	Thin hose that does not significantly affect the dimensions of the foot.
Volumental	Barefoot or thin socks recommended	Other socks of any color and pattern.

3.1.2. POSTURE AND WEIGHT BEARING

Foot structure includes soft and hard parts that are flexible and articulated. Foot shape changes during activity (e.g., gait cycle) but also between different loading or weight bearing conditions in static postures. These shape changes affect foot measurements (Yamazaki N., 1999 [39]; Tsung et al., 2003 [40]; Houston et al., 2006 [41]; Xiong et al., 2006 [42]; Ballester et al., 2019 [43]).

These differences can be as large or larger as shoe size grading intervals. It is therefore important that measurement consumers are aware of the conditions under which the foot was measured to account for its application (e.g., made-to-measure or size recommendation).

Procedures used to scan feet may consist of:

- Full-weight bearing (FWB): the user stands erect on one foot on a flat surface.
- Half-weight bearing (HWB): the user stands erect distributing body weight equally on both feet on a flat surface. This is the most commonly used condition for footwear applications.
- Non-weight bearing (NWB): foot is in the air when measured not supporting any body weight. Foot pose is not usually standardized. This condition is sometimes used in clinical applications. This condition is challenging to digitize because the user should remain still during the scanning process.
- Partial-weight bearing, sitting (SWB): the user sits on a chair resting most of his/her body weight on the chair and the foot lies on a flat surface.
- Partial-weight bearing, inclined plane (IWB): the user sits on a chair resting most of his/her body weight on the chair and the foot lies on a flat surface inclined at some degree (FIGURE 1).

It is recommended that, at least, each scanning or foot measuring technology state the weight bearing conditions required or recommended, especially if support is involved. Ideally, the weight bearing condition should be provided as metadata. TABLE 2 summarizes the requirements and recommendations made by different measurement providers in this regard.

TABLE 2 Requirements and recommendations for weight bearing made by different measurement providers

Provider	Requirements/recommendations	Other conditions supported
ISO/TS 19408:2015, JIS S 5037:1998, SATRA and Aetrex	HWB required	
Bodyform3D	NWB recommended	FWB
I-Ware	HWB recommended	NWB, FWB, SWB (knee and ankle joints have to be 90°), IWB
IBV	HWB recommended	FWB, SWB
TechMed3D	FWB, HWB, NWB, SWB, IWB supported. No particular recommendation or requirement	
TryFit and Volumental	HWB recommended	

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FIGURE 1 Example of other weight bearing conditions (IWB)
Foot positioning optimization module to allow scanning the dorsum of the foot at the same time as the plantar surface, developed by TechMed 3D.

3.1.3. USE OF PHYSICAL MARKERS OR STICKERS

Foot measurements are defined using landmarks. Scan-derived measurements are calculated using landmark positions and surface data. Landmark positions are automatically calculated in some software, while with other software, users put marker stickers at manually determined landmark positions which are automatically detected. Different types of errors are involved in landmark positions obtained by the two types of methods. Automated landmarking includes errors in estimating landmark positions, while using physical markers includes errors in detecting marker positions and the artifact caused by the physical markers (Kouchi and Mochimaru, 2011 [14]).

It is recommended that each scanning or foot measuring technology state if the use of markers is required/recommended or supported or required. TABLE 3 summarizes the requirements and recommendations made by different measurement providers in this regard.

TABLE 3 Requirements and recommendations for marker use made by different measurement providers

Provider	Requirements/recommendations	Other conditions supported
Aetrex, Bodyform3D, IBV, SATRA, TryFit, Volumental	Markerless	
I-Ware	Markers recommended for detecting landmarks on bones and for more precise measurements	Markerless
TechMed 3D	Markerless	Markers with Bodyscan scanner

3.2. KEY ANATOMICAL REFERENCES

Anatomical references are used in measurement definitions. Such references are typically points, lines, planes and sections. Different contexts (e.g., academic, health, or footwear) and different measurement providers use different terminology to refer to the same foot anatomical features. Similar terminology can also have slightly different definitions, as utilized by the different measurement providers.

Anatomical features are used in this paper for being the most concise and unambiguous way to designate a reference.

3.2.1. ACROPODION (AP)

It is the end of the most prominent toe. It is also designated as: “furthest toe,” “foremost point of the foot,” or “tip of the longest toe.” See FIGURE 2.

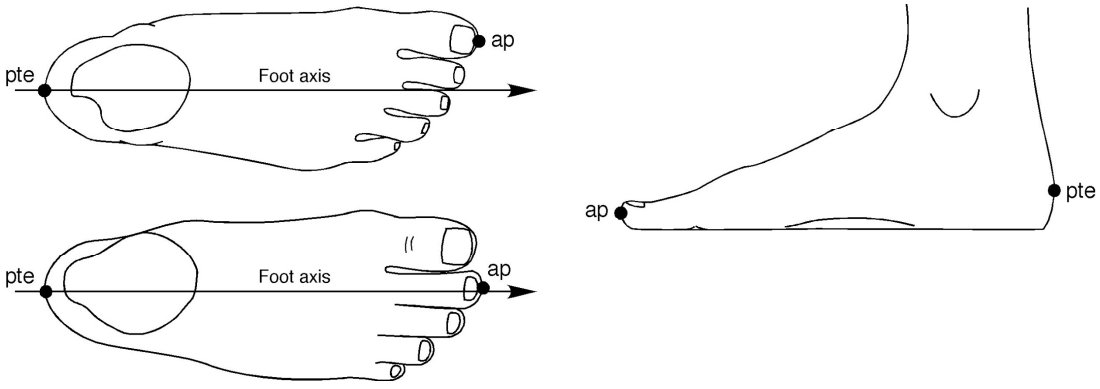

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FIGURE 2 Acropodion (ap) (Section 3.2.1) and pternion (pte) (Section 3.2.2)

3.2.2. PTERNION (PTE)

It is the maximum point of the heel curve. It is also designated as the “center of the back of the heel,” “back of the heel,” “rearmost point of the foot,” or “furthest point of the back of the heel.” See FIGURE 2.

3.2.3. LANDING POINT

It is the rearmost transition point of the weight-bearing surface to the posterior non-weight-bearing surface of the heel. This is the point where the dorsal surface of the heel meets the sole of the foot. It is also designated as “rearmost point of the foot sole/plant/tread.” See FIGURE 3.

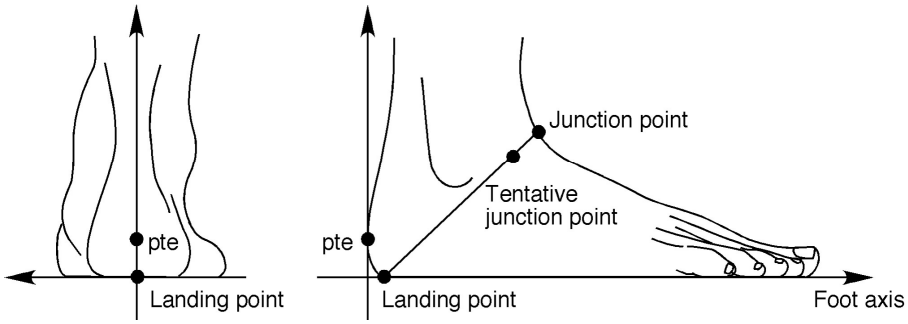

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FIGURE 3 Landing point (Section 3.2.3), tentative junction point (Section 3.2.4), and junction point (Section 3.2.5). pte: pternion. Actual position of junction point may depend on the definition of the foot axis

3.2.4. TENTATIVE JUNCTION POINT

It is the crossing point of the skin crease at the ankle and the tendon of the toe extensor muscle to the 5th toe. The tendon is easily visible when the toes are dorsiflexed. The skin crease at the ankle is easily visible when the knee and ankle joints are bent while standing. See FIGURE 3.

3.2.5. JUNCTION POINT

The point furthest from the landing point on the cross section that passes the landing point and tentative junction point and perpendicular to the sagittal plane including the foot axis. See FIGURE 3.

3.2.6. METATARSALE TIBIALE (MT)

It is the projection to the skin of the most medial point (outside swell) of the head of the first metatarsal bone. See FIGURE 4.

3.2.7. METATARSALE FIBULARE (MF)

It is the projection to the skin of the most lateral point (outside swell) of the head of the fifth metatarsal bone. See FIGURE 4.

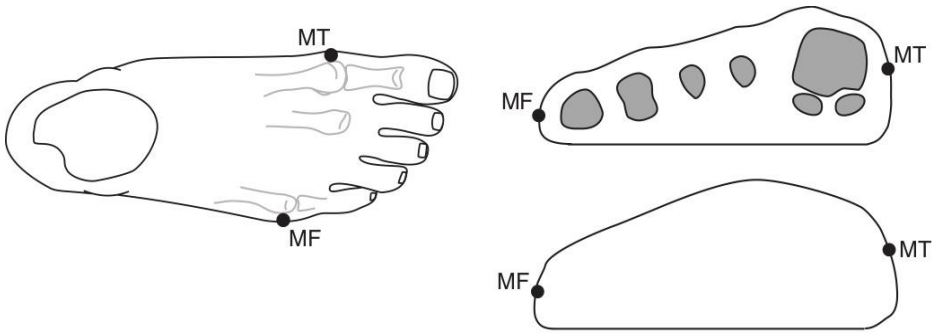

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FIGURE 4 Metatarsale tibiale (MT, Section 3.2.6), metatarsale fibulare (MF, Section 3.2.7)

Note that MT is not always the most medial point on the ball of the foot section, or MF is not always the most lateral point on the ball of the foot section.

3.2.8. BALL OF THE FOOT SECTION

It is a cross section of the metatarsophalangeal (or metatarsal) joint of the foot. In most cases it is defined by passing through two points located, respectively, at first and fifth metatarsal heads. The metatarsal heads are relatively large (centimeters) and the location of the specific points used by each measurement provider can be different. TABLE 4 summarizes the definitions according to different measurement providers. See FIGURE 5.

TABLE 4 Ball section definitions and providers that use them

#	Definition	Measurement providers*
1	Cross section of the foot perpendicular to the standing surface and passing metatarsale tibiale (MT) and metatarsale fibulare (MF).	JIS S 5037:1998, I-Ware, Bodyform3D, SATRA, IBV, TechMed 3D (method 1)
2	Cross section of the foot by a plane inclined 80˚ from the standing surface (horizontal plane) and passing metatarsale tibiale and metatarsale fibulare.	TechMed 3D (method 2)
3	Cross section of the foot perpendicular to the standing surface at the widest part of the ball of the foot, passing through the most medial and most lateral points of the metatarsal joint in the soft tissue.	Aetrex
4	Cross section of the foot perpendicular to the standing surface and passing through the 1st and 5th metatarsal heads, which is estimated as a plane that passes a point at 69% foot length (FL) on foot axis #8 (midpoint of the breadth at 10% FL – point at 66% FL and 40% width from medial side) and it is rotated around the vertical axis by 16°.	Volumental

* ISO 19408:2015 and TryFit do not have this definition.

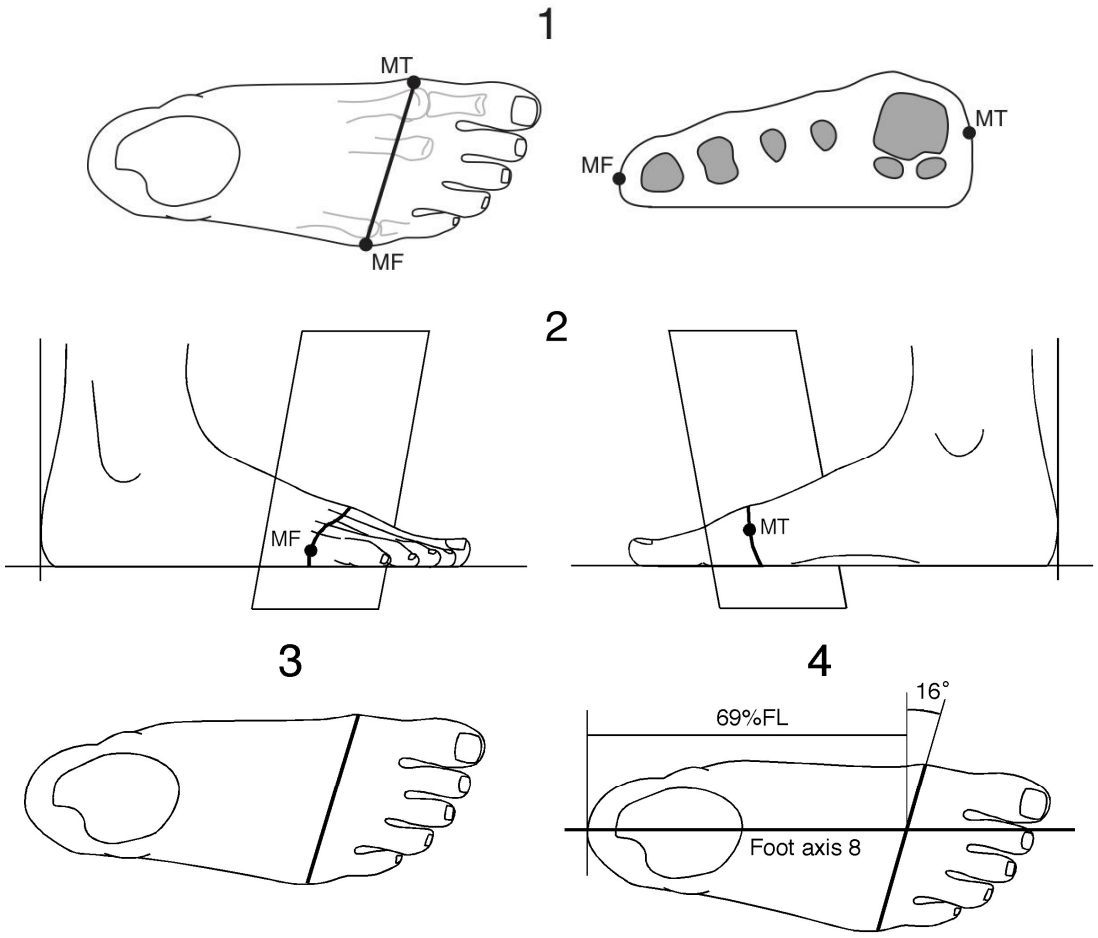

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FIGURE 5 Ball of the foot section (Section 3.2.8).
FL: foot length, MF: metatarsale fibulare, MT: metatarsale tibiale

3.2.9. MEDIAL TANGENT PLANE

It is the vertical plane tangential to the point of maximum inside heel swell (medial side) and the point of maximum swell at the first metatarsal head. It is also designated as an “inside tangent plane.” See FIGURE 6.

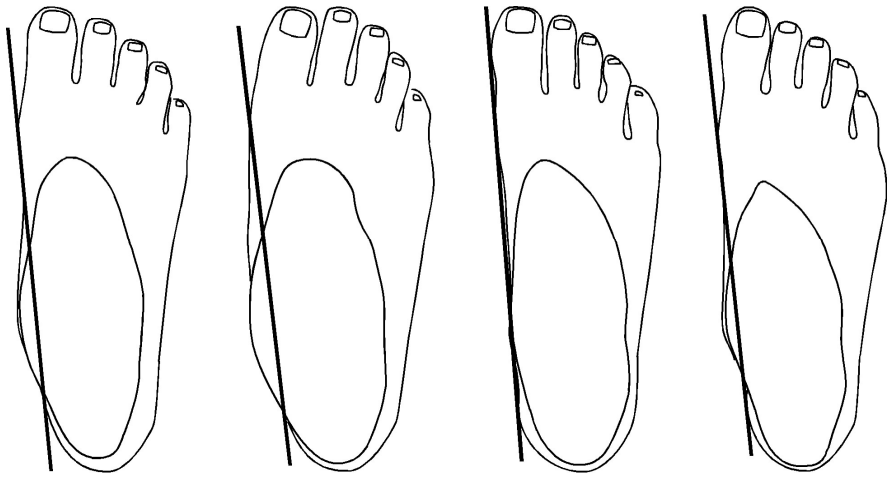

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FIGURE 6 Examples of medial tangent plane (Section 3.2.9). All feet are cut at the height of 40 mm.

3.2.10. FOOT AXIS

Foot axis is an imagined line indicating the longitudinal axis of the foot. It is also designated as “central line of foot,” “longitudinal axis of the foot,” “center axis,” or “central axis.” Usually it is defined using two points, one at the heel and the other at the forefoot and projected to the standing surface. Foot axis is used to define foot measurements. TABLE 5 summarizes the different definitions of this reference axis. See FIGURE 7.

