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SEMI ACTIVE HAND ORTHOSIS

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ABSTRACT
This paper presents a semi active orthosis designed for recovering the mobility on a paralyzed hand because of a fifth cervical injury, C5. The orthosis is based on a six bar mechanism and a circular slide, using the hand as a part of the mechanism. Other similar devices were developed around the world, nevertheless this design is independent of an actuator, and can be used with or without one. As a result, the mechanism and tests with the user are presented; the user of the mechanism can hold different objects with his hand using the orthosis.

INTRODUCTION
The Mechanical Design and Technological Innovation Centre (CDMIT) of the National Autonomous University of Mexico (UNAM) has a research area focused on the design of upper limb prosthesis.

The human hand is a critical organ, its value resides on its ability to enable the human body to manage its environment, in a manner no other animal can. According to Schott (1), more than a quarter of the brain motor cortex is dedicated to it. Thus, it has been a relatively important subject for research, currently, the progresses reached on its study are applicable to industry, military, sports and medicine, the last one through biomechanics and kinesiology, plays a significant role in the development of the device presented in this paper.

A semi active orthosis used to treat arm diseases, specifically those known as brachial plexus paralysis was designed. The brachial plexus is a nervous assembly located at the lateral base of the neck; its main functions are motor innervation, sensory innervation and sympathetic innervation (i.e. sweat glands and blood vessels). Plexus injuries usually cause mobility loss, which includes elbow, forearm and hand paralysis. Plexus paralysis is commonly related to contact sports, birth complications, stab trauma and vehicular accidents; in adults, the majority of these injuries are caused by car accidents. According to the National Institute of Statistic and Geography of Mexico (INEGI) , between 2006 and 2012, there was an annual average of 435.330 terrestrial vehicular accidents, Narakas (6) states that 70% of brachial plexus injuries happen in vehicular accidents and that 70% of them are caused by motorcycle vehicles. An epidemiological study made by Midha (7) explains that brachial plexus injuries occur in 4.2% of motorcycle accidents. According to official numbers, just in Mexico accidents statistics of this type of vehicles, between 2006 and 2012, ranged from 28,000 to 52,000 cases, with an annual average of 36,000 cases. According to those numbers there are a range between 1,176 and 2,184 cases of brachial plexus injuries related with car accidents and motorcycles in Mexico.

There are many options of exoskeletons or orthosis for grasping assistance, the main idea is to promote the movement. The designed device has the advantage that during the grasp, the user can passively exercise his or her joints, bones, muscles through the links of the mechanism. Other devices paralyze the hand for making a support for a mechanical prosthesis; some others, like Jaeco's orthosis (2), tried to use only the index, middle index and thumb to give the user a hook structure for grasping task.

Active and passive orthosis has been developed for rehabilitation until now. The US patent US5103807 (3) uses nytinol wires to act the orthosis, this device holds and fixes the proximal phalange which is not as convenient as we wish, because that phalange allow us to mold the grasp, also the volume of the orthosis is significantly bigger than the hand, disappointing the user that needs it for performing daily tasks.

The exoskeleton hand system for index finger rehabilitation mechanism proposed in 2012 by Li (4) cannot be used out of a laboratory, this mechanism uses a linear slide on each phalange, which allows having more freedom for each movement; its design is too complex to use it on daily basis because of the kind of actuator used.

This paper presents the design of an orthosis that can be used by someone that has brachial plexus paralysis; the device uses a circular slide to adapt it better to the three arches of the hand, when the grasp task is performed. Its height above the hand is 3 cm, and uses the fingers to move and realize the grasp. The device was designed for rehabilitation or for assistance.

NOMENCLATURE

An orthosis is a device externally adapted to body and modifies some of its structural and functional features.

A prosthesis is a substitute's device of a body part and performs the task that is missing.

An orthoprosthesis is externally adapted to body but realizes the task that the body cannot do, can partially or fully retrieve lost functions. Also is named as dynamic orthosis.

ORTHOPROSTHESIS DESIGN

The procedures applied in all paralysis cases are virtually the same; therefore, it is necessary to establish treatment, monitoring methods and medical devices associated with the specific condition. In some cases there is no alternative for people with hand problems, even when some authors say that the use of dynamic orthoses (orthoprosthesis), may be useful for those people who have this kind of injury. These devices would be the key to reincorporate them in daily activities, recreational life, and considered as a therapy (13), (14).

A 43 years old woman with brachial plexus paralysis was the user for the design; she had never been able to use her hand for grasping something. She had several surgeries for fixing her arm at 90 degrees in flexion. Wrist and index cannot flex, her thumb is free to move, but the user does not have enough force to move it.

