DEVELOPING A THREE-DIMENSIONAL (3D) ASSESSMENT METHOD FOR CLUBFOOT

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Developing A Three-Dimensional (3D) Assessment Method for Clubfoot

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CERTIFICATE OF ORIGINALITY

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ABSTRACT

Congenital talipes equinovarus (CTEV) is one of the most common complex orthopedic deformities in newborn babies which is more in males than females (3:1). The condition is characterized by four components of foot deformities: cavus, adductus, varus and equinus (CAVE). The rate of prevalence of CTEV is 1 in per 1000 live births. The etiology, classification, assessment, and management of clubfoot remain controversial. There is no standardized assessment for clubfoot deformity. An accurate evaluation of clubfoot is very essential for quantifying the initial severity of the deformity and determining the treatment options, as well as predicting the prognosis and treatment outcomes. Although there are a number of evaluation methods have been proposed to assess the severity of clubfoot, most of the assessment methods are too subjective. These assessment systems will not provide strongly objective measured clinical evidence. Imaging modalities such as magnetic resonance imaging (MRI), and computerized tomography (CT) scanning can be used to evaluate the initial severity of the clubfoot, but these techniques are too expensive for repeated use at each weekly casting session. Reliable, valid and accurate assessments would help to reducing relapses and the burden to the children and their family in terms of hospital expenses, and other long term complications to children with clubfoot. There is a necessity to develop a valid, reliable and objective tool to evaluate clubfoot. Thus, this study has developed an effective 3D assessment system, based on 3D scanning, to measure clubfoot severity and response to casting intervention. As a secondary aim, the thermo-physiological changes in the clubfoot was observed and correlated with the response to the casting intervention. This study is an explorative study and the study design has been approved by the Human Research Ethics Committees (HREC); registration number HREC/16/SCHN/163. The study was reviewed and approved on 17 August 2016 by the Sydney Children's Hospitals Network Human Research Ethics Committee in Sydney, Australia.

To develop the 3D assessment system for clubfoot, two experiments were conducted in this study. Five samples (N=5) were used in the experiments. Two rubber clubfoot models (N=2) were ordered online from Massons Healthcare, a private limited company that imports and distributes orthotics in Australia. One child with clubfoot was selected to develop the 3D scanned clubfoot model with pre and post intervention scans (N=2). In addition, one normal foot 3D scan (N=1) was collected to compare the difference between normal foot and clubfoot. A Kinect XBOX was used as a 3D scanner to obtain the scanned images from the child with unilateral clubfoot, normal foot, and the two rubber models. The scanned 3D images were processed by using Artec 9 Studio (3D scanner software) and CATIA V5 software (3D modeling software). Based on the 3D modelling, the 3D scanned images of the clubfoot were sectioned into five anatomical areas. Then, 5 cross sections were created from 5 anatomical surface lines. From the 5 surface lines, 5 cross section areas were developed: cross section angles of the center point, maximum lateral border, maximum medial border, maximum dorsal side, and maximum plantar side of the foot. The final step in developing the new 3D measurement scale was the development of 3 angles under the components of 5 cross section areas:

A. Center of cross section angle

1. Ankle-Heel-Midfoot-Area cross section angle (AHMA Angle)

2. Heel-midfoot-metatarsal phalangeal joint area cross section angle (HMMA Angle).

3. Midfoot- metatarsal phalangeal joint -proximal phalangeal joint area cross section angle (MMPAA)

B. Maximum lateral border cross section angle

1. Lateral border of Ankle-Heel-Midfoot-Area cross section angle (LBAHMA Angle)

2. Lateral border of Heel-midfoot-metatarsal phalangeal joint area cross section angle (LBHMMA).

3. Lateral border of Midfoot- metatarsal phalangeal joint -proximal phalangeal joint area cross section angle (LBMMPA)

C. Maximum medial border cross section angle

1. Medial border of Ankle-Heel-Midfoot-Area cross section angle (MBAHMA Angle)

2. Medial border of heel-midfoot-metatarsal phalangeal joint area cross section angle (MBHMMA).

3. Medial border of midfoot- metatarsal phalangeal joint -proximal phalangeal joint area cross section angle (MBMMPA)

D. Maximum dorsal side cross section angle

1. Dorsal side of Ankle-Heel-Midfoot-Area cross section angle (DS-AHMA Angle)

2. Dorsal side of Heel-midfoot-metatarsal phalangeal joint area cross section angle (DS-HMMA).

3. Dorsal side of Midfoot- metatarsal phalangeal joint -proximal phalangeal joint area (DS MMPA) center of cross section angle

