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Design and Development of an Adjustable Dynamic Hand Splint

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ABSTRACT

Introduction: Radial nerve injury is comparatively a common occurrence. Recovery, however, depends on the level of injury. Medication, rest and surgery are among treatment regime, although, Orthotic splints are frequently used in its management to compensate for failure of motor power. The aim of this study was to modify existing design and fabricate an adjustable Dynamic Hand Splint utilizing locally sourced materials for the management of radial nerve palsy.

Materials and Mathods: Autodesk Revit software and the cast of a patient were used for both the schematic designs and to obtain the measurements for the device. The cast was transferred to the lamination jig were it was moulded with EVA foam (ethylene vinyl acetate) under heat from electric oven, epoxy resin was also applied all over the EVA foam and the plastic lamination, fibre glass and stockinet was done. The final product was able to fit optimally on patients with varying circumferences and could be used for both the left and right sides of the upper extremities.

Discussion: The mean of maximum active flexion was 98.70 this is within the range of standard maximum flexion and gives an idea of the quantity of rehabilitative force our device generates when the patient pushes the spring and its efficiency.

Conclusion: The splint was used on 5 subjects, the angle of extension in degrees obtained at normal wrist when at rest and measured with a goniometer range from 30^0 to 35^0 with mean of 32.6^0 while the maximum Active Flexion range from 95^0 with a maximum finger flexion of 100^0.

KEYWORDS: Radial Nerve Palsy, Adjustable, Hand Splint, Orthoses, Upper Estremity

1.0 INTRODUCTION

1.1 Radial Nerve Palsy and Causes

The radial nerve is a member of the terminal branches of the posterior cord, lying behind the axillary and upper brachial arteries and passes anterior to the tendons of teres minor, latissimusdorsi and subscapularis, powering the muscles that extend through elbow, wrist, finger, metacarpalphalangeal (MCP) joints and thumb (Gracies *et al*., 2000, Shulman *et al*., 2008, Pandian S and Arya K., N. 2012). It is the most frequently injured nerve of the upper estremity in human (Barton, 1973, Jacobs M. and Austin N. 2003, Serrano *et al*., 2012). Injury to the radial nerve, which could either be open or closed often result to paralysis and could be cause by fracture to the shaft of the humerus (Lowe, J. B *et al.*, 2002, Li, H. *et al.*, 2013).

Although, routine procedure involving the upper estremity may lead to Iatrogenic injuries to the radial nerve, which is characterized by wrist drop or a deficit in finger extension in metacarpophalangeal (MCP) joints and or sensory loss (Wright *et al.*, 2005, Wen-Dien, C and Ping-Tung L. 2015). Severe traumas resulting from lacerations, missiles, injections, or traction are all known to induce radial nerve paralysis. Clinical symptoms such as weakness in wrist extension have been reported from chronic or acute radial nerve compression. Rarely, though, neuritis or tumor of the radial nerve at the brachial plexus will initiate radial nerve palsy (Wright *et al.*, 2005, Hoffman H., B and Blakey G., L. 2011, Okafor *et al*., 2022).

1.2 Symptoms, Diagnosis, Treatment and Management of Radial Nerve Palsy

The symptoms of radial nerve palsy include numbness of the fingers, difficulty extending wrist or fingers, pinching/ grasping difficulties, muscle weakness, inability to control muscles from tricep to the finger and wrist drop, diagnosis include physical examinations, Electromyogram (EMG), X-ray, ultrasound or MRI and nerve conduction studies. Treatment regime for radial nerve paralysis is mostly dependent upon the primary cause and severity of the injury (Wright *et al.*, 2005, Andringa *et al.*, 2013, Yu-Sheng *et al.*, 2021) minor injury is treated with rest, modification of activity and use of anti inflammatory drugs which enabling axons in the peripheral nervous system to regenerate and, under optimal circumstances, re-establish contact with the appropriate end organs: motor endplates or sensory receptors, thus restoring motor and sensory innervation (Dellon *et al.*, 2000, Greg Pitts D., Peganoff O’Brien S. 2008) while severe paralysis is treated with surgery (Dellon, *et al.*, 2000, Sharon *et al.*, 2006, Hammert, W. C, 2016). Nerve grafts, or tendon transfers are surgical repair procedure used for the treatment of radial nerve injuries, while tumour exclusion are employed for the treatment of neuritis (Thomas, *et al.*, 2000).