Fig. 1: Brachial plexus paralysis user's hand.

All orthoses available for that case, use or interfere with the user's palm, fix and/or blocks her fingers, are for rehabilitation and not for restore the grasping function. A prosthetic device was given to the user to replace the hand, but the user did not have the force to open it.

The main goal for this design was to restore the grasping function; this means that the orthoprosthesis must have a mechanism that generates the grip and passively exerts the force over the natural bone joints (19); particularly, the required movement involves flexion and extension of metacarpophalangeal (MCP) and proximal interphalangeal (IP) joints. Also this may be controlled in order to maintain the force (15), the mechanism should be installed on the index and middle fingers, otherwise space constraints were unable to be satisfied.

After an extensive testing process with patients, some criteria were generated from observation. These criteria were considered as design guidelines, they can be applied in the development of any other mechanism that performs similar tasks:

- There is a constrain of space on the wide direction, when fingers are closed for performing the grasping task, the mechanism must avoid collision with an adjacent finger.
- The bloodstream in fingers could not be blocked, so the mechanism cannot be held near the interphalangeal corners, as it could damage the user, deficient in people affected by brachial paralysis (21).
- The mechanism must be safely attached to the fingers, in a way that after performing the grasping function, it does not slide off.

The device was designed applying the graphical linkages synthesis method, with the support of CAD design packages under a procedure called Geometric Constrain Programing GCP, (22) (23). The method allowed to focus the creativity through the simplification of other, more analytical tasks, as those that deal with identifying space limits, mechanism mobility or detection of branch defects (15).

To achieve certain movements and fit to the user anthropometry (kinematic task), user's hand was modeled on CATIA. The model was used to intro the input parameters for the GCP.

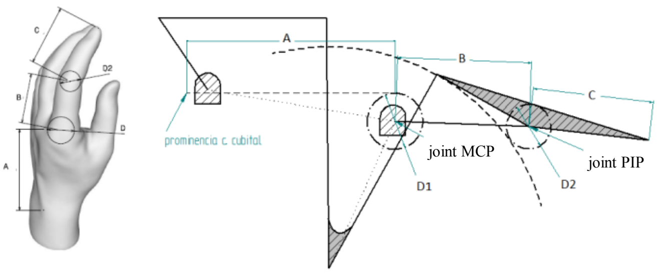

Fig. 2: User hand model.

The limits considered for the linkages were the fingers dimensions; joints also constrain the mechanism, as it is shown on Figure 2. Due to the fact that the finger trajectory in grasping is a curve, for the synthesis a circle define the position for the medial and distal phalanges. The fingers dimensions considered are shown in Table 1.

Table 1: Fingers dimensions in mm.

Finger	A	B	C	D1	D2
Index	68.2	42.2	24.5	21.1	17.5
Middle	69.4	43.9	31.4	22.1	18.2

Two positions were considered: open hand and cylindrical grasp. The dorsal hand was set as a fixed point, two of the tree phalanges were going to move like one link, but not fixed, as shown in Figure 2.

At the same time the GCP synthesis was defined, linkages were drawn in 3D. Constrains used were the most important for moving the mechanism as desired, the full analysis was presented in the Hand Orthoprosthesis design (5).

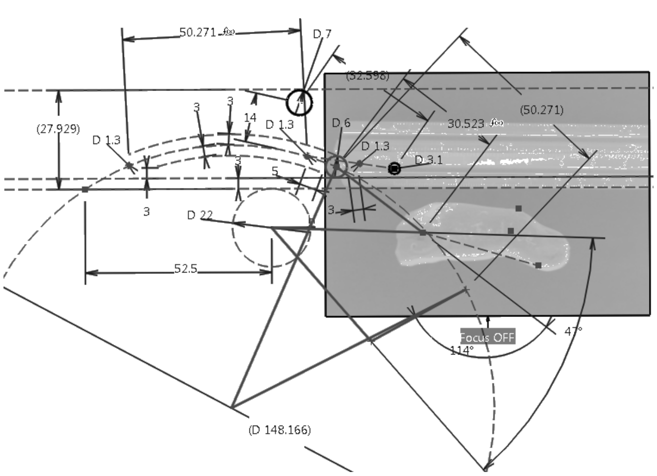

Fig. 3: GCP synthesis for mechanism.

Values from A, B, C and D were obtained from the considered dimensions of the index and middle fingers, because those were the ones that perform the grip. The flexion angle dimensions were obtained from MCP and IP joints. The circular slide parameters were CR and λ_{car}.

The ring and little fingers were aligned with a glove, for a posture correction of the deflected fingers. The thumb was fixed in front of the fingers for obtaining the palm grasp.

