Comparative Biomechanical Investigation in the Denis Browne Splint and Abduction Dorsiflexion Mechanism

Contents

Amendment Record

Date	Issue	CR	Reason for Amendment
15/11/17	001a		First version

1. Purpose

1.1. This document describes a comparative biomechanical investigation into the function of the Denis Browne brace clubfoot brace (Boots and Bar) and Abduction Dorsiflexion Mechanism.

1.2. Despite its very long history and that it is the established standard of care for the prevention of clubfoot relapse there is little detailed technical documentation describing the function of the Denis Browne brace in biomechanical terms. We are aware of two notable exceptions in recent times [1,2]

1.3. The Abduction Dorsiflexion Mechanism is a comparatively new Orthopaedic Device designed for the prevention of clubfoot relapse and other conditions. In order to make effective comparisons between the biomechanical characteristics of the ADM and Denis Browne brace there is a need to define the behaviour of both devices in common terms.

1.4. This document accompanies two video animations available from C-Pro Direct and details the method and results of the investigation.

1.5. The video animations can be found at:

1.6. Denis Browne Brace animation: https://vimeo.com/242624495

1.7. ADM and Denis Browne Brace comparison: https://vimeo.com/243366114

1.8. This document is best read and understood in conjunction with viewing the two video animations.

2. Hypothesis

2.1. The fundamental hypothesis behind the investigation is that the biomechanical characteristics of the Denis Browne splint are not well understood. Commonly, the External Rotation of the sandals in the Denis Browne brace is considered analogous to foot abduction and the angle of inclination of the sandals to the bar is considered analogous to Dorsiflexion.

2.2. Our hypothesis, which was tested by the investigation, was that the Denis Brown splint delivers varying amounts of Abduction, Dorsiflexion and Eversion dependent on the patient's body position. We also predicted the external rotation angle and angle of inclination of the sandals attached to the Denis Browne splint was not analogous with the foot positions achieved by the brace.

2.3. Recent work by Anil Agarwal et. al. [1] supported the hypothesis. This [1] was a clinical study. Our investigation was a purely biomechanical technical analysis.

2.4. The ADM brace has been designed using methods that enable the foot position to be accurately determined. It was hypothesised that the ADM brace and Denis Browne brace achieved similar foot positions in many scenarios.

3. References

Reference	Title
1	The foot abduction characteristics following Steenbeek foot abduction brace J Orthop Surg (Hong Kong). 2017 Jan;25(1):2309499016684085. doi: 10.1177/2309499016684085. PMID: 28118804 Agarwal A, Kumar A, Mishra M.
2	A BIOMODELING INVESTIGATION OF BRACING ON CLUBFOOT CHILDREN TREATED BY THE METHOD OF PONSETI Andrew J. DiMeo, Sr, 2009, University of North Carolina at Chapel Hill

4. Method

4.1. An anatomically proportioned computer model "avatar" was developed based on the sketches included in Appendix 1.

4.2. The computer model supported ball and socket type hip motion – 60 degrees external rotation of the Femur was possible

4.3. The computer model supported leg flexion at the knee. When the knee joint was in flexion a maximum of 30 degrees external tibial rotation was possible. In our modelling we assumed there was 30 degrees of rotation without significant resistance at the knee joint. This meant that with legs flexed the tibia would rotate 30 degrees before the foot abducted. The assumption being the resistance to abduction at the ankle joint was greater than the resistance to tibial rotation (up to 30 degrees of tibial rotation).

4.4. The computer model's foot motion at the ankle joint could occur in all three anatomical planes and was not constrained. This allowed the foot to be moved into the position determined by the brace, thereby allowing the biomechanical animation to deliver a foot position result.

4.5. Computer models of the Denis Browne splint and ADM were also build based on a standard Denis Browne splint configuration of 60 degrees external rotation, 15 degree bar angle to the transverse plane and the sandals being held by a bar at shoulder width apart. For unilateral scenarios the External Rotation of the sandal was set to 30 degrees on the unaffected foot. It is noted that some Denis Browne configurations set the sandals at 65 or 70 degrees of external rotation.

4.6. For the Denis Browne splint modelling the computer model avatar was moved to various body position scenarios, the Denis Browne splint was applied to the feet and the position of the feet with respect to the tibia was measured in terms of abduction, dorsiflexion and eversion. The foot position results were determined with respect to the three cardinal planes:

4.6.1. Abduction was expressed as an angular measurement to the sagittal plane of foot rotation with respect to the front of the tibia.

4.6.2. Dorsiflexion was expressed as an angular measurement to the sagittal plane of the plane of the underside of the foot with respect to the transverse plane with the tibia vertical (or orthogonal to the transverse plane).

4.6.3. Eversion was expressed as an angular measurement to the frontal plane of the plane of the underside of the foot with respect to the transverse plane with the tibia vertical (or orthogonal to the transverse plane).

4.7. For ADM modelling the device was set to certain positions in terms of rotation of its Sub-Talar and Tibio-Talar joint mechanisms. The foot of the avatar was then moved to fit the brace. This allowed for like-for-like comparisons to be made between the foot positions achieved by each brace.

4.8. The computer model or avatar and models of the ADM and Denis Browne splint were built in Autodesk 3ds max - See Appendix 2. To verify the avatar foot positions measured in Autodesk 3ds max 9 ie., the results) the ADM scenarios were also modelled and verified in the Solidworks Computer Aided Design package, using the actual CAD models used for ADM manufacture. See Appendix 3. The measurements taken from Solidworks can be considered as an absolute and correct based on the designs to which the ADM is manufactured. The measurements of the avatar body position taken from Autodesk 3ds max are also exact. However, manoeuvring the avatar foot to fit the Denis Browne brace in the various scenarios required an CAD technician to use a degree of skill and judgement. The Denis Browne splint results may not therefore be "perfect", but can be reasonably judged to be within a tolerance of plus or minus 1 degree.

