Analysis, Design And Manufacturing Of Ankle Foot Orthoses
تحليل وتصميم وتصنيع مسند قدم ـ كاحل

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Abstract:

Ankle foot orthoses (AFOs) are prescribed to paraplegic patients with low level spinal cord injury and with good control of the trunk muscles.

In this work, plastic materials (polypropylene) are used for manufacturing ankle foot orthoses (AFO) with drop foot fabricated using vacuum molding technique. The tensile test results showed that the mechanical properties for polypropylene were, σ_y= 24.73Mpa σ_{ult}=35.76 MPa σ_b max=67.66Mpa and Elongation at Break=38.26mm. The data of gait cycle (Ground Reaction Force (GRF) by using force plate and pressure distribution by using F-socket) were collected for two patients, the first of age about (42 years) with height (173cm) and weight(82kg) suffered from drop foot due to severing of the nerve damage and the second have age about (10 years) with height (130cm) and weight (23 kg) suffered from drop foot due to cerebral palsy which makes the patients unable to control for lift the foot. The gait velocity without AFO equals to 0.43m/sec when wearing plastic AFO equal to 0.64m/sec for first patient and gait velocity without AFO equal to 0.697m/sec when wearing plastic AFO equal to 0.756m/sec for second patient. The gait cycle time for patients without AFO equal to 42.6% but when wearing ankle foot orthosis (AFO) equals to 97%.The two patients were wearing orthosis type AFO for drop foot with right lower extremity.

Key words :AFO, Tensile, flexural bending , Force plate, F-socket polypropylene, drop foot.

1. INTRODUCTION

For most of the time, ankle foot orthosis (AFO) **Fig. 1** are commonly used in clinical practice to supplement gait abilities of hemiplegic patients. Orthosis is usually used to correct foot abnormalities such as foot drop during swing and insufficient push-off during stance whereby it allows ambulatory safety by ensuring mediolateral stability during stance and adequate toe clearance during swing phase [1].

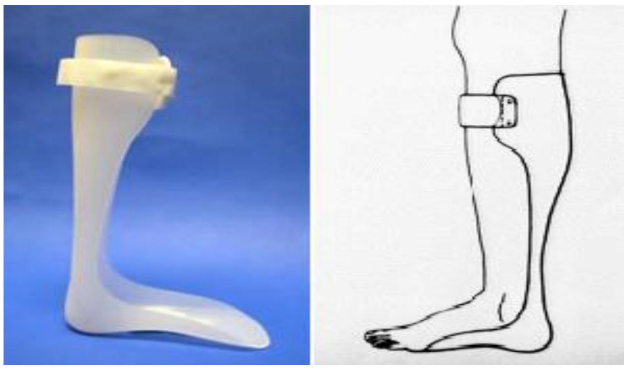

Figure 1. Solid ankle-foot orthosis[1].

The motion of the foot is mainly governed by two joints, the ankle joint and the subtalar joint. The ankle joint is the joint between the talus and the tibia, and the subtalar joint is between the talus and the calcaneus [2]. Pathological conditions, such as stroke, lead to abnormal rotations at the ankle-foot complex that profoundly affects the persons ability to walk. For example, the drop foot problem developed by the stroke patient involves excessive and uncontrolled motion at the ankle joint, often leading to a toe drag instead of the heel contact motion during gait [3]. Drop foot is a reduced or lack of action from the muscles that lift the foot when these muscles lack function they are unable to dorsiflex the ankle which causes the foot to be dragged on the ground. For some people the lack of function is so severe that they are not able to walk without treatment, while others have a steppage gait. The recommended treatment depends on the etiology of drop foot. Sometimes surgery is necessary while some patients can be treated by wearing an ankle foot orthosis, a brace that stabilizes the foot and lifts it in an upright position while the foot swings. A very large number of people suffering from drop foot but no exact numbers is to the authors knowledge available. Nevertheless, it can be estimated that 20 % of those surviving stroke suffer from drop foot [4].

2. EXPERIMENTAL PROCEDURES

In this work, a characterization of polypropylene material to be used in the case of manufacturing the flexible AFO and its effectiveness in the above applications due its safe mechanical properties and high stiffness weight ratio. Then will be tested experimentally to get the properties in real applications on two patients.