TABLE 5 Foot axis definitions and providers that use them

#	Definition	Measurement providers
1	Intersection between inside tangent and standing surface (ground plane).	ISO/TS 19408:2015 (2.1.4 method 1), TechMed 3D (method 1)
2	Line connecting the projection on the ground plane of the pternion and the midpoint of the points defining the ball tread width (maximal swell of the first metatarsal as a point of the foot line touching the ground and maximal swell of the fifth metatarsal as a point of the foot line touching the ground).	ISO/TS 19408:2015 (2.1.1 method 2, 2.1.4 method 2b)
3	Line connecting the projections on the ground plane of the back of heel and tip of the second toe.	ISO/TS 19408:2015 (2.1.1 method 1, 2.1.4 method 2a), JIS S 5037:1998, TechMed 3D (method 2)
4	Line connecting the projections on the ground plane of the pternion and the midpoint between MT and MF.	SATRA, IBV

Table continues

#	Definition	Measurement providers
5	Line connecting the projection on the ground plane of the pternion and the midpoint of the breadth of ball cross section.	I-Ware (method 1), Aetrex
6	Line connecting the projections on the ground plane of the pternion and the center of second metatarsal head in the dorsum of the foot.	I-Ware (method 2), Bodyform3D
7	Line connecting the projections on the ground plane of a point at heel (midpoint of the breadth at 10% of foot length) and a point at forefoot (midpoint of a point at 73% of foot length on medial side and a point 62% of foot length on lateral side).	TryFit (method 1)
8	Line connecting the midpoint of the heel breadth at 10% of foot length (height ≤ 30 mm) and the point that divides the forefoot breadth at 66% of foot length into 40% medial side and 60% lateral side.	Volumental
9	Line connecting the midpoint of the heel breadth at 10% of foot length (height ≤ 25 mm) and the point that divides the forefoot breadth at 68% of foot length into 40% medial side and 60% lateral side.	TryFit (method 2)

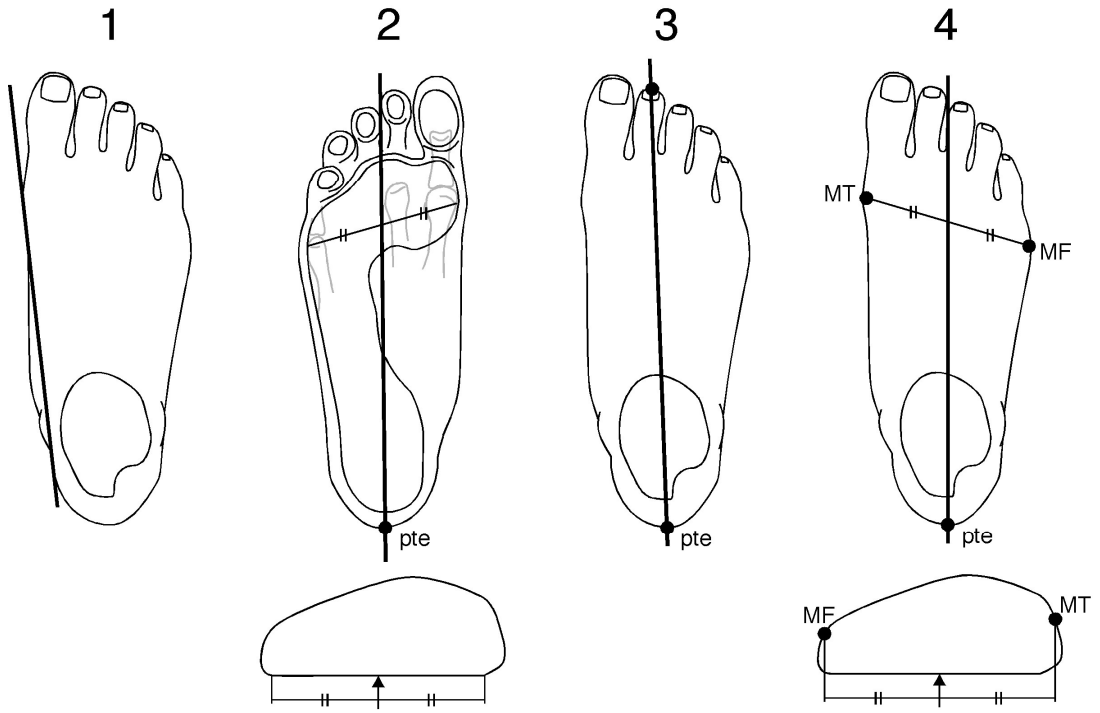

Figure 7 continues

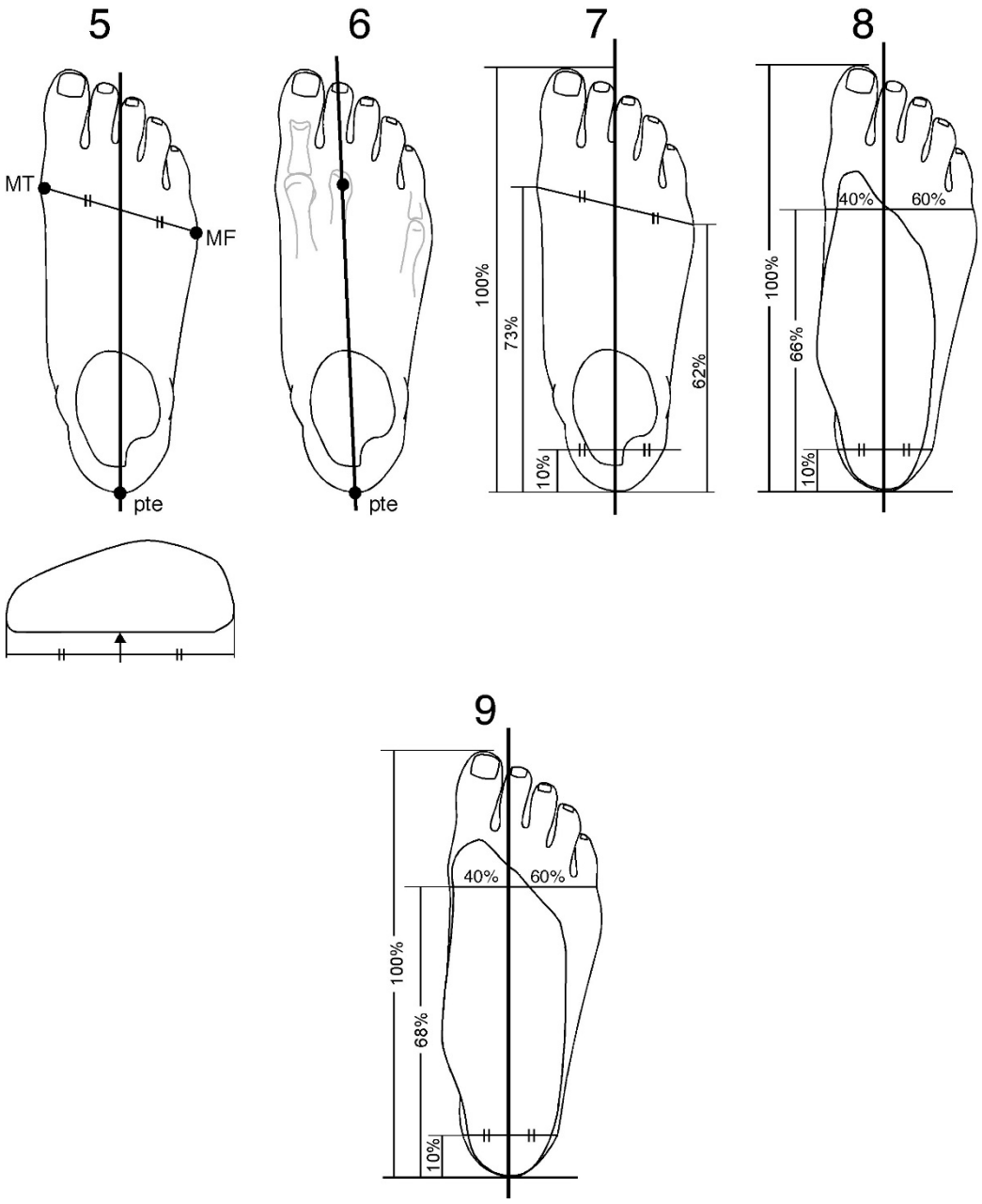

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FIGURE 7 Foot axis (Section 3.2.10). MF: metatarsale fibulare, MT: metatarsale tibiale, pte: pternion. Foot in 8 is cut at the height of 30 mm. Foot in 9 is cut at height of 25 mm.

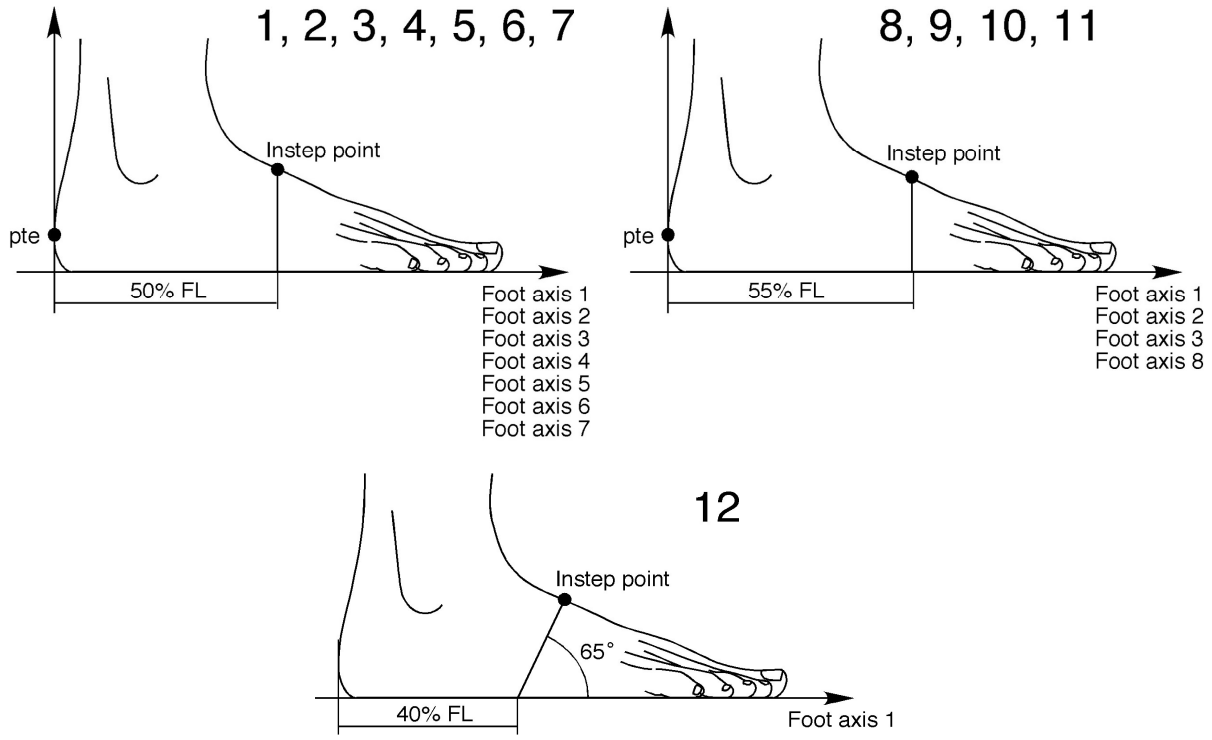
3.2.11. INSTEP POINT

It is the highest point of the dorsum of the foot at a specific position of the midfoot. TABLE 6 summarizes the different definitions. See FIGURE 8.

TABLE 6 Instep point definitions and providers that use them

#	Definition	Measurement providers*
1	Highest point of the foot at 50% FL. Foot axis #1 (medial tangent) is used	ISO/TS 19408:2015 (2.1.7 method 1 using foot axis 2.1.4 method 1)
2	Highest point of the foot at 50% FL. Foot axis #2 (pternion – midpoint of ball tread width) is used	ISO/TS 19408:2015 (2.1.7 method 1 using foot axis 2.1.4 method 2b)
3	Highest point of the foot at 50% FL. Foot axis #3 (pternion – tip of the second toe) is used	ISO/TS 19408:2015 (2.1.7 method 1 using foot axis 2.1.4 method 2a), TechMed 3D (method 2)
4	Highest point of the foot at 50% FL. Foot axis #4 (pternion – midpoint of MT and MF) is used	SATRA, IBV
5	Highest point of the foot at 50% FL. Foot axis #5 (pternion – midpoint of the breadth of ball cross section) is used	I-Ware (method 1), Aetrex
6	Highest point of the foot at 50% FL. Foot axis #6 (pternion – center of second metatarsal head) is used	I-Ware (method 2), Bodyform3D
7	Highest point of the foot at 50% FL. Foot axis #7 (midpoint of the breadth at 10%FL – midpoint of a point at 73%FL on medial side and a point 62% FL on lateral side) is used	TryFit
8	Highest point of the foot at 55% FL. Foot axis #1 (medial tangent) is used	ISO/TS 19408:2015 (2.1.7 method 2 using foot axis 2.1.4 method 1)
9	Highest point of the foot at 55% FL. Foot axis #2 (pternion – midpoint of ball tread width) is used	ISO/TS 19408:2015 (2.1.7 method 2 using foot axis 2.1.4 method 2b)
10	Highest point of the foot at 55% FL. Foot axis #3 (pternion – tip of the second toe) is used	ISO/TS 19408:2015 (2.1.7 method 2 using foot axis 2.1.4 method 2a), TechMed 3D (method 2)
11	Highest point of the foot at 55% FL. Foot axis #8 (midpoint of the breadth at 10% FL – point at 66% FL and 40% of its width from medial side) is used	Volumental
12	Highest point of the circumference of the foot positioned at 40% of foot length from the heel and inclined at 65 degrees from the horizontal plane. Foot axis #1 (medial tangent) is used	TechMed 3D

*JIS S 5037: 1998 does not have this definition.



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NOTE—See Table 5 for the definition of foot axis.

FIGURE 8 Instep point (Section 3.2.11). FL: foot length, pte: pternion. Actual position of instep point differs according to the definition of foot axis.

3.3. FOOT MEASUREMENTS

3.3.1. FOOT LENGTH (FL)

TABLE 7 summarizes the different definitions of this measurement. See FIGURE 9.

TABLE 7 Foot length definitions and providers that use them

#	Definition	Measurement providers
1	Distance from pternion to acropodion projected to foot axis #1 (medial tangent).	ISO/TS 19408:2015 (2.1.17, method 1), TechMed 3D (method 1)
2	Distance from pternion to acropodion projected to foot axis #2 (pternion – midpoint of ball tread width).	ISO/TS 19408:2015 (2.1.17, method 2b)
3	Distance from pternion to acropodion projected to foot axis #3 (pternion – tip of the second toe).	ISO/TS 19408:2015 (2.1.17, method 2a), JIS S 5037:1998, TechMed 3D (method 2)

Table continues

#	Definition	Measurement providers
4	Distance from pternion to acropodion projected to foot axis #4 (pternion – midpoint of MT and MF).	SATRA, IBV
5	Distance from pternion to acropodion projected to foot axis #5 (pternion – midpoint of the breadth of ball cross section).	I-Ware (method 1), Aetrex
6	Distance from pternion to acropodion projected to foot axis #6 (pternion – center of second metatarsal head).	I-Ware (method 2), Bodyform3D
7	Distance from pternion to the acropodion projected to foot axis #7 (midpoint of the breadth at 10% FL – midpoint of a point at 73% FL on medial side and a point 62% FL on lateral side).	TryFit
8	Distance from pternion to the acropodion projected to foot axis #8 (midpoint of the breadth at 10%FL – point at 66% FL and 40% of its width from medial side).	Volumental

