Bunion Symptom Disorder: Surgical and Non-Surgical Treatment

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Abstract

Bunion or Hallux valgus as a definition is one of the most common deformity in the forefoot, with a spread rate of 23% to 35%. The causes of this deformity might be hereditary or by wearing tight shoes. The bunion deformation passes through many stages; in the first stage patient might not feel pain but in the last stages s/he can have a severe symptoms and complications if not treated probably. There are two types for bunion treatments; surgical and nonsurgical. However, studies have shown that surgical treatment is the best way to get rid of the bunion. This article includes a survey to investigate more about bunion in the UAE and shoe model that reduces stress concentration in the bunion region.

Introduction

Bunion is a bony bump that form in the joint at the base of the big toe. It happens when the big toe push against the next toe causing the joint of the big toe to get huge and get out which will cause the area around the bunion to be red and burning. Bunion causes can be congenital, that's mean it exist at birth or hereditary were they mostly run-in families [1]. In addition, tight, unfit and high heels shoes might cause bunions. Also, conditions that are inflammatory such as arthritis, or foot injuries may cause bunion. Furthermore, some patients do not feel any pain or symptoms in the first stages of bunion formation but those symptoms start to be noteworthy in the last stage where the bunion gets worse. In the last stage of bunion, the patient starts to have many symptoms such as pain, feel of burning, redness, big swelling, insensibility and walking problems. If the patient didn't treat the bunions, other complications may develop [2]. Arthritis in the big toe can be caused because of the bunions. Additionally, bursitis which is a painful condition happen when tendons and muscle that are located nearby joints become inflamed. Hammertoes and Metatarsalgia are another bunion complication. In hammertoes, there is abnormal bend that is located in the middle joint of the toe where it causes pain and pressure. Metatarsalgia causes a pain and a high inflammation in the ball of the foot. Complications might occur also after the bunion surgery such as toe joints gets stiffer, failure or delay in the healing of the bone, wrong position for the healing bone, pain that is located beneath ball of the foot, harm to the foot nerves, long period of swelling and harm in the surgery location and lastly the need for a second surgery [3]. Due to these post-surgery complications, new non-surgical pathways need to be developed. In fact, this is the main purpose of the study. But before designing the shoe, statistical analysis of the prevalence and the causes of bunion should be conducted. Furthermore, the effect of bunion on gait motion should be analyzed.

Metatarsal Angle

Hallux valgus is a constant abduction for the first metatarsophalangeal joint of the big toe. It is mostly caused by the metatarsus primus Varus that is a medial deviation or the adduct of the first metatarsal which will increase the first-second metatarsal angle. The normal first metatarsophalangeal angle is equal to or greater than 15° and for the first-second intermetatarsal angle it should be greater than 9°on AP weight-bearing foot radiograph. There is a relative relation between bunion and the degree of metatarsus [4]. Bunion mostly are resulted from metatarsus primus Varus. Usually, to measure the severity of bunion, the intermetatarsal angle is measured. The first-second intermetatarsal angle (IMA) is formed by the intersection of the longitudinal axis of the first and second metatarsal. As we have clarified, the normal IMA is <9°. When the IMA is between 9° and 11°, it is considered as a mild bunion. However, when the IMA is ≥ 18°, the patient is diagnosed with a sever bunion that will require a surgical intervention [5].

Statistical Analysis

It has been predicted that the prevalence of bunion in the UAE is 48,585 of the population [6]. However, that was an extrapolated prevalence. There were no country-specific data sources used to figure out the real prevalence and the reason behind the prevalence of bunion in the UAE.
Therefore, we have conducted a survey to be able to analyze statistically the spread of hallux valgus in the UAE. The survey has 9 questions needs to be answered by the respondents that are related to gender, race, age, type of shoes that they wear, the degree of bunion, the presence of pain, and the prevalence of bunion in their families. We have collected 45 responses using social media platforms. The majority of the survey respondents were females and they were around 18-24 years old. The survey results have shown that most of the respondents don't have a deep knowledge about bunion.

Further, the survey has shown that the majority of people who took the survey don't wear tight shoes and they don't have bunion. Moreover, from the survey results, we have deduced that bunion is not related to genetic reasons since only 17% of the respondents have most of their family members suffering from bunion. However, the survey has failed in showing us the link between the race and bunion incidence. Most of the respondents didn't know their races and choose the option of another race.

