International Journal of Anatomy and Research,
Int J Anat Res 2020, Vol 8(3.3):7715-21. ISSN 2321-4287
DOI: https://dx.doi.org/10.16965/ijar.2020.199

Original Research Article

CALCANEAL ARTICULAR FACET CONFIGURATION TYPES: A REPORT OF A CADAVERIC STUDY AND THE CALCANEAL CONSTRICTION INDEX

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ABSTRACT

Background: The superior surface of the calcaneus will frequently demonstrate 3 articular facets for the articulation with the talus: anterior, middle, and posterior. There are several possible configurations of these articular facets. The present article is a reporting of a cadaveric study of facets on the superior calcaneal surface as well as a literature review of current classification schemes of calcaneal facets. The Calcaneal Constriction Index is introduced as a better measuring method for classification of the non-constricted and constricted types of fused calcaneal middle and anterior facets.

Results: Of 158 total cadaveric specimens, there were seven types of calcanei observed. Using the Calcaneal Constriction Index for measurement of fused Type 1A non-constricted and Type 1B constricted yielded 21 specimens and 29 specimens, respectively. In Type 2A there were 18, Type 2B had 40. Type 2C had 39 specimens included and in Type 2D there were 3 specimens found. For Type 3, anterior facets were absent in 8 specimens.

Conclusions: For assigning the Type 1A and Type 1B into their proper calcaneal configuration categories, the Calcaneal Constriction Index is shown to provide a simple, intuitive, reproduceable and easily measurable method for the fused middle and anterior type of calcaneal facets. Review of the literature shows that there is a need to establish a consensus between future authors in naming of the types of articular facets on the superior aspect of the calcaneus.

Key Words: calcaneus, variations, anterior facet, constricted, non-constricted, fused, calcaneal facets, subtalar joint, articular facets, absent anterior facet

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Access this Article online	Journal Information
Quick Response code	**International Journal of Anatomy and Research**
	RG Journal Impact: 0.21*
	ISSN (E) 2321-4287 | ISSN (P) 2321-8967
	https://www.ijmhr.org/ijar.htm
	DOI-Prefix: https://dx.doi.org/10.16965/ijar
DOI: 10.16965/ijar.2020.199	

Article Information

Received: 28 Jul 2020	Accepted: 26 Aug 2020
Peer Review: 29 Jul 2020	Published (O): 10 Sep 2020
Revised: None	Published (P): 10 Sep 2020

INTRODUCTION

The calcaneus is the largest bone of the human foot. The articular surfaces between the calcaneus and the talus in the foot establish the subtalar joint, which is mostly responsible for inversion and eversion of the foot. *All* calcanei demonstrate posterior and middle facets. Most (but not all) calcanei possess an anterior facet. The configuration of the facets of the superior aspect of the calcaneus have been categorized by various authors into groups based on 1) whether the anterior and middle facets are fused or separate and 2) whether the anterior facet is missing/absent and 3) whether the posterior facet is fused or separate from the middle facet. There is contradicting evidence within the literature to support a consensus on the naming of calcaneal facet configurations.

After studying several various category schemes of many authors reporting on the calcaneal facet

configurations, this study will use a classification scheme modified from the Iamsaard [1] article (Figure 1):

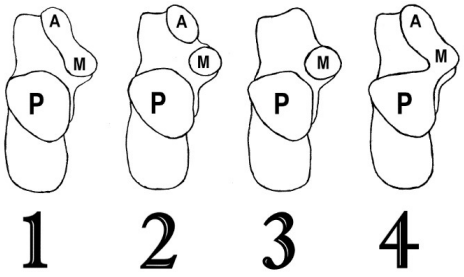

Fig. 1: Dorsal calcaneus demonstrating the four configurations of calcaneal facets used in this study. P=posterior facet, M=middle facet, A=anterior facet. 1=fused M and A, 2=separate M and A, 3=absent A, 4=fused P and M. See text.