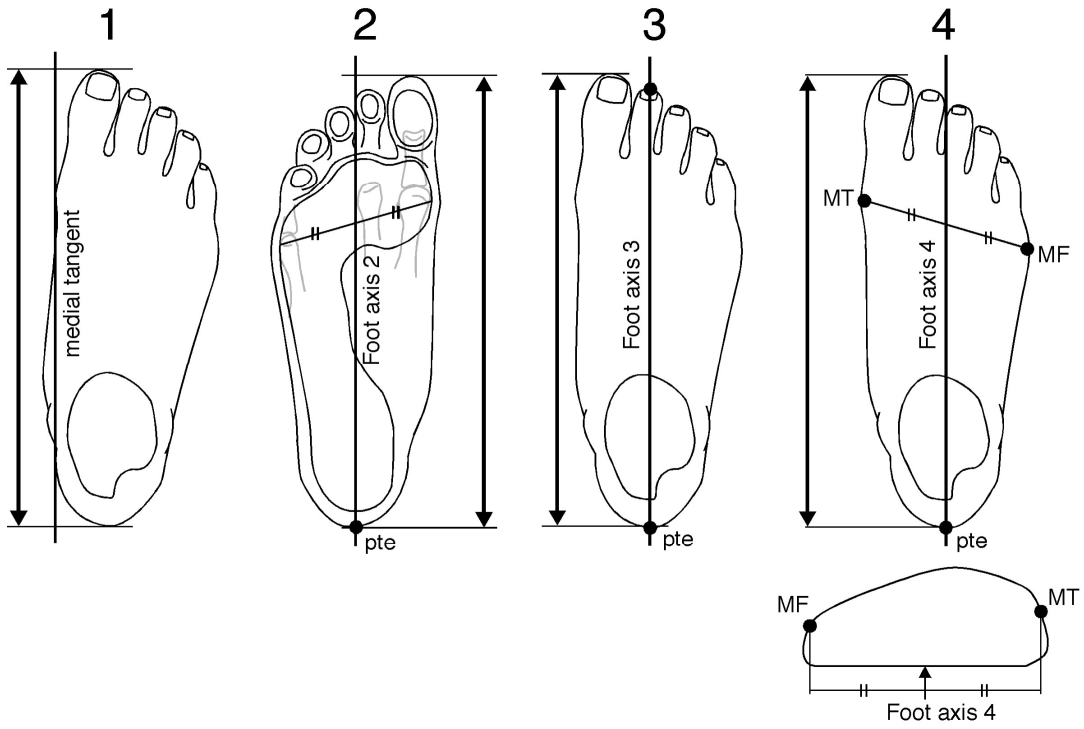
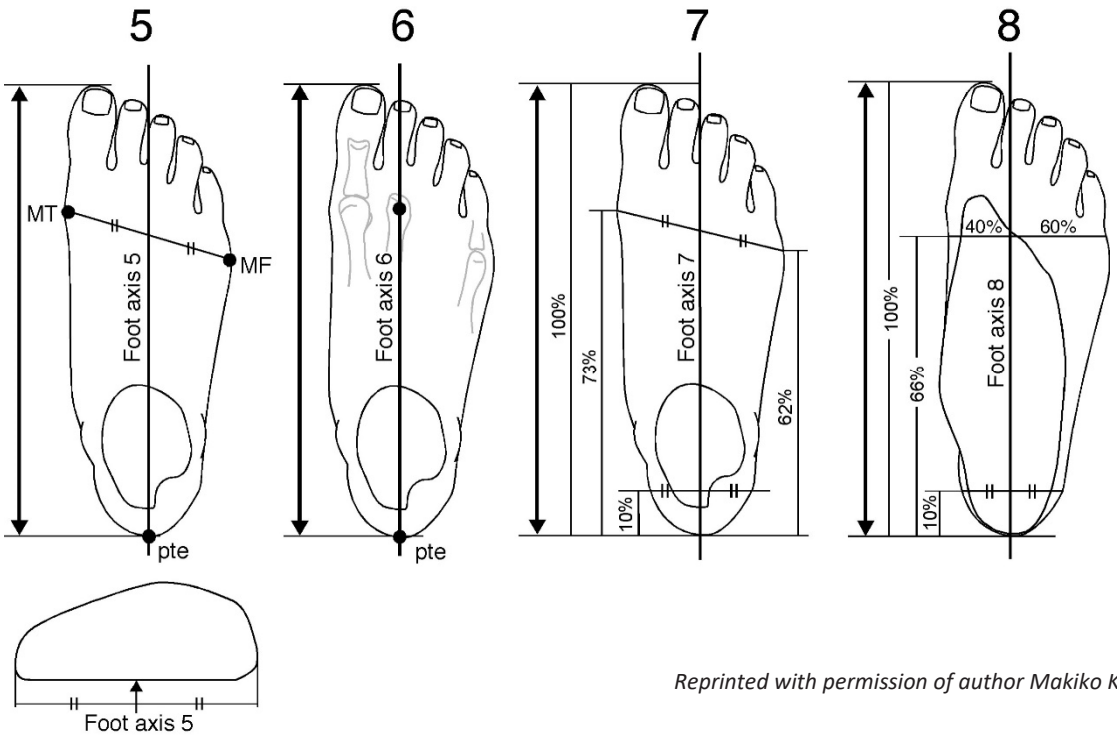


Figure 9 continues



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NOTE—See Table 5 for the definition of foot axis.

FIGURE 9 Foot length (Section 3.3.1). MF: metatarsale fibulare, MT: metatarsale tibiale, pte: pternion.

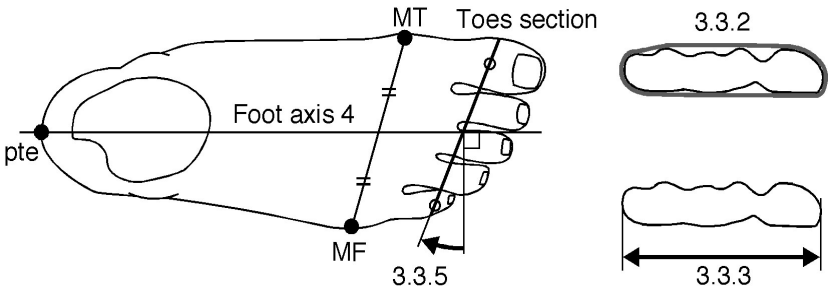
3.3.2. TOE GIRTH

It is also designated as "Toes section girth." TABLE 8 summarizes the different definitions of this measurement. See FIGURE 10.

TABLE 8 Toe girth definitions and providers that use them

#	Definition	Measurement providers*
1	Perimeter of the convex hull of the toes section, which is the vertical section passing the highest point of the interphalangeal joint of the first toe and the highest point of the distal interphalangeal joint of the fifth toe.	IBV

*All other providers do not have this definition.



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NOTE—See Table 5 for the definition of foot axis.

FIGURE 10 Toe girth (Section 3.3.2), toe width (Section 3.3.3), and toe angle (3.3.5). MF: metatarsale fibulare, MT: metatarsale tibiale, pte: pternion.

3.3.3. TOE WIDTH

It is also designated as "Toes section width." TABLE 9 summarizes the different definitions of this measurement. See FIGURE 10.

TABLE 9 Toe width definitions and providers that use them

#	Definition	Measurement providers*
1	Maximum breadth of the toes section, which is the vertical section passing the highest point of the inter-phalangeal joint of the first toe and the highest point of the distal inter-phalangeal joint of the fifth toe, projected to the standing surface.	IBV

*All other providers do not have this definition.

3.3.4. TOE HEIGHT

It is also designated as "Toes section height." TABLE 10 summarizes the different definitions of this measurement. See FIGURE 11.

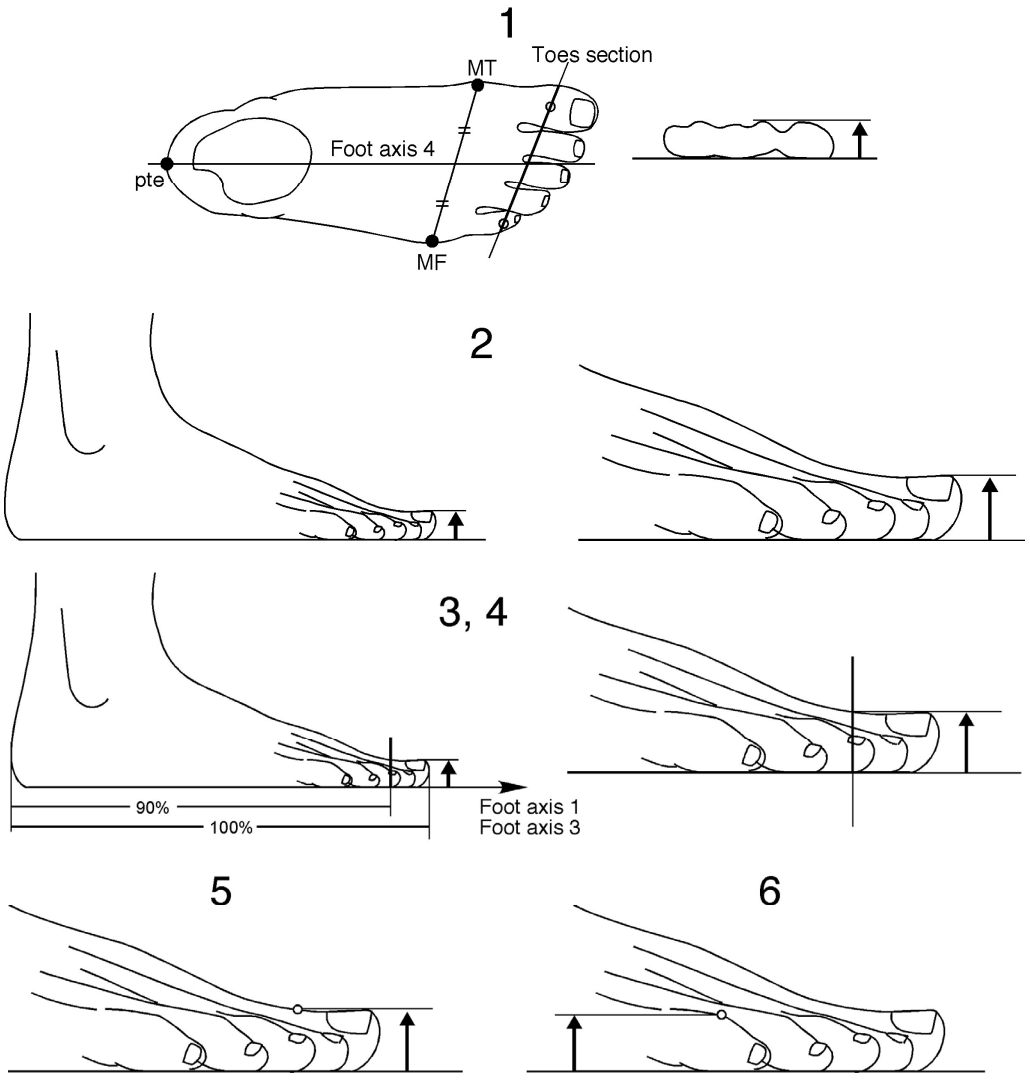
TABLE 10 Toe height definitions and providers that use them

#	Definition	Measurement providers*
1	Maximum height of the toes section, which is the vertical section passing the highest point of the inter-phalangeal joint of the first toe and the highest point of the distal inter-phalangeal joint of the fifth toe, projected to the standing surface.	IBV
2	Height of the highest point of the tip of the first toe.	Bodyform3D
3	Height of the highest point of the foot in the area ranged from 90% FL to 100% FL from pternion. Foot axis #1 (medial tangent) is used.	TechMed 3D (me thod 1)

Table continues

#	Definition	Measurement providers*
4	Height of the highest point of the foot in the area ranged from 90% FL to 100% FL from pternion. Foot axis #3 (pternion – tip of the second toe) is used.	TechMed 3D (method 2)
5	Height of the highest point of the interphalangeal joint of the first toe.	I-Ware (toe #1 height)
6	Height of the highest point of the distal interphalangeal joint of the fifth toe.	I-Ware (toe #5 height)

* ISO/TS 19408:2015, JIS S 5037:1998, Aetrex, SATRA, TryFit, and Volumental do not have this definition.



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NOTE—See Table 5 for the definition of foot axis.

FIGURE 11 Toe height (Section 3.3.4). MF: metatarsale fibulare, MT: metatarsale tibiale, pte: pternion.

3.3.5. TOE ANGLE

It is also designated as “Toes section angle.” TABLE 11 summarizes the different definitions of this measurement. See FIGURE 10.

TABLE 11 Toe angle definitions and providers that use them

#	Definition	Measurement providers*
1	Angle between the line perpendicular to the foot axis and the line connecting the highest point of the inter-phalangeal joint of the first toe and the highest point of the proximal inter-phalangeal joint of the fifth toe, projected to the standing surface.	IBV

*All other providers do not have this definition.

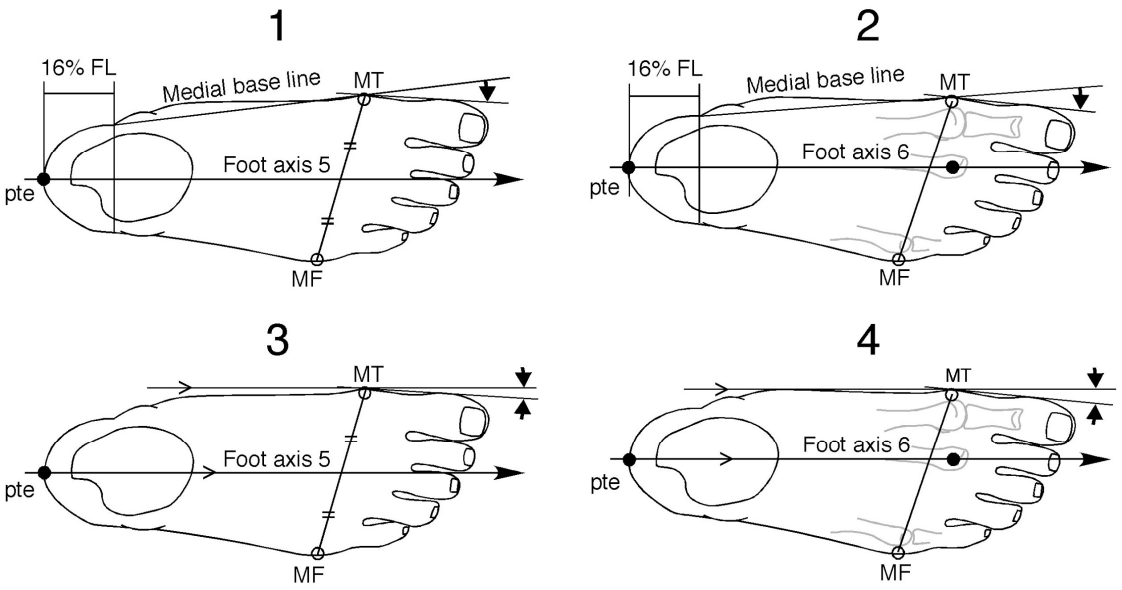
3.3.6. FIRST TOE ANGLE

It is also designated as “Toe #1 angle.” This measurement quantifies the degree of valgus of the first toe. TABLE 12 summarizes the different definitions of this measurement. Names assigned to different definitions by the measurement provider are in brackets. See FIGURE 12.

TABLE 12 First toe angle definitions and providers that use them

#	Definition	Measurement providers*
1	(Toe #1 angle) Angle between medial base line (line connecting the medial edge of heel breadth and the most medial point of ball cross section, projected to the standing surface) and the line passing the most medial point of ball cross section and tangential to the medial side of first toe, projected to the standing surface. Foot axis # 5 (pternion – midpoint of the breadth of ball cross section) is used for defining heel breadth.	I-Ware (method 1)
2	(Toe #1 angle) Angle between the medial base line (line connecting the medial edge of heel breadth and the most medial point of ball cross section, projected to the standing surface) and the line passing the most medial point of ball cross section and tangential to the medial side of first toe, projected to the standing surface. Foot axis # 6 (pternion – center of second metatarsal head) is used for defining heel breadth.	I-Ware (method 2)
3	(Toe #1 angle (foot axis)) Angle between foot axis #5 (pternion – midpoint of the breadth of ball cross section) and the line passing the most medial point of ball section and tangential to the medial side of first toe, projected to the standing surface.	I-Ware (method 3)
4	(Toe #1 angle (foot axis)) Angle between foot axis #6 (pternion – center of second metatarsal head) and the line passing the most medial point of ball section and tangential to the medial side of first toe, projected to the standing surface.	I-Ware (method 4)

*All other providers do not have this definition.



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NOTE—See Table 5 for the definition of foot axis.

FIGURE 12 First toe angle (Section 3.3.6). FL: foot length, MF: metatarsale fibulare, MT: metatarsale tibiale, pte: pternion.

3.3.7. FIFTH TOE ANGLE

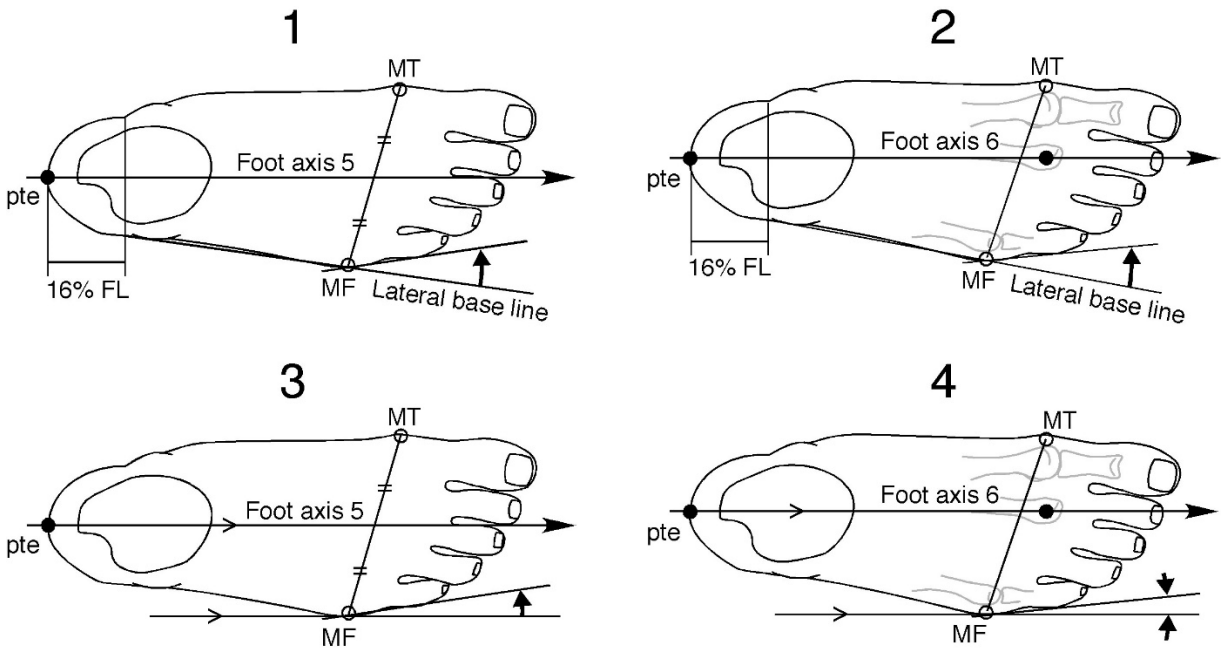
The fifth toe angle is also designated as "Toe #5 angle." This measurement quantifies the degree of varus of the fifth toe. TABLE 13 summarizes the different definitions of this measurement. Names assigned to different definitions by measurement providers are in brackets. See FIGURE 13.