1.3 Orthotic Intervention

Splints have been used to rehabilitate patients with radial nerve palsy; however, for a splint to effectively rehabilitate a patient, it must be able to attend to the functional needs of the patient as well as the biological needs of the tissues (Wilton *et al.*, 1997, Chan R. K.. 2002). Some splints such as the tenodesis splints harness active wrist flexion to produce passive finger MCP extension and also conversely harness active MCP flexion to produce passive wrist extension (Colditz *et al.*, 1987, Alsancak S *et al.*, 2003, Van Veldhoven G *et al.*, 2005 *and* Sammons *et al.*, 2006). This dynamic extension power requires an outrigger projecting from above the dorsal surface of the hand for the fingers and above the radial surface for the thumb (Crochetiere W. Goldstein S. and Granger C.V. 1975).

There are the Rogers splints which provided dynamic extension assistance to the MCPs without a projecting outrigger and the Dynamic splints that use elastic materials (springs, or spring wire) to pull affected joint(s) in one direction hence allowing in the opposite direction of the dynamic force an active-resisted movement. In most hand splint design, though, a static support is provided for the wrist across the palmar arch, while the fingers and thumb have dynamic extension assists by means of cuffs around the proximal phalanges (Van Veldhoven G *et al.*, 2005). In this design, however, and using locally sourced materials with attention to high strength, low weight ratios, patient acceptability and durability, we presented an adjustable Dynamic hand splint that can be used for the both left and right sides of the upper extremities and by people with varying hand cuff sizes. This design would help to overcome the encumbrances of custom fit Dynamic hand splint.

2.0 MATERIALS AND METHODS

2.1 Materials

Table 2.1: Materials Used and Uses

S/N	Materials	Specifications	Uses
1	Fiberglass	1/4kg	Plastic reinforcement
2	epoxy resin	2kg	Plastic reinforcement
3	Epoxy Resin Saturator	20millimeter	Plastic reinforcement
4	Cobalt Catalyst	20millimeter	Acts as a catalyst for the plastic curing process
3	Ethylene Vinyl Acetate (EVA) foam-	10cmx10cmx3mm thickness	Padding material
4	Velcro strap (Hook and Hair); Strap leather	1cm thickness	For suspension
5	Press pins	25pcs	Joining materials together
6	Elastic Springs	3.5cm length	For Downward/flexion Therapy
7	Adhesives	1l	For joining of materials
8	Stockinette	(3inch) X 200cm	For plastic reinforcement
9	Plaster of Paris (POP) bandage	2 rolls	For cast impression taking
10	POP powder	5kg	For positive cast formation and modification
11	Aluminium Bars	60 x 2 x 0.6cm	For suspension of elastic Spring and sling

Table 2.2: Tools Used for Fabrication

S/N	Tools	Uses
1	Hammers	Hitting objects
2	Scissors	Cutting objects
3	Pliers	Holding and cutting of objects
4	Jig saw machine	Cutting of hard objects
5	Drill machine	Drilling holes
6	Stone grinder	Smoothening of edges of materials
7	Anvil	Hitting of objects
8	Drill bits	Drilling holes
9	Vice	Used to securely hold work objects
10	Working bench	for workshop activities
11	Measuring tape	Measurements
12	Hand drill machine	Drilling holes
13	Plastic suction machine	Forming of heated plastics over positive casts
14	Surform files	Modification of positive casts
15	Hand files	Smoothening of hard edges

2.2 Methodology of Fabrication of our Device

The Modified Dynamic Cockup Brace (MDCB

This modified dynamic cockup brace (MDCB) design consist of wrist cockup splint and a system of elastic springs that is suspended from plastic projections; each of the five springs if for each of the fingers. This design is an improvement from existing designs with features that enable it to be used for both the left and right sides of the upper extremities and to fit various sizes of the limb. This is enabled by adjusting its length and width.

