Chulalongkorn Medical Journal

Volume 55
Issue 3 *May 2011*

Article 1

5-1-2011

Ankle morphometry for development ofankle prosthesis

Y Khanasuk

P Itiravivong

P Tangpornprasert

C. Virulsri

Chula Med J Vol. 55 No. 3 May-June 2011

Ankle morphometry for development of ankle prosthesis

Yutthana Khanasuk* Pibul Itiravivong*
Pairat Tangpronprasert** Chanyaphan Virulsri**

Khanasuk Y, Itiravivong P, Tangpornprasert P, Virulsri C. Ankle morphometry for development of ankle prosthesis. Chula Med J 2011 May – Jun; 55(3): 193 - 205

Background : *Ankle arthroplasty plays an important role in pain relieve and improving the functions of end-stage ankle osteoarthritis. Now the ideal prosthesis is being developed. The fundamental data for invention of a novel design is ankle morphology*

objective : *To study ankle morphology in the Thai population and compare with the current morphologic data. This study also seeks for the most compatible design for the Thai population.*

Design : *Descriptive study*

Setting : *Department of Orthopaedics, Faculty of Medicine, Chulalongkorn University*

Material and Methods : *Ankle images from MRI were collected and measured parameters that are important for develop ankle prosthesis were measured.*

Results : *The ankle parameters are described in detail. Thai ankles are smaller than the current data. The study found some parameters that are different from the previous ones because of the methods of measurement. When compare with the current prosthesis available now, TNK from Japan is the most compatible with the Thai population.*

* Department of Orthopaedics ,Faculty of Medicine, Chulalongkorn University

** Department of Mechanical Engineering, Faculty of Engineering, Chulalongkorn University

Conclusions : *The present data demonstrates the valid ankle parameter and play an important role to develop the new ankle prosthesis.*

Keywords : *Ankle, total ankle arthroplasty, ankle morphology.*

Reprint request: Khanasuk Y. Department of Orthopaedics, Faculty of Medicine, Chulalongkorn University, Bangkok 10330, Thailand.

Received for publication. June 2, 2010.

ยุทธนา คณาสุข, พิบูลย์ อิทธิระวิวงศ์, ไพรัช ตั้งพรประเสริฐ, ชัญญาพันธ์ วิรุฬห์ศรี. การศึกษาขนาดของข้อเท้า เพื่อการออกแบบพัฒนาข้อเท้าเทียมสำหรับประชากรไทย. จุฬาลงกรณ์เวชสาร 2554 พ.ค. – มิ.ย.; 55(3): 193 – 205

เหตุผลของการทำวิจัย : *การผ่าตัดข้อเท้าเทียมเป็นการผ่าตัดที่ใช้รักษาผู้ป่วยที่เป็นโรคข้อเท้าเสื่อม ซึ่งช่วยลดอาการปวด และไม่สูญเสียการทำงานของข้อเท้า ในปัจจุบัน ยังไม่มีข้อเท้าเทียมชนิดใดที่ให้ผลการรักษาที่ยอมรับว่าดีที่สุด จึงมีการคิดค้นออกแบบข้อเท้าเทียมชนิดใหม่ ข้อมูลที่จำเป็นต่อการออกแบบคือ ขนาดของข้อเท้า*

วัตถุประสงค์ : *เพื่อศึกษาขนาดของข้อเท้าในประชากรไทย และนำข้อมูลที่ได้เปรียบเทียบกับข้อมูลที่มีอยู่เดิม รวมทั้งเปรียบเทียบกับข้อเท้าเทียมที่มีอยู่ในปัจจุบัน เพื่อหาข้อเท้าเทียมที่ขนาดเหมาะสมกับประชากรไทย*

รูปแบบการวิจัย : *การศึกษาเชิงพรรณนา*

สถานที่ทำการศึกษา : *ภาควิชาออร์โธปิดิกส์ คณะแพทยศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย*

ตัวอย่างและวิธีการศึกษา : *รวบรวมภาพข้อเท้าที่ได้จากการตรวจด้วยภาพสะท้อนคลื่นแม่เหล็กและวัดตัวแปรที่สำคัญของข้อเท้าที่จำเป็นต่อการออกแบบพัฒนาข้อเท้าเทียม*