TABLE 13 Fifth toe angle definitions and providers that use them

#	Definition	Measurement providers*
1	(Toe #5 angle) Angle between lateral base line (line connecting the lateral edge of heel breadth and the most lateral point of ball cross section, projected to the standing surface) and the line passing the most lateral point of ball cross section and tangential to the lateral side of fifth toe, projected to the standing surface. Foot axis # 5 (pternion – midpoint of the breadth of ball cross section) is used for defining heel breadth.	I-Ware (method 1)
2	(Toe #5 angle) Angle between lateral base line (line connecting the lateral edge of heel breadth and the most lateral point of ball cross section) and the line passing the most lateral point of ball cross section and tangential to the lateral side of fifth toe. Foot axis # 6 (pternion – center of second metatarsal head) is used for defining heel breadth.	I-Ware (method 2)

Table continues

#	Definition	Measurement providers*
3	(Toe #5 angle (foot axis)) Angle between the foot axis # 5 (pternion – midpoint of the breadth of ball cross section) and the line passing the most lateral point of ball cross section and tangential to the lateral side of fifth toe, projected to the standing surface.	I-Ware (method 3)
4	(Toe #5 angle (foot axis))Angle between the foot axis line 6 (pternion – center of second metatarsal head) and the line passing the most lateral point of ball cross section and tangential to the lateral side of fifth toe, projected to the standing surface.	I-Ware (method 4)



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NOTE—See Table 5 for the definition of foot axis.

FIGURE 13 Fifth toe angle (Section 3.3.7). FL: foot length, MF: metatarsale fibulare, MT: metatarsale tibiale, pte: pternion.

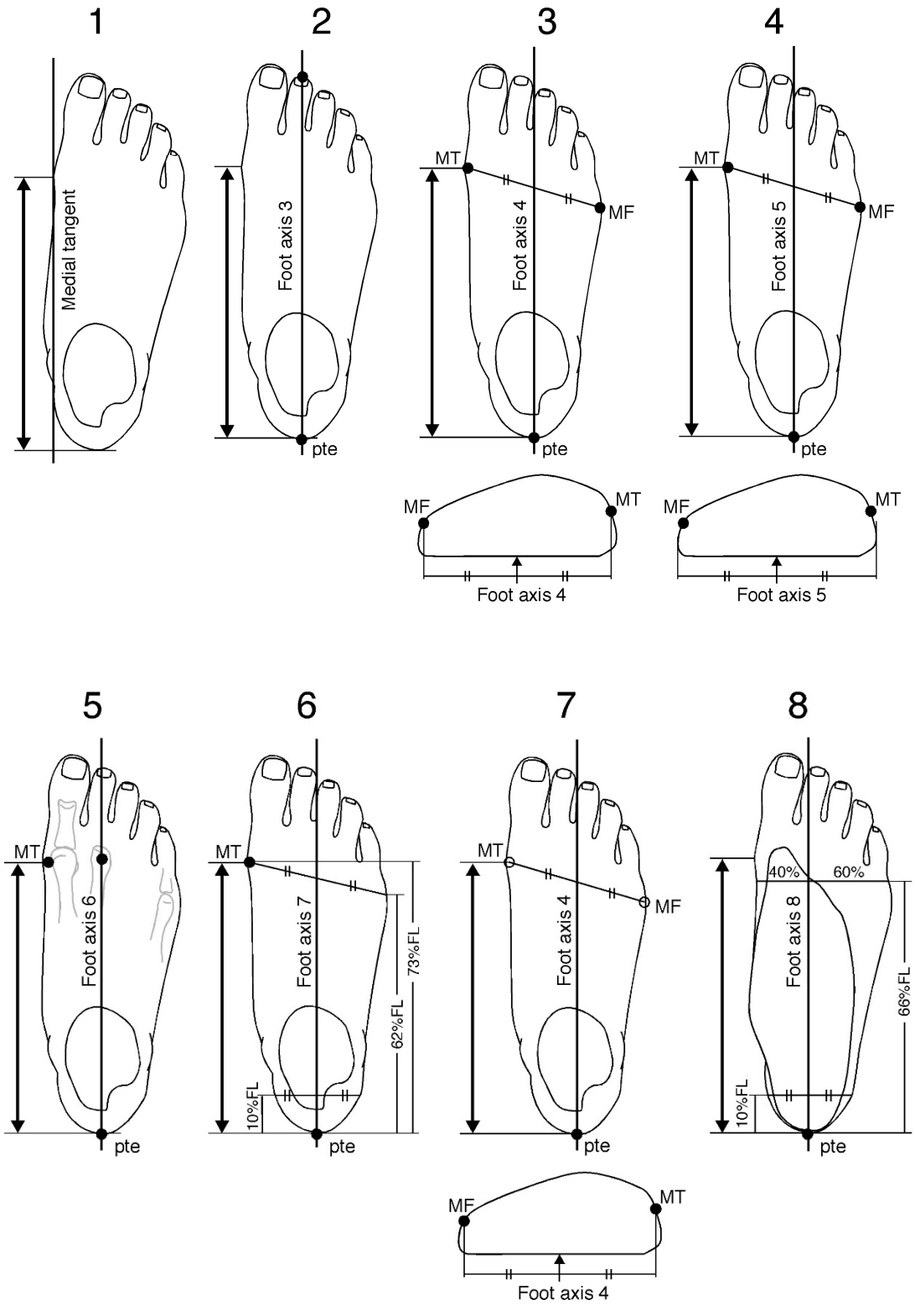
3.3.8. LENGTH TO 1ST METATARSAL HEAD

It is also designated as “length to the first metatarsal head,” “position of the first metatarsal head,” “ball of foot length,” “heel-to-ball length,” “arch length,” or “instep length.” TABLE 14 summarizes the different definitions of this measurement. See FIGURE 14.

TABLE 14 Length to first metatarsal head definitions and providers that use them

#	Definition	Measurement providers*
1	Distance from pternion to the first metatarsal protrusion projected to foot axis #1 (medial tangent).	TechMed 3D (method 1)
2	Distance from pternion to the first metatarsal protrusion projected to foot axis #3 (pternion – tip of the second toe).	TechMed 3D (method 2)
3	Distance from pternion to MT projected to foot axis #4 (pternion – midpoint of MT and MF).	SATRA, IBV
4	Distance from pternion to MT projected to foot axis #5 (pternion – midpoint of the breadth of ball cross section).	I-Ware (method 1)
5	Distance from pternion to MT projected to foot axis #6 (pternion – center of second metatarsal head).	I-Ware (method 2)
6	Distance from pterion to MT projected to foot axis #7 (midpoint of the breadth at 10% FL – midpoint of a point at 73% FL on medial side and a point 62% FL on lateral side).	TryFit (method 1)
7	Distance from pternion to the widest part of the ball of the foot medially projected to foot axis #4 (pternion – midpoint of MT and MF).	Aetrex
8	Distance from pterion to the widest part of the ball projected to foot axis #8 (midpoint of the breadth at 10% FL – point at 66% FL and 40% of its width from medial side).	Volumental
9	Distance from pternion to first metatarsal head projected to foot axis #6 (pternion – center of second metatarsal head).	Bodyform3D
10	Distance from pterion to the widest part of the ball projected to foot axis #9 (midpoint of the breadth at 10% FL – point at 68% FL and 40% of its width from medial side).	TryFit (method 2)

*ISO/TS 19408: 2015 and JIS S 5037:1998 do not have this definition.



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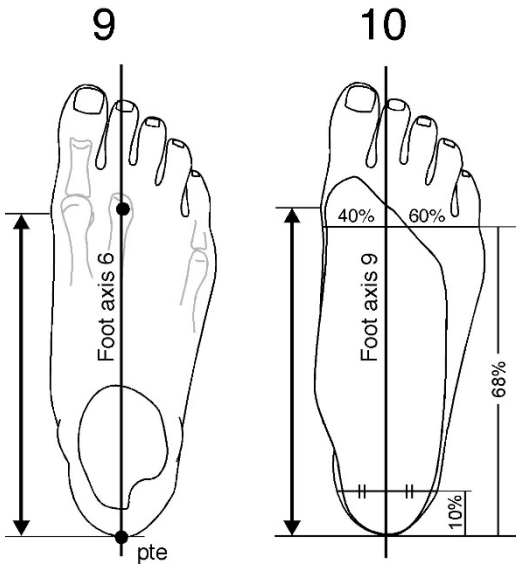

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NOTE—See Table 5 for the definition of foot axis.

FIGURE 14 Length to first metatarsal head (Section 3.3.8). FL: foot length, MF: metatarsale fibulare, MT: metatarsale tibiale, pte: pternion.

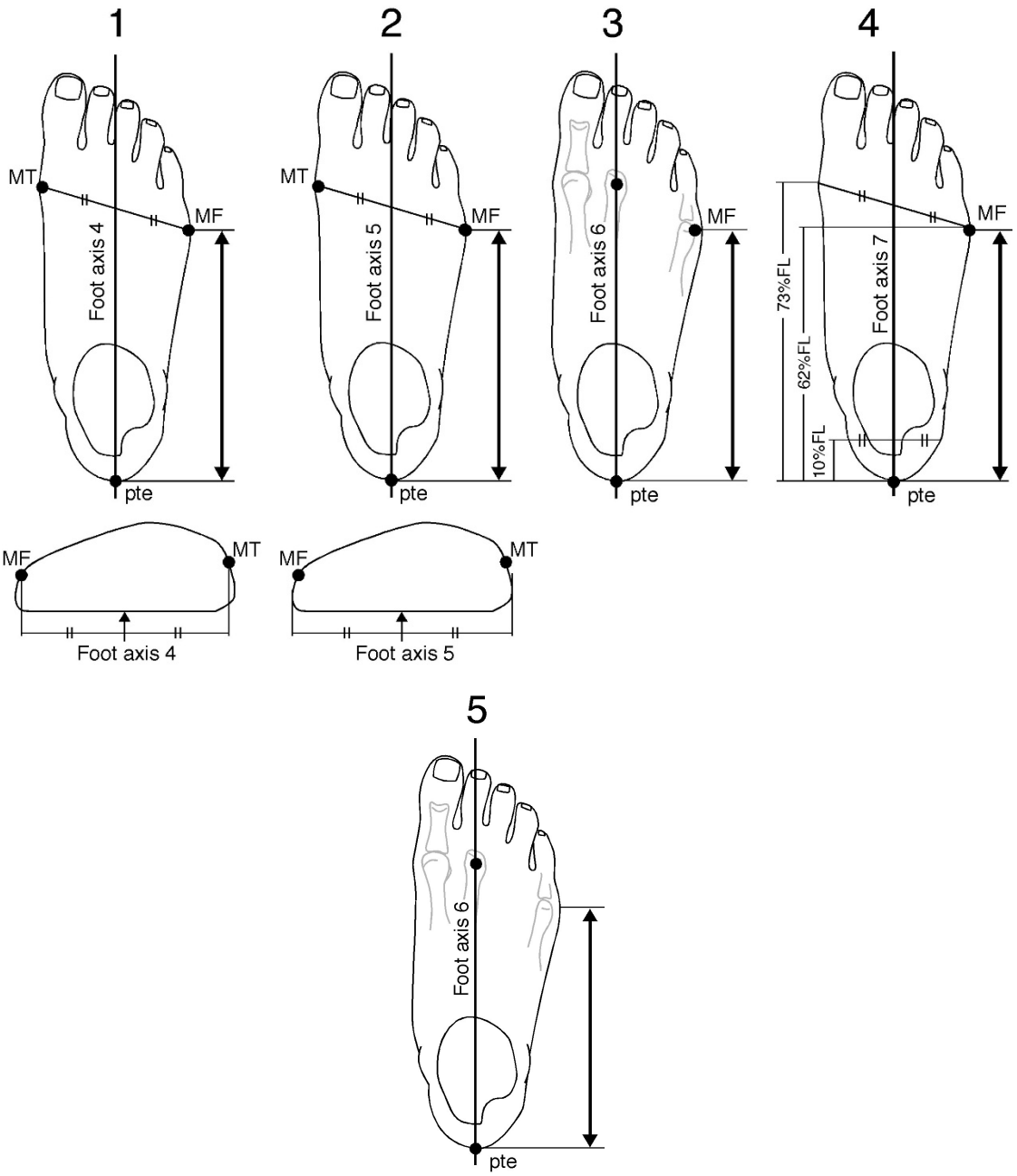
3.3.9. LENGTH TO 5TH METATARSAL HEAD

The length to the 5th metatarsal head is also designated as “fibular instep length,” “length to the fifth metatarsal head,” or “position of the fifth metatarsal head.” FIGURE 15 summarizes the different definitions of this measurement. See FIGURE 15.

TABLE 15 Length to 5th metatarsal head definitions and providers that use them

#	Definition	Measurement providers*
1	Distance from pternion to MF projected to foot axis #4 (pternion – midpoint of MT and MF).	SATRA, IBV
2	Distance from pternion to MF projected to foot axis #5 (pternion – midpoint of the breadth of ball cross section).	I-Ware (method 1)
3	Distance from pternion to MF projected to foot axis #6 (pternion – center of second metatarsal head).	I-Ware (method 2)
4	Distance from pternion to MF projected to foot axis #7 (midpoint of the breadth at 10% FL – midpoint of a point at 73% FL on medial side and a point 62% FL on lateral side).	TryFit
5	Distance from pternion to fifth metatarsal head projected to foot axis #6 (pternion – center of second metatarsal head).	Bodyform3D

*ISO/TS 19408: 2015, JIS S 5037:1998, Aetrex, TechMed 3D, and Volumental do not have this definition.



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NOTE—See Table 5 for the definition of foot axis.

FIGURE 15 Length to fifth metatarsal head (Section 3.3.9). FL: foot length, MF: metatarsale fibulare, MT: metatarsale tibiale, pte: pternion.

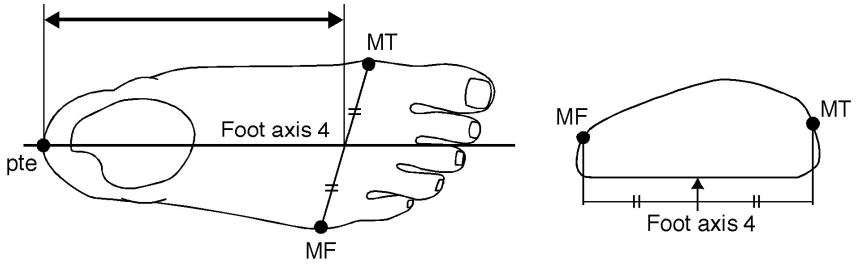
3.3.10. LENGTH TO BALL SECTION

The length to ball section is also designated as “ball/joint position.” TABLE 16 summarizes the different definitions of this measurement. See FIGURE 16.

TABLE 16 Length to ball section definitions and providers that use them

#	Definition	Measurement providers*
1	Distance from pternion to the intersection of the ball section and foot axis #4 (pternion – midpoint of MT and MF).	IBV

*All other providers do not have this definition.



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NOTE—See Table 5 for the definition of foot axis.

FIGURE 16 Length to ball section (Section 3.3.10). MF: metatarsale fibulare, MT: metatarsale tibiale, pte: pternion.

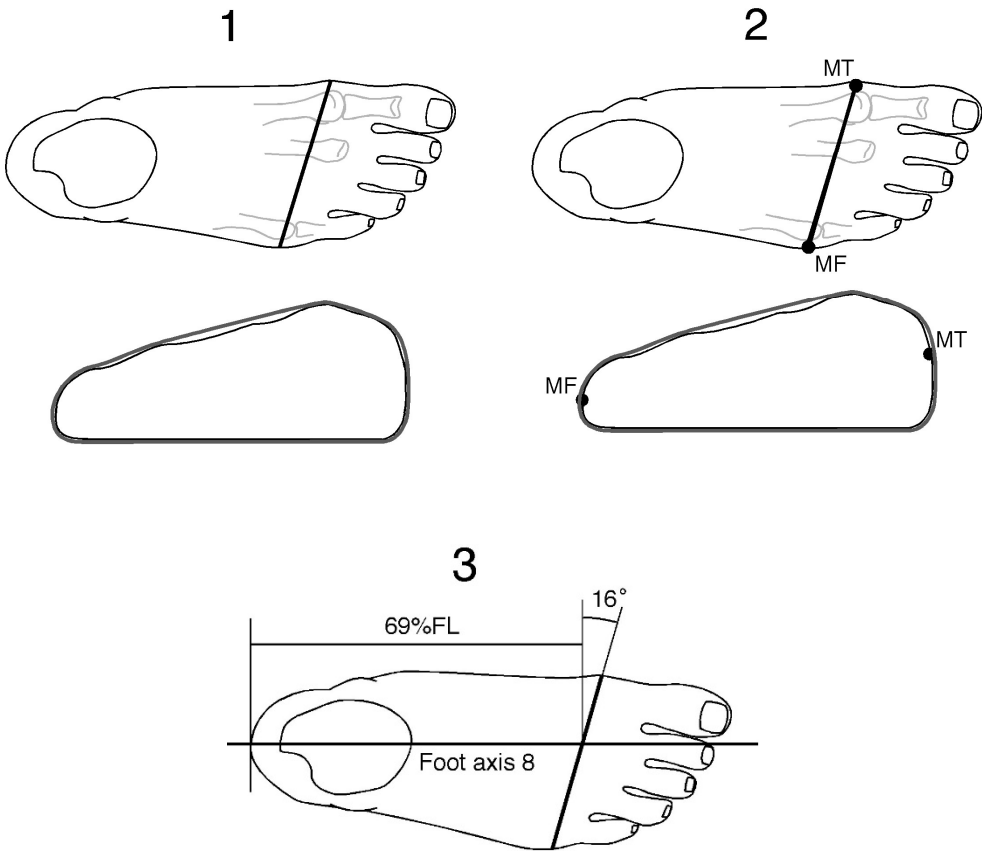
3.3.11. BALL GIRTH

The ball girth is also designated as “joint girth of the foot,” “anatomic ball girth of the foot,” “metatarsophalangeal joint girth,” or “metatarsal girth/circumference.” TABLE 17 summarizes the different definitions of this measurement. See FIGURE 17.