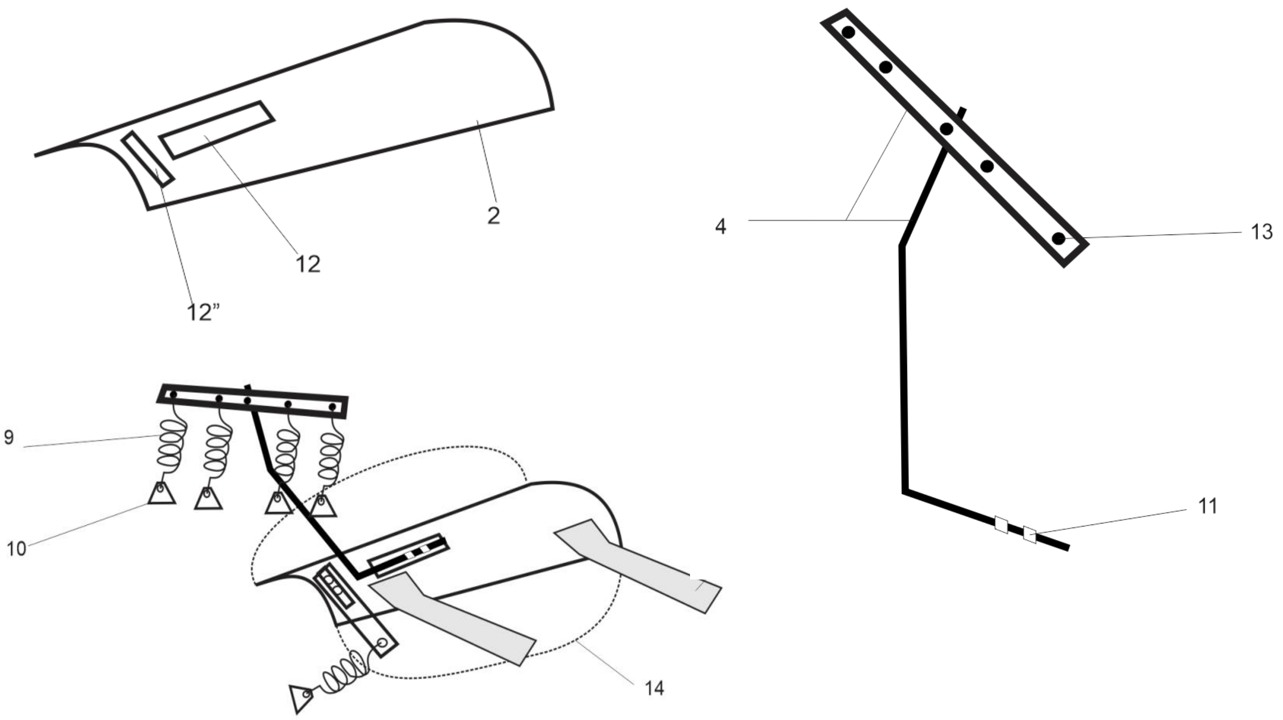


Figure 2.1: Schematic Description of MDCB

1 = MDCB 2 = Plastic shell
4 = Adjustable Finger Bar (ATB) 5 = Adjustable Thumb Bar (ADB)
9 = spring 10 = sling
11 = Holes on AFB 11” = Hole on ATB
12 = Slot on plastic shell (AFB) 12” = Slot on the plastic shell (ATB)
13 = Holes 14 = Cell foam
15 = Velcro straps

Schematic Design Specifications

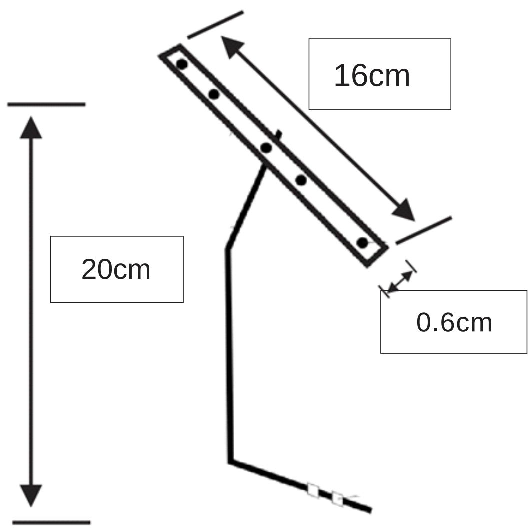


Figure 2.2: Extension Bar

Derivation: The sized shape was derived from the following measurements.
Length = 20cm- for Adjustable Finger Bar (Horizontal)
Width =2cm- for Adjustable Finger Bar (Horizontal)
Width = 2cm- for Adjustable Finger Bar (vertical)
Length = 16cm- for Adjustable Finger Bar (Horizontal) used to suspend the elastic spring and sling.
Thickness = 0.6cm-for a less bulky plastic shell.
This piece measured the lengths, width, and the thickness of the Adjustable Finger bar (AFB). It is used to suspend the elastic spring and sling through 5mm holes, into which the elastic springs insert securely. AFB has 2 holes (5mm each) and together with a slot on the plastic shell that helps to adjust the length of the brace. Hence, ensuring that patients with longer upper extremities can equally use the device.