ผลการศึกษา : *การศึกษานี้ได้แสดงขนาดของข้อเท้าที่สำคัญ และพบว่าขนาดข้อเท้าของประชากรไทย มีขนาดเล็กกว่าข้อมูลเดิมที่ส่วนมากเป็นคนยุโรป มีบางตัวแปรที่มีความคลาดเคลื่อนกันสูง เนื่องมาจากการวัดด้วยเครื่องมือที่ต่างกัน การศึกษายังพบว่า ข้อเท้าเทียมจากบริษัทที่ผลิตในประเทศญี่ปุ่นมีขนาดใกล้เคียงกับข้อเท้าของคนไทยมากที่สุด*

สรุป : *ข้อมูลของข้อเท้าที่ได้เป็นข้อมูลที่มีความถูกต้อง และเป็นประโยชน์ต่อการออกแบบพัฒนาข้อเท้าเทียมต่อไป*

คำสำคัญ : *ข้อเท้า, ข้อเท้าเทียม, ขนาดของข้อเท้า.*

Ankle osteoarthritis (OA ankle) is a progressive degeneration of articular cartilage characterized by pain, a reduced range of motion, loss of quality of life, generalize disability and other invaliding symptoms. The goal of end-stage OA ankle treatment is to relieve symptoms, such as pain and stiffness and improve function. Ankle arthrodesis (ankle fusion) has been the typically chosen orthopaedic treatment for OA ankle. However, the complication in ankle arthodesis, such as degeneration of adjacent joints, non-union and malunion and diffucult walking on uncover platform led to the introduction of total ankle replacement (TAR).[1,2]

There are several designs in total ankle replacement that are different in concepts and mechanincs of the current implants but the ideal ankle implant has yet to be developed.[3-11] Current systematic reviews of 49 studies[12] show the better result of TAR from new designs, but is not the best option for all patient. Because of improving of the ankle biomechanic knowledge and modern technology[13], the novel TAR designs are developing. The basic data to produce the implant is morphology.

Only few studies have reported on ankle joint geometrical measurement[14-18] The methods used to measure ankle morphology are vary. Fessy M.H. et al.[14] used standard radiograph and measured joint morphometry directly by using protractors or goniomters. Whereas Stagni R. et al.[15,16] proposed a new semi-automatic method based on standard radiograms that is accurate, repeatable and little dependent on operator's skill. This method used software designed for for this purpose and developed in MATLAB (The Mathworks, Inc.). Only studies of Andrea Hayes et.al. [17] and Chien et.al. [18] revealed ankle morphology on 3D-CT images. Andrea measured only the talar dimension (anterior, middle and posterior of superior talar dome) and the arc radius of talar dome from Europe patient. Chien studied from 10 chinese cadavers followed by Stagni's study. [15]

The result of reports are comparable in some dimensions because of various technique and parameters. In overall, there are a lillte difference. Stagni also presented that the currently available TAR designs seems to cover a very limited range and generally underestimated of real ankle dimensions. [15]

This study is made to evaluate the ankle morphology of thai population for developing the ankle prosthesis. The study also compare these data with current ankle morphologic data [14-18] and prostheses that are available now.

Material and Method

From June 2009 to March 2010, 32 consecutive ankle magnetic resonance imaging (MRI) studies were performed in Thai subjects who have ankle problem. We study only skeletal part of the ankle, we exclude the patient with bony problem. 27 from Chulalongkorn memorial hospital, 12 from Prachacheun Imaging Center. The selection criteria of each subject included 20 to 60 years of age with out clinical symptom and sign of ankle arthritis. The exclusion criteria are patients with ankle fracture and dislocation, inflammatory joint disease eg: rheumatoid arthritis, gouty arthritis, osteoarthritic change or bony deformity.

This study evaluates ankle morphology using MRI base because it is three dimension (3D) image study. Computer tomography (CT) is also 3D image study but we common use CT in case of fractures or bony problem. Whereas MRI is common use to diagnose the soft tissue problems.

