Mesh three-dimensional arm orthosis with built-in ultrasound physiotherapy system

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Abstract. The possibility of using the built-in ultrasound physiotherapy system of the hand orthosis is explored in the work. The individual mesh orthosis from nylon 12 was manufactured by the 3D prototyping method on the installation of selective laser sintering SLS SPro 60HD. The applied technology of three-dimensional scanning made it possible to obtain a model of the patient's hand and on the basis of it to build a virtual model of the mesh frame. In the course of the research, the developed system of ultrasound exposure was installed on the orthosis and its tests were carried out. As a result, the acceleration of the healing process and the reduction in the time of wearing orthosis were found.

Introduction

In recent years, 3D printing technologies are increasingly being used in medicine. Additive technologies are widely used in neurosurgery, dentistry, traumatology, orthopedics and many other areas [1],[2],[3],[4],[5],[6]. One of the widely used orthopedic devices is orthosis.

Orthosis is a special device designed for unloading, fixing, activating and correcting the functions of a damaged joint or limb. It is used for instability of the ligamentous apparatus of joints, trauma in sports, arthrosis and arthritis of joints, in the postoperative period. Until recently, the solution of such conditions was the imposition of a plaster bandage. Orthoses made with the help of 3D-technologies have significant advantages over the old methods, namely before the traditional gypsum bandages.

The disadvantages of gypsum dressings are primarily its mass, they are quite heavy. Plaster bandages are hygroscopic, which causes the patient does not come into contact with moisture. Over time, the plaster grows old and begins to crumble. When wearing a cast plaster, there is a risk of abrasions and diaper rash. With a sharp squeezing of the limb improperly impregnated plaster bandage sometimes there is a breakdown of the nerve function. It is manifested by certain types of paralysis, which are difficult to treat. Finally, a long immobility in the joints causes wrinkling of the bag and ligamentous apparatus and changes in articular ends, which leads to a sharp decrease in mobility and soreness in the joint when moving. Due to inactivity of muscles and insufficient blood supply, their sharp atrophy sets in, and only after a certain time after removal of the bandage return normal working capacity. Orthoses are much easier, less restrict the patient's movements, are not afraid of water and are hygienic. However, orthoses do not affect the speed of healing of tissues and bones and do not shorten
the period of treatment. At the moment, the acute issue is to find methods to increase the speed of rehabilitation and return the patient to an efficient state. One of such methods is the use of physiotherapy. The most effective method of physiotherapy is considered to be ultrasound physiotherapy. Physiotherapy by ultrasound is caused by mechanical, physicochemical and thermal effects caused by it. Ultrasound performs microvibration, performs massage at the cellular and subcellular levels. This stimulates the function of cellular elements and the whole cell, leads to an increase in the permeability of cell membranes, rupture of weak bonds, a decrease in the viscosity of the cytosol, a change in microcirculation, loosening of connective tissue, acceleration of diffuse processes. The physicochemical effect of ultrasound is also determined by mechanical resonance, under the influence of which the movement of molecules is accelerated, their decay into ions is increased, new electric fields are formed, free radicals appear and various products of sonolysis of biological solvents. Electronic excited states arise, lipid peroxidation is activated, enzymatic activity and mitochondrial activity are changed, physicochemical and biochemical processes in tissues are stimulated, metabolism is activated, the amount of prostaglandins of the P2a group increases, the pH of the tissues is increased, BAS-histamine, serotonin, heparin are released from mast cells. Ultrasound stimulates tissue respiration and oxidative processes in tissues, has a normalizing effect on carbohydrate, fat and mineral metabolism. These changes largely determine the stimulating effect of ultrasound on the processes of physiological and reparative regeneration. Due to the above properties, ultrasound under certain conditions may have analgesic, antispasmodic, anti-inflammatory and bactericidal effects. The use of ultrasound can be combined with other types of therapy. Ultrasound accelerates the processes of regeneration and repair, restoration of conduction of nerve fibers in peripheral nerve injuries, resorption of infiltrates, traumatic edema, exudates and hemorrhages, has anti-inflammatory (secondary effect), analgesic, ganglion blocking, spasmolytic, metabolic, hypotensive, desensitizing, fibrinolytic, defibrizing and bactericidal action, increases the adsorption properties of the skin and enhances the adaptive-trophic processes in the body and the regional blood flow. At the moment, patients can undergo physical therapy in the hospital and only a specific course.

The aim of the work was the use of additive manufacturing technology in the process of creating an individual model of the orthosis with integrated ultrasound generator. The product was manufactured on an SLS unit (selective laser sintering). As a result, based on the scanning and 3D modeling of the patient’s arm, an individual arm orthosis was made. The ultrasonic generator was installed in the orthosis. A study was conducted to describe the results and justify the benefits. The practical application of this model of orthosis by different groups of patients was studied. As a result, it has been established that the orthosis, in which the ultrasonic generator is integrated, significantly alleviates the condition of the patients after injuries and fractures, and allows to shorten the period of the latch wear. The most optimal course of treatment was daily therapy with ultrasound 3 times a day for 15 days.

The process of creating an orthosis model consists of several stages. The first step is to scan the patient's hand. Scanning is performed using the Artec Eva device (Fig. 1). The scanner makes it possible to obtain a mathematical model of a solid object. The technology of three-dimensional scanning, used in this scanner, allows to extract information about the surface of objects (depth) with high accuracy and speed, using the principle of structured illumination. All data is obtained by projecting a special grid at the parallax angle to the scene objects. Distortions of the projection of the lattice, created by the geometry of objects, allow to calculate the exact position of each of its points in three-dimensional space. The resulting points are triangulated to form a polygonal surface that can be represented in any of the common formats. Texture camera, synchronized with the wide-field 3D-sensor, allows you to simultaneously remove the surface texture of the object.
At the second stage, 3D modeling of the orthosis is carried out. For this, 3DS max, Meshmixer, Netfabb were used. We get the 3D model of the patient's hand (Fig. 2). After that, we make the 3D model of the orthosis in the program. (Fig. 3)
The finished 3D model of the orthosis is started to be printed on the SLS SPPro 60HD device. The product prints last 7 hours. After this, the finished product should cool down. It takes about three hours. After the product has cooled, it is necessary to get rid of excess powder by sandblasting. We get the finished orthosis model.

The orthosis itself is made of polyamide Nylon 12 (Fig. 4). The dimensions of the product are selected individually for each patient. It consists of two devices: an orthosis for fixing the limb and an ultrasonic generator with a detachable speaker, for directional action of ultrasonic waves. The orthosis consists of two parts connected by two cable ties (Fig. 5).

Fig. 4 Orthosis from polyamide Nylon 12

Fig. 5 Two parts of the orthosis, fastened with clamps

To accelerate the healing processes, it was decided to install an ultrasonic generator into the orthosis. The ultrasonic generator is assembled according to the following electrical scheme (Fig. 6).

Fig. 6. Scheme of ultrasonic generator
The radiation power should be 0.2 W/cm². The pulse frequency is 1.5 MHz. The obtained system is attached to the finished orthosis by means of a special bracelet.

To substantiate the benefits, practical experience in using this orthosis model and describing the results obtained is important. For this, three groups of patients with diaphyseal fractures of the upper extremities were selected. The first group used an orthosis with physiotherapy ultrasound daily in unlimited quantities. The second group of patients used orthosis every day 3 times a day for 15 days. The third group of patients used orthosis every day 1 time per one for 15 days. The fourth group of patients were impregnated with gypsum bandages. Ultrasound physiotherapy in this group was performed in