2-1.Materials

The materials of the AFO needed for this study are as follows.[5]

- Materials for Jepson.
- Perlon stockinet white (Ottobock health care 623T3).using for covering the Jepson.
- Polypropylene.

2-2.Equipment

- Oven for heating plastic (polypropylene) which available in Alibtisam center for prosthetics and orthotics.
- Vacuum forming system including vacuum pump and different types of stands, pipes and tubes available in Alibtisam center for prosthetics and.
- Universal instrument machine test(testometric) for tensile test.
- Universal instrument machine test(testometric) also used for flexural bending test(three point load).
- Force plate devise are used to analysis the gait cycle of patient

with AFO as shown in **Fig. 2**.

Figure 2. Force plate device.

- F -Socket Testing for calculate Interface Pressure By The Sensor Of The The alternating load between the calf and patient's leg, who was wearing the AFO, was measured as pressure. The sensor type (MatScan) is more acceptable for this type of dynamic load.

2-3.Preparing of Materials For Testing The Samples.

- Polypropylene will be cut according to the standard and the thickness depends on the patient's weight. The polypropylene sheet will be heated at (180C°) for (20 to 25 minutes), depending on the thickness of the polypropylene and the performance of the oven. Take the polypropylene sheet from the oven and put it between two mold to prevent buckling and leaving the plastic to cold by air.
- Cutting the polypropylene after cold to manufacturing samples for tensile and flexural bending testing.
- For tensile test three samples for polypropylene were machined according to ASTM D638[6] with thickness 5mm as shown in **Fig. 3**.

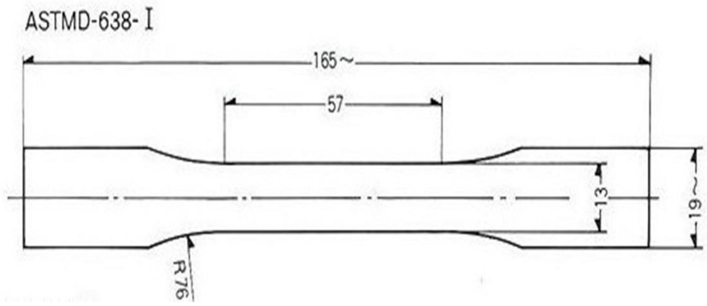

Figure 3. The shape and dimensions of tensile.

- For flexural bending test three samples for polypropylene were machined according to ASTM D790[7] with thickness 5mm as shown in **Fig. 4.**

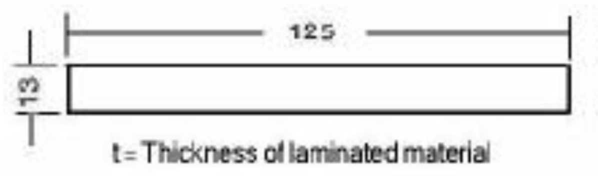

Figure 4. The shape and dimensions of flexural bending specimens.

2.4 Manufacturing Of Ankle Foot Orthosis (AFO).

1- The sheet of Polypropylene will be cut according to knowing dimensions of the patients and the thickness depends on the patient's weight. These information were taken from the orthotist of (Alibtisam center for prosthetics and orthotics. Baghdad).

2- The polypropylene sheet will be heated at (180C°) for (20 to 25 minutes), depending on the thickness of the polypropylene and the performance of the oven available in Alibtisam center for prosthetics and orthotics.

3- The polypropylene can be draped over the plaster model, laying the polypropylene over the mould without stretching it with sticking it together along the anterior side as shown in **Fig. 5.**

(a) (b)

Figure 5. Laying the polypropylene over the mold.

1- The polypropylene will be tightened around the suction cone with a rope or something similar. Then, by opening the vacuum valve, the most of remaining air between the negative pattern and PP sheet will be vacuumed. After this, leaving the plastic model to cold by air, the polypropylene model can be now carved by special tool (vibrational cutter).[8].

The ankle foot orthoses for two patients are shown in **Fig. 6.**

Figure 6. Ankle foot orthoses for two patients

RESULTS AND DISCUSSION

3-1.Tensile Properties Results

The mechanical properties of PP are listed in tables (1), Three specimens for Polypropylene were tested to get stress-strain curve. **Fig. 7** shows stress-strain curve for one of the samples of the Polypropylene. from these curves the mechanical properties of each sample determined and record in table (1) by taking the average value of the mechanical properties (σ_y, σ_{ult} , E and Elongation at Break) in table(2).