Gait Cycle Analysis

Most of the studies related to bunion are discussing the abnormal gait as a cause for bunion but we can rarely find researches that consider abnormal gait as a consequence of bunion. Therefore, we have designed an experiment to analyze the gait of a person with bunion. We have used two samples; a control (without bunion), and a case (with bunion). The two participants were of the same BMI and same age and both of them don't have diabetes and flatfoot issue. However, they were of different sexes. To be able to analyze the gait of each participant, we have used Tekscan Stride way system. The participants have walked on the tiles with a regular speed of walking and both the force applied on the foot and the plantar pressure were measured and plotted versus time.
For the control, as figure 1 shows, the peak average plantar pressure of the foot were 90 kPa and 110 kPa during heel strike and toe off phases respectively. On the other hand, figure 1 shows abnormal gait cycle. The shape of the curve is different from the curve for the foot without bunion. Moreover, the average plantar pressure was very high. For the left foot, the average plantar pressure during heel strike and toe off was 210 kPa and 360 kPa respectively. For the right hand, the average plantar pressure during heel strike and toe off was 350 kPa and 390 kPa respectively.
A very important note to mention, the gait cycle and the average plantar pressure were analyzed for walking barefoot. Doing the experiment with shoes may yield different result especially the average plantar pressure results.

Bunion Treatment

There are two pathways to treat bunion (hallux valgus) either the surgical pathway or the non-surgical pathway.

Surgical pathway

In the first place, the most effective pathway to remove bunion is the surgical one. The aim of bunion surgery is to diminish both pain and deformity caused by the bunion. However, not all types of bunion are treated using surgery. For a bunion patient to be treated using surgery, s/he should have a series pain in the foot that happens even if s/he is wearing a comfortable shoe or while resting. Additionally, patient with chronic big toe inflammation and swelling demands a surgery if the inflammation wasn't cured by medicines [7]. Also, patients with severe big toe deformity such as being drifted toward the smaller toes need an urgent surgery.
Furthermore, there are many types of surgeries that can be done to remove bunion. In this research paper, two of the surgery types will be discussed; chevron osteotomy and Lapidus procedure [7].

chevron osteotomy

In chevron osteotomy, a distal cut near the metatarsophalangeal joint (MTP) in the first metatarsal, which is a long bone found behind the big toe is done. The cut should have a V shape since this will allow the sliding the rest of the bone laterally [8]. The sliding of the bone laterally helps in correcting the misalignment. To make sure that the metatarsal bone is fixed in its new position, the orthopedic surgeon uses permeant screws or removable wires. Sometimes the orthopedic surgeons in conjugation with osteotomy, they tighten or loosen the soft tissues around the MTP joint. Also, they begin the procedure by having an incision then removing the prominent bony pump on the inside of the big toe [8].