TABLE 17 Ball girth definitions and providers that use them

#	Definition	Measurement providers
1	Vertical circumference of the foot passing the heads of first and fifth metatarsal bones*.	ISO/TS 19408:2015, TechMed 3D (method 2)
2	Vertical circumference of the foot passing MT and MF (perimeter of ball section). May be the smallest circumference.	SATRA, I-Ware, JIS S 5037:1998, IBV, Aetrex, TryFit
3	Vertical circumference of the foot passing 69% FL on the foot axis # 8 and rotated 16˚ around the vertical axis so that it passes the first and fifth metatarsal heads.	Volumental
4	Circumference of the foot passing MT and MF and inclined at 80° from the horizontal plane. Foot axis # 1 (medial tangent) is used.	TechMed 3D (method 1)
5	Circumference of the foot passing MT and MF and inclined at 80° from the horizontal plane. Foot axis # 6 (pternion – center of second metatarsal head) is used.	Bodyform3D

*This definition is not specified if it is at the widest point



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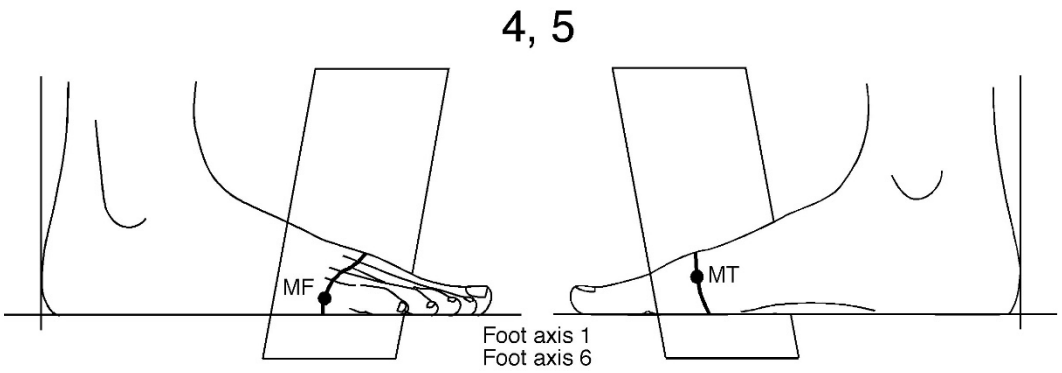

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NOTE—See Table 5 for the definition of foot axis.

FIGURE 17 Ball girth (Section 3.3.11).
FL: foot length, MF: metatarsale fibulare, MT: metatarsale tibiale.

3.3.12. BALL WIDTH

The ball width is also designated as “ball breadth,” “foot width/breadth,” “linear width,” “ball section width/breadth,” or “metatarsophalangeal joint width/breath.” Please note that these terms are used ambiguously by different providers to designate other measurements (compare Section 3.3.14 Stick width of foot). TABLE 18 summarizes the different definitions of this measurement. Due to the ambiguous use of the term and its interpretation, in this case, the designation used by every measurement provider is provided in brackets. See FIGURE 18.

TABLE 18 Ball width definitions and providers that use them

#	Definition	Measurement providers*
1	Distance between the outside swell of the first metatarsal head and outside swell of the fifth metatarsal head.	ISO/TS 19408:2015 (linear width of the foot)
2	Maximum breadth of ball section that passes MT and MF projected to the standing surface.	I-Ware (foot breadth), JIS S 5037:1998, IBV (ball width)
3	Distance between MT and MF projected to the standing surface.	SATRA (foot breadth), TryFit (ball width)
4	Maximum distance between the first and fifth metatarsophalangeal joints projected to the standing surface.	TechMed 3D (foot width), Bodyform3D (Linear ball width)

*Aetrex and Volumental do not have this definition.

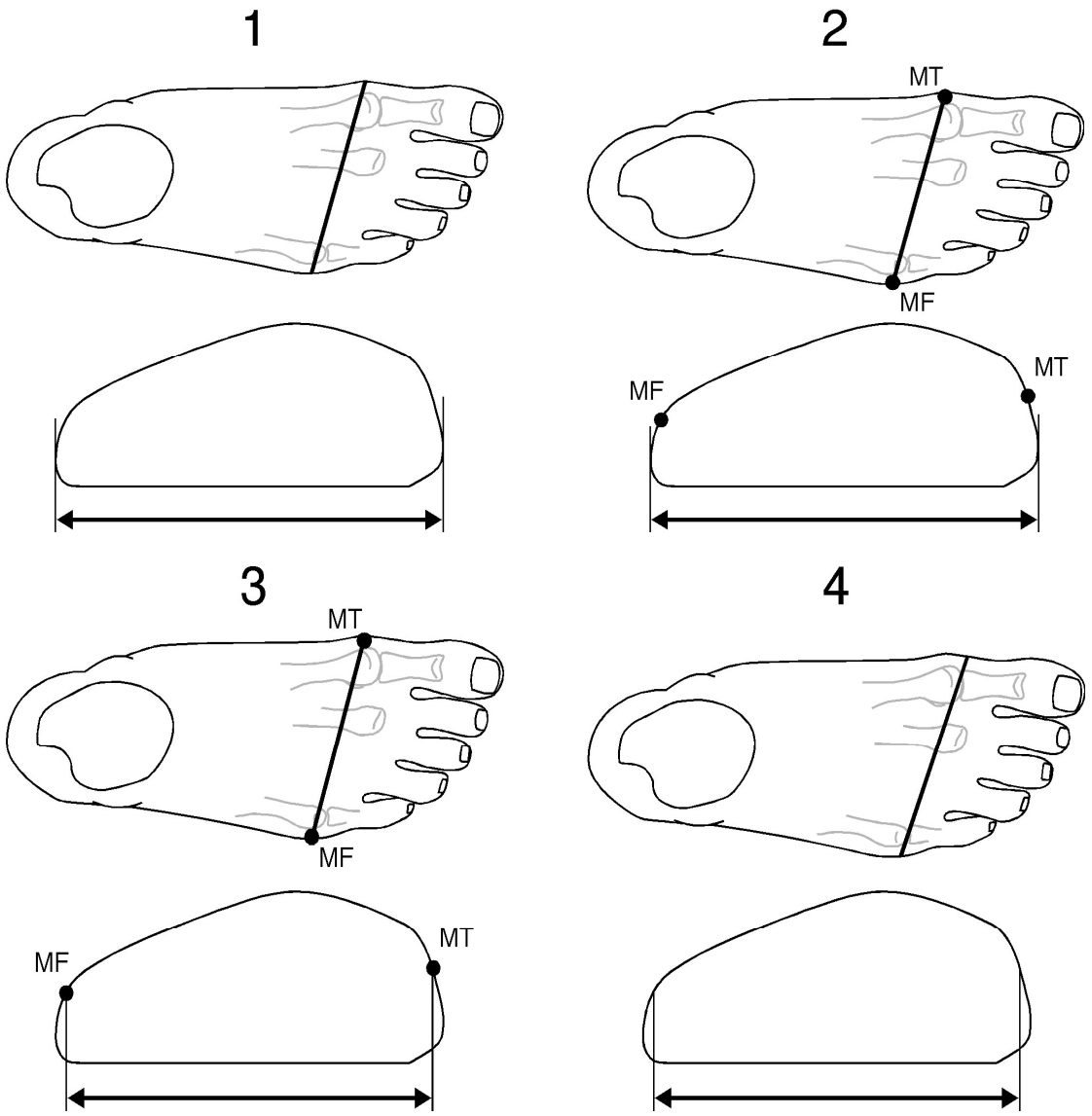

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FIGURE 18 Ball width (Section 3.3.12). MF: metatarsale fibulare, MT: metatarsale tibiale.

3.3.13. BALL TREAD WIDTH

The ball tread width is also designated as “tread width of the ball of the foot.” TABLE 19 summarizes the different definitions of this measurement. See FIGURE 19.

TABLE 19 Ball tread width definitions and providers that use them

#	Definition	Measurement providers*
1	Distance between the points where the medial and lateral surfaces join the sole surface at the maximum swell of the first and fifth metatarsal heads	ISO/TS 19408:2015

*All other providers do not have this definition.

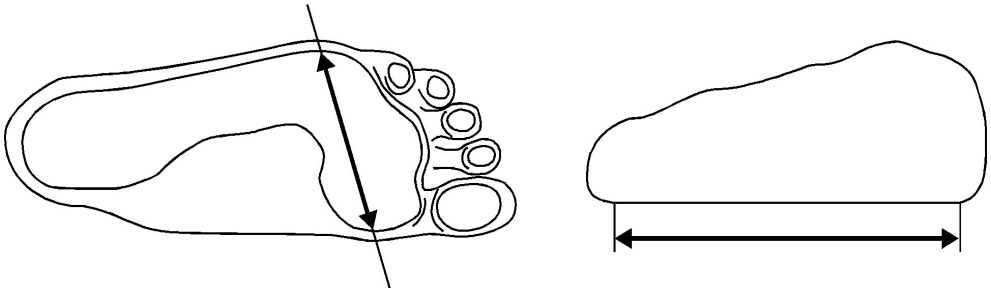

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FIGURE 19 Ball tread width (Section 3.3.13)

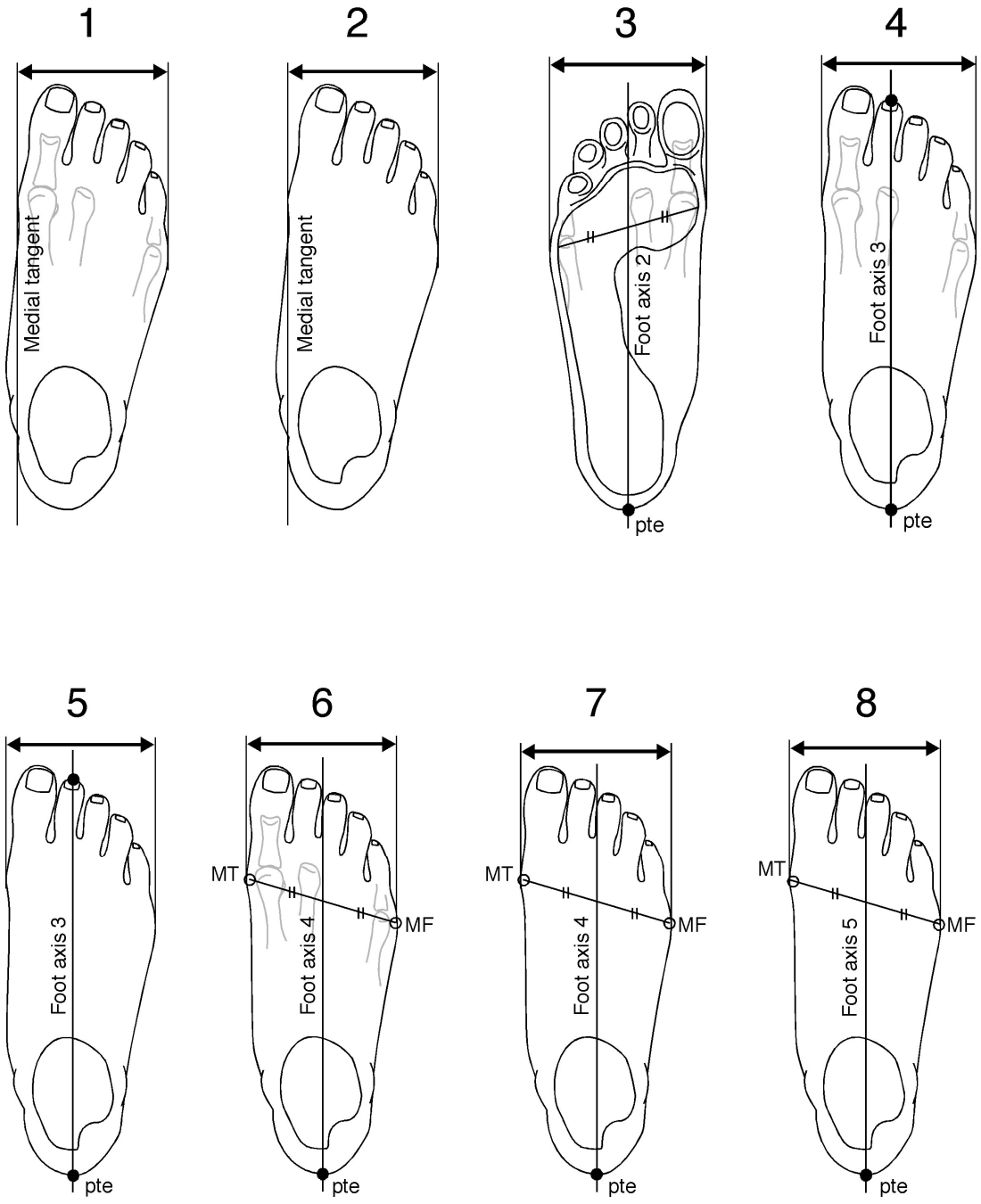
3.3.14. STICK WIDTH OF FOOT

The stick width of foot is also designated as “foot width,” “ball width/breadth,” or “joint width/breadth.” Please note that these terms are used ambiguously by different providers to designate other measurements (compare Section 3.3.12 Ball width). TABLE 20 summarizes the different definitions of this measurement. Due to the ambiguous use of the term and its interpretation by each measurement provider, in this case the designation used by every measurement provider is provided in brackets. See FIGURE 20.

TABLE 20 Stick width of ball area of foot definitions and providers that use them

#	Definition	Measurement providers*
1	Distance between first metatarsal head and fifth metatarsal head measured perpendicular to the foot axis #1 (medial tangent) and projected to the standing surface.	ISO/TS 19408:2015 (stick width of the foot, method 1)
2	Maximum distance across the foot measured perpendicular to the foot axis #1 (medial tangent) and projected to the standing surface.	TechMed 3D (ball width, method 1), SATRA (stick width, method 1)
3	Distance between first metatarsal head and fifth metatarsal head measured perpendicular to the foot axis #2 (pternion – midpoint of ball tread width) and projected to the standing surface.	ISO/TS 19408:2015 (stick width of the foot, method 2b)
4	Distance between first metatarsal head and fifth metatarsal head measured perpendicular to the foot axis #3 (pternion – tip of the second toe) and projected to the standing surface.	ISO/TS 19408:2015 (stick width of the foot, method 2a)
5	Maximum distance across the foot measured perpendicular to the foot axis #3 (pternion – tip of the second toe) and projected to the standing surface.	TechMed 3D (ball width, method 2)
6	Distance between the outside swell of the first metatarsal head and outside swell of the fifth metatarsal head measured perpendicular to the foot axis #4 (pternion – midpoint of MT and MF) and projected to the standing surface.	Aetrex (foot width)
7	Maximum distance across the foot measured perpendicular to the foot axis #4 (pternion – midpoint of MT and MF) and projected to the standing surface.	SATRA (stick width, method 2)
8	Maximum width of the ball section (vertical cross section passing MT and MF) measured perpendicular to the foot axis #5 (pternion – midpoint of the breadth of ball cross section) and projected to the standing surface.	I-Ware (foot breadth 2, method 1)
9	Maximum width of the ball section (vertical cross section passing MT and MF) measured perpendicular to the foot axis #6 (pternion – center of second metatarsal head) and projected to the standing surface.	I-Ware (foot breadth 2, method 2)
10	Distance between MT and MF measured perpendicular to the foot axis #7 (midpoint of the breadth at 10% FL – midpoint of a point at 73% FL on medial side and a point 62% FL on lateral side.	TryFit (foot width/ball width)
11	Distance across the foot between point P (most medial point between 65% and 80% FL) and point Q (most lateral point between 50% and 80% FL) measured perpendicular to the foot axis #8 (midpoint of the breadth at 10%FL – 66% FL and 40% of its width from medial side) and projected to the standing surface.	Volumental (ball width)

*JIS S 5037:1998, Bodyform3D, and IBV do not have this definition.