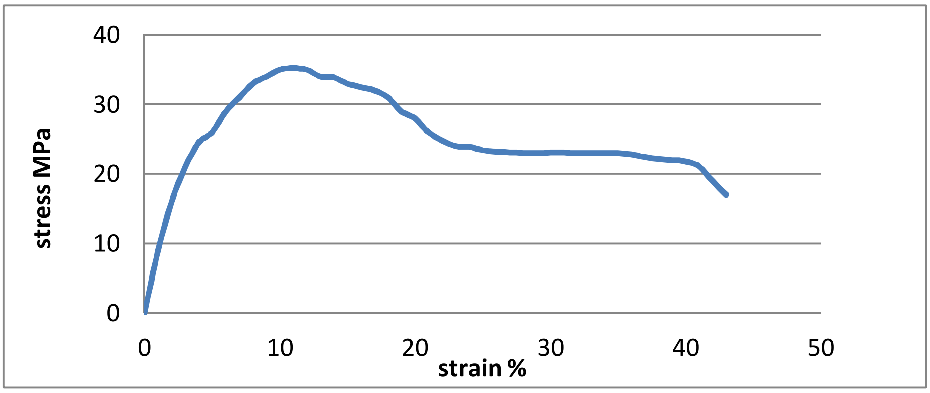

Figure 7. Stress-strain curve for Polypropylene

Table 1.The mechanical properties of Polypropylene

Sample No	Thickness (mm)	Ϭy MPa	Ϭult MPa	E GPa	Elong. at Break (mm)
1	5	25.8	36.8	1.26	45.8
2	5	24.1	35.2	1.24	24.5
3	5	24.3	35.3	1.25	44.5

Table 2.The average value of the mechanical properties from stress strain curves

Thickness (mm)	Ϭy MPa	Ϭult MPa	E GPa	Elong. at Break (mm)
5	24.73	35.76	1.25	38.26

3-2.Flexural Properties Results.

The flexural properties can be calculated from the bending curves of three samples for Polypropylene and by averaging the results , the mechanical bending properties are listed in table (3) , **Fig. 8** shows stress-deflection curve for one of the samples of Polypropylene. from these curves the mechanical properties of Polypropylene sample determined and record in table (3).

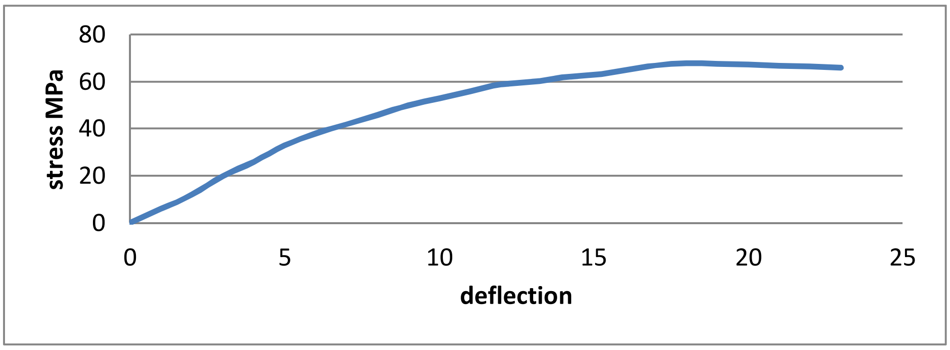

Table 3. Mechanical properties that determined from stress -deflection curves

Sample No	Ϭb max Mpa	E flexural Gpa
1	65.8	3.15
2	78	3.6
3	59.2	2.5

3-3 .The Results And Discussion Of The Gait Cycle Parameters.

The ground reaction force (GRF) introduced under sole, due to biomechanical effects on leg during gait and stance cases, can be done for patient who has drop foot in right foot using force plate, walk over fixed plate where the force distribution is developed under sole due to patient gait.

The obtained data from the gait cycle test were compared between the patient with and without AFO for two cases, to recognize the major differences for the parameters of the right and the left leg.

The test includes walking two main parts: before and after wearing Ankle-Foot-Orthosis (AFO).

