A Novel Automated Device for Jaw Rehabilitation

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***Abstract*— In this paper we discuss a possibility to create an automated device which purpose is human jaw rehabilitation in every degree of freedom. A problem of jaw rehabilitation after variety of surgical procedures is shown and discussed. Also, a list of currently available rehabilitation devices and methods are shown. The conclusion is presentation of a concept of a novel device along with first functional model along with forthcoming works and test.**

***Index Terms*—jaw rehabilitation, automated device, pneumatic propulsion**

I. Introduction

A lockjaw or trismus stands for inability of opening mouth of human caused by reflex muscle spasm of temporomandibular joint. While range of mouth opening for healthy adult is ca. 35-55mm, in case of lockjaw it decreases to couple millimeters only [1]. A lockjaw can be a result of multiple causes. In case of stemmatological procedures of teeth extractions it affects ca. 40% patients and should subsite on its own in 2-5 days after the procedure [2]. Lockjaw can also be caused by inflammation in the area of temporomandibular joint – this case covers 25% of patients. This ailment is also often caused by mechanical injuries, e.g. shocks or contusions. The research shown that lockjaw is present in ca. 33% patient harmed in mechanical way, e.g. as a result of working out [3].

According to the therapists the problem of inability to open mouth, even slightly results in a number of issues. Patient suffering from named trauma is unable to consume normal food, obviously, therefore it is necessary to provide him special nourishment, which of course causes a great inconvenience a generates additional treating costs to the hospital. It is worth mentioning that such patient who requires special treatment can seldom leave hospital earlier in order to continue the treatment at home. No need to mention that such prolonged stay in the hospital generates enormous costs to the facility and decreases its treating potential, as it limits the room for new patients. It can be concluded that providing a method of fast treatment to be used in presented cases is really desirable, both by the patients and the hospitals, as currently there is no complete solution to that problem.

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II. State of the Art

In case of lockjaw caused by an inflammation a pharmacological treatment is accessible. Yet, if lockjaw is caused in result of mechanical injury or tooth extraction, the full functionality of a jaw is being restored during rehabilitation process. It is done by increasing jaw's motion range by using special tools enabling mechanical opening of the jaw [1]. The motion capabilities of jaw must be taken into account while using such devices. Mentioned motion capabilities can be divided into three motion types which can be described in following planes [4]:

- Frontal (up-down motions),
- Transverse (side to side motions),
- Sagittal (towards – backwards motions).

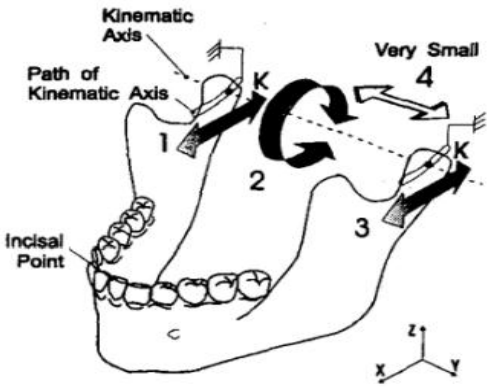

Figure 1. Heister jaw opener [5]

According to Okino [5] [human jaw possess 4 degrees of freedom (DoF), which means that in order to perform a complete rehabilitation process, the device that is to be used to perform rehabilitation should be able to enforce the motion of the jaw in all these DoF. Such device should also provide smoothness of all rehabilitation motions and the ability to change the their operation range easily, as – like was mentioned before – in the initial stage of treatment process, the patient is able to open his mouth by only couple of millimetres. If such device enforced patient's jaw to open completely, it would cause trauma, a lot of pain and could easily damage not fully treated tissues. The last feature that such device should possess is the ability to be controlled by the patient himself, as

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currently the rehabilitation process requires the therapists to be present, which obviously elongates rehabilitation process of all patients as the number of personnel is really limited in many cases. If the rehabilitation device could be controlled solely by the patient, a number of therapies could have been done in the same time. In such case the patient should also be able to easily stop the rehabilitation process in any time, as soon as pain caused by the process becomes unbearable.

The following sections provide the survey of currently used jaw rehabilitation instruments and techniques including their advantages and disadvantages.