RESULTS

- The mechanism designed has an auto-locking linkage for the grip.
- The system has two defined positions: normally closed and auto-lock, what lets the user graduate the stress on her hand; it depending of the level of use that the therapist recommends.
- The user can hold several objects and different shapes, as shown in Figure 6.
- The designed glove is easy to wear; the user needs only a couple of minutes to wear it in her hand.

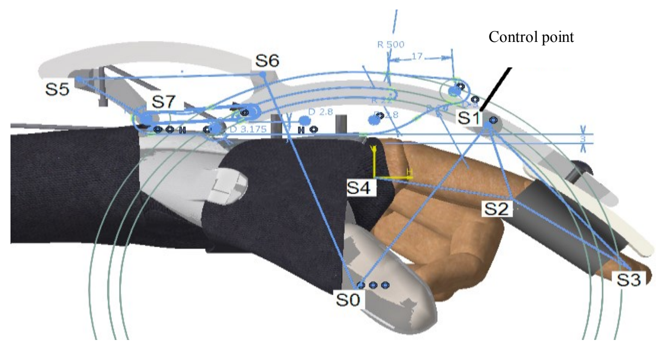

Fig. 4: Assembly model, mechanism and user hand.

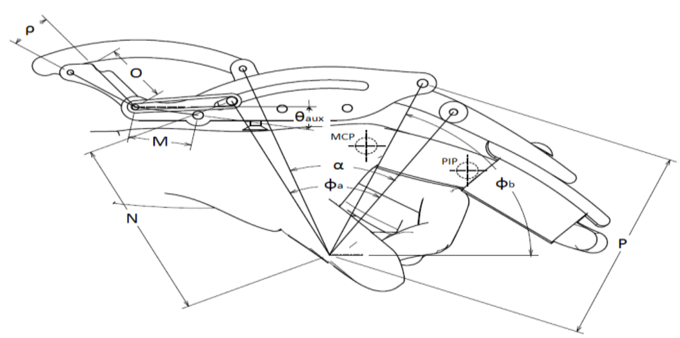

Fig. 5: Final mechanism and main dimensions.

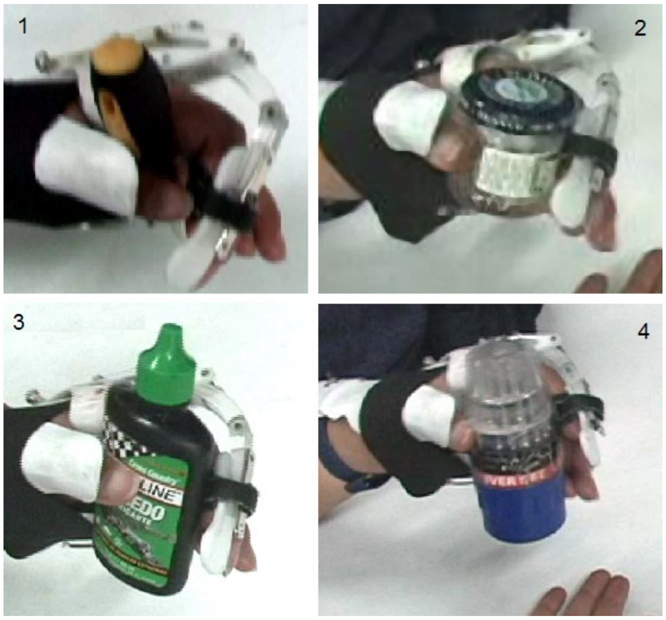

Figure 6: User grasping several things, 1. Screwdriver; 2. Cylindrical container; 3. Plane container; 4. Screwdriver kit.

DISCUSSION

A six bar mechanism with a circular slide was designed. The device does not block the user palm, and lets the user grasp different kind of shapes.

The mechanism can be blocked by the user to hold the objects.

The proposed mechanism keeps the fingers closed, this action allows the user to do a little force to open the fingers and the elastic band, which close the device, do the work for holding the object.

Grip strength became a requirement of great importance for the design of this device; it must be such as to allow a user to grasp objects with a minimum weight added by the orthoprosthesis (200 gr. is the maximum). We propose to increase the number of fingers involved in the action of the maximum clamp.

It is completely feasible assimilating the proximal and middle phalanx for orthoprosthesis operation; predominantly due to inconsistency of the bone structure in a user with obstetric brachial palsy, was thought to be not possible to use the same fingers to form the flexion-extension mechanism

The mechanism designed doesn´t require an adjustment to the interphalangeal joints centroids. This helps reducing design complexity (i.e. the number of parts is reduced), while the adaptability of the device is improved.

CONCLUSION

The designed device is useful for the user; she had never used her hand until she wore the orthosis.