The results will be detailed in each case as follows:

3.3.1 Patient 1

A- Testing without AFO**.**

The main parameters shown in Table (4) describes the behavior of the gait cycle for patient separately as average data for one complete gait cycle from heel to heel strike. The results of the right foot were different from the left foot of the patient.

Table 4. Gait Cycle Table (sec)

Gait Cycle Table (sec)	Patient 1		
	Left	Right	Difference
Gait Cycle Time	3.82	1.63	-2.18
Stance Time	1.03	0.93	-0.10
Swing Time	2.79	0.70	-2.08
Single Support Time	0.67	0.64	-0.03
Initial Double Support Time	0.15	0.17	0.02
Terminal Double Support Time	0.17	0.15	-0.02
Total Double Support Time	0.33	0.33	0.00
Heel Contact Time	0.73	0.35	-0.37
Foot Flat Time	0.64	0.03	-0.61
Mid stance Time	1.1	0.2	-0.9

the force distribution is developed under sole due to patient gait are shown in **Fig. 9.**

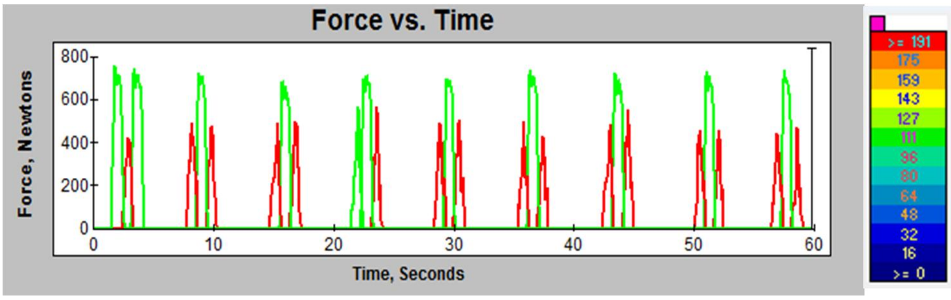

Figure 9. Force vs. Time

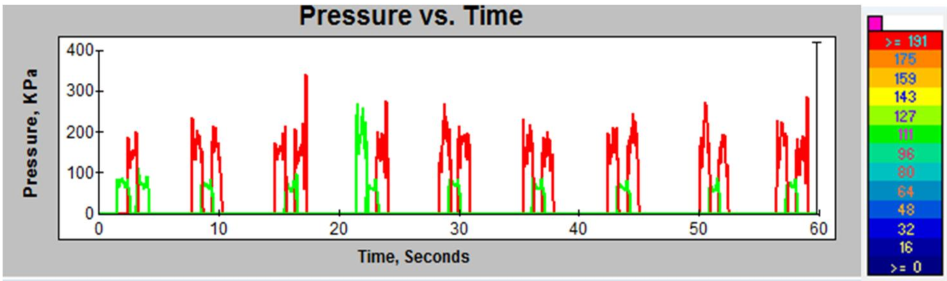

Figure 10. Pressure vs. Time

B- Testing with plastic (polypropylene) AFO.

The main parameters shown in Table (5) describe the behavior of the gait cycle for patient wearing plastic AFO separately as average data for one complete gait cycle from heel to heel strike. The results of the right were different from the left foot of the patient.

Table 5. Gait Cycle Table (sec)

Gait Cycle Table (sec)	Patient1		
	Left	Right	Difference
Gait Cycle Time	1.23	1.19	-0.04
Stance Time	0.79	0.74	-0.08
Swing Time	0.44	0.48	0.04
Single Support Time	0.46	0.45	-0.01
Initial Double Support Time	0.17	0.18	0.01
Terminal Double Support Time	0.18	0.17	-0.01

Total Double Support Time	0.34	0.34	0.00
Heel Contact Time	0.64	0.45	-0.19
Foot Flat Time	0.58	0.17	-0.41
Mid stance Time	0.45	0.27	-0.18
Propulsion Time	0. 15	0.24	0.08
Active Propulsion Time	0.03	0.06	0.03

the force distribution is developed under sole due to patient gait are shown in **Fig. 11**.