Because ankle MRI is an uncommon study, data collection from Chulalongkorn Memorial Hospital and Prachacheun will shorten the time to collect data. In Chulalongkorn Memorial Hospital, MRI was performed by Signa 1.5 Tesla Exite HD, General Electric (G.E.) and for Prachacheun Imaging Center, MRI was performed using a 1.5 Tesla whole body MR imaging system (Siemens 1.5 Tesla, Avanto, Germany) with an extremity coil. Pulse sequences were T1-weighted images. The direction of axial slice imaging placed the slice perpendicular to the ankle joint in the coronal plane and perpendicular to the long axis of tibia in the saggital plane. All images were reconstructed at 3-mm intervals. The parameters are measured by program eFilm (DICOM images program) and recorded in millimeters.

Effect of ankle external rotation and modification method

The natural ankle are 15-20 degree external rotation. Some parameters as mentioned before are not accurate. For example the talar anteroposterior (AP) length that measure from plain film on lateral view are distort the true length. By the axial view MRI image show sagital legth is longer than true AP length. We can calculate the true AP legth of the talus by trigonometrical formula and we can measure the true AP length directly.

We compare the calculated value with the true length. The mean is -0.73, SD 1.73, range from -2.51 to 1.76. 95% confidence interval is -1.21 to -0.25. The mean of different and 95% confidence interval are in the clinically acceptable. We assume this method can be applied to the other parameters.

Ankle parameters

Not all parameter that propose by Stagni is important to the new total ankle implant design. The important parameter include.

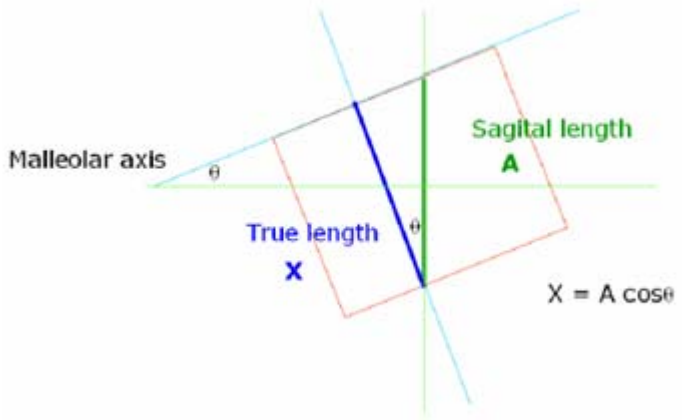

Figure 1. The effect of ankle rotation, the sagital length (A) is longer than true length (X). we can calculate the true length by trigonometrical formula.

Table1. Important ankle parameters.

Parameters	Talus	Tibia
Anteroposterior (AP)	Talar arc length (TaAL) Talar AP diameter (TaAP) Sagital radius of talar trochlea (SRTa)	Maximal tibial thickness (MTiTh) Tibial arc length (TiAL)
Mediolateral (ML)	Talar width (TaW)	Tibial width (TiW) Malleolar width (MalW) Malleolar axis (axis)

Parameters of the talus (Figure 2)

AP dimension

1. Talus anteroposterior diameter (TaAP)

From axial view, the anterior border of talus to posterior border in line that perpendicular to the malleolar axis. This is true AP length of talus.

2. Talar arc length (TaAL)

From sagital view, the line from the anterior border to posterior of talus are called talar arch legth. This is not true length because of ankle external rotation.

3. Sagital radius of talar trochlea (SRTa)

From sagital view, circle was created that covering the most circumstance of the talar dome and report the radius of this circle. Because of the ankle rotation SRTa will correct to adjusted SRTa (aSRTa) by calculation as described in figure1.

ML dimension

1. Talar width (TaW)

From axial view, the line joining the medial and lateral edge of talus from anterior part are called anterior talar width (aTaW) by the same method measurement on posterior and middle part of talus are called posterior TaW (pTaW) and middle TaW (mTaW) respectively.