Type 1: the middle and anterior Calcaneal facets are fused. Type 2: the middle and anterior facets are separate. Type 3: the anterior facet is absent. Type 4 is defined as: the posterior and middle facets are fused, with or without fusion of the anterior facet.

Regarding types 1 and 2, two subtypes for Type 1 (fused middle and anterior facets) are recognized and four subtypes for Type 2 (separate middle and anterior facets) are recognized.

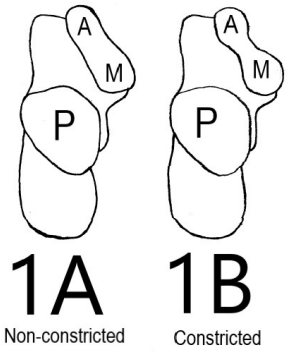

Fig. 2: Dorsal/superior calcaneus view of Type 1 specimens. P=posterior facet, M=middle facet, A=anterior facet.

See Figure 2. In type 1 specimens the fused middle and anterior facets are non-constricted (1A) or constricted (1B).

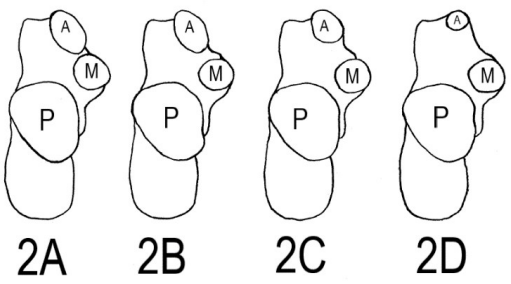

Fig. 3: Dorsal calcaneus, type 2 specimens. P=posterior facet, M=middle facet, A=anterior facet. See text.

In type 2A and 2B (Figure 3): the middle and anterior facets are separated by <2mm and 2-5 mm, respectively, as defined by the Iamsaard [1] classification. The current author defines 2C as the anterior and middle separation being greater than 5 mm up to 10mm. Further, when the anterior and middle facets are separated by >10mm this is defined as class 2D.

A Literature Review Regarding Nomenclature. Currently in the literature there is no universal naming scheme that all authors utilize regarding calcaneal facet configuration. This lack of standardized nomenclature can promote significant confusion. In order to show the confusion possible in studying the calcaneal articular types, the following paragraph reviews the various names of just the calcaneal Type 1A and 1B facets given by different authors. Further, only 1 article, Jung [2] attempted to report the fused facet types with use of a measurable, metric method.

The 28 various authors reviewed in the English language who report on Type 1 calcanei *and also* distinguish the two fused subtypes (1A and 1B) have used the following different wording to delineate the two subtypes (Table 1):

Names given by authors for Type 1A: not-constricted: 17 authors, plus the current author, use the term not (or un- or non) constricted [1,3-18]. To be accurate, the unconstricted nomenclature for type 1A is synonymous with non-constricted or not constricted. Six authors use the words 'completely fused' or 'fused' in describing Type 1A [2,19-23]. 'No separation' are the words used by 2 authors [24,25]. Two authors [26,27] used the term 'long continuous facet'. Yang [28] calls Type 1A specimens calabash-shaped. **Names given For Type 1B: constricted:** 17 authors [1,3-18], plus the current author, use the word constricted. Three authors use the words 'fused with notch or fused with narrowing' [19,20,23]. Two authors [21,22], use the words 'incomplete separation by a notch'. Two authors [24,25], use the words 'separation not complete'. Jung [2], used the wording 'partially connected'. Two authors [26,27] used 'figure 8' forms and Yang [28] used 'pear shaped'. For Table 1: NP=No photographs of sketches were submitted for fused FAM types.