4.9. The body position / bracing scenarios used for the Denis Browne splint and ADM were as follows:

Scenario	Body Position (or device position for ADM)
1	Boots and Bar: Bilateral / Supine symmetrical / Legs extended
2	Boots and Bar: Bilateral / Hips and Knees flexed 90 degrees / Symmetrical
3a	Boots and Bar: Bilateral / Both legs swing Left 15 degrees
3b	Boots and Bar: Bilateral / Hips and Knees flex 90 degrees / Both legs swing Left 15 degrees / Left leg extends 15 degrees
4	Boots and Bar: Bilateral / Left Knee raised 8 degrees / Right Knee lowered 7 degrees
5a	Boots and Bar: Right Unilateral / Hips and Knees Flexed 90 degrees / Symmetrical

Scenario	Body Position (or device position for ADM)
5b	Boots and Bar: Right Unilateral / Hips and Knees Flexed 90 degrees / Both legs swing to Right 30 degrees
5c	Boots and Bar: Right Unilateral / Hips and Knees Flexed 90 degrees / Both legs swing to Right 30 degrees / Right Leg extends by 17 degrees
6a	ADM: TTJ 15 / STJ 15- all body positions
6b	ADM: TTJ 15 / STJ 30 - all body positions

5. Results

5.1. The results are detailed at Appendix 4, but are best understood by viewing the video animation sequences indicated in section 1. Figure 1 shows two stills from the animations.

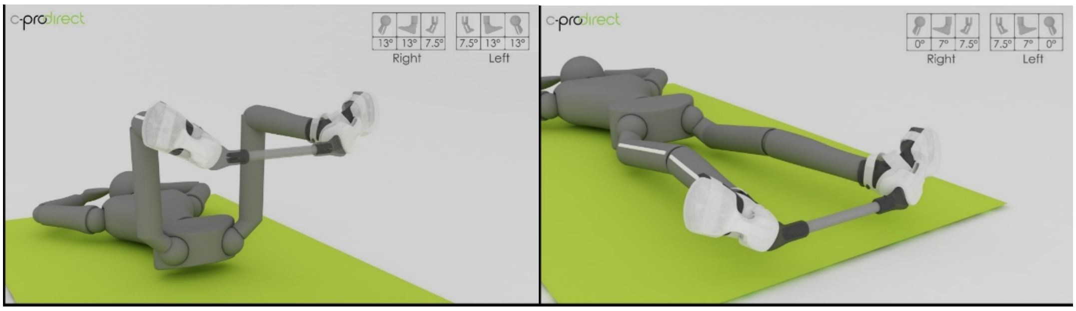
5.2. 

Figure 1 – Animation Stills

5.3. The results are consistent with the clinical study [1] and suggest that leg rotation at the hip and knee has an impact on the function of the Denis Browne splint. The results also suggest that patient motion or "dynamicity" plays a significant role in the clinical performance of the Denis Browne splint.

5.4. The results do also enable comparisons between the function of the Denis Browne splint and Abduction Dorsiflexion Mechanism to be made in a way that was previously not possible. The results are best understood by viewing the video animations. These make it clear that there are both similarities and differences between the foot positions that may be achieved in ADM and Denis Browne splint. The results also clearly demonstrate that External Rotation as set in the Denis Browne splint is not analogous to abduction and the angle of inclination of the sandals is not analogous to dorsiflexion.

5.5. The animations also show that eversion is a very significant property of the Denis Browne splint. It is shown that because the Denis Brown splint does not constrain the feet from rotating about an axis in the frontal plane the feet are free to dorsiflex and plantarflex. But with greater plantarflexion comes increased eversion and with greater dorsiflexion comes reduced eversion.

5.6. Foot position in the Denis Brown Splint is determined by body position, foot position in the ADM is determined by the strength of the springs, the resistance to motion and range of motion in the patient and the patient's state of relaxation.

6. Conclusions and Discussion

6.1. Clinical conclusions are beyond the scope this purely biomechanical investigation.

6.2. We believe the function of the Denis Browne splint has now been better documented in biomechanical terms than before and that this function is broadly consistent with the recent clinical investigation [1] and with our hypothesis. The scope of the clinical investigation [1] in terms of body positions and the foot positions measured was not as great as this biomechanical investigation. However, the results in symmetrical supine legs extended body positions (scenario 1) are consistent with those reported in [1] in that zero foot abduction with respect to the tibia was recorded. The clinical study [1] also found, as we have, that tibial rotation was a significant factor in symmetrical body positions with legs flexed (scenario 2). The study [1] reported about

10 degrees greater foot abduction on average than our results for scenario 2. Possible reasons for this difference are being investigated.

6.3. Whilst there are some detailed discrepancies between the clinical results of [1] and modelled results of this study the broad picture is clear and consistent. The Denis Browne splint does not work by holding the feet in 60 degrees abduction and 15 degrees dorsiflexion. Foot position varies enormously as a function of body position and other anatomical variables.

6.4. This study has also shown that the Denis Browne splint does not lock the feet into dorsiflexion. The feet are free to plantarflex, but at a cost of increased eversion. It seems that a dorsiflexed position is held due to limits on the patient's ability to evert the foot. Eversion, is clearly an important property of the Denis Browne splint.