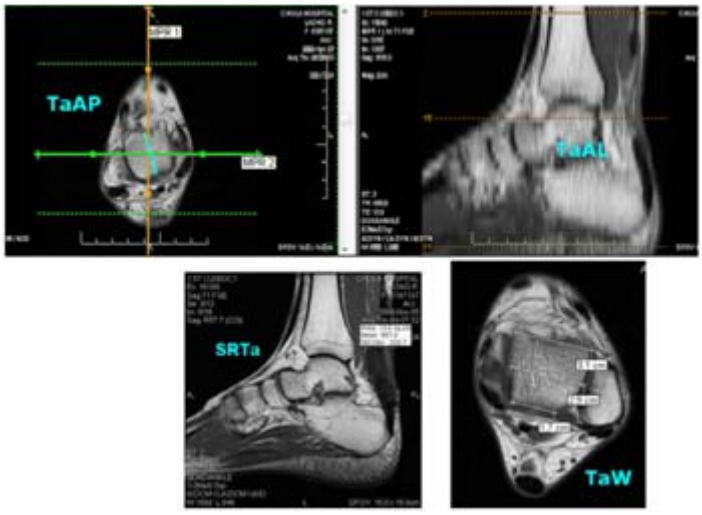

Figure 2. The parameters of talus.

Parameters of the distal tibia (Figure 3)

AP dimension

1. Maximal tibial thickness (MTiTH)

From sagital view, the distance from the apex of anterior and posrterior cortical convexity is measured. This metaphyseal flare was assumed for the bone stock to accommodate the prosthesis.

2. Tibial arc length (TiAL)

From sagital view, we measure the distance from the most anterior to posterior portion of ankle mortise.

Because these AP diameters are measured on anatomical position which is not true sagital view. The adjusted value, adjusted MTiTh (aMTiTH) and adjusted TiAL (aTiAL) could be calculated as described in figure1.

ML dimension

1. Tibial width (TiW)

From coronal view, the parameter is measured from the most lateral border of distal tibia to the angle formed by inner cortex of medial malleolus and tibial plafond. This parameter was adjusted to true length by same calculation (see figure1). The adjusted parameter was called adjusted TiW (aTiW).

2. Malleolar width (MalW)

From axial view, we measured the distance from the most prominence from the medial malleolus to the lateral malleolus.

3. Malleolar axis (axis)

We evaluate the degree of ankle external rotation by measure the angle of intersection between malleolar axis and coronal axis.

Statistical analysis

The results were represented as mean, standard deviation (SD), 95% confidence interval are also present to compare various parameters of ankle joint between the genders. Statistical analysis of the results was done using t-test by two-tailed p-values option. A p-value of < 0.05 indicated a significant effect. The program using to calculated is Microsoft Excel XP and SPSS version 11.5 for Windows.

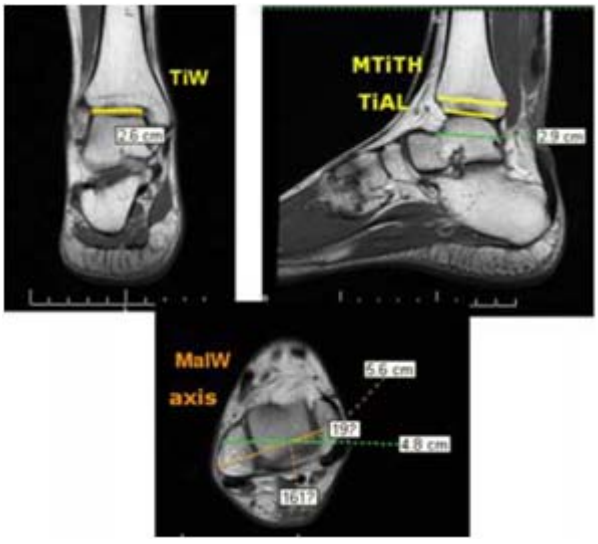

Figure 3. The parameters of distal tibia.

Result

The demographic data are shown in table 2.

Table 2. The basic information of the subjects

Sex	Subjects	Age (year)	SD
Total	32	42.53	9.22
Male	11	43.55	9.37
Female	21	42.00	9.33

The result of ankle parameters are shown in table 3.

Table 3. The mean, standard deviation and 95% confidence interval of parameters.