Table 1: Names given by authors for Type 1A and Type 1B calcaneal configurations.

bib#	FAM articles	year	# spec	FAM%	names for 1A/1B
4	Agarwal	2016	580	66.50%	unconst/constr
3	Anjaneyulu	2014	100	62.00%	unconst/constr
5	Campos-Pel	1989	176	53.40%	unconst/constr
6	Gindha	2015	325	69.50%	uncons/constr
7	Gupta	1977	401	66.80%	uncons/constr
1	Iamsaard	2015	396	60.90%	uncons/constr
8	Kori	2016	600	73.70%	uncons/constr
9	Kullar NP	2015	200	72.50%	uncons/constr
10	Kumar	2017	200	54.00%	uncons/constr
11	Laxmi	2018	50	66.00%	uncons/constr
12	Mini	2012	50	74.00%	uncons/constr
13	Parimala	2016	88	60.20%	uncons/constr
14	Patel/Patel	2013	205	64.90%	uncons/constr
	Present	2019	158	31.60%	uncons/constr
15	Sarvaiya	2012	250	69.00%	uncons/constr
16	Sharada	2012	300	67.00%	uncons/constr
17	Ukoha	2017	220	63.20%	uncons/constr
18	Uygur	2009	221	58.40%	uncons/constr
28	Yang	2019	505	60.80%	pear shaped/calabash
24	Boyan	2016	57	61.40%	no separation/sep not complete
25	Seema NP	2012	300	56.00%	no separation/sep not complete
26	Nemade	2014	220	65.50%	long cont facet/trans fig 8
27	Drayer-Verhag	1993	191	54.50%	long cont facet/fig 8
2	Jung	2015	118	61.00%	fused/partially connected
23	Shahabpour NP	2011	49	53.10%	comp fusion/narrowing
21	Jha	1972	1600	59.50%	comp fusion/incomplsep by notch
22	Nagar NP	2012	529	76.40%	comp fusion/incomplsep by notch
19	Anbumani	2017	110	69.10%	comp fusion/fused w notch
20	Barbaix NP	2000	134	28.40%	comp fusion/fused w narrowing

FAM=fused anterior and middle calcaneal facets. NP=no photographs or sketches were submitted with the article.

As one can see, if there are too many different names used to delineate non-constricted versus constricted then it becomes challenging to accurately correlate the category types from author to author. Furthermore, 27 previous authors publishing in the English language studied by this author [1,3-28] have not defined **how constricted the constriction must be** in order for a specimen to be categorized as constricted versus non-constricted. This article reports 1) the number and types of calcaneal facets from 3 successive years at the anatomy lab, 2) the use of the calcaneal constriction index (CCI) for measuring Type 1A and 1B types from the anatomy lab, and 3) the use of CCI to measure photographs/sketches from other authors in the literature.

METHODS

In May of 2006, 2007, 2008, three separate anatomical dissection studies of the subtalar joint were performed at Dr. William M. Scholl College of Podiatric Medicine at Rosalind Franklin University of Medicine and Science (SCPM) in North Chicago, Illinois, USA on 169 foot specimens. This study was performed using volunteer students, residents, and attending physicians. All specimens were either wet cadaver specimens or fresh frozen specimens. No dry bones were measured or reported. Race, sex, identities were not recorded. Photographs were taken of the superior surface of each of the calcanei, capturing the posterior and middle facets in all specimens and capturing anterior facets when present. Photographs of 158 calcaneal superior surfaces were deemed useable for purposes of this study. The calcaneal photographs were later used to measure and place each specimen in type 1A, 1B (using the CCI method described below) or type 2A, 2B, 2C, 2D or type 3 categories. No Type 4 specimens were observed in either of the three

years studied.

Analysis of the photographs.

When one assigns the Calcaneal specimens in the 2A, 2B, 2C, and 2D subtypes, there is no real challenge, as they are placed into the subtypes based on only one metric measurement: the distance between the calcaneal anterior and middle facets (Figure 3). However, for the Type 1 specimens, when one attempts to place the specimens into constricted or non-constricted categories one finds that there is no clear constriction definition in the literature. Thus, one realizes that most of the previous authors have placed the specimens into the Type 1A or 1B subtypes using a rather subjective empirical method. An empirical method can be prone to error, as some researchers would have a more stringent requirement and other researchers would have a less stringent requirement regarding what is considered constricted. The one exception using a metric, rather than empirical definition is described in the Jung et al [2] article. The Jung method is recognized as a valid, definitive, metric measurement method but is deemed too cumbersome. Thus, the current author's calcaneal constriction index (CCI) was conceived and executed for the 50 fused types (Types 1A and 1B) out of the158 total calcaneal specimens in the present study.