A. Spatulas Insertion Based Rehabilitation

The most common type of trismus treatment is done with wooden spatulas (Fig. 2) [6]. In this form of exercise, patient puts two spatulas between teeth. Then, there are placed additional spatulas between already stacked, to keep the mouth open. The number of used spatulas is controlled by patient to increase opening range of the mouth and depends on condition and advance level of the therapy. This form of the therapy is the most accessible and cheap, yet provides little control and repeatability of the rehabilitation process and uses patient's teeth as a lever to generate jaw's motions, which may result in enamel damage in longer term.

Figure 2. Wooden spatulas

B. Screw Based Rehabilitation

Threaded tapered screw (Fig. 3) [7] is a device which resembles the toy Top. This item, placed between the patient teeth and turned gradually allows spreading the teeth apart. The force used to open the mouth is controlled by the patient. However, the acrylic resin which the item is made of combined with the high values of generated forces can cause damage or loss of teeth on prolonged use.

Figure 3. Screw [8]

Another device used by therapists in order to perform rehabilitation can be done by Heister Jaw Opener (Fig. 4)[8]

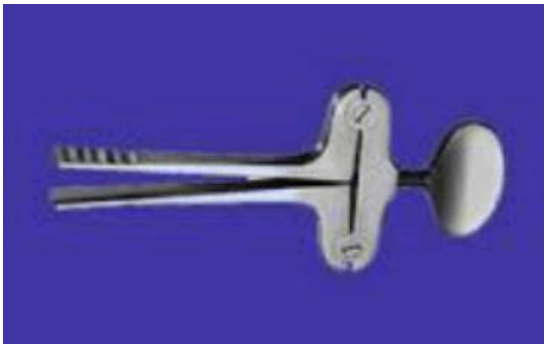

Figure 4. Heister Jaw Opener [8]

During the procedure, tips of the device are being inserted between patient's teeth. Next, these tips can be moved away from each other by making turn of the handle – number of turns corresponds to the distance between tips. The applied force can be easily controlled by turns ratio, yet the device is unlikely to be used without help of the therapist. Also, previously stated problem of damaging teeth remains unsolved.

The general problem of all devices and methods named in this section is that they can enforce jaw motion in only one DoF and require a lot of long and monotonous procedures to repeated aver and over again for really long time. Yet, it needs to be mentioned that despite the presence of named issues these techniques are widely used (especially the last one) by the therapists and are desired by the patients as they still decrease convalescence process.

C. Commercially Available Rehabilitation Devices

The most known device available in the market is TheraBite [9]. The device consists of two plates to be inserted between patient's teeth and a lever (Fig. 5).

Figure 5. TheraBite device [9]

After both plates are inserted inside patient's mouth, rehabilitation process is being done by pressing the lever. It results in moving plates away from each other pushing resulting in jaw movement.

Such rehabilitation method is characterized by a limited effectiveness as it is nearly impossible to obtain a swift and repeatable motion while using manual lever. Additionally, a limited motion range to be obtained by the device can cause rehabilitation process elongation.

Another drawback is the fact that device can cause jaw motion in only one plane – other directions are not to be obtained.

The pointed problem of non-smooth motion has been solved by the device shown in [10], where away motion of plates is being controlled with air pressure supplied by the syringe (Fig. 6).

Figure 6. E-Z Flex II TMJ Exerciser [10]

Yet, the problem of the possibility of damaging patient's teeth is still present in that solution. The main problematic feature in this case is the fact that each of presented devices base on pushing away teeth, while only couple of them are being used.

The solution to this issue can be found in [11] where it is necessary to create patient's teeth cast. This cast is also equipped with soft pneumatic actuator (SPA) that can be inflated in order to move to casts away each other (Fig. 7).

Figure 7. SPA device [11]

The problem with this device is that rehabilitation motion is again performed in only one plane, or combination of two planes – that depends on bellow deformation and cannot be controlled in any way.

D. Robotic and Exoskeleton Devices

In order to adapt real patient's natural jaw motion, there was developed the 6-DOF parallel robot WY-5 (Fig. 8). This is a master-slave system [12, 13], which consists of two parts. First is the patient manipulator, build of an u-shaped effector inserted to the patient mouth and controlled by six linear actuators. The second part is doctor manipulator used to control the patient manipulator. The doctor manipulator obtains only 2 DOF so allows only open-close and forward-backward movement of the jaw. During the rehabilitation process, the values of displacement obtained by doctor manipulator are sent to patient manipulator. Then, the force information from patient manipulator is sent back to doctor manipulator in order to control the biting force values and protect the patient. Despite of the effectiveness of the system, WY-5 requires full participation of the therapist in rehabilitation process, what is an obstacle due to the limited number and availability of therapists.