Parameters	Total (N=32)		
	mean(mm)	SD	95% CI(mm)
TaAP	28.5	2.4	27.7 - 29.3
aTaW	28.0	3.5	26.8 - 29.3
mTaW	26.9	2.9	25.9 - 27.9
pTaW	19.6	2.2	18.8 - 20.4
aSRTa	16.7	1.8	16.1 - 17.4
aMTiTh	33.4	2.8	32.3 - 34.4
aTiAL	24.1	2.8	23.1 - 25.1
aTiW	31.9	4.5	30.2 - 33.5
MalW	58.5	4.8	56.8 - 60.2
Mal axis	21.7	6.6	19.3 - 24.0

The non-adjusted parameters are shown in table 4 to compare the current morphologic data.

The parameters that Stagni[15] and Chien[18] report were not measure from anatomic position including sagital radius of talus, talar arc length, tibial arc length, maximal tibial thickness and tibial width. This study modified some parameters in order to obtain the anatomic diameter. Whereas Hayes[17] report the anatomic measurement, we can compare to Hayes's report.

Table 4. The mean, standard deviation and 95% confidence interval of non-adjusted parameters.

Parameters	Total (N=32)		
	mean(mm)	SD	95% CI (mm)
TaAL	31.7	2.9	30.6 - 32.7
SRTa	18.1	1.9	17.4 - 18.8
MTiTh	36.2	3.1	35.6 - 37.3
TiAL	26.1	2.9	25.0 - 27.1
TiW	29.3	3.5	28.1 - 30.6

In order to determine the racial variation, we compare non-anatomic diameter to the Stagni and Chien report. The comparison data are shown in table 6,7 and figure 4,5

This parameters from the study compare with the total ankle prostheis available now are shown in the figure 6,7

The figure 6,7 demonstrate talar component from 3 company have overestimation in anteroposterior aspect. In mediolateral aspect, anterior part diameters are in length but some company have overestimation to the posterior part. The tibial component in almost designs are in the range. The most compatible designs with Thai population is TNK from Japan.

Table 5. Comparison of parameters between male and female group.

Parameters	Male (n=11)		Female (n=21)		p-value
	mean(mm)	SD	mean(mm)	SD	
TaAP	30.2	1.2	27.6	2.3	0.000
aTaW	30.3	4.2	26.9	2.5	0.028
mTaW	29.0	2.4	25.8	2.5	0.002
pTaW	21.5	1.8	18.6	1.7	0.000
aSRTa	18.1	1.5	16.0	1.5	0.002
aMTiTh	35.4	2.7	32.3	2.3	0.004
aTiAL	25.9	2.3	23.1	2.6	0.004
aTiW	35.3	4.3	30.1	3.6	0.003
MalW	62.8	3.3	56.2	3.8	0.000
Mal axis	22.5	5.2	21.2	7.3	0.590

Table 6. Comparison data: current data with this study.

Parameters	Stagni[15](n=36)		Chien[18] (n=10)		This study	Adjusted
	mean±SD	p-value+	mean±SD	p-value++	(n=32)	data
SRTa*	23.4 ± 3.1	0.1426	22.1 ± 2.7	0.8151	21.6 ± 6.5	18.1 ± 1.9
Taw	30.4 ± 3.3	0.0049	29.9 ± 2.1	0.1131	28.0 ± 3.5	NA
TaAL*	41.7 ± 4.4	0.0000	32.3 ± 2.9	0.5607	31.7 ± 2.8	28.5 ± 2.4
TiAL*	31.4 ± 3.5	0.0000	NA	NA	26.1 ± 2.9	24.1 ± 2.8
MTiTh*	46.4 ± 3.9	0.0000	NA	NA	36.2 ± 3.1	33.3 ± 2.8
SRTi	27.8 ± 4.4	NA	29.8 ± 7.9	NA	NA	NA
MalW	69.0 ± 7.6	0.0000	61.5 ± 2.8	0.0689	58.5 ± 4.8	NA
TiW*	31.9 ± 3.5	0.0032	31.9 ± 2.4	0.0348	29.3 ± 3.5	31.8 ± 4.5

* non-anatomic parameters.

* p-value , compare Stagni's parameters with this study.

** p-valure, compare Chien's parameters with this study.

Table 7. comparison data: current data with this study.