The Calcaneal Constriction Index.

The CCI measurement method is defined as follows for Type 1 calcanei, see Figure 4:

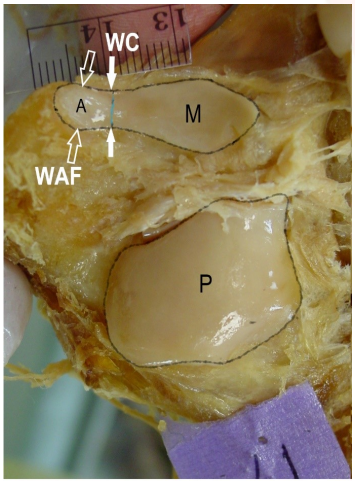

Fig. 4: SCPM cadaveric photo of the dorsal calcaneus. The small white arrows=the minimum width of the constriction (WC) between the middle (M) and anterior (A) facets. The large white arrows=the maximum width of the anterior facet (WAF). P is the posterior facet. WC/WAF=CCI=0.83

Measure the minimum width of the constriction (WC=smaller white arrows) between the anterior and middle facets, then measure the maximum width of the anterior facet (WAF=larger white arrows). The calcaneal constriction index (CCI) is simply the width of the constriction divided by the width of the anterior facet (CCI=WC/WAF). If an anatomic specimen's calcaneal constriction index measures 0.80 or greater, it is defined as non-constricted. If the CCI is less than 0.80 it is placed in the constricted category. This method of measurement can be performed directly in the cadaver lab or can also be done from photographs of the superior surface of the calcaneus. It is observed that the anterior facet is almost always smaller than the middle facet. It is also observed that the constriction between the anterior and middle facets is almost always smaller than the anterior facet. Indeed, in reporting the findings of the current cadaveric study, the constriction index was less than 1.0 in every Type 1 calcaneal specimen, meaning that the anterior facet width was always larger than the constriction between the middle and anterior facets.

The above CCI measurement method was performed on the 50 Type 1 specimens. Figure 5 (CI $\geq$80%) demonstrates four examples of specimens which are non-constricted, Type 1A.

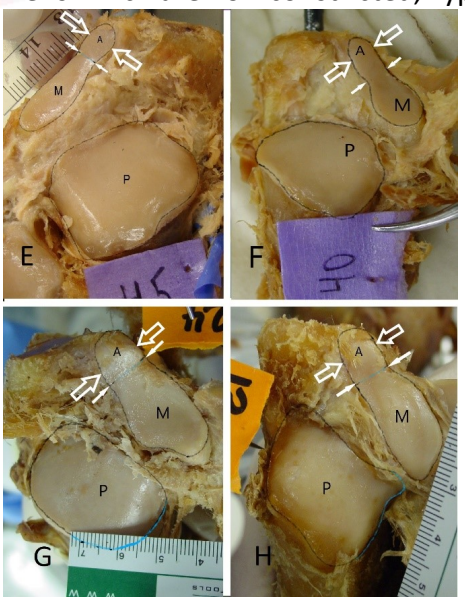

Fig. 5: Cadaveric calcanei from SCPM dissection. Four examples of Type 1A **non-constricted** middle and anterior calcaneal facets. P, M, A are posterior, middle and anterior facets. Small arrows=width of the constriction and large arrows=width of the anterior facet. The CCI for E=0.80, F=0.83, G=0.94 and H=0.96.

Figure 6 shows four constricted specimens, where the CCI is less than 0.80 (<80%), Type 1B.