Adjustable Extension Bars

Both the Adjustable Thumb Bar and Adjustable Finger Bar were made from Aluminium Metal bars. A 20 x 2 x 0.6 cm (bent as shown in the schematics) and 16 x 2 x 0.6cm aluminium bars were used for the Adjustable Finger bar while an 11 x 2 x 0.6cm aluminium bar was used for the Thumb bar. A 5mm drill bit was used to drill holes as shown in the schematics for the suspension of the elastic springs and for affixation on the plastic shell.

Schematic Design specification

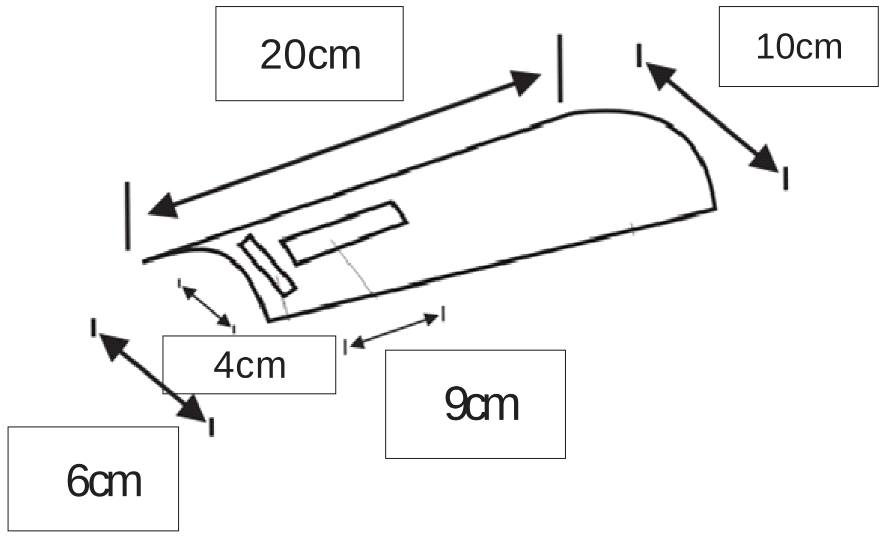


Figure 2.3: Cockup Splint Section

Derivation: The sized shape was derived from the following measurements.

Length = 20cm- for the cockup brace (determined from arm length of the test subject)

Width =10cm- for the cockup brace (determined from arm width of the test subject)

Slot = 9cm- for Adjustable Finger Bar on the plastic shell

Slot = 4cm – for the Adjustable Thumb Bar on the plastic shell

Thickness 0.6cm-for a less bulky plastic shell

This piece measured the length, width, slots on both the Adjustable Finger Bar (AFB) and Adjustable Thumb Bar (ATB). The cockup splint section which was fabricated using epoxy resin/fiber glass and ethylene vinyl acetate plastic (EVA) foam which is used for padding and it also have a flap on either lateral sides. The flaps helps to make the brace to be adjustable (width) since it is from a flexible material and can conform easily to the curve of the forearm.