Parameters	Hayes[17] (n = 21)	This study (n = 32)
Talar radius (mid sagital)	**20.7 ± 2.6**	**21.6 ± 6.5**
Talar dome		
Anterior	29.9 ± 2.6	28.03 ± 3.53
Middle	27.9 ± 3.0	26.91 ± 2.86
posterior	25.2 ± 3.7	19.59 ± 2.17

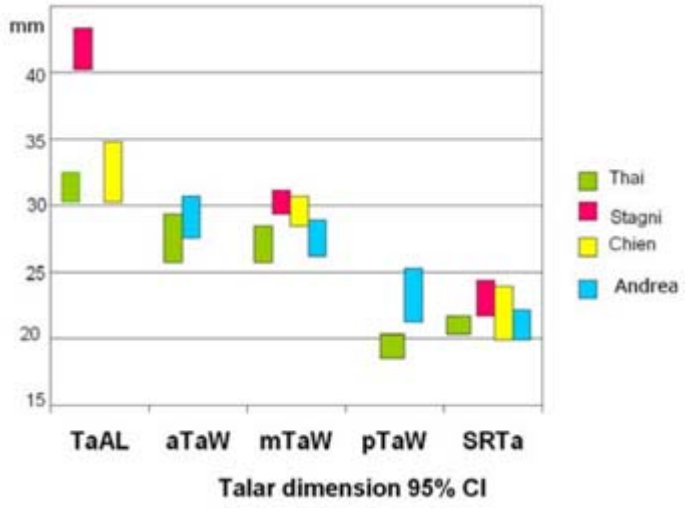

Figure 4. Comparison of current data of talus by 95% confidence interval.

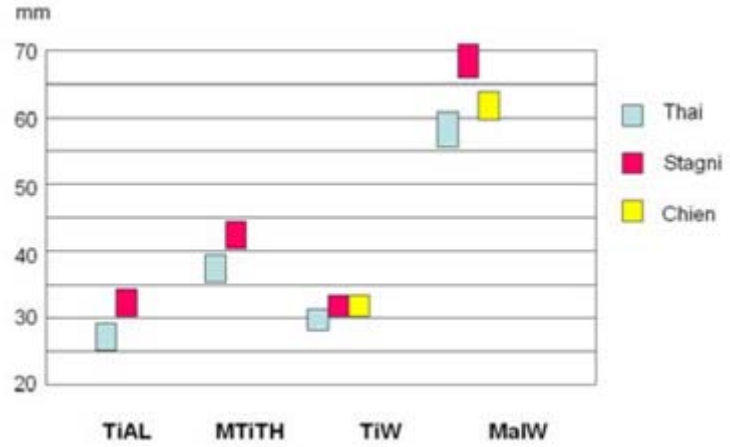

Figure 5. Comparison of current data of distal tibia by 95% confidence interval.

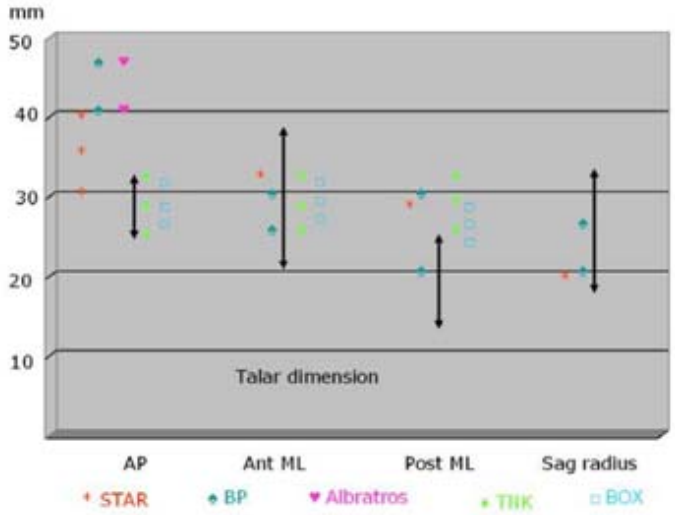

Figure 6. The comparison of the current designs in terms of talus. The two head arrow demonstrate the rage of parameter. The symbols present the various systems of total ankle arthroplasty.