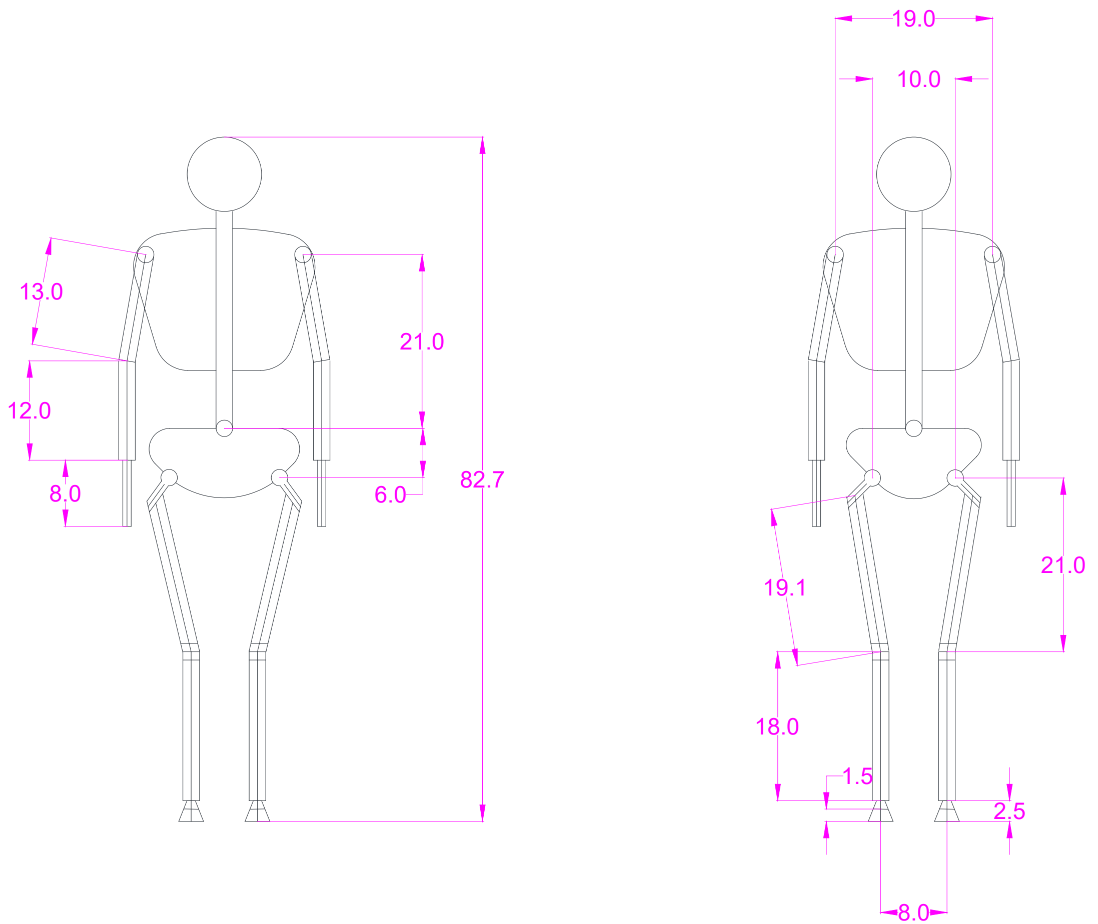
6.5. There remains much to learn about how exactly clubfoot relapse is prevented by the use of orthopaedic braces. There are many body positions in which the Boots and Bar have been shown to hold the feet in less "extreme" positions of "over-correction" than expected. This is most profound for the modelled unilateral scenarios (scenarios 5a, 5b and 5c). The use of the Denis Browne splint is more frequently challenged by parents or carers of children with unilateral clubfoot than with bilateral clubfoot. The results give greater credibility to the case for testing and using of alternative "unilateral" brace designs like the ADM providing they hold the feet in what can be shown to be reasonable positions to prevent clubfoot relapse.

6.6. The results also backup the authors observations of Boots and Bar function made in 2010. See Appendix

6.7. Currently, there is no defined ideal prescription for the prevention of clubfoot relapse. We do not know what are the ideal position or positions to hold the feet in, for how long and for what frequency etc. Whilst the function of the Denis Browne splint has not been well documented to date there is a long-term body of evidence to suggest that it works. The results demonstrate that, like the Denis Browne splint, the ADM holds the feet in what can be reasonably assumed as good therapeutic positions for the prevention of clubfoot relapse. There are both similarities and differences between the Denis Browne splint and ADM. Given the obvious potential advantages for clubfoot patients in using a more convenient and easy to tolerate brace this study reinforces the case for further investigation of the ADM.

6.8. Apparently, Dr Ponseti once said, "I don't know how the Boots and Bar really work, they just do". The authors hope this work will contribute to a growing body of knowledge relating to the treatment of clubfoot and will play a small part in helping to deliver the best possible outcomes for those born with clubfoot.