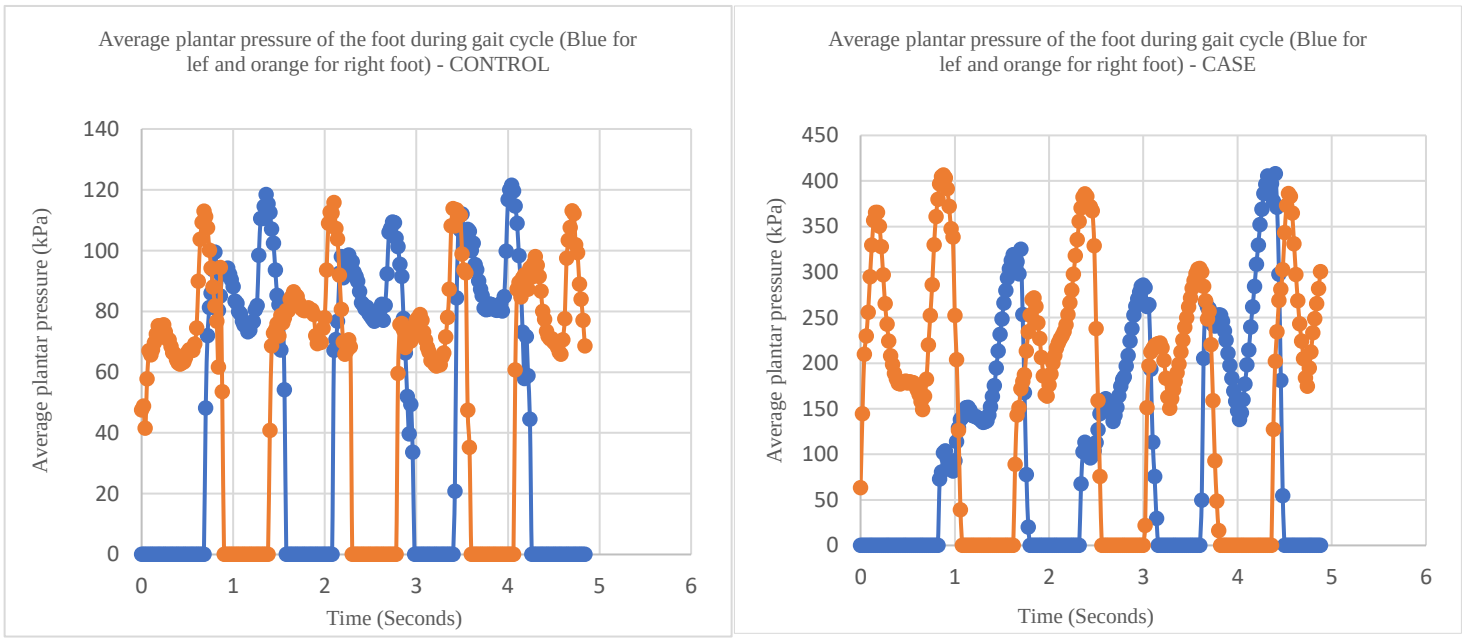

Figure 1. The gait cycle of two participants; the above graph is for a case and the below is for the control. The orange curve is the right foot and the blue curve is the left foot.

Overall, chevron osteotomy is considered one of the main surgeries used to remove bunion deformity. However, usually orthopedics suggests chevron osteotomy for those who have mild or moderate bunion.

Figure 2. Radiograph of a foot with mild bunion: (a) foot with bunion deformity and intermetatarsal angle of 13°. (b) the same foot after chevron osteotomy procedure.

Lapidus procedure

One of the bunion causes is the hypermobility of the first tarsometatarsal joint (TMT joint). To be able to treat this kind of bunion using surgery, a procedure called Lapidus is done [9]. In Lapidus procedure, the first metatarsal bone is straightened with the cuneiform bone by the fusion of the two bones together. In fact, the orthopedic surgeon starts Lapidus procedure by making an incision in the top of the first metatarsal bone to uncover the first TMT joint. After exposing the first tarsometatarsal joint, the articular cartilage within the joint is removed. The removal of the cartilage will allow the surgeon to move the first metatarsal bone and the big toe and make them straight. Then, the two bones will be fused together. To stabilize them, screws and plates will be used [9].

Surgical pathway limitations

Despite the bunion surgery is considered as an effective solution to remove bunion, the surgical pathway has some limitations and can cause dangerous side effects. Firstly, usually bunion surgery includes the usage of screws. Using screws may cause a defect called stress raiser. Inserting a screw in the bone will produce a discontinuity which in turn causes non-uniform load distribution and hence cause stress concentration. This high stress concentration may lead to a decrease in the bone strength and toughness under torsional loading.

A second side effect of the surgical pathway is stress shielding phenomenon. As mentioned previously in Lapidus surgery, plates can be used in the surgery. If the plate is made from a material with a stiffness higher than the bone, this will remove the load from the bone. According to Wolff's law, unloading the bone will induce bone resorption. Bone resorption can decrease bone stiffness and strength dramatically.

Non-Surgical pathway

The other pathway to treat bunion is the non-surgical pathway. It is less effective than the surgical pathway but it can be safer. The non-surgical pathway involves several types of treatments such as; wearing toe spacer, wearing well-fitting shoes, walking barefoot, and physiotherapy [7]. The aim of this study is to design a shoe that will help treating bunion effectively without having the need of surgical pathway.

The Shoe Design

Initial design

Figure 3 illustrates the initial shoes prototype for Bunion disorder patients. The design has focused on using the concept of Invisalign aligners and implement it on a show model by proposing few aligners on the side of the bumped bone. Aligner's curvature would change according to patient's case where eventually the target is to reach the normal bone curvature. The aligner is proposed to be changed biweekly where its main function is to apply a compressive force to the bumped area. However, after consulting a podiatrist specialist in the UAE, we have realized that it is not the best way to treat Bunion patients and it is highly possible for this design not to achieve an effective result for the patient. In fact, the curved aligner concept at the side of the shoe would make the Bunion disorder much worse than what we though initially as a treatment. To illustrate that, the applied compressive force would increase the bone curvature to a higher degree and cause a higher Bunion degree instead of curing the patient with this initial concept that we had.