Measurement, Casting and Lamination of the Plastic Shell

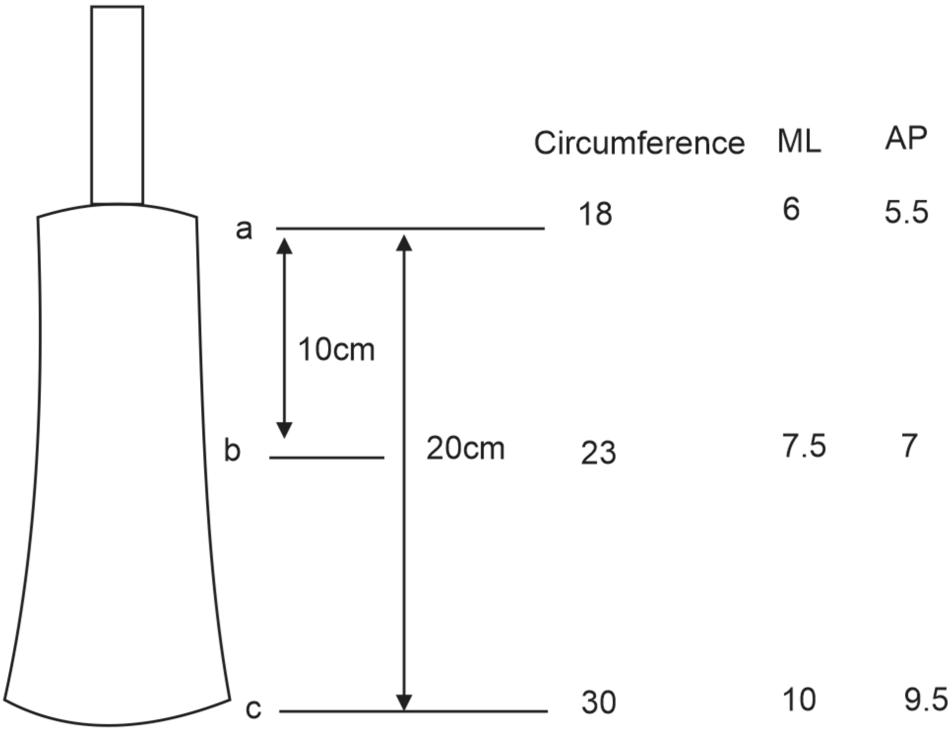


Figure 2.4: Measurement on the positive cast (measurements from the test subject)

Measurements for the fabrication of the brace were obtained from a staff of ROPOC. Cast was taken from the hand to the elbow in a cocked up position. Measurements were obtained at the following landmarks: the wrist, the mid forearm and the distal forearm. Cast was removed and used to form the positive cast. Rectification of the positive cast was done by the Orthotist to ensure that the measurement taken on the subject tallied with that on the cast in line with standard orthotic principles.

During the rectification process, the cast was reshaped to become ambidextrous (able to be used for either left or right hand). After modification, the cast was transferred to the lamination jig where plastic lamination with epoxy resin, fiber glass and stockinet was done. After the setting of the plastic (2days), the plastic was removed from the positive mould using a cast cutter in line with the schematics. All holes, slots and grooves on the schematics were made with the help of the drilling machine and jig saw.

Coupling and Finishing

The plastic shell was padded as shown in the schematics. The padding was made of a 2 layered 1mm thick EVA foam with a fabric stockinette glued in between to ensure toughness of the lining. The flap of the padding was made to ensure that the device can be used by both patients with fat and slim hands. The components were then coupled with bolts and nuts, the holes of the adjustable extension bars were connected to the nuts of slots on the plastic shell in order to ensure adjustability of the device.

Testing

The device was fit on the patient and the suspension straps applied across the forearm.

The following tests were conducted with the brace on:

Test 1: Angle of extension obtained at the wrist with the device at rest: A goniometer was used to measure the amount of extension obtained at a normal wrist with the brace applied in degrees.

Test 2: Maximum Active Flexion obtainable with the brace on. This is also measured with the goniometer. This range of motion gives an idea of the quantity of rehabilitative force generate able when the patient pushes the springs into flexion.

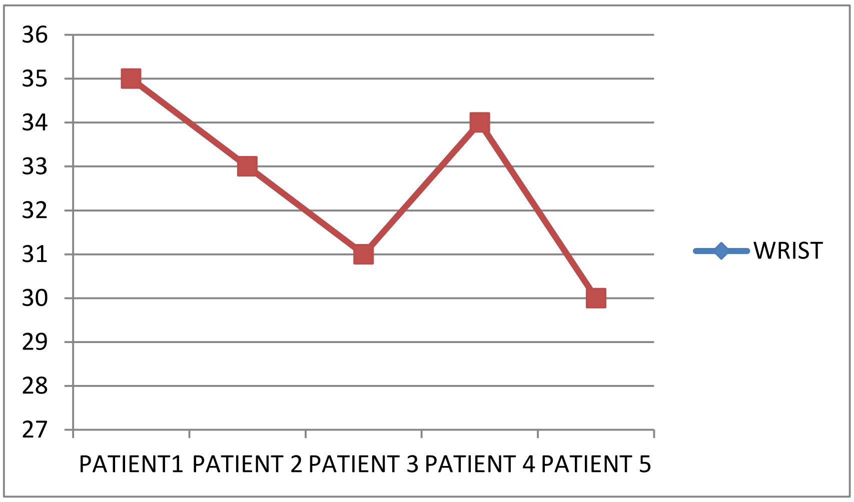
Test 3: Also, Angle of extension was re-measured after maximum flexion. This is to assess the ability of the springs to return to their original length after load is removed.