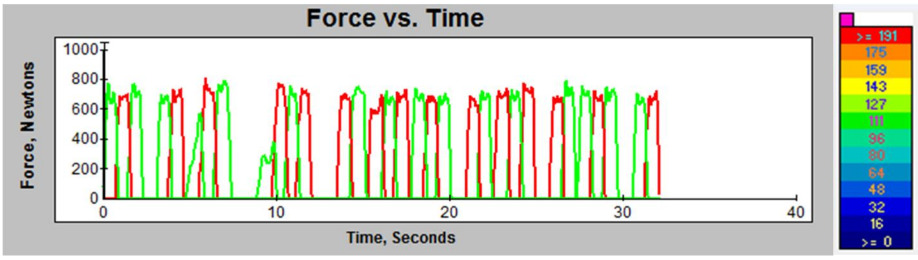

Figure 11. Force vs. Time

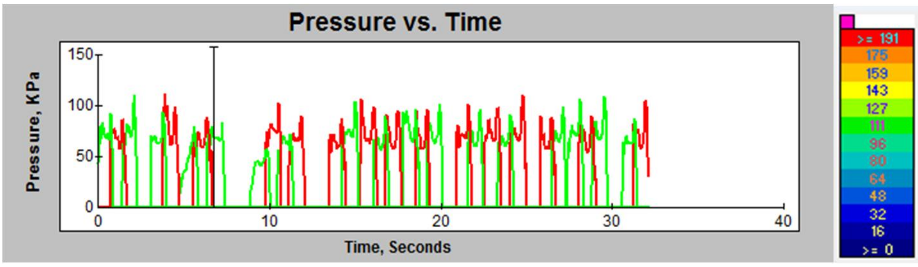

Figure 12. Pressure vs. Time

3.3.2 Patient 2

A- Testing without AFO.

The main parameters shown in Table (6) describe the behavior of the gait cycle for patient separately as average data for one complete gait cycle from heel to heel strike. The results of the right were different from the left foot of the patient.

Table 6. Gait Cycle Table (sec)

Gait Cycle Table (sec)	Patient 2		
	Left	Right	Difference
Gait Cycle Time	1.38	1.27	-0.10
Stance Time	0.85	0.66	-0.18
Swing Time	0.53	0.61	0.08
Single Support Time	0.66	0.43	-0.23
Initial Double Support Time	0.08	0.12	0.04
Terminal Double Support Time	0.12	0.08	-0.04
Total Double Support Time	0.21	0.21	0.00
Heel Contact Time	0.42	0.16	-0.26
Foot Flat Time	0.17	0.00	-0.17
Mid stance Time	0.30	0.00	-0.30
Propulsion Time	0.42	0.49	0.06
Active Propulsion Time	0.35	0.37	0.01
Passive Propulsion Time	0.07	0.12	0.05

the force distribution is developed under sole due to patient gait are shown in **Fig. 13**.

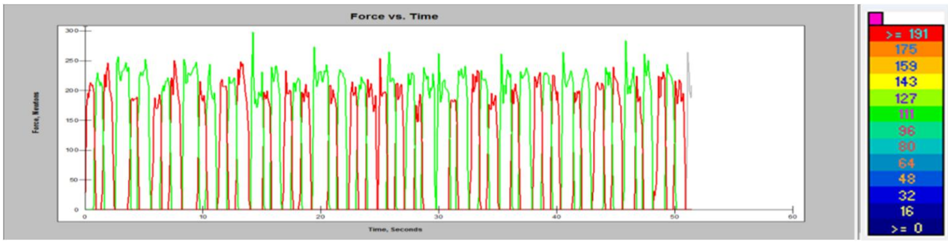

Figure 13. Force vs. Time

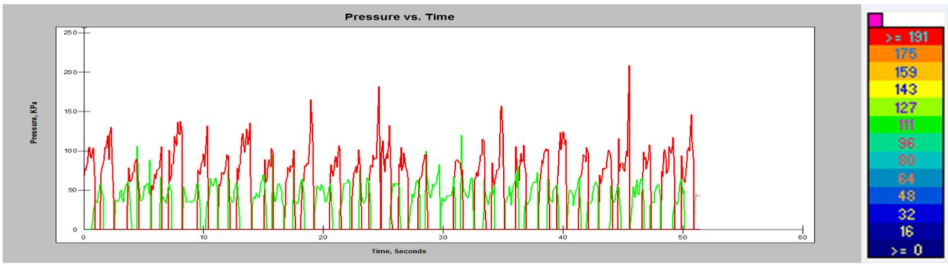

Figure 14. Pressure vs. Time.