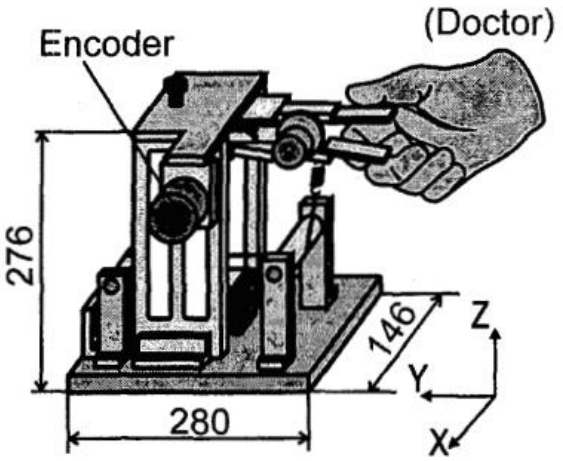

Figure 8. 6-DOF parallel robot - doctor manipulator [12]

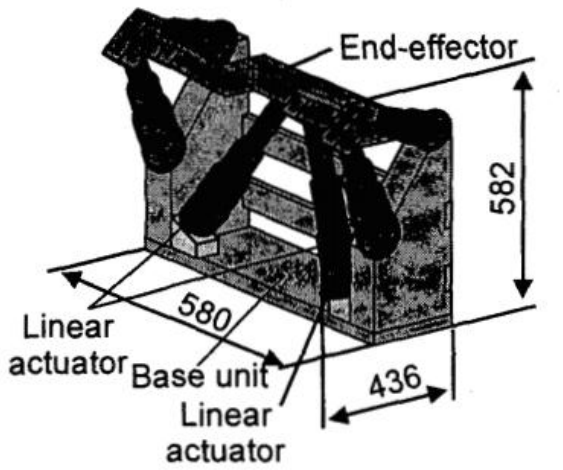

Figure 9. 6-DOF parallel robot - patient manipulator [12]

Another type of devices which can be used for rehabilitation are exoskeletons. A Shoulder-Mounted Robotic Exoskeleton [14] is a device which allows jaw motion in two degrees of freedom using geared DC motors. The exoskeleton is mounted to human body by bracing system (Fig. 10). The system provides a control of the amount of applied force and the rehabilitation process is controlled by therapy routines, which can be reprogrammed based on range of motion and required difficulty level.

Figure 10. The exoskeleton [14]

As the control system of the robotic and exoskeleton devices is the most complex issue, due to patient's personal limitations of jaw mobility range, there was proposed the neurological rehabilitation of lockjaw. The exoskeleton [15] is provided with EMG sensors which detects jaw movements by capturing brain and muscle signals. Then, achieved values are adjusted to required level and given to servomotors which rotates the jaw. However, these perspective exoskeleton solutions are just concepts and cannot be considered as devices for common use.

Figure 11. The EMG exoskeleton [15]

A proper rehabilitation should enable smooth motion in each of named planes in order to restore full functionality of jaw motions. Yet, because of a complex nature of jaw motions, there is no device enabling jaw rehabilitation in full extent, as shown above. It results in rehabilitation process taking longer than necessary as availability of therapists and devices is very limited.

III. A New Type of Device Development

In order to eliminate all the drawbacks of existing devices and to enlarge motion range, a complex device of human jaw rehabilitation has been designed in Institute of Machine Tools and Production Engineering of Lodz University of Technology. There are no mechanical levers used in case of this device – instead a pneumatic propulsion system was introduced. The recent research conducted in the Institute showed that pneumatic-based devices [16] are promising in medical robotics field [17].

The novel device (Fig. 12) consists of movable frame with a system of pneumatic actuators and custom made pneumatic bellows. The frame of the device can be divided into two parts: upper one (1) and lower one (2) which are connected by 3 DOF joints. It enables the independent motions of both frame elements in all three planes of jaw. Both parts of frame are equipped with insert plates (3) that are fitted to shape of human jaw and are to be placed between patient's teeth. Between these plates pneumatic bellows are present. Pneumatic actuators (5) are fixed in a way that enables independent motion of both frame elements. Back part of actuator frame is connected to insert plate of upper part of frame by spherical joint. Piston is connected to lower part of frame with ball joint. During the rehabilitation process the device is being placed on patient's head in order to align insert plates with teeth line.