Test 4: The device was then applied to the contralateral forearm to determine whether the brace was ambidextrous as was speculated.

Test 5: Finally, the brace was applied on two subjects. The first with a slim forearm (Measured as follows: Wrist =; mid forearm =; and distal forearm =) while the second subject had the following (Wrist =; mid forearm =; and distal forearm =). The aim of the test was to verify if the same brace can be fitted on individuals irrespective of their size.

3.0 RESULT AND DISCUSSION

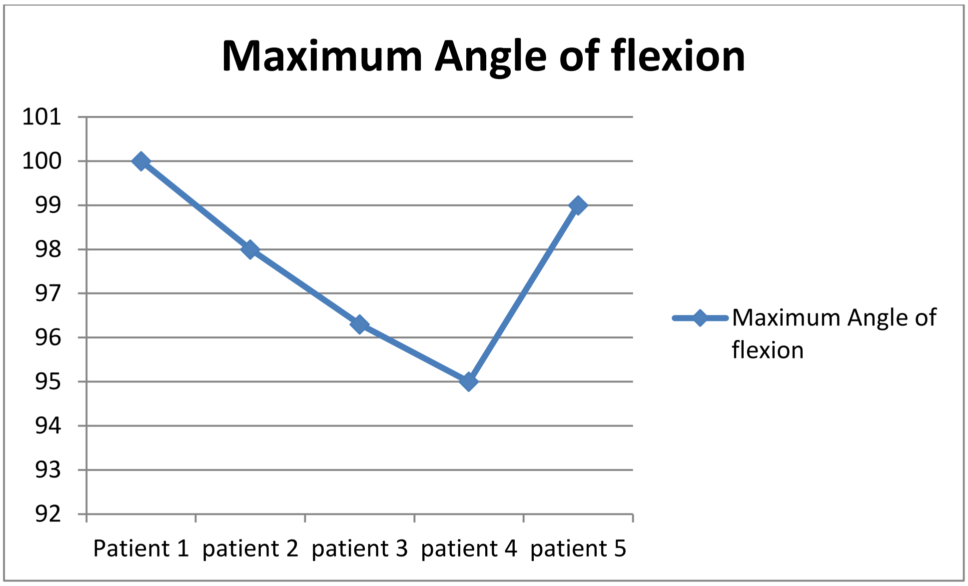
3.1 Result



Graph 3.1: Showing Angle of extension (in degrees) of the wrist on five subjects when the device is at rest.

Using the formular Mean = $\frac{\text{sum of all data points}}{\text{Number of data points}}$

$$\frac{35+33+31+34+30}{5} = 32.6$$



Graph 3.2: Showing Maximum Angle of flexion on five subjects with the brace on

Using the formular Mean = $\frac{\text{sum of all data points}}{\text{Number of data points}}$