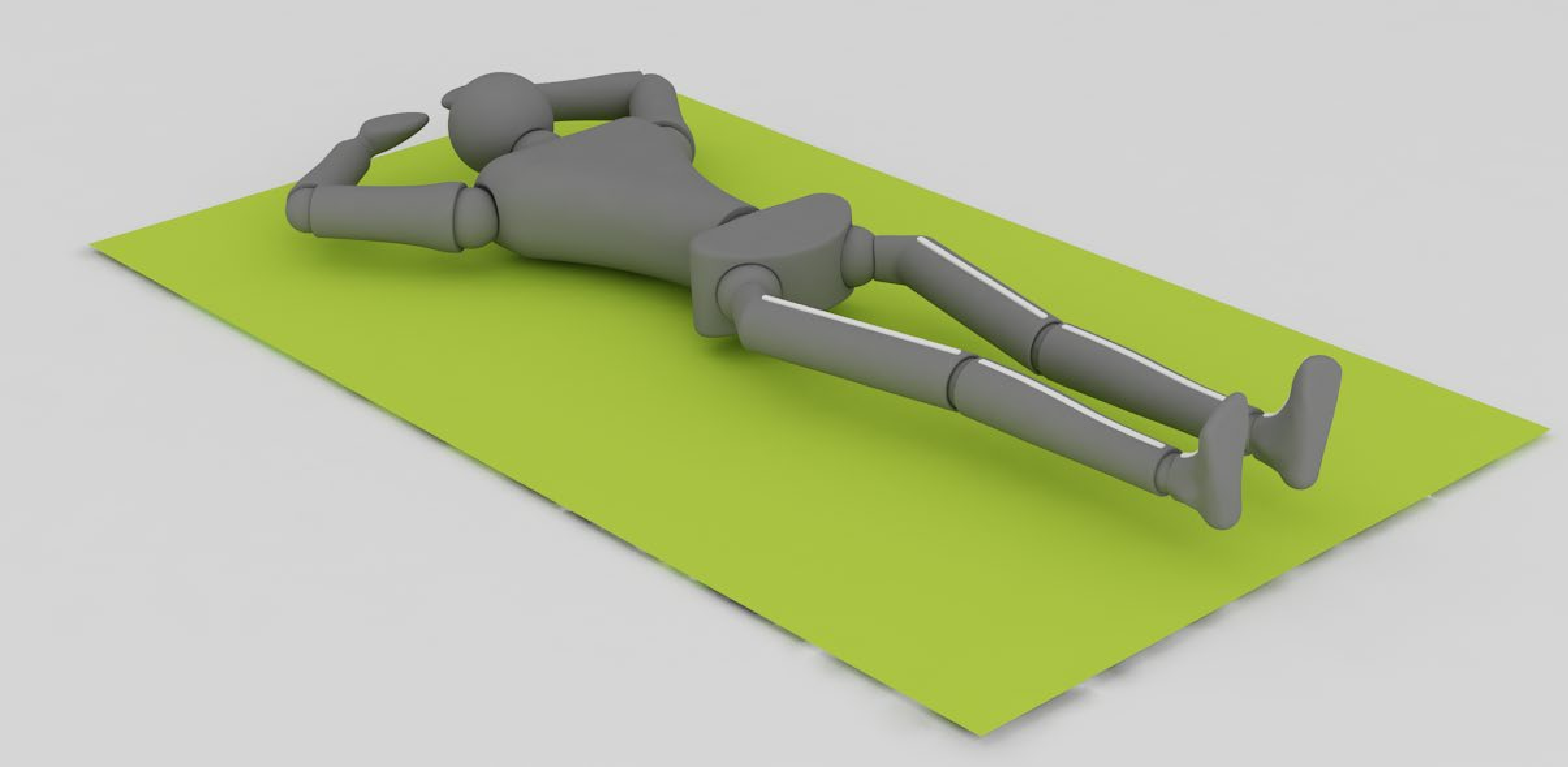
Appendix 1 – Computer Modelled Avatar



Femoral neck angle - normal range is 125 to 135 degrees

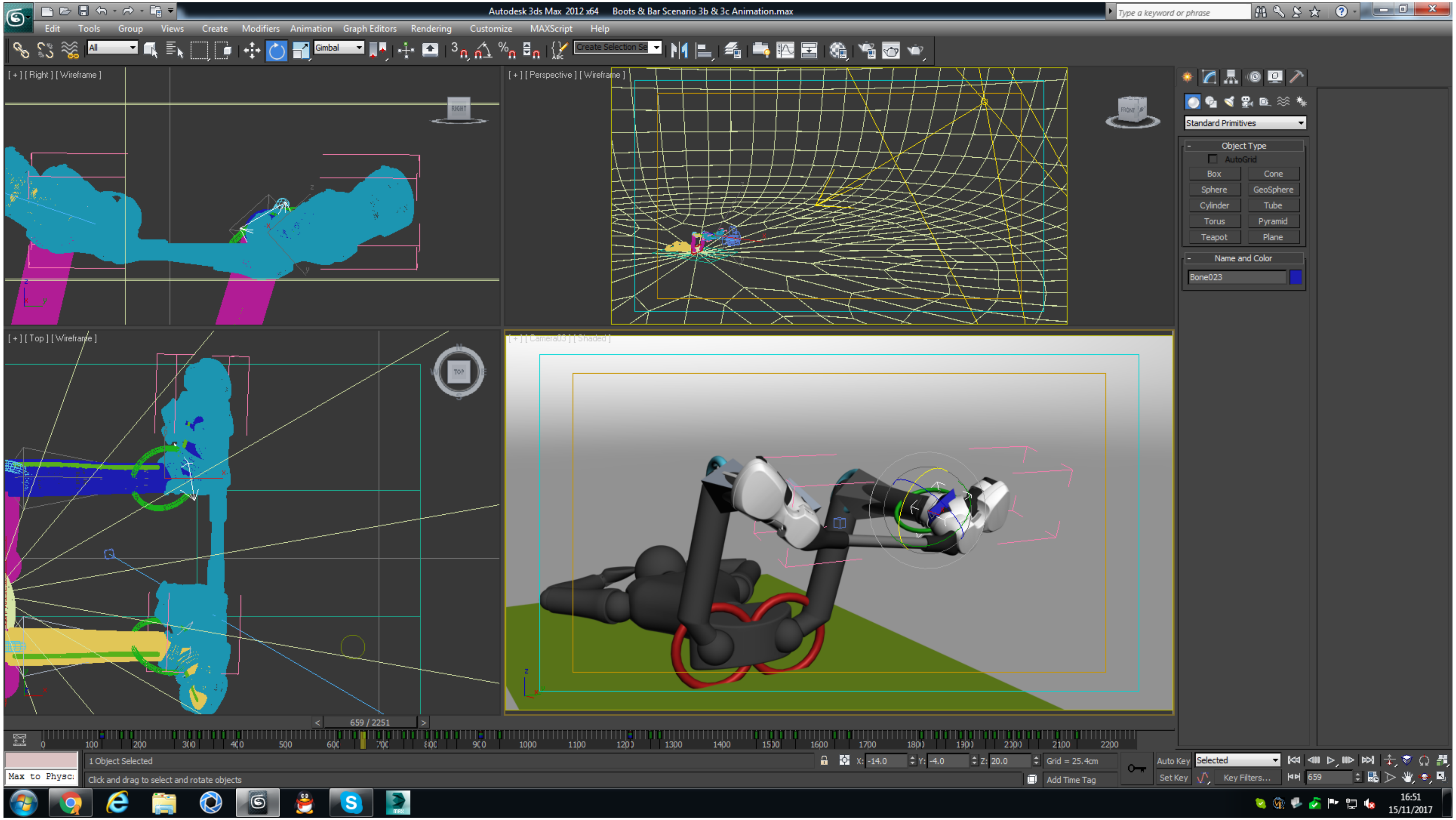
Q Angle - normal is 13 degrees (male) and 18 degrees (degrees adult female)