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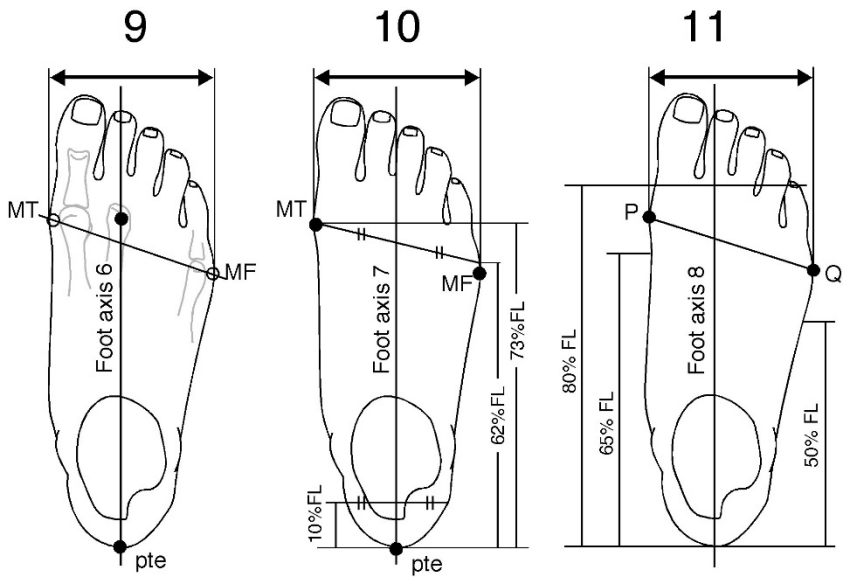

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NOTE—See Table 5 for the definition of foot axis.

FIGURE 20 Stick width of foot (Section 3.3.14). FL: foot length, MF: metatarsale fibulare, MT: metatarsale tibiale. pte: pternion, P: see TABLE 20, #11 for definition, Q: see TABLE 20, #11 for definition.

3.3.15. BALL HEIGHT

It is also designated as “joint height,” “ball section height,” or “metatarsophalangeal joint height.” TABLE 21 summarizes the different definitions of this measurement. See FIGURE 21.

TABLE 21 Ball height definitions and providers that use them

#	Definition	Measurement providers*
1	Height of the highest point on the ball section (vertical section passing MT and MF).	SATRA, I-Ware, IBV
2	Height of the highest point on the vertical circumference of the foot passing the heads of first and fifth metatarsal bones.	TechMed 3D (method 1)
3	Height of the highest point on the circumference of the foot passing metatarsale tibiale and MF and inclined at 80° from the horizontal plane. Foot axis #1 (medial tangent) is used.	TechMed 3D (method 2)

*ISO/TS 19408:2015, JIS S 5307:1998, Aetrex, Bodyform3D, TryFit, and Volumental do not have this definition.

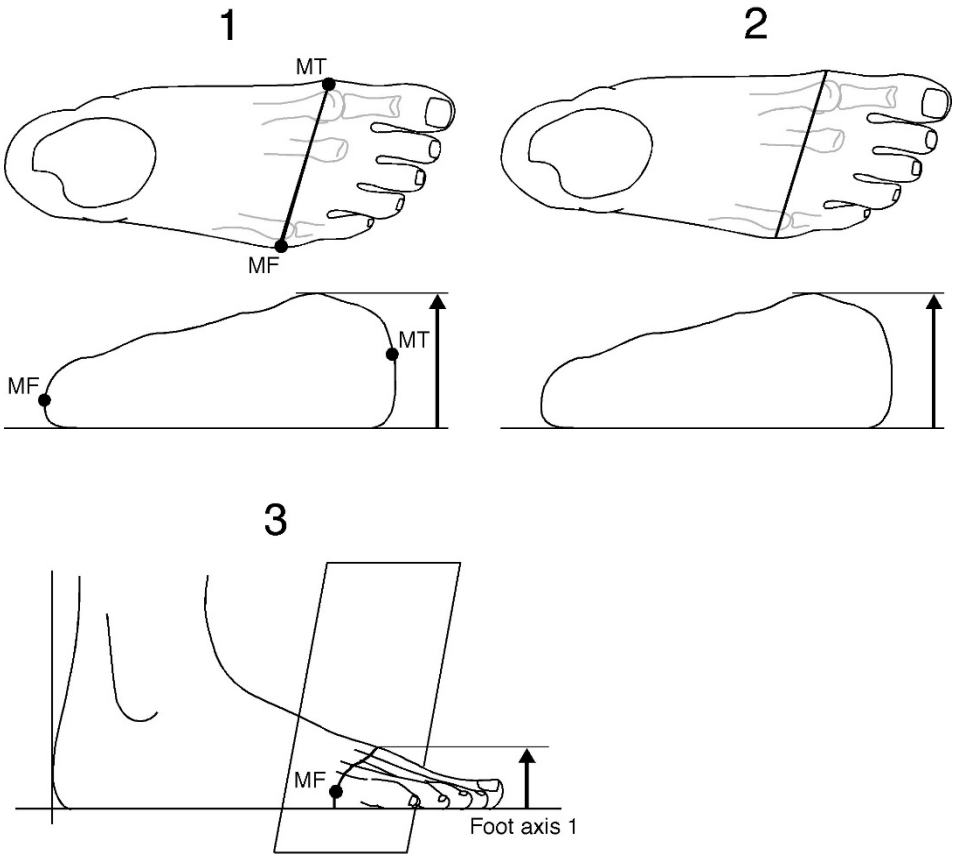

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FIGURE 21 Ball height (Section 3.3.15). MF: metatarsale fibulare, MT: metatarsale tibiale.

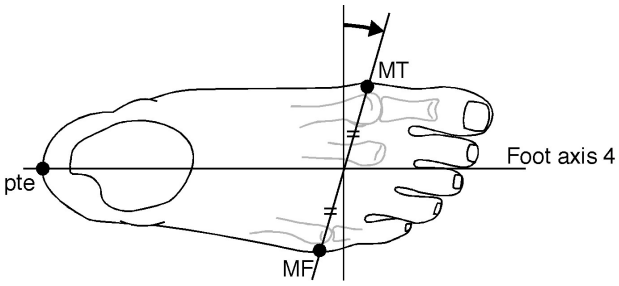
3.3.16. BALL ANGLE

TABLE 22 summarizes the different definitions of this measurement. See FIGURE 22.

TABLE 22 Ball angle definitions and providers that use them

#	Definition	Measurement providers*
1	Angle between foot axis #4 (pternion - midpoint of MT and MF) and the line connecting MT and MF projected to the standing surface (ball of the foot section #1)	IBV

*All other providers do not have this definition.



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NOTE—See Table 5 for the definition of foot axis.

FIGURE 22 Ball angle (Section 3.3.16). MF: metatarsale fibulare, MT: metatarsale tibiale, pte: pternion.

3.3.17. INSTEP GIRTH

TABLE 23 summarizes the different definitions of this measurement. See FIGURE 23.

TABLE 23 Instep girth definitions and providers that use them

#	Definition	Measurement providers*
1	Vertical circumference of the foot measured at 50% FL, perpendicular to foot axis #1 (medial tangent).	TechMed 3D (method 1)
2	Vertical circumference of the foot measured at 50% FL, perpendicular to foot axis #3 (pternion – tip of the second toe).	TechMed 3D (method 2)
3	Vertical circumference of the foot measured at 50% FL, perpendicular to the foot axis #4 (pternion – midpoint of MT and MF).	SATRA, IBV
4	Vertical circumference of the foot measured at 50% FL perpendicular to the foot axis #5 (pternion – midpoint of the breadth of ball cross section).	I-Ware (method 1), Aetrex
5	Vertical circumference of the foot measured at 50% FL perpendicular to the foot axis #6 (pternion – center of second metatarsal head).	I-Ware (method 2), Bodyform3D
6	Vertical circumference of the foot measured at 55% FL, perpendicular to the foot axis #8 (midpoint of the breadth at 10% FL – point at 66% FL and 40% of its width from medial side).	Volumental
7	Circumference of the foot positioned at 40% FL from the heel and inclined at 65 degrees from the horizontal plane. Foot axis #1 (medial tangent) is used.	TechMed 3D (method 3)

Table continues

#	Definition	Measurement providers*
8	Circumference of the foot positioned at 40% FL from the heel and inclined at 65 degrees from the horizontal plane. Foot axis #3 (pternion – tip of the second toe) is used.	TechMed 3D (method 4)
9	Minimal circumference of the foot measured at 45% FL at the standing surface and perpendicular to the dorsal surface of the foot. Foot axis #7 (midpoint of the breadth at 10% FL and midpoint of a point at 73% FL on medial side and a point 62% FL on lateral side) is used.	TryFit

*ISO/TS 19408:2015, JIS S 5037:1998 do not have this definition.

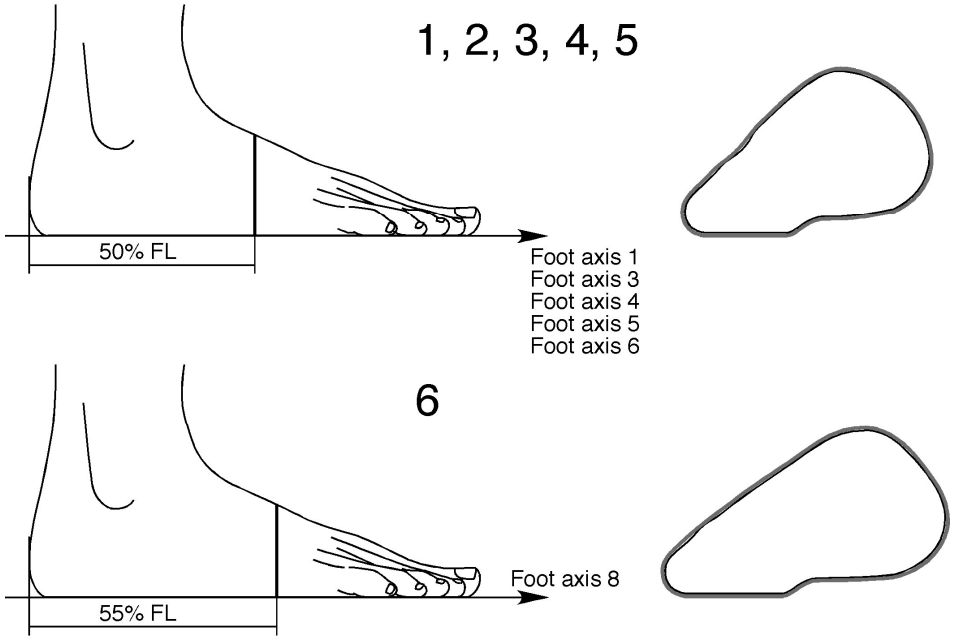
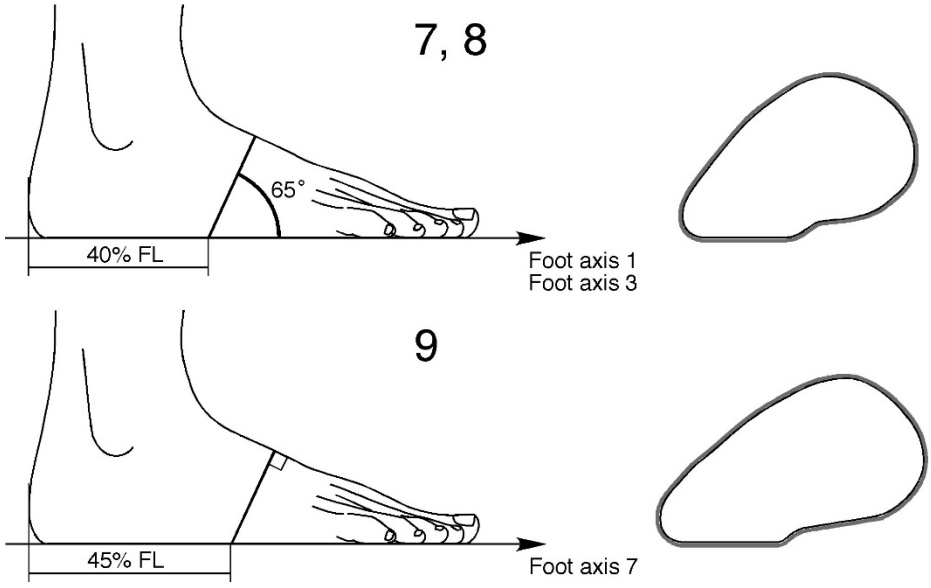


Figure 23 continues



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NOTE—See Table 5 for the definition of foot axis.

FIGURE 23 Instep girth (Section 3.3.17). FL: foot length. Actual position of instep girth depends on the definition of foot axis.

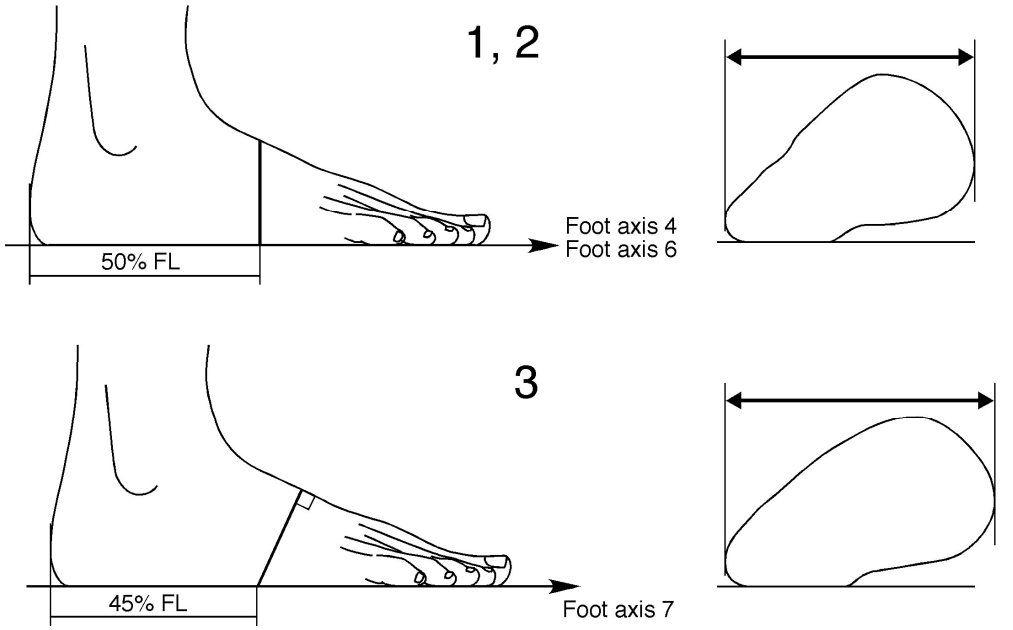
3.3.18. INSTEP WIDTH

The instep width is also designated as “instep breadth” or “midfoot width.” TABLE 24 summarizes the different definitions of this measurement. See FIGURE 24.

TABLE 24 Instep width definitions and providers that use them

#	Definition	Measurement providers*
1	Width of the foot at 50% FL measured perpendicular to the foot axis #4 (pternion – midpoint of MT and MF).	SATRA, IBV
2	Width of the foot at 50% FL measured perpendicular to the foot axis #6 (pternion – center of second metatarsal head).	Bodyform3D
3	Maximum horizontal width of the instep cross section that passes at 45% FL at the standing surface and perpendicular to the dorsal surface of the foot and perpendicular to the foot axis #7 (midpoint of the breadth at 10% FL – midpoint of a point at 73% FL on medial side and a point at 62% FL on lateral side).	TryFit

*ISO/TS 19408:2015, JIS S 5037:1998, Aetrex, I-Ware, TechMed 3D, and Volumental do not have this definition.



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NOTE—See Table 5 for the definition of foot axis.

FIGURE 24 Instep width (Section 3.3.18). FL: foot length. Actual position of instep girth depends on the definition of foot axis.

3.3.19. INSTEP HEIGHT

The instep height is also designated as "midfoot height." TABLE 25 summarizes the different definitions of this measurement. See FIGURE 25.