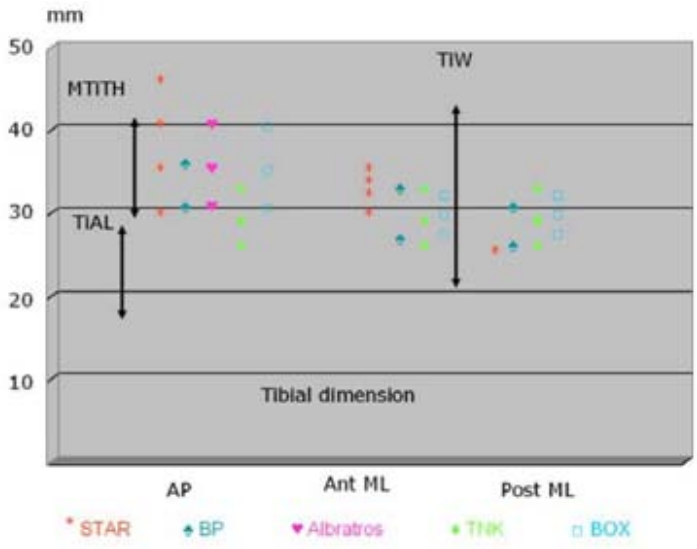

Figure 7. The comparison of the current designs in terms of distal tibia. The two head arrow demonstrate the rage of parameter. The symbols present the various systems of total ankle arthroplasty.

Discussion

Ankle morphologic studies are available in a few amount. Most come from the west. The technique to measure are vary: 2 dimension by plain x-ray, 3 dimension by CT scan, MRI. The error of measurement may caused by interposition of 2 D technique and ankle external rotation. The rotation of ankle make the anteroposterior diameter larger and mediolateral diameter smaller. This effect can be modified by calculation. The degree of external rotation (malleolar axis) influence of the overestimation of the AP length, so trigonometric formula will adjust that parameter close to the reality. The different of true length and adjust legth shows no clinical significant. We implied that the modification technique can applied to the other parameters.

Thai data present male parameters are statistical significantly larger than female. The only one parameter that has no significant is malleolar axis. This fact is the same of the current data which come from European and Chinese.

The current data compare with this study demonstrate Thai ankles have smaller diameter than European significantly but not significant with Chinese. This comparison exclude the variation of measure method by using non-adjusted parameters compared. The overestimation of the technique that come form technique of semi-automated measurement. This technique measure dimensions base on the plain x-ray. We believe that there is an effect of interposition of the view. Both Stagni and Chien did not recognize the effect of ankle external rotation that can mask the true length. This study modified the effect by calculation and proved the calculated method had smaller different length compared to true length.

The only one parameter that Thai parameter had no statistical significant compare with European or Chinese. The explaination is adjusted tibial width has larger width compare to the original width.

The other current data is Andrea which measure the ankle parameter only talus by CT scan. This report is the only one that present the anterior,

middle and posterior talar width. When compare to this study, Thai parameter has no statistical significant by 95% confidence interval in anterior and middle talar width but Thai tend to be smaller. The posterior talar width demonstrate Thai has less width significantly. It may be from the different cut of determination. Posterior talus tend to has more curve than anterior so the different cut effect the width easily.

The limitation and error of this study may by small population, simple sampling technique, not vary in the other part of Thailand so this study can not represent of Thai ankle completely but the information from this study can clue the design and developing of the novel total ankle arthoplasty for Thai people. It is better if we do a reconstruction of the ankle MRI to real 3D and use the program creat the plane of interest then measure of the parameters. This recommend technique has higher validity.

Conclusion

Ankle osteoarthritis has different natural history from hip or knee. The main cause is post traumatic. The major age group is younger. The goal standard treatment of the disease is ankle arthrodesis that has limit range of motion in activity. The new operation to promote ankle function is total ankle arthroplasty.

Total ankle arthroplasty in the past had low survival rate. Better knowledge of material and biomechanic help the total ankle arthroplasty had longer survival rate. But until now there is no design which is the best. The new design are still developing. The fundamental data to design and sizing is morphology of ankle.

This study presents the ankle dimensions in anteroposterior and mediolateral that seems different from the current data. Thai population are smaller in size than those European and Chinese people. This phenomenon can be explained by race, different technique used to measure (plain x-ray 2D and MRI 3D) and the effect of ankle external rotation . The study described the important parameter to design the ankle prosthesis for Thai.