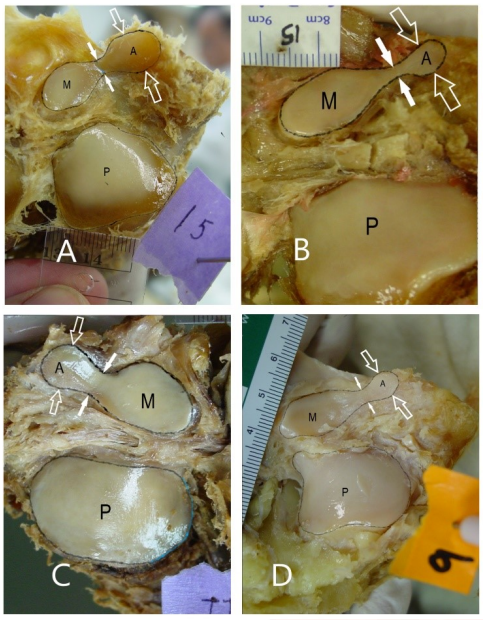

Fig. 6: Cadaveric calcanei from SCPM dissection. Four examples of Type 1B **constricted** middle and anterior facets. P, M, A are posterior, middle and anterior facets. Small arrows=width of the constriction and large arrows=width of the anterior facet. The CCI for A=0.36, B=0.36, C=0.71 and D=0.64.

DISCUSSION

Table 2: Calcaneal Constriction Index numbers of Type 1 specimens from photos of 24 articles.

REF	Author	Year	Photo source	1A CCI	1B CCI	Error type
1	Iamsaard	2015	Fig 1	80%	45%	sketch
3	Anjaneyulu	2014	Fig 5,6	82%	70%	wide ink
10	Kumar	2017	Fig 2,3	82%	50%	n/a
4	Agarwal	2016	Fig 4 1A,B	83%	42%	n/a
13	Parimala	2016	Fig 1	84%	33%	wide ink
8	Kori	2016	Fig 1,2	85%	44%	n/a
16	Sharada	2012	Fig 1: 1a, 1b	86%	57%	wide ink
26	Nemade	2014	Fig 1, 2	87%	45%	n/a
19	Anbumani	2017	Fig 3,4	88%	69%	n/a
7	Gupta	1977	Fig 1, 2	88%	57%	wide ink
14	Patel/Patel	2013	Fig 1	88%	56%	n/a
18	Uygur	2009	Fig 3 B2,B1	89%	60%	n/a
15	Sarvaiya	2012	Fig 3 B2,B1	89%	61%	blurry
27	ayer-Verhag	1993	Fig 1 a, b	90%	42%	sketch
2	Jung	2015	Fig 5: B,C	90%	55%	n/a
24	Boyan	2016	Fig2 E,F	90%	49%	n/a
17	Ukoha	2017	Fig 2: B, A	90%	61%	WI, oblvw
12	Mini Mol	2012	Fig 2: B1,B2	94%	48%	n/a
18	Uygur	2009	Fig 3: B2, B1	93%	41%	B1 oblique
6	Gindha	2015	Photo2 A,B	95%	60%	wide ink
11	Laxmi	2018	Fig 3, Fig 2	96%	89%	WI, oblvw
21	Jha	1972	Plate 2,3	100%	58%	n/a
5	Campos	1989	Fig 2: B2, B1	110%	52%	sketch
28	Yang	2019	Fig 2 I,IV	110%	44%	author tracing

Table 2 is listed in ascending order of the 1A non-constricted column. The reasons for possible measurement error are in the error column. Photo source is the named location of the photo/sketch in each author's article.

Why 80%? Application of the constriction index to photos and sketches in previous literature. Of the articles reviewed for this topic, 24 authors published sketches or photographs of examples of non-constricted and constricted fused anterior and middle facets. These authors are listed in Table 2.