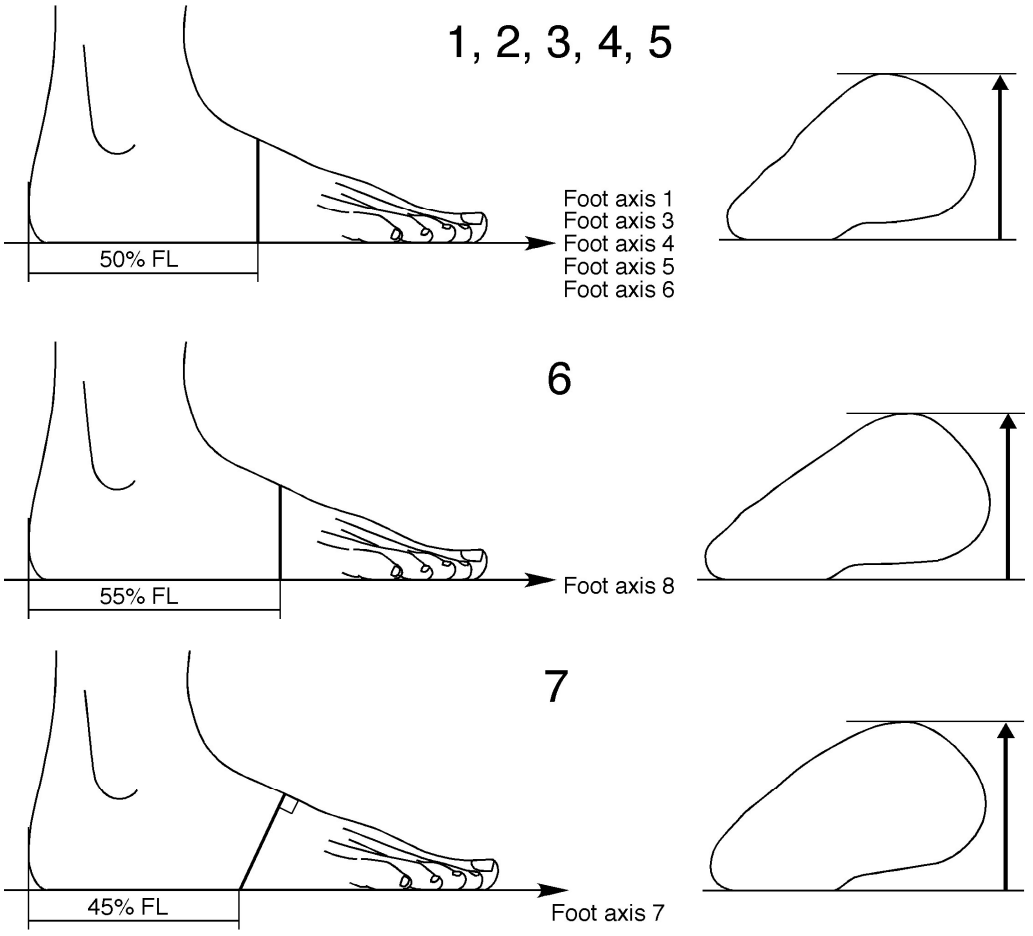
TABLE 25 Instep height definitions and providers that use them

#	Definition	Measurement providers*
1	Height of vertical cross section at 50% FL perpendicular to foot axis #1 (medial tangent) (Height of instep point #1).	TechMed 3D (method 1)
2	Height of vertical cross section at 50% FL perpendicular to foot axis #3 (pternion – tip of the second toe) (Height of instep point #3).	TechMed 3D (method 2)
3	Height of vertical cross section at 50% FL perpendicular to foot axis #4 (pternion – midpoint of MT and MF) (Height of instep point #4).	SATRA, IBV
4	Height of vertical cross section at 50% FL perpendicular to foot axis #5 (pternion – midpoint of the breadth of ball cross section) (Height of instep point #5).	I-Ware (method 1), Aetrex
5	Height of vertical cross section at 50% FL perpendicular to foot axis #6 (pternion – center of second metatarsal head) (Height of instep point#6).	I-Ware (method 2)

Table continues

#	Definition	Measurement providers*
6	Height of vertical cross section at 55% FL perpendicular to foot axis #8 (midpoint of the breadth at 10% FL – point at 66% FL and 40% of its width from medial side) (Height of instep point #8).	Volumental
7	Height of the instep cross section that passes at 45% FL at the standing surface and perpendicular to the dorsal surface of the foot and perpendicular to the foot axis #7 (midpoint of the breadth at 10% FL – midpoint of a point at 73% FL on medial side and a point 62% FL on lateral side).	TryFit

*ISO/TS 19408:2015, JIS S 5037:1998, and Bodyform3D do not have this definition.



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NOTE—See Table 5 for the definition of foot axis.

FIGURE 25 Instep height (Section 3.3.19). FL: foot length. Actual position of the instep section depends on the definition of foot axis.

3.3.20. LONG HEEL GIRTH

The long heel girth is also designated as “instep-to-heel girth.” TABLE 26 summarizes the different definitions of this measurement. See FIGURE 26.

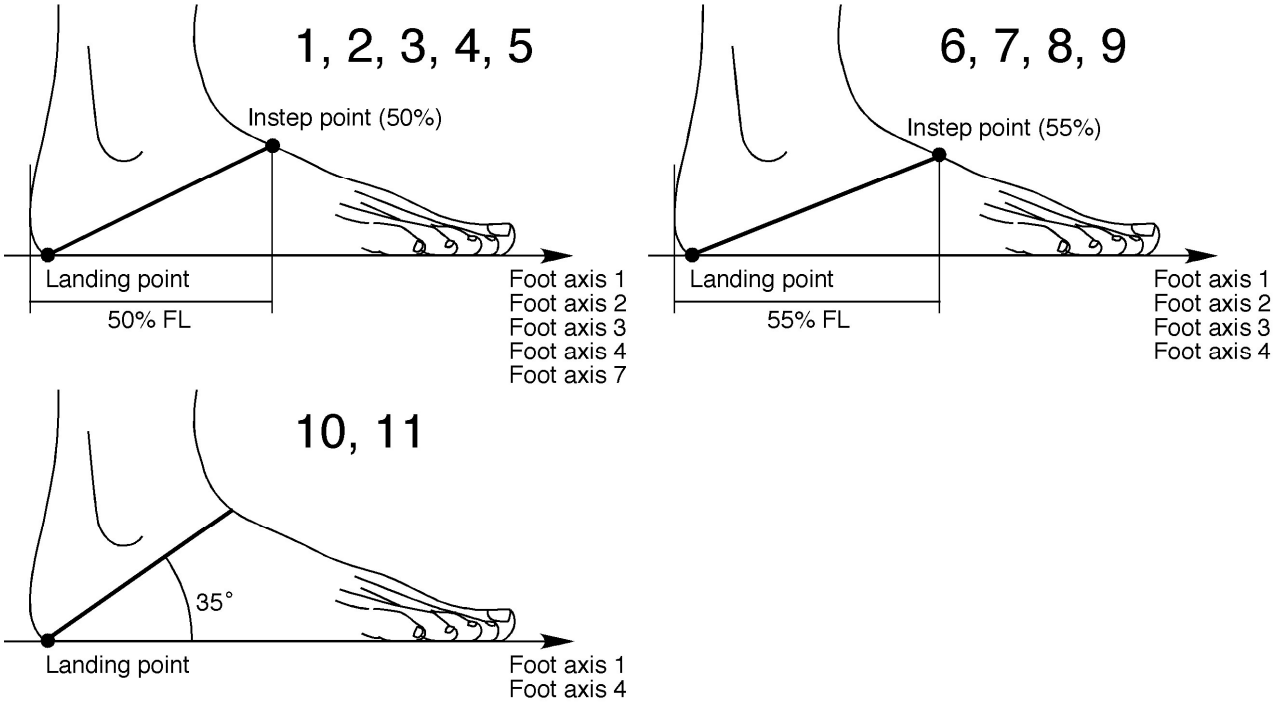
TABLE 26 Long heel girth definitions and providers that use them

#	Definition	Measurement providers*
1	Circumference passing the landing point and instep point (50%) perpendicular to the foot axis #1 (medial tangent).	ISO/TS 19408:2015 (2.1.16 using instep point 2.1.7 method 1 and foot axis 2.1.4 method 1)
2	Circumference passing the landing point and instep point (50%) perpendicular to the foot axis #2 (pternion – midpoint of ball tread width).	ISO/TS 19408:2015 (2.1.16 using instep point 2.1.7 method 1 and foot axis 2.1.4 method 2b)
3	Circumference passing the landing point and instep point (50%) perpendicular to the foot axis #3 (pternion – tip of the second toe).	ISO/TS 19408:2015 (2.1.16 using instep point 2.1.7 method 1 and foot axis 2.1.4 method 2a)
4	Circumference passing landing point and instep point (50%) perpendicular to the foot axis #4 (pternion – midpoint of MT and MF).	SATRA, IBV
5	Circumference passing the landing point and the highest point at the 50% FL and perpendicular to the foot axis #7 (midpoint of the breadth at 10% FL – midpoint of a point at 73% FL on medial side and a point 62% FL on lateral side).	TryFit
6	Circumference passing the landing point and instep point (55%) perpendicular to the foot axis #1 (medial tangent).	ISO/TS 19408:2015 (2.1.16 using instep point 2.1.7 method 2 and foot axis 2.1.4 method 1) TechMed 3D (method 1)
7	Circumference passing the landing point and instep point (55%) perpendicular to the foot axis #2 (pternion – midpoint of ball tread width).	ISO/TS 19408:2015 (2.1.16 using instep point 2.1.7 method 2 and foot axis 2.1.4 method 2b)
8	Circumference passing the landing point and instep point (55%) perpendicular to the foot axis #3 (pternion – tip of the second toe).	ISO/TS 19408:2015 (2.1.16 using instep point 2.1.7 method 2 and foot axis 2.1.4 method 2a)
9	Circumference passing the landing point and instep point (55%) perpendicular to the foot axis #4 (pternion – midpoint of MT and MF).	TechMed 3D (method 2)
10	Circumference passing the landing point and inclined at 35° from the horizontal plane and perpendicular to the foot axis #1 (medial tangent).	TechMed 3D (method 3)

Table continues

#	Definition	Measurement providers*
11	Circumference passing the landing point and inclined at 35° from the horizontal plane and perpendicular to the foot axis #4 (pternion – midpoint of MT and MF).	TechMed 3D (method 4)

*JIS S 5037:1998, Aetrex, Bodyform3D, I-Ware, and Volumental do not have this definition.



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NOTE—See Table 5 for the definition of foot axis.

FIGURE 26 Long heel girth (Section 3.3.20). FL: foot length. Actual position of long heel girth depends on the definition of foot axis.

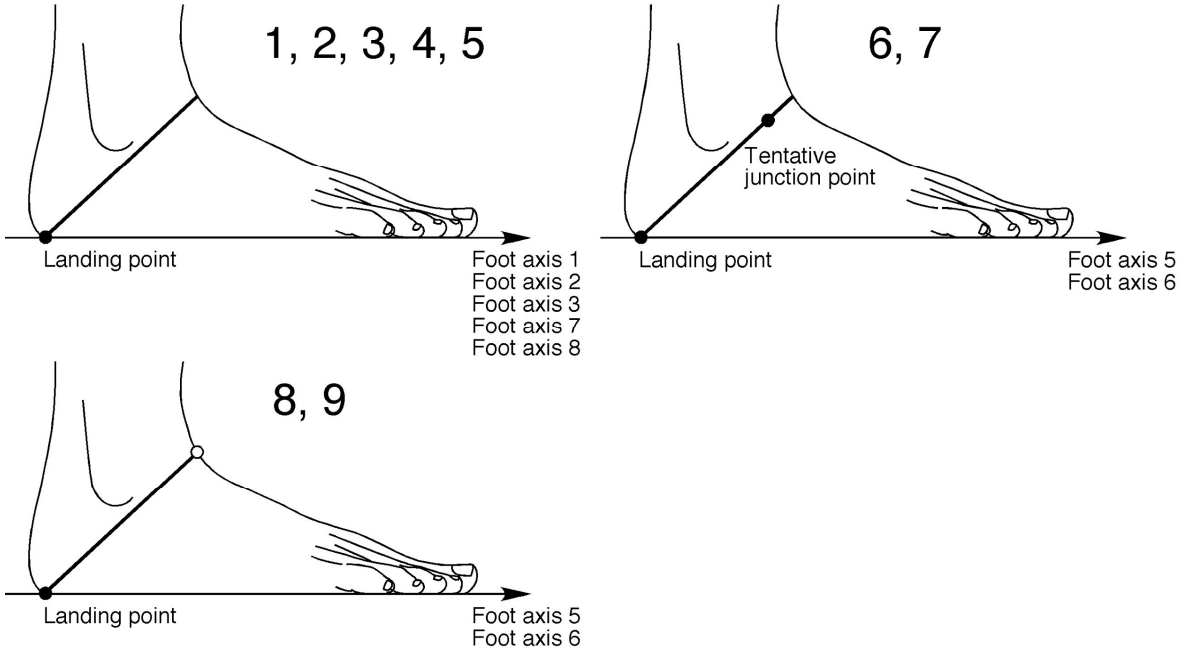
3.3.21. SHORT HEEL GIRTH

The short heel girth is also designated as “heel girth.” TABLE 27 summarizes the different definitions of this measurement. See FIGURE 27.

TABLE 27 Short heel girth definitions and providers that use them

#	Definition	Measurement providers*
1	Shortest circumference passing the landing point and perpendicular to the foot axis #1 (medial tangent).	ISO/TS 19408:2015 (method 1), TechMed 3D (method 1)
2	Shortest circumference passing landing point and perpendicular to the foot axis #2 (pternion – midpoint of ball tread width).	ISO/TS 19408:2015 (method 2)
3	Shortest circumference passing landing point and perpendicular to the foot axis #3 (pternion – tip of the second toe).	ISO/TS 19408:2015 (method 3), TechMed 3D (method 2)
4	Shortest circumference passing the landing point and perpendicular to the foot axis #7 (midpoint of the breadth at 10% FL – midpoint of a point at 73% FL on medial side and a point 62% FL on lateral side).	TryFit
8	Shortest circumference passing landing point and perpendicular to the foot axis #8 (pternion – midpoint of the breadth at 10% FL – point at 66% FL and 40% of its width from medial side).	Volumental
6	Circumference passing the landing point and tentative junction point and perpendicular to foot axis #5 (pternion – midpoint of the breadth of ball cross section).	I-Ware (method 1)
7	Circumference passing the landing point and tentative junction point and perpendicular to foot axis #6 (pternion – center of second metatarsal head).	I-Ware (method 2)
8	Circumference perpendicular to the foot axis #5 (pternion – midpoint of the breadth of ball cross section), passing the landing point and the closest point from the landing point on the dorsal part of the side silhouette of the foot.	I-Ware (Method 3)
9	Circumference perpendicular to the foot axis #6 (pternion – center of second metatarsal head), passing the landing point and the closest point from the landing point on the dorsal part of the side silhouette of the foot.	I-Ware (Method 4)

*JIS S 5307:1998, Aetrex, Bodyform3D, IBV, and SATRA do not have this definition.



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NOTE—See Table 5 for the definition of foot axis.

FIGURE 27 Short heel girth (Section 3.3.21). Actual position of short heel girth depends on the definition of foot axis

3.3.22. HEEL WIDTH

The heel width is also designated as “heel breadth” or as “linear heel width.” TABLE 28 summarizes the different definitions of this measurement. See FIGURE 28.

TABLE 28 Heel width definitions and providers that use them

#	Definition	Measurement providers*
1	Width of the heel measured at 16% of foot length perpendicular to foot axis #4 (pternion – midpoint of MT and MF) and projected to the standing surface	SATRA, IBV
2	Width of the heel measured at 16% of foot length (= default) perpendicular to foot axis #5 (pternion – midpoint of the breadth of ball cross section) and projected to the standing surface	I-Ware (method 1)
3	Width of the heel measured at 16% of foot length (= default) perpendicular to foot axis #6 (pternion – center of second metatarsal head) and projected to the standing surface	I-Ware (method 2)

Table continues

#	Definition	Measurement providers*
4	Width of the heel measured at 15% of foot length at the height of ≤ 30 mm measured perpendicular to foot axis #8 (midpoint of the breadth at 10% FL – point at 66% FL and 40% of its width from medial side) and projected to the standing surface.	Volumental
5	Maximum width of the heel part, measured perpendicular to the foot axis #1 (medial tangent) and projected to the standing surface.	TechMed 3D (method 1)
6	Maximum width of the heel part, measured perpendicular to the foot axis #3 (pternion – tip of the second toe) and projected to the standing surface.	TechMed 3D (method 2)
7	Maximum width of the heel area perpendicular to the foot axis #5 (pternion – midpoint of the breadth of ball cross section) and projected to the standing surface.	Aetrex

*ISO/TS 19408:2015, JIS S 5037:1998, Bodyform3D, and TryFit do not have this definition.