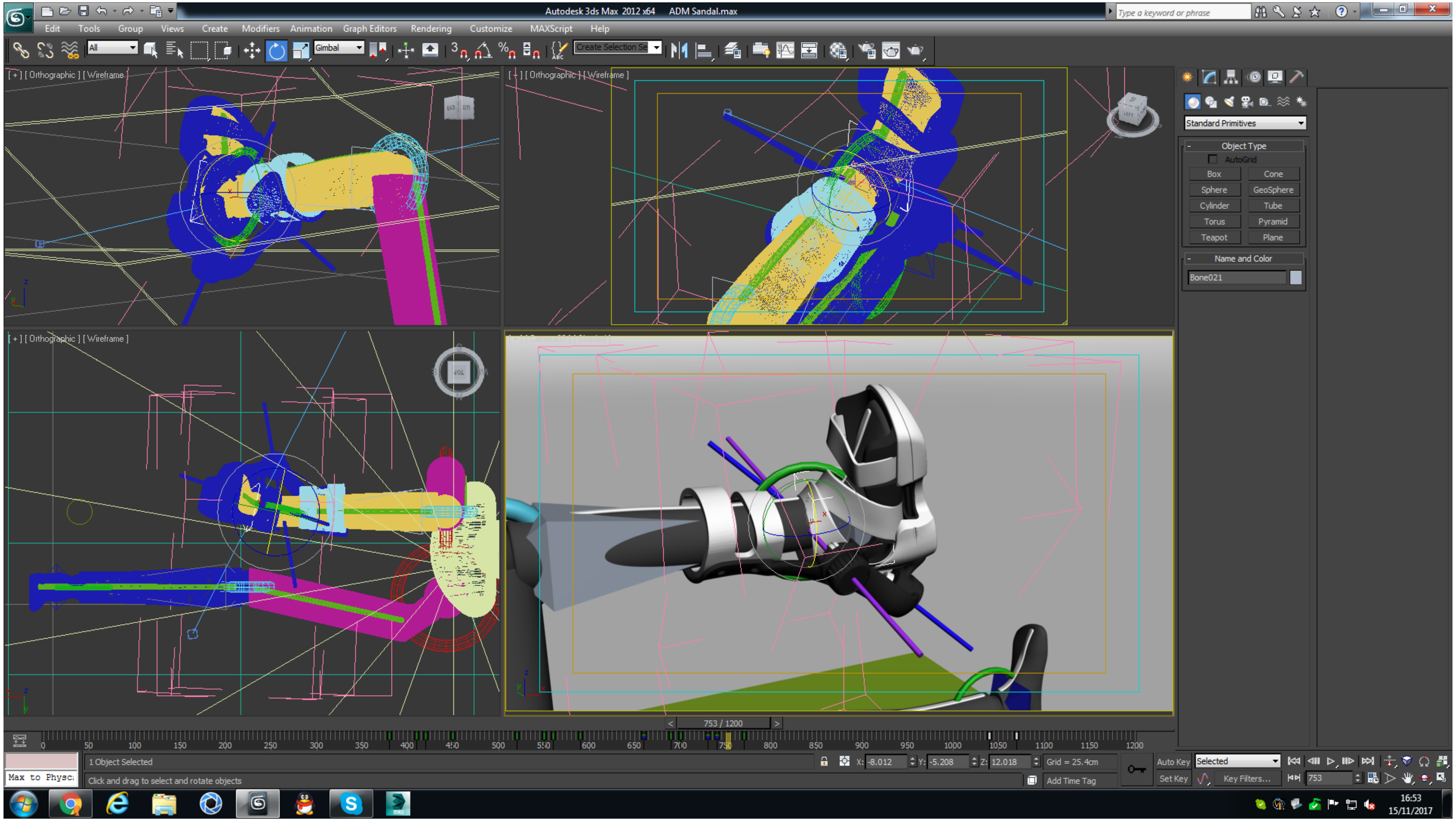
Animated “avatar” based on sketches above