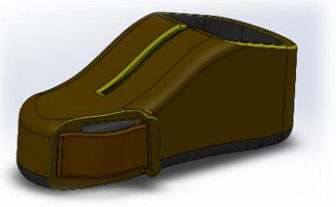

Figure 3. Initial prototype

Final design

Figure 4 and 5 demonstrate the anterior shoe part for our final design (figure 7). In this final design, we have used toe separators as a way to apply an opposite direction force to the toe itself. By this, a dislocation movement is achieved by forming a load on the toe bringing it to normal position over time by replacing the toe separators in the shoe after few weeks (figure: 6). One of the toe separator models is illustrated below are used for the treatment. The number of toe aligner changes depending on how severe the Bunion disorder is. Table 1 shows the dimension of the toe separators.

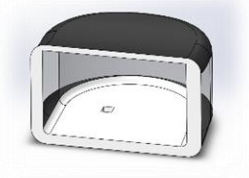

Figure 4. Anterior part of the shoe without toe separator.

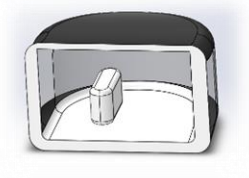

Figure 5. Anterior part of the shoe with the toe separator.

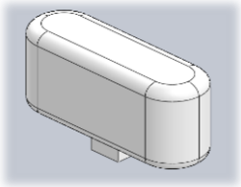

Figure 6. The toe separator

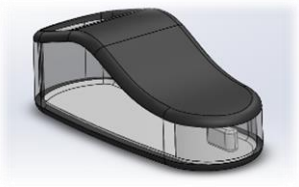

Figure 7. Final prototype design.

Table 1 below shows the dimension in mm for the toe separator in which we can see an increase in the width of the separator as we proceed to the next aligner. This indeed explains the idea of increasing the load applied on the toe by playing with the width of the separator and consider it as the main variable that plays a major role in determining the load value through Mechanical simulations. In our case, 2 cm is considered as the normal dislocation distance that a control person has. Moreover, we suggest to use each aligner for a period of 5 weeks before using the next aligner.

Table 1. Toe separator (1,2, and 3) information in mm.

Separator no.	Length	Width	Height
1	30	10	20
2	30	15	20
3	30	20	20

Environmental impact

While we are designing a shoe that can treat bunion as effective as surgery pathway, we have also considered the environmental impact of manufacturing our design. to analyze this impact, sustainability simulation, SolidWorks software was used. As figure 8 below shows, the negative impact of shoe manufacturing on carbon emission, energy consumption and water eutrophication are considered low since it is below 50%. However, the negative impact of the manufacturing on air is very high, above 100%. It may increase the air acidification.

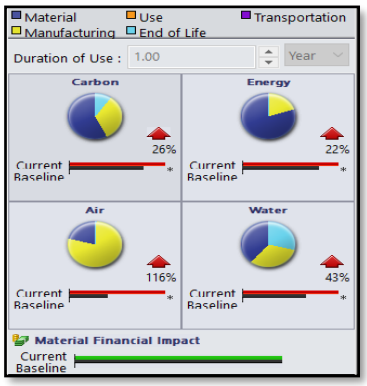

Figure 8. the sustainability results.

Discussion of the Results

In the first place, the conducted survey has shown that 56% of the participants wear do not wear tight shoes and 50% have a normal foot shape. This can be considered as an evidence for the strong link between wearing tight shoes and bunion incidence. In fact, a study done by Frey et al on 356 women have proved that women who wore 0.5 cm wider shoes than the foot have no foot pain and less deformity. Furthermore, as we have stated in the statistical analysis part, only 17% of the respondents have many of their family members suffering from bunion. This indicates that bunion incidence may not be genetic. It is logical the bunion is not caused by a genetic factor since it occurs in advanced in life. In addition, until now there is no gene that is identified to contribute in bunion [10]. Although the survey allows us to understand several facts about bunion incidence, some aspects of the survey needs to modified. For example, the survey needs to be sent for topic-related targets. Also, we can gather a group of participants and let them take the survey under our supervision.