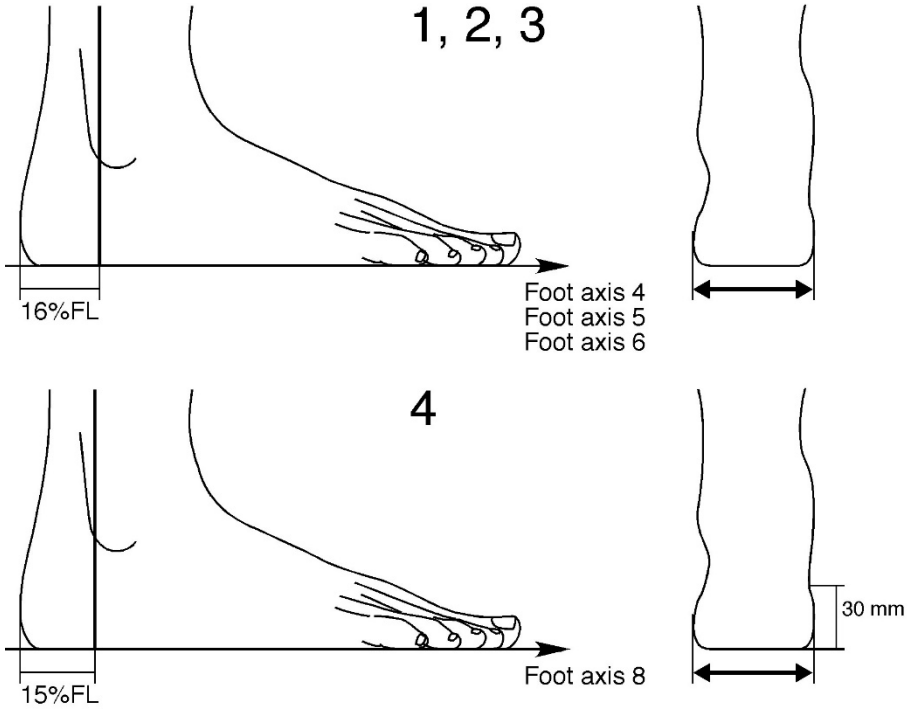
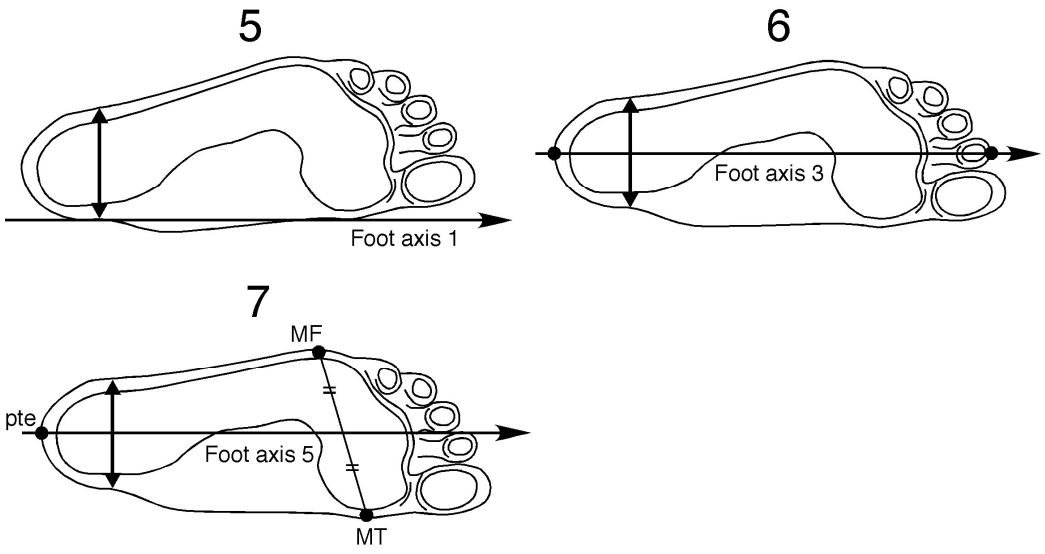


Figure 28 continues



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NOTE—See Table 5 for the definition of foot axis.

FIGURE 28 Heel width (Section 3.3.22). FL: foot length, MF: metatarsale fibulare, MT: metatarsale tibiale, pte: pternion. Actual position of heel breadth depends on the definition of foot axis.

3.3.23. PTERNION HEIGHT

The pternion height is also designated as “heel point height.” TABLE 29 summarizes the different definitions of this measurement. See FIGURE 29.

TABLE 29 Pternion height definitions and providers that use them

#	Definition	Measurement providers*
1	Height of pternion	SATRA, TechMed 3D

*ISO/TS 19408: 2015, JIS S 5037:1998, Aetrex, Bodyform3D, I-Ware, IBV, TryFit, and Volumental do not have this definition.

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FIGURE 29 Pternion height (3.3.23). pte: pternion

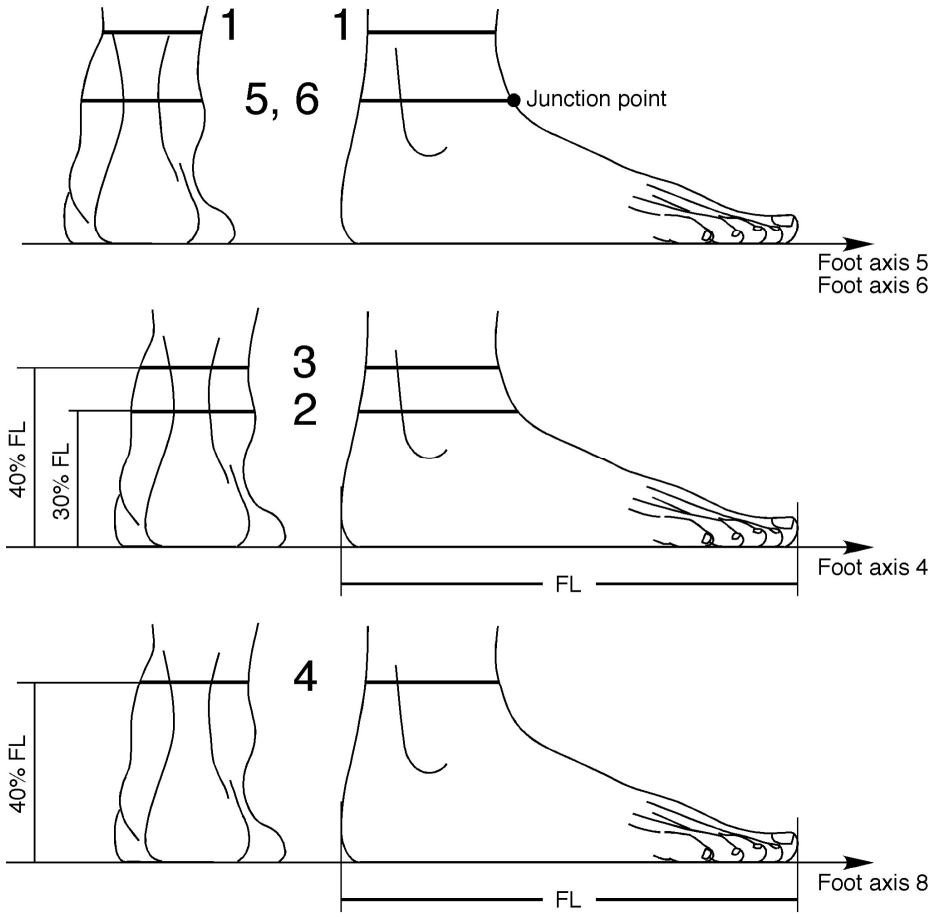
3.3.24. ANKLE GIRTH

The ankle girth is also designated as “Minimum leg girth.” TABLE 30 summarizes the different definitions of this measurement. Some providers do not use the name “ankle girth.” Commonly used names are given in the bracket. See FIGURE 30.

TABLE 30 Ankle girth definitions and providers that use them

#	Definition	Measurement providers*
1	Smallest horizontal circumference of the leg above the malleolus. Does not depend on the foot axis.	ISO/TS 19408:2015 (minimum leg girth), TechMed 3D (ankle circumference), TryFit (ankle girth)
2	Horizontal circumference of the leg at the height of 30% FL. Foot axis #4 (pternion – midpoint of MT and MF) is used.	SATRA (method 1, maximum circumference)
3	Horizontal circumference of the leg at the height of 40% FL. Foot axis #4 (pternion – midpoint of MT and MF) is used.	SATRA (method 2, minimum circumference)
4	Horizontal circumference of the leg at the height of 40% FL. Foot axis #8 (midpoint of the breadth at 10% FL – point at 66%FL and 40% of its width from medial side) is used.	Volumental (ankle girth)
5	Horizontal circumference of the leg at the height of junction point. Foot axis #5 (pternion – midpoint of the breadth of ball cross section) is used.	I-Ware (horizontal ankle circumference, method 1)
6	Horizontal circumference of the leg at the height of junction point. Foot axis #6 (pternion – center of second metatarsal head) is used.	I-Ware (horizontal ankle circumference, method 2)

*JIS S 5037:1998, Aetrex, Bodyform3D, and IBV do not have this definition.



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NOTE—See Table 5 for the definition of foot axis.

FIGURE 30 Ankle girth (Section 3.3.24). FL: foot length. Actual position of the junction point depends on the definition of foot axis.

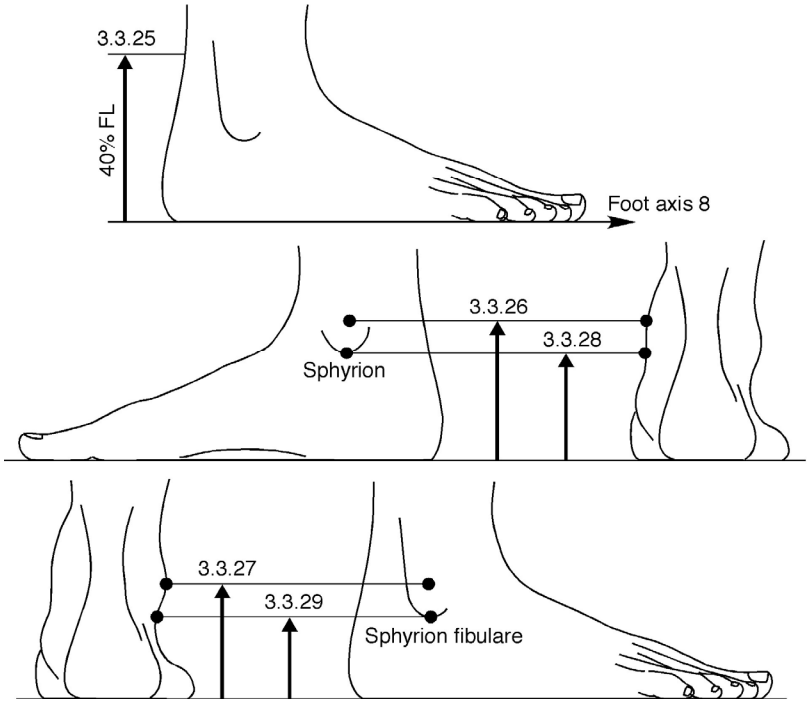
3.3.25. ANKLE HEIGHT

Please note that the term “ankle” is used ambiguously by different providers to designate other measurements (compare Section 3.3.26 medial malleolus height, Section 3.3.27 lateral malleolus height and Section 3.3.24 ankle girth). TABLE 31 summarizes the different definitions of this measurement. Due to the ambiguous use of the term and its interpretation, in this case, the designation used by every measurement provider is provided in brackets. See FIGURE 31.

TABLE 31 Ankle height definitions and providers that use them

#	Definition	Measurement providers*
1	Height equal to 40% FL. Foot axis #8 (midpoint of the breadth at 10% FL – point at 66%FL and 40% of its width from medial side) is used.	Volumental

*All other providers do not have this definition.



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NOTE—See Table 5 for the definition of foot axis.

FIGURE 31 Ankle height (Section 3.3.25), medial malleolus height (Section 3.3.26), lateral malleolus height (Section 3.3.27), sphyrion height (Section 3.3.28) and sphyrion fibulare height (Section 3.3.29). FL: foot length.

3.3.26. MEDIAL MALLEOLUS HEIGHT

The medial malleolus height is also designated as “ankle height” or “inner ankle height.” Please note that the term “ankle” is used ambiguously by different providers to designate other measurements (compare Section 3.3.25 ankle height, Section 3.3.27 lateral malleolus height and Section 3.3.24 ankle girth). TABLE 32 summarizes the different definitions of this measurement. Due to the ambiguous use of the term and its interpretation, in this case, the designation used by every measurement provider is provided in brackets. See FIGURE 31.

TABLE 32 Medial malleolus height definitions and providers that use them

#	Definition	Measurement providers*
1	Height of the most medial point of medial malleolus.	SATRA, I-Ware (height of the most medial point of medial malleolus), TechMed 3D (Medial malleolus height)

*ISO/TS 19408:2015, JIS S 5036:1998, Aetrex, Bodyform3D, IBV, TryFit, and Volumental do not have this definition.

3.3.27. LATERAL MALLEOLUS HEIGHT

The lateral malleolus height is also designated as “ankle height” or “outer ankle height.” Please note that the term “ankle” is used ambiguously by different providers to designate other measurements (compare Section 3.3.25 ankle height, Section 3.3.26 medial malleolus height, and Section 3.3.24 ankle girth). TABLE 33 summarizes the different definitions of this measurement. Due to the ambiguous use of the term and its interpretation, in this case, the designation used by every measurement provider is provided in brackets. See FIGURE 31.

TABLE 33 Lateral malleolus height definitions and providers that use them

#	Definition	Measurement providers*
1	Height of the most lateral point of lateral malleolus.	SATRA (Lateral malleolus height), I-Ware (height of the most lateral point of lateral malleolus), TechMed 3D (Lateral malleolus height)

*ISO/TS 19408:2015, JIS S 5037:1998, Aetrex, Bodyform3D, IBV, TryFit, and Volumental do not have this definition.

3.3.28. SPHYRION HEIGHT

TABLE 34 summarizes the different definitions of this measurement. See FIGURE 31.

TABLE 34 Sphyrion height definitions and providers that use them

#	Definition	Measurement providers*
1	Height of sphyrion, which is the lowest point of the medial malleolus.	I-Ware

*All other providers do not have this definition.

3.3.29. FIBULAR SPHYRION HEIGHT

TABLE 35 summarizes the different definitions of this measurement. See FIGURE 31.

TABLE 35 Sphyrion fibulare height definitions and providers that use them

#	Definition	Measurement providers*
1	Height of the fibular sphyrion, which is the lowest point of the lateral malleolus.	I-Ware

*All other providers do not have this definition.

3.3.30. CALF GIRTH

TABLE 36 summarizes the different definitions of this measurement. The designation used by every measurement provider is provided in brackets. See FIGURE 32.

TABLE 36 Calf girth height definitions and providers that use them

#	Definition	Measurement providers*
1	Maximum horizontal circumference of the calf.	ISO/TS 19408:2015, SATRA
2	Horizontal circumference at a height of 230 mm.	I-Ware (calf circumference height 230 mm)

*JIS S 5037:1998, Aetrex, Bodyform3D, IBV, TechMed 3D, TryFit, and Volumental do not have this definition.

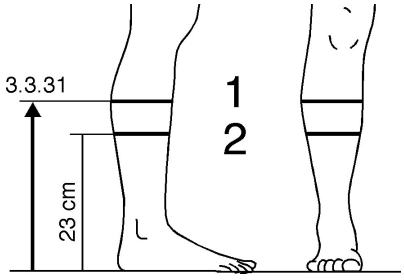

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FIGURE 32 Calf girth (Section 3.3.30) and maximum calf girth height (Section 3.3.31)

3.3.31. MAXIMUM CALF GIRTH HEIGHT

TABLE 37 summarizes the different definitions of this measurement. See FIGURE 32.

TABLE 37 Calf girth height definitions and providers that use them

#	Definition	Measurement providers*
1	Height of the maximum calf girth	SATRA

*All other providers do not have this definition.

3.3.32. UNDER KNEE GIRTH

TABLE 38 summarizes the different definitions of this measurement. See FIGURE 33.

TABLE 38 Under knee girth definitions and providers that use them

#	Definition	Measurement providers*
1	The smallest horizontal girth below the knee and above calf	ISO/TS 19408:2015

*JIS S 5037:1998, Aetrex, Bodyform3D, I-Ware, IBV, SATRA, TechMed 3D, TryFit, and Volumental do not have this definition.

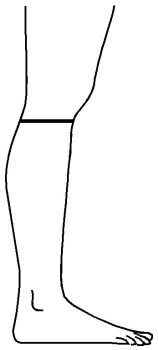

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FIGURE 33 Under knee girth (Section 3.3.32)

4. CONCLUSIONS

4.1. GAPS IDENTIFIED

The gaps that the IEEE 3DBP have identified are the following:

- Sources may use the same terminology, but the assumption cannot be made that the definitions and measurement methods are the same, which means the results may vary.
- Terminology may be based on manufacturing, medical or anatomical terms, or any combination of all.
- Not all sources list the definitions – many sources have only partial definitions.
- Not all sources specify how each measurement is taken – no weight bearing (in air), partial weight bearing (sitting position), half weight bearing (on both feet, bilateral stance)., or full weight bearing (standing on one foot).
- Not all sources specify the foot attire (i.e., barefoot, light stocking, sock).

In addition, the IEEE 3DBP have identified knowledge gaps in anatomy and common foot ailments. A companion paper, IEEE SA 3D Body Processing Industry Connections Functional Anatomy, Terms, and Common Foot Conditions by Dr. Paul Langer will be published at the same time as this paper.

Definitions associated with new measurements for foot or leg comfort have been identified, but clear definitions do not exist yet. Thus, there are a number of metrics that could be of interest to different use cases, especially custom-made footwear. In this case, the measured characteristics are generally continuous rather than discrete, such that none of them have been clearly defined. A second companion paper to be published (date undetermined), Proposed Additional Foot Metrics by IEEE 3DBP group will establish these definitions. Some examples include pternion heel curve, the arch and foot mobility. Other metrics may also be identified and defined.

4.2. EXPECTED FUTURE WORK

Future work will focus on three areas. One will explore if definitions associated with lasts are sufficient or whether additional definitions are needed, given the foot definitions listed in this paper. Lasts are measured for construction. Consequently, there are more definitions associated with lasts than for feet. Consumers of last definitions will need to address the same issues as those associated with feet.

The interaction between feet and footwear is a second area for exploration. Input will come from the paper on Proposed Additional Foot Metrics by the IEEE 3DBP group.

The third area will study how footwear construction materials and design affect consumer fit preference, and last design. Last design “rules of thumb” will be scrutinized, especially regarding length, width and fit preference.

5. REFERENCES

The following list of sources either has been referenced within this paper or may be useful for additional reading:

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