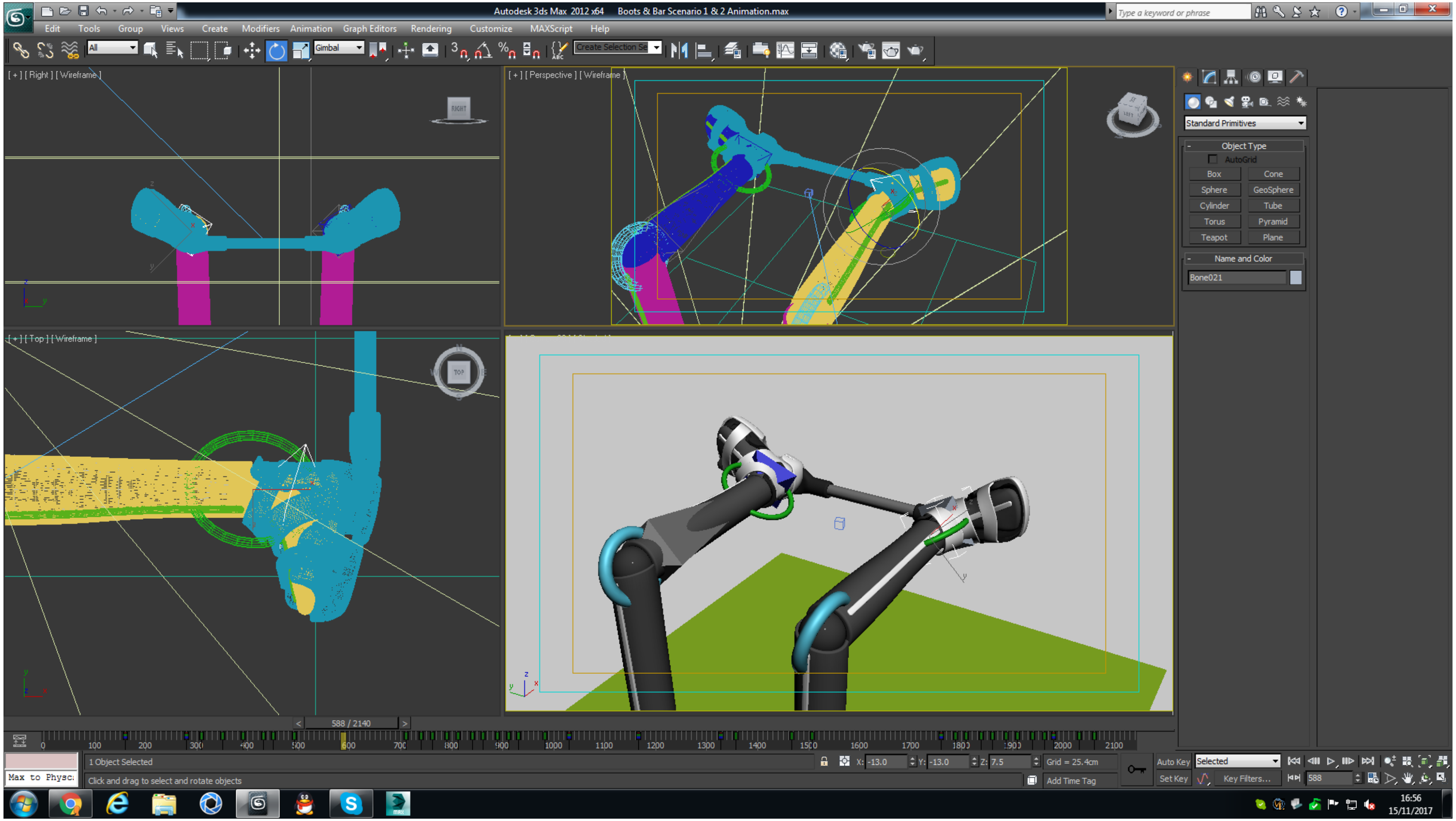


Appendix 2 – Autodesk 3ds Max

The following screens show the Computer Model in Autodesk 3ds Max, which was used to measure the results