Furthermore, as we have seen in the gait cycle analysis part, the gait motion of two participants was analyzed to figure out the effect of bunion on the gait pattern in bunion patient and the average plantar pressure of the foot. The analysis has proved that bunion has resulted in an altered gait cycle. Additionally, the gait pattern of the left and right feet was different. This can be due to that the degree of bunion in each foot is different. Also, the average plantar pressure is higher in bunion patient than the control. This high pressure can reduce the thickness of the plantar tissues of the foot. In general, the Tekscan walkway software has given us a simple tool to understand one of the complicated applications of the biomechanics of the Musculoskeletal system, which is the gait cycle. However, some points should be adjusted in the performed experiment. First, the sex should be matched between the participants. Also, the number of participants should be increased to get more accurate results and to able to generalize our results.

Last but not least, we have designed a shoe to treat bunion. We can't finalize whether the shoe will be an effective treatment or not since we haven't tried it on a patient. Moreover, as figure 6 illustrates, we have used a toe spacer to apply pressure on the opposite direction of the movement of the toe to align the big toe. We have designed three toe spacer sizes to apply different pressure on the toe. As a recommendation, a more advanced way can be utilized which is using sensors. A sensor can be hybridized with the toe spacer in a way makes the dimension of the spacer changes automatically with time according to the therapy plan. Also, the toe separator was made from ABS material, which is not considered as a comfortable material to patients compared to biomaterials in which it exhibits viscoelastic behaviors. Therefore, replacing material classification of the toe separator to a biomaterial is one of major enhancements that is recommended regarding material selection. Another design recommendation for our show model can be reducing stress concentrated regions in our design and model as stress concentration increases the possibility of material failure and reduces material life cycle when it gets exposed to high stresses and loads or cyclic loading (fatigue). Reducing stress concentration factors will enable patients use their shoe for longer periods of time. In addition to that, reducing the weight of the shoe is another design optimization that we recommend in which it helps patients consume less

energy while walking or performing certain type of activities. Weigh reduction can be achieved by reducing or removing unnecessary materials from the shoe itself that do not have major contributions to the mechanical properties of the shoe, such as load bearing and shoe stability. In brief, bunion or hallux valgus is one of the most common foot deformity especially among female population. This proves that bunion causes are more related to the type of shoes but not to genetic causes. Also, the study has proven that bunion can result in an abnormal gait motion therefore people who suffer from bunion needs to seek for an appropriate treatment. Surgical pathway can be the easiest but the most dangerous pathway. A shoe can be designed to treat bunion as effective as surgery.

Acknowledgment

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Appendix

The intermetatarsal angle explained in the metatarsal angle section is shown in figure 9 on the right.

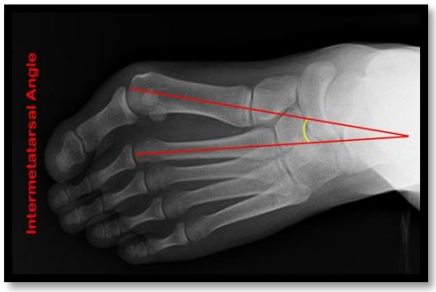

Figure 9: *The intermetatarsal angle shown in an X-ray.*

More information about the material used in the prototype manufacturing are shown in table 2 below.

Table 2. The prototype data.

Material	ABS plastic
Mass	269.51 g
Approximated Cost	0.048 USD / g
Surface Area	0.106 m^2
Volume	264.22 cm^3

The thickness analysis for the shoe in different locations is shown in figure 10 below. The thickness scale in the figure tells how much the thickness is with regards to different colors represented in the shoe.

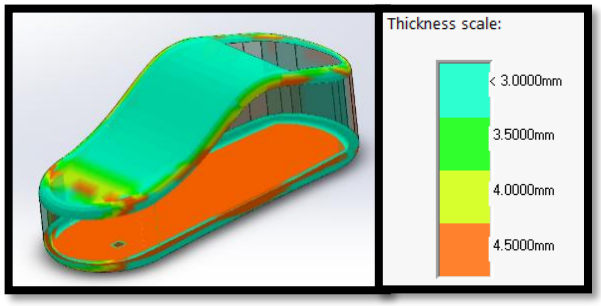

Figure 10. The thickness analysis of the shoe.