$$\frac{100+98+96.3+95+99}{5} = 98.7$$

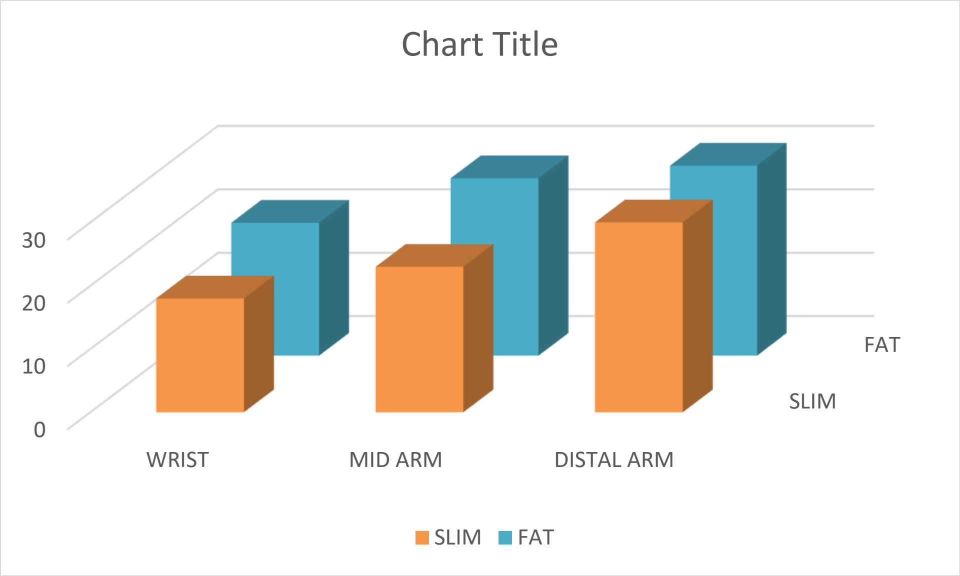


Figure 4.3: Graph showing for more than one patient; Blue = Fat, Brown = Slim

Plate 3.1: Fabricated Dynamic Adjustable Hand Splint

Plate 3.2a Splint on a Slim Patient

Plate 3.2b Splint on a Fat Patient

Plate 3.2c Splint on a Right Hand

Plate 3.2d Splint on a Left Hand

3.2 Discussion

The angle of extension in degrees obtained at normal wrist with our fabricated device when at rest and measured with a goniometer for 5 subjects range from 30^0 to 35^0 with mean of 32.6^0, (see graph 3.1) this result is consistent with conventional dynamic hand splints and is within the standard range of 29^0 t0 36^0 (McKee P. and Morgan L. 1998, Alsancak S. 2003, Lannin *et al.*, 2007). The result for the test for maximum Active Flexion using our device on 5 subjects when measured with a goniometer range from 95^0 with a maximum finger flexion of 100^0 (see graph 3.2). The mean of maximum active flexion was 98.7^0 this is also within the range of standard maximum flexion which, gives an idea of the quantity of rehabilitative force our device generates when the patient pushes the spring (Cheshire L., 2000, Chan R. K., 2002, Lannin N.A., Herbert R.D. 2003, Wright *et al*., 2005, Hammert W. C., 2016).

The elasticity of the spring was tested after maximum flexion test for the five patients (Bianca et al., 2018) by re-measuring the angle of extension of the spring using goniometer, an angle of 0^0 (Zero degree) was recorded by the goniometer, indicating that the springs were fully elastics even after the maximum 100^0 finger flexion range. Our device was applied to the contralateral forearm to determine whether the brace was ambidextrous as was intended, however, upon application to the contralateral forearm, the brace fitted well both on the left and right hand of the patient, hence, the device is not specific to any hand, making our device unique (See plate 3.2c and 3.2d).

The device was tested on patients to ascertain the adjustability (Chan R. K., 2002, Hammert W. C., 2016) in both length and width of the device in line with the standard of testing by sliding the extension bars up and down the slots on the plastic shell, it fitted two patients optimally and with the aid of an aluminum bar on the plastic shell it gave a good fit indicating that its adjustability is effective. It was also able to fit on either sides of the forearm as well as extends the fingers and thumb (See plate 3.2a and 3.2b). Our device also fitted two patients of varying body circumferences, although, it was adjusted to get an optimal fit for each of the patients by sliding the extension bars (See plate 3.2a and 3.2c). This indicates that our orthotic device (See plate 3.1) could be used by more than one patient as against the conventional dynamic hand splint that is customized for an individual.

CONCLUSION

Using locally sourced cheap materials, we fabricated an adjustable dynamic hand splint which presented angle of extension that range from 30^0 to 35^0 with mean of 32.6^0, and was able to achieve a maximum finger flexion of 100^0. The device fitted both left and right upper extremities and could be used by patients of varying body circumferences due to the possibility of adjusting its width and length. Although, conventional dynamic hand splint that is cast on the hand in functional position is between 30^0 – 35^0 of wrist extension, our device presented mean of 32.6^0 which is within the standard range, therefore, implying that our orthotic device is efficient.

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