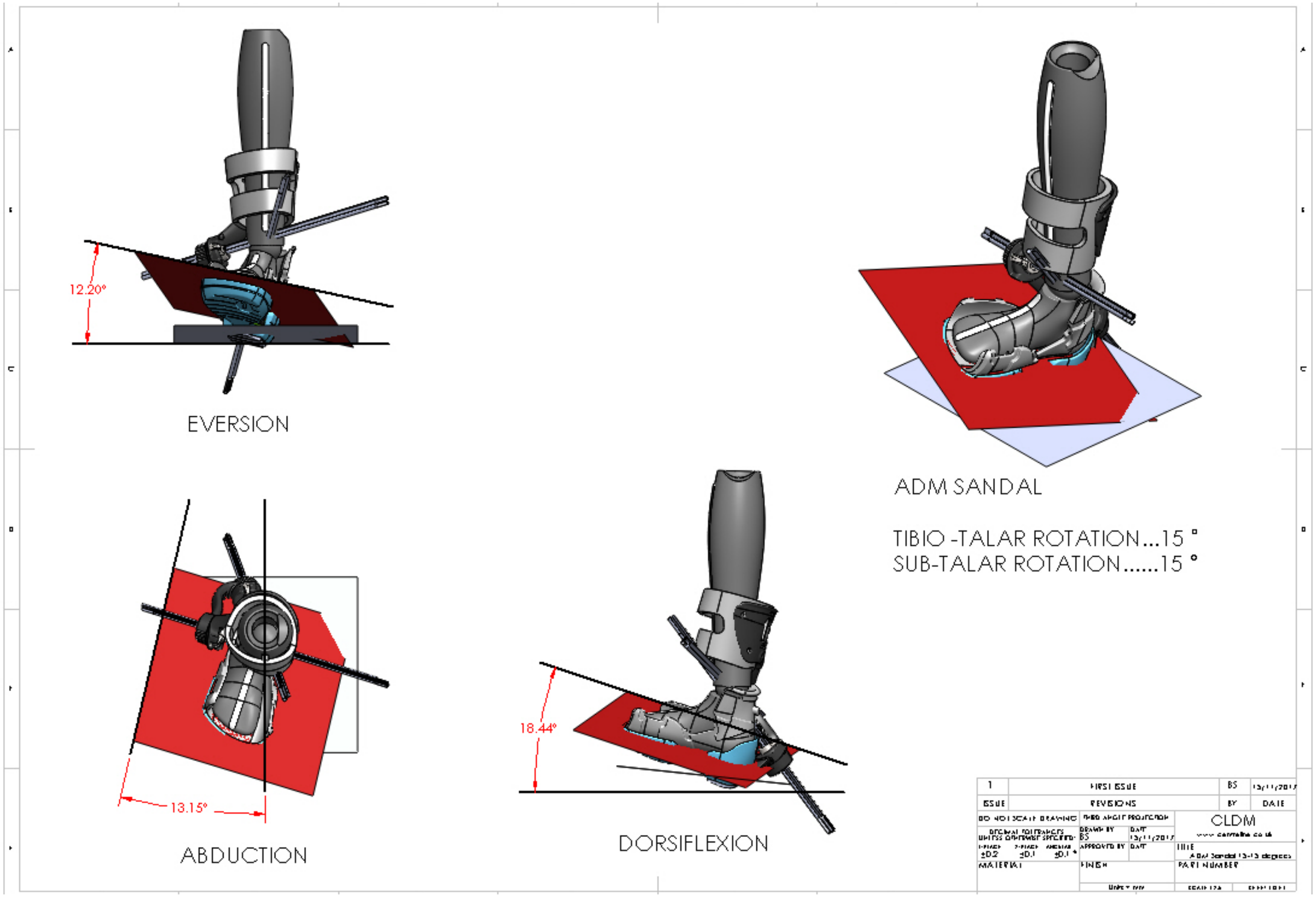


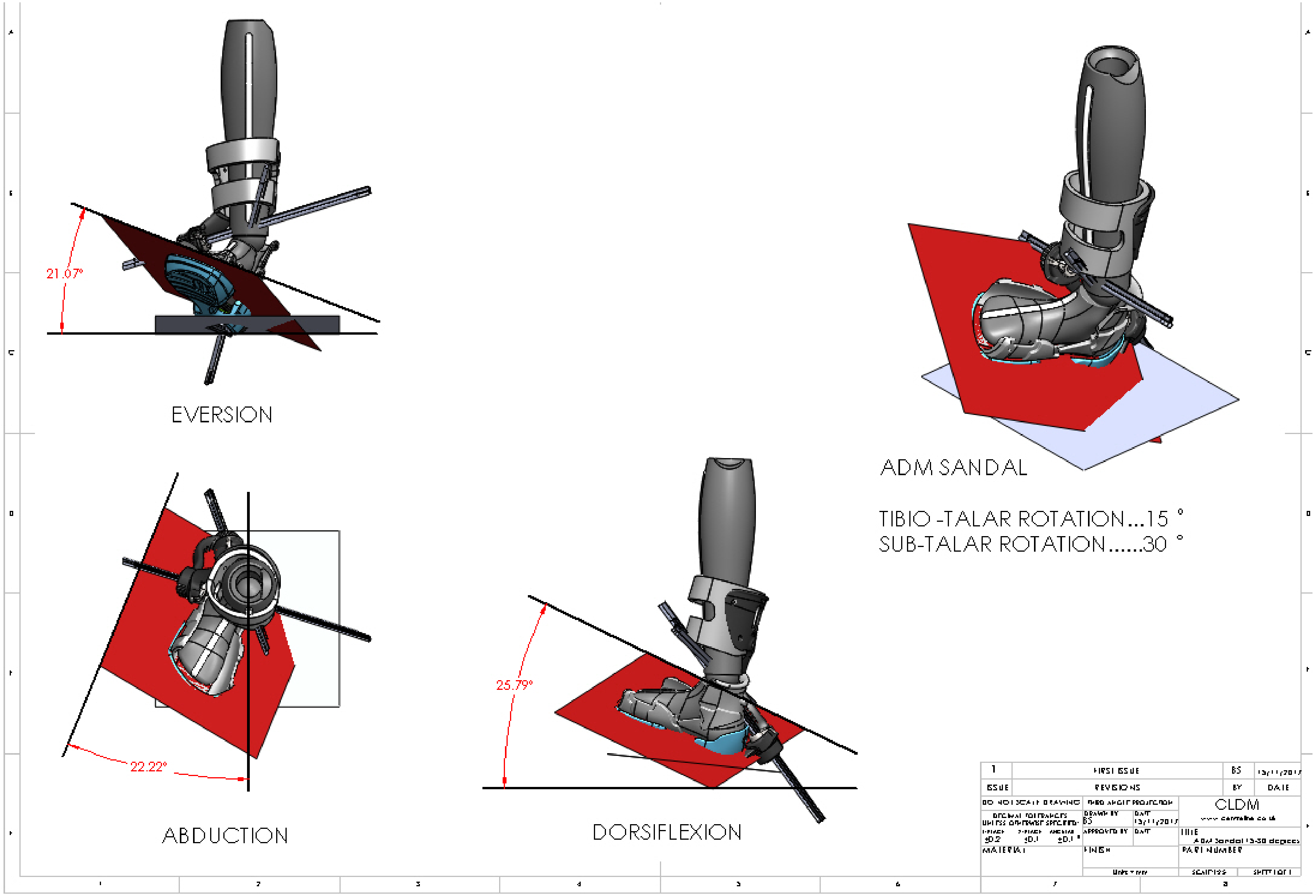

Autodesk 3ds Max 2012 x64 ADM Sandal.max
Edit Tools Group Views Create Modifiers Animation Graph Editors Rendering Customize MAXScript Help
[+] [Orthographic] [Wireframe]
Standard Primitives
Object Type
AutoGrid
Box Cone
Sphere GeoSphere
Cylinder Tube
Torus Pyramid
Teapot Plane
Name and Color
Bone021
753 / 1200
1 Object Selected
Click and drag to select and rotate objects
Grid = 25.4cm
Auto Key
Selected
Set Key
Key Filters...
Add Time Tag
16:53
15/11/2017