B- Testing with plastic (polypropylene) AFO.

The main parameters shown in Table (7) describe the behavior of the gait cycle for patient wearing plastic AFO separately as average data for one complete gait cycle from heel to heel strike. The results of the right were different from the left foot of the patient.

Table 7. Gait Cycle Table (sec)

Gait Cycle Table (sec)	Patient2		
	Left	Right	Difference
Gait Cycle Time	1.28	1.15	-0.13
Stance Time	0.79	0.65	-0.13
Swing Time	0.50	0.50	0.00
Single Support Time	0.50	0.43	-0.07
Initial Double Support Time	0.11	0.11	0.00
Terminal Double Support Time	0.11	0.11	-0.00
Total Double Support Time	0.22	0.22	0.00
Heel Contact Time	0.41	0.23	-0.18
Foot Flat Time	0.27	0.06	-0.21
Mid stance Time	0.33	0.10	-0.23
Propulsion Time	0. 35	0.41	0.06
Active Propulsion Time	0.24	0.31	0.06
Passive Propulsion Time	0.10	0.10	0.00

the force distribution is developed under sole due to patient gait are shown in **Fig. 15**.

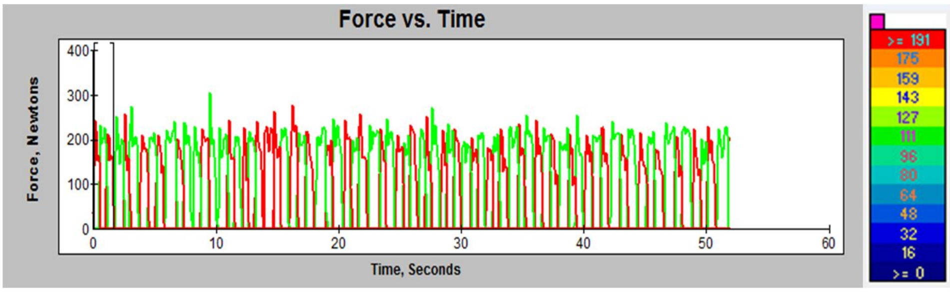

Figure 15. Force vs. Time

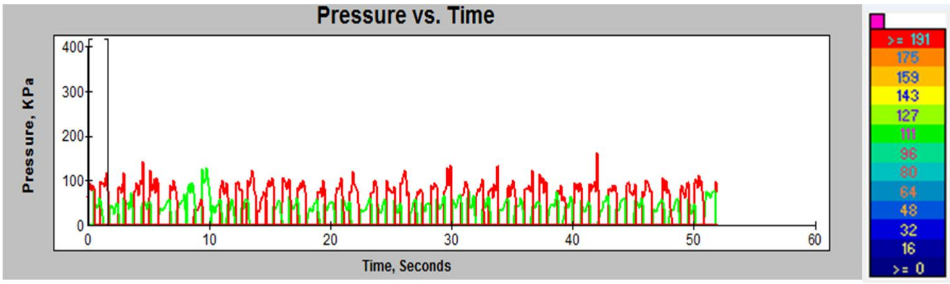

Figure 16. Pressure vs. Time

3-4 Interface Pressure Between The Leg of Patients and AFO

The pressures were only considered over the gait cycle by contact method between the patients and AFO at the calf reign . The data were normalized to 100 percent of gait cycle. The pressure for subjects were different at weight acceptance from one patient to another as shown in **Fig. 17& Fig. 18.**

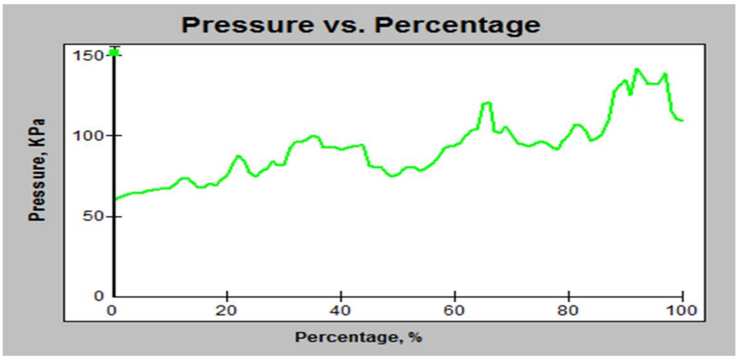

Figure 18. Pressure vs. Percentage for patient one.