E. Maximum planter side cross section angle

1. Plantar side of Ankle-Heel-Midfoot-Area cross section angle (PSAHMA Angle)

2. Plantar side Heel-midfoot-metatarsal phalangeal joint area cross section angle (PSHMMA).

3. Plantar side Midfoot- metatarsal phalangeal joint -proximal phalangeal joint area cross section angle (PSMMPA)

The measurement of pre and post casting intervention were compared and the results showed the differences between pre and post intervention. In addition, the severe and corrected clubfoot were compared with normal foot and the results showed the all the angles of sixth week correction is closely reached to the range of normal foot cross section angles. The results of this study show that these measurements can be used to predict the four components of the clubfoot deformities.

In this study, infrared (IR) thermography is used to collect thermal images of the children with clubfoot (N=4) before and after casting. The study explored the thermophysiological changes between the casting interventions. In total, 120 thermal images were collected from the dorsal, plantar, medial, lateral and heel sides of the foot. FLIR and MATLAB software were used to obtain ten cutoff mean temperatures. The results showed reduced temperature after the first casting and temperature difference between the weekly castings. This novel method can be used to observe thermal changes in the clubfoot between castings to avoid complications such as pressure ulcers, swelling, pressure sores and related complications and relapses. Furthermore, this research study finding shows that IR thermography can be used as an additional diagnostic tool to evaluate and observe the thermophysiological changes in the clubfoot.

In this study, a new 3D objective analysis (objective assessment) method has been developed for analyzing clubfoot deformity. This 3D method is developed from 2D images of severe clubfoot, which was obtained from computed tomography. This method provides a new way to create a 3D model of the bones of a severe clubfoot from 2D slices as well as helps to analyze the relative position of the foot bones and objectively quantify the severity of the clubfoot.

Furthermore, a systematic review study was conducted to examine how the technical protocols in the Ponseti treatment followed in the selected 12 studies could achieve the initial correction, and better understand the outcomes of the study, including success rate, number of castings and percentage of surgical recommendations, as well as review the rate of relapse and relapse patterns of the causative factors of clubfoot for relapses. It is found that the

Ponseti method requires fewer castings and shorter duration to achieve correction, and has a lower relapse rate in comparison to other methods. However, few studies have focused and described the relapse pattern, and causes of relapse. There is still lack of information regarding the causes of relapse or recurrences of clubfoot. In addition, this study found that variations in the bracing protocol schedule.

As described above, this study results provide useful information and new objective assessment methods to quantify the severities of the clubfoot. In addition, this study used infrared imaging method and the results provided a useful information about skin temperature distribution between the castings and this infrared imaging can be used to prevent the complications from casting and relapses. The output of this research project can be extended to develop objective assessment methods for quantifying the initial severities of the clubfoot and provide new knowledge on developing 3D based objective assessment methods.

LIST OF PUBLICATIONS

Manuscripts under preparation

1. **Ganesan Balasankar**, Joanne Yip, Adel Al-Jumaily, Luximon Ameersing, Ey Batlle, Anna. A new method of computed tomography based three-dimensional evaluation for bone to bone alignment analysis in clubfoot. *In submission to Plos one*
2. **Ganesan Balasankar**, Joanne Yip, Adel Al-Jumaily, Luximon Ameersing, Paul Gibbons & Alison Chivers. Thermographic evaluation of clubfoot casting intervention. *In submission to Nature Scientific Reports*
3. **Ganesan Balasankar**, Joanne Yip, Adel Al-Jumaily, Luximon Ameersing, Paul Gibbons & Alison Chivers. Developing a three-dimensional (3D) assessment method for clubfoot. *In submission to Nature Scientific Reports*.

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4. **Ganesan Balasankar**, Luximon Ameersing, Adel Al-Jumaily, Joanne Yip, Paul Gibbons & Alison Chivers. (2017). Developing a three-dimensional (3D) assessment method for clubfoot- A study protocol. *Front. Physiol*. doi: 0.3389/fphys.2017.01098
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3. **Ganesan Balasankar**, Luximon Ameersing, Adel Al Jumaily, Jiang Lanyin & Younus Abida (2016). Development of 3D depth image clubfoot model based on Kinect 3D printing technology. Textile Summit and Postgraduate Student Conference, 28-30 June 2016, Hong Kong
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