According to the user's therapist, she can use the device almost all the time, and not only for rehabilitation therapy.

The device let the user to hold many thinks, but it is important not to exceed 1kg in weigh, because the mechanism will fail, that was a design parameter.

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REFERENCES

1. *Penfield's homunculus: a note on cerebral cartography.* **Schott, G. G.** s.l. : Journal of Neurology, Neurosurgery & Psychiatry, 1993, Vol. 54. 10.1136/jnnp.56.4.329 .
2. **Jaeco .** Jaeco Orthopedic. *Jaeco Orthopedic.* [Online] April 13, 2014. [Cited: April 13, 2014.] http://www.jaecoorthopedic.com/Manuals/JAECOCatalog2011Complete.pdf.
3. **Makaran, John.** *US5103807 A* US, 1992.
4. *Development of a hand exoskeleton system for index finger rehabilitation.* **Li, Jiting and Wang, Shuang and Wang, et al.** 2012, Chinese Journal of Mechanical Engineering, pp. 223-233.
5. **Torres-Martinez, Pol D.** *Diseño de ortoprótesis para mano.* Mexico : Facultad de Ingeniería, UNAM, 2012.
6. *The treatment of brachial plexus injuries.* **Narakas, AO.** 1985, International orthopaedics , pp. 29-36.
7. *Epidemiology of brachial plexus injuries in a multitrauma population.* **Midha, Rajiv.** 1997, Neurosurgery 40, pp. 1182-1189.
8. *Brachial plexus injury after robotic-assisted thoracoscopic thymectomy.* **Pandey, Ravindra and Elakkumanan et all.** 2009, Journal of cardiothoracic and vascular anesthesia 23, pp. 584--586.
9. *Functional outcome at 5 years in children with obstetrical brachial plexus palsy with and without microsurgical reconstruction.* **Strömbeck, Christina and Krumlinde-Sundholm et al.** 2000, Developmental Medicine & Child Neurology, pp. 148-157.
10. *Incidencia y factores de riesgo de trauma obstétrico en recién nacidos en el Hospital Regional General Ignacio Zaragoza agosto 2005-mayo 2006.* **Baños, Toscano, Contreras, Vazquez- and Trejo, San German.** 2007, Revista de Especialidades Médico-Quirúrgicas, pp. 32-36.
11. *Parálisis braquial obstétrica, Importancia de la utilización de un protocolo, diagnótico y terapéutico.* **Conde.** 2002, Bol Pediatr 42, pp. 106-113.
12. **Al-Mohanna.** Physical Therapy Management of obstetric brachial plexus injury. *Kuwuait University.* 2004.
13. *"Use of the dynamic movement orthosis of Prosthetics and Orthotics to provide compressive shoulder support form children with brachial plexus palsy.* **Yasukawa.** 2011, JOP Jour o Prosthetics and Orthotics, pp. 23(3) 159-164.

14. *Reconstructive operations for the paralyzed shoulder in brachial plexus palsy: concept of treatment.* **Rühmann, O and Goss, F and Wirth, CJ and Schmolke, S.** 1999, Injury 30, pp. 609--618.
15. **Norton, Robert L.** *Diseño de Máquinas* . s.l. : Pearson Prentice Hall, 1999.
16. **Kapandji, A. I.** *Fisiología Articular.* s.l. : Editorial Médica Panamericana, 2006.
17. **Nordin, Margareta.** *Basic biomechanics of the musculoskeletal system* . Philadelphia : LEA & FEBIGER , 1989.
18. **Emmet Holt, L. and Howland, John.** *Tratado de Pediatría vol. 1.* s.l. : Uteha, 1947.
19. *Finger exoskeleton for treatment of tendon injuries.* **Ertas, I.H., et al., et al.** s.l. : IEEE ASSP Magazine, 2009, IEEE ASSP Magazine, pp. 194-201.
20. **Stergiopoulos, P., Fuchs, P. and Laurgeau, C.** *Design of a 2-finger hand exoskeleton for VR grasping simulation.* Dublin : Eurohaptics, 2003.
21. **Emmet Holt, L. and Howland, John.** *Tratado de Pediatría vol. 1.* s.l. : Uteha, 947.
22. *Kinematic synthesis for finitely separated positions using geometric constraint programming.* **Kinzel, E.C, Schmiedeler, J.P. and Pennock, G.R.** s.l. : Journal of Mechanical Design, 2006, Vol. 128. 1070.
23. *Function generation with finitely separated precision points using geometric constraint programming.* **Kinzel, E.C., Schmiedeler, J.P. and Pennock, G.R.** s.l. : Journal of Mechanical Design , 2007, Vol. 129.