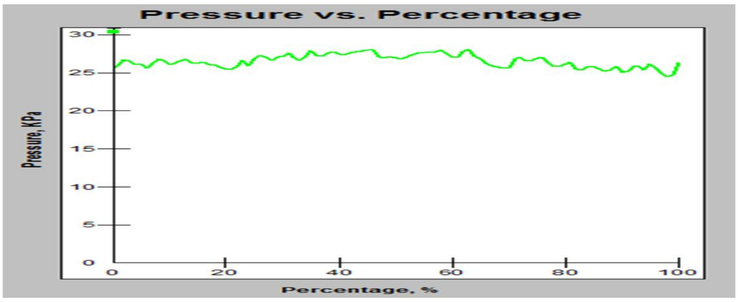

Figure 19. Pressure vs. Percentage for patient two.

4. CONCLUSIONS

This study gives a good database for the manufacturers which can help them to manufacture the suitable of ankle foot orthoses with drop foot.

These are as follows.

1- For plastic material (polypropylene) .the mechanical properties are acceptable to give the flexibility, Strength and durability for AFO.

2- The comparison process between the pathological subject and the normal subject in the gait cycle test showed major differences between the two subjects and that back to the foot drop.

3- There is a delay to stance time the right foot from the left margin 0.1seconds and after wearing AFO the delay became only 0.08 seconds for first patient(42years) and from0.18 seconds to 0.13 seconds for second patient(10years). As well as the difference in heel contact time between the feet step transformation of 0.37 seconds to 0.19 seconds for patient one and from0.26 to 0.18 for patient two.

4- Increasing of dorsiflexion angle at the metatarsal to 30 ^{o} which obtained in present new AFO severs to restore normal motion for patients suffered from foot drop

الخلاصة:

توصف المساند نوع (قدم - كاحل) AFO لمرضى الأطراف السفلى لذوي الاصابات الطفيفة في الحبل الشوكي وإصابات أصابع القدم والكاحل والأعصاب الناتجة من اضطرابات النظام العصبي المركزي التي تؤثر على الحبل الشوكي أو الدماغ مثل السكتة الدماغية وتصلب الأنسجة والشلل المخي. في هذا العمل تم تصنيع مسند من البلاستيك (البولي بروبلين) لمنع سقوط القدم من مفصل

الكاحل (AFO) مع هبوط القدم باستخدام تقنية سحب الهواء. وأظهرت نتائج اختبار الشد أن الخصائص الميكانيكية لمادة البولي بروبيلين كانت، Mpa = Ϭy 24.73Mpa Ϭult = 35.76

Ϭb =67.66MPa والاستطالة عند الكسر = ٣٨.٢٦mm.

وقد تم جمع البيانات من دورة مشية لحساب قوة رد الفعل الأرضي (GRF) باستخدام plate (force) وتوزيع الضغط باستخدام (F-socket) لاثنين من المرضى، الأول يبلغ من العمر حوالي (٤٢ عاما) مع ارتفاع (١٧٣ سم) والوزن (٨٢ كجم) يعاني من سقوط القدم بسبب قطع في الأعصاب، والثاني يبلغ من العمر حوالي (١٠ عاما) مع ارتفاع (١٣٠سم) والوزن (٢٣ كجم) يعاني من سقوط القدم بسبب الشلل الدماغي مما يجعل المرضى غير قادر على السيطرة على رفع القدم. سرعة المشية بدون استخدام المسند (AFO) يساوي m٠.٤٣ / ثانية وعند ارتداء المسند AFO يساوي m٠.٦٤ / ثانية للمريض الأول و سرعة المشية بدون AFO يساوي m٠.٦٩٧ / ثانية عند ارتداء البلاستيك AFO يساوي m٠.٧٥٦ / ثانية للمريض الثاني. زمن دورة المشية للمرضى بدون AFO يعادل ٤٢.٦٪ ولكن عند ارتداء المسند قدم - كاحل (AFO) يساوي ٩٧٪.

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