Autodesk 3ds Max 2012 x64 Boots & Bar Scenario 1 & 2 Animation.max
Edit Tools Group Views Create Modifiers Animation Graph Editors Rendering Customize MAXScript Help
[+] [Right] [Wireframe]
[+] [Perspective] [Wireframe]
[+] [Top] [Wireframe]
Standard Primitives
Object Type
AutoGrid
Box
Cone
Sphere
GeoSphere
Cylinder
Tube
Torus
Pyramid
Teapot
Plane
Name and Color
Bone021
588 / 2140
1 Object Selected
Click and drag to select and rotate objects
Grid = 25.4cm
Auto Key
Selected
Set Key
Key Filters...
Add Time Tag
16:56
15/11/2017

Appendix 3 – Solidworks

The following screens show the ADM modelled in the Solidworks CAD package. Solidworks was used to further verify the Autodesk 3ds Max results.




21.07°
EVERSION
ADM SANDAL
TIBIO -TALAR ROTATION...15 °
SUB-TALAR ROTATION......30 °
22.22°
ABDUCTION
25.79°
DORSIFLEXION
1
FIRST ISSUE
BS
ISSUE
REVISIONS
BY
DATE
CLDM
TITLE
MATERIAL
FINISH
PART NUMBER

Appendix 4 – Results

The following table summarises the results in terms of foot position. For further detail please view the video animations mentioned in section 1.

		Left					Right				
Scenario	**Body Position (or device position for ADM)**	**Femur Rotation**	**Tibial Rotation**	**Abduct**	**Dorsiflex**	**Evert**	**Femur Rotation**	**Tibial Rotation**	**Abduct**	**Dorsiflex**	**Evert**
1	Boots and Bar: Bilateral / Supine symmetrical / Legs extended	60.0	0.0	0.0	7.0	7.5	60.0	0.0	0.0	7.0	7.5
2	Boots and Bar: Bilateral / Hips and Knees flexed 90 degrees / symmetrical	0.0	30.0	13.0	13.0	7.5	0.0	30.0	13.0	13.0	7.5
3a	Boots and Bar: Bilateral / Both legs swing Left 15 degrees	0.0	30.0	1.0	14.0	12.0	0.0	30.0	18.0	10.0	10.0
3b	Boots and Bar: Bilateral / Hips and Knees flex 90 degrees / Both leg swing Left 15 degrees / Left leg extends 15 degrees	0.0	30.0	0.0	-7.5	12.0	0.0	30.0	38.0	3.0	15.5
4	Boots and Bar: Bilateral / Left Knee raised 8 degrees / Right Knee lowered 7 degrees	0.0	30.0	14.5	32.0	31.0	0.0	30.0	5.0	-3.5	-1.5
5a	Boots and Bar: Right Unilateral / Hips and Knees Flexed 90 degrees / Symmetrical	0.0	15.0	0.0	8.0	11.0	0.0	30.0	15.0	10.0	12.0
5b	Boots and Bar: Right Unilateral / Hips and Knees Flexed 90 degrees / Both legs swing to Right 30 degrees	0.0	30.0	3.0	7.0	15.5	0.0	15.0	0.0	15.0	11.5

		Left					Right				
Scenario	**Body Position (or device position for ADM)**	**Femur Rotation**	**Tibial Rotation**	**Abduct**	**Dorsiflex**	**Evert**	**Femur Rotation**	**Tibial Rotation**	**Abduct**	**Dorsiflex**	**Evert**
5c	Right Unilateral / Hips and Knees Flexed 90 degrees / Both legs swing to Right 30 degrees / Right Leg extends by 17 degrees	0.0	30.0	22.0	2.0	16.5	0.0	15.0	0.0	-8.0	11.0
6a	ADM: TTJ 15 / STJ 15- all body positions	0.0	0.0	13.2	18.4	12.2	0.0	0.0	13.2	18.4	12.2
6b	ADM: TTJ 15 / STJ 30 - all body positions	0.0	0.0	22.6	25.8	21.1	0.0	0.0	22.6	25.8	21.1

Appendix 5 – Patient Observations 2010

The following patient observations (of the authors son born July 2004 with bilateral clubfoot) were made in February 2010 when Anthony was 5.5 years of age. These observations ultimately led to a keen interest in the function of the Denis Browne splint, this study and the design of orthopaedic braces for clubfoot.

The observations illustrate the characteristics of the Denis Browne splint reported herein.

Legs extended – supine. No Bar The subject is relaxed. The legs and feet naturally rotate outwards in a supine position. The feet are naturally in plantarflexion and there is no abduction	
Legs extended – supine. With Bar. Sandals at 60 degrees External Rotation and 15 degree angle of inclination There is no foot abduction with respect to the tibia. The is some dorsiflexion (or less plantarflexion) and some eversion.	
As above	
Legs flexed at hips and knee. With Bar. Sandals at 60 degrees External Rotation and 15 degree angle of inclination There may be some foot abduction with respect to the tibia, but not much. The feet are plantarflexed and in eversion	
Any Leg Position – With Bar Feet are not held in dorsiflexion. Significant plantarflexion is possible. Though they are likely to be in eversion when plantarflexed.	

Eversion This foot is clearly in eversion