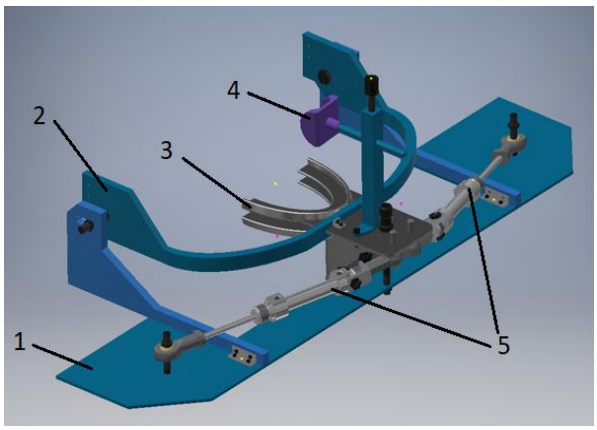

Figure 12. Human jaw rehabilitation device; 1) upper frame, 2) lower frame, 3) teeth insert plates, 4) positioning cap, 5) pneumatic actuators

After that device position is being aligned by strips and positioning cap (4) that needs to be placed on the bridge of the nose.

The prototype of pneumatic bellows was created based on technology developed during works on Transversal Pneumatic Muscles [18]. The bellows were designed to fit molar teeth area and created with use of composite material made of polyester fabric with silicone layer attached. The bellows can be seen in Fig. 13. As assumed it can be inflated with air, which source is a hand manual pump.

Figure 13. Pneumatic bellow prototype

Basing on the designed 3D model, a functional one has also been created using 3D printing techniques (Fig. 14). This model serves as a technology demonstrator that shows the range and types of motions to be achieved during the rehabilitation. It was also used to perform a preliminary test to prove the correctness of project assumptions and appropriateness of actuation method selection.

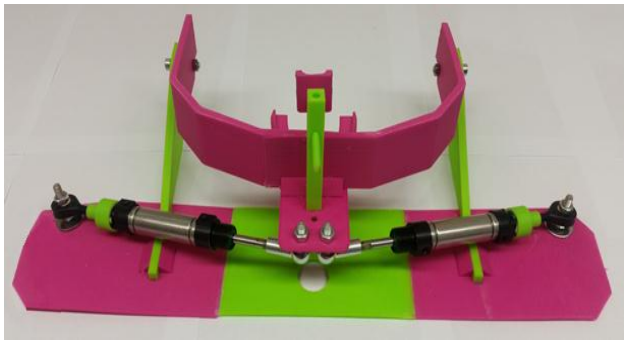

Figure 14. The functional model of human jaw rehabilitation device

Performed tests had proven that it is possible to use the designed device for jaw rehabilitation in all three planes of motion. Motions can be done independently and it is possible to control their smoothness because of using pneumatic-based propulsion system. Because of fact that jaw motion during rehabilitation process is forced by insert plates the possibility of damaging teeth is minimal. Also, preliminary tests show that selected techniques will provide enough amount of force during the rehabilitation – its value was determined during interviews with therapists and jaw surgeons, who defined the necessary values as 80N. The specified value has also been confirmed in [19].

IV. Further Works

The functional model will be created one more time using stainless alloy. Such device will serve as a test stand which will enable the possibility of determining important factors, such as: maximum applicable force, the dependency between inflation rate and generated force, possibility to generate force in each of the planes, etc. The stand will also under go strength and earing tests. It will also be introduced to the surgeons and therapists in order to obtain suggestions for development. Basing on these a prototype will be created and tested on humans.

V. Summary

As shown in the paper, the problem of human jaw rehabilitation exists and has not been solved. There is a number of methods and devices to perform such procedure, yet none of them provides possibility of a complex jaw rehabilitation. They lack safety factor, possibility to move in each plane, ability to perform smooth and repeatable motions, etc. The solution to all these problems is possible and available as stated above – the functional model has been designed and created using 3D printing techniques. It provides the possibility to verify necessary motion range and shows the variety of forthcoming tests to be performed. Type and characteristics of these tests were presented.

Conflict of Interest

The authors declare no conflict of interests.

Author Contributions

Katarzyna Koter proposed a construction of the device, propulsion system, conducted bibliographical research and partly wrote the paper.

Paweł Żak performed interviews with surgeons and therapists in order to collect data on problem and solution methods and partly wrote the paper.

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