The CCI for each author's photograph of Type 1 specimen was measured and calculated by the current author. The photographs/sketches of Type 1 specimens of Table 2 were enlarged as necessary by the current author in order to measure WC/WAF and calculate constriction indices for each of these photos/sketches. **Possible errors in measuring photos of other authors:** This author admits that some of the calcaneal surfaces are obscured or obliterated by lines drawn by the observed author delineating the articular surfaces, introducing possible error in measuring WC and WAF. Other possible errors include the photos not showing the facets well because of obliquity, or the photo is blurry. Additionally, error is possibly introduced because some of the examples are free-hand sketches. Regardless, Table 2 summarizes various calcaneal constriction index (CCI) values for these photos/sketches of Type 1A and 1B specimens. The calcaneal constriction index measured from **non-constricted** photos varies from 0.80 to 1.10 with average CI of 90%. The CCI values for **constricted** photos/sketches vary from 0.33 to 0.70 with an outlier of 0.89 from the Laxmi [11] photo. This outlier is likely suspect because of the obliqueness of the photo in capturing the anterior facet and constriction. Even with the Laxmi [11] outlier, the average of all the Type 1B photos calculates to 53%. Keep in mind that these measurements only reflect visual evidence of "good examples" of non- constricted and constricted samples chosen by each author and do not reflect the full variance in each author's Type 1A and Type 1B specimens.

CONCLUSION

Summarizing for calcaneal Types 1, 2, 3 in the SCPM study reporting 158 specimens: There were 50/158 Type 1 specimens (32%), 100/158 Type 2 specimens (63%). There were eight Type 3 (5%) specimens identified. Regarding

the calcaneal constriction index: the CCI is shown to be simple, intuitive and easily executed by either direct lab measurement or from photos taken in the anatomy lab. The CCI applied to the photos/sketches of previous articles show non-constricted values of 0.80 to 1.10 and constricted index values from 0.33 to 0.70 (less the outlier of 0.89). Thus, the CCI 80% threshold seems to be a valid demarcation for non-constricted versus constricted. It is shown in Table 1 that too many authors use too many naming schemes for describing calcaneal facet configuration. There needs to be a consensus established utilizing a single naming system for the dorsal calcaneal configurations. It is also hoped that future authors who are reporting findings for the types of calcaneal facets will be able to use a metric definition for both the non-constricted and constricted calcaneal specimens instead of an empiric definition for Type 1 specimens. The calcaneal constriction index is shown to be a pathway to complete one of these goals, as the CCI method is reproduceable between authors.

ABBREVIATIONS

CCI or CI - Calcaneal Constriction Index
DPM - Doctor of Podiatric Medicine
FAM - Fused anterior and middle facets (Types 1A and 1B)
NP - No photographs/sketches of Type 1 were submitted (Table 1)
P, M, A - Posterior, Middle, Anterior calcaneal facets
SCPM - Dr. William M. Scholl College of Podiatric Medicine at Rosalind Franklin University of Medicine and Science
WAF - Width of the anterior facet (maximum width)
WC - Width of the constriction (minimum width)

ACKNOWLEDGEMENTS

Brad Ross, DPM. Private practice, Lincolnwood, Illinois, USA for providing oversight as attending physician at the SCPM dissection.

Bruce Manion, PhD Emeritus professor, Rosalind Franklin University of Medicine and Science, North Chicago, Illinois, USA, for coordinating the students and the dissection facility.

Dr. William M. Scholl College of Podiatric Medicine at Rosalind Franklin University of Medicine and Science, North Chicago, Illinois, USA for allowing the use of their anatomy facilities for the students, residents and attendings. Funds for transportation, lodging, meals or other miscellaneous expenses for the project were provided by McShane Foot and Ankle, LLC, the employer of the author.

Illustrations were drawn by the author, Patrick McShane, DPM. The photographs were taken by the author and annotated by the author.

Conflicts of Interests: None

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How to cite this article:

Patrick Anderson McShane. CALCANEAL ARTICULAR FACET CONFIGURATION TYPES: A REPORT OF A CADAVERIC STUDY AND THE CALCANEAL CONSTRICTION INDEX. Int J Anat Res 2020;8(3.3):7715-7721. **DOI:** 10.16965/ijar.2020.199