Ankle parameter plays an important role to design and size the novel total ankle prosthesis. No system design for Thai people that is now available now. This study shows that TNK (from Japan) is the most compatible one for the Thai population.

Acknowlegement

We would like to thank Dr.Nampheung Namkarunarunrote and Dr.Phatthana Wangayattawanitch, Department of Radiology, Faculty of Medicine, Chulalongkorn University for every suggestion and data management. And we also thank Prachachuen MRI Center for the permission to use MRI data. We also thank Mr. Suphap Ngoenthom and Mr. Sripet Chobaroon , the Managing Director of Prachachuen MRI Center and Radiographic of Technologist for their assistance in MRI measurements

References

1. Valderrabano V, Nigg BM, Tscharner VV, Stefannyshyn DJ, Goepfert G, Hintermann B. Gait analysis in ankle osteoarthritis and total ankle replacement. Clin Biomech 2007 Oct; 22(10):894-904

2. Haddad SL, Coetzee JC, Estok R, Fahrbach K, Banel D, Nalysnyk L. Intermediate and long-term outcomes of total ankle arthroplasty and ankle arthrodesis. J Bone Joint Surg Am 2007 Sep; 89(9):1899-905
3. Jame KD, Mark EE. Total ankle arthroplasty. Instructional course lectures 2008; 57: 383-413
4. Rippstein PF. Clinical experiences with three different designs of ankle prostheses. Foot Ankle Clin N Am 2002 Dec; 7(12):817-31
5. Raikin MR, Meyerson MS. Avoiding and managing complications of the total ankle replacement system. Orthopedics 2006 Oct; 29(10): 931-8
6. Spirt AA, Assal M, Hansen ST. Complications and failure after total ankle arthroplasty. J Bone Joint Surg Am 2004 Jun; 86(6):1172-8
7. Cerrato R, Meyerson MS. Total ankle replacement. The Agility LP prosthesis. Foot Ankle Clin N Am 2008 Sep; 13(9):485-94
8. Alvine FG. The Agility ankle replacement the good and the bad. Foot Ankle Clin N Am 2002 Dec; 7(12):737-53
9. Knecht SI, Eastin M, Callaghan JJ. The Agility total ankle arthroplasty: seven to sixteen-year follow up. J Bone Joint Surg Am 2004 Jun;86(6):1161-71
10. Wood PLR, Prem H, Sutton C. Total ankle replacement, medium-term result in 200 Scandinavian total ankle replacement. J Bone Joint Surg Br 2008 May; 90B(5):605-9
11. Buechel FF, Pappas MJ. Twenty-year evaluation of cementless mobile-bearing total ankle replacement. Clin Orthop Relat Res 2004 Jun; 424(6):19-26
12. Stengel D, Bauwens K, Ekkern-Kamp A, Cramer J. Efficacy of total ankle replacement with meniscal-bearing devices, A systematic review and meta-analysis. Arch Orthop Trauma Surg 2005 Mar; 125(5): 109-119
13. Leardini A. Geometry and mechanics of the human ankle complex and ankle prosthesis design. Clin Biomech 2001Oct; 16(10):706-9
14. Fessy MH, Carret JP, Bejui J. Morphometry of the talocrural joint. Surg Radiol Anat 1997; 19(5):299-302
15. Stagni R, Leardini A, Ensini A, Cappello A. Ankle morphometry evaluated using a new semi-automated technique based on x-ray pictures. Clin Biomech 2005 Mar; 20(5):307-11
16. Stagni R, Leardini A, Catani F, Cappello A. A new semi-automated measurement technique based on x-ray pictures for ankle morphometry. J Biomech 2004 Jul; 37(7): 1113-8
17. Hayes A, Tochigi Y, Saltzman CL. Ankle morphometry on 3D-CT images. Iowa Orthopaedic J 2006;26:1-4
18. Chien CK, Guan YL, Chia MC, Horng CH, Alberto L, Tung WL. Ankle morphometry in the Chinese population. J Foot Ankle Res 2008:1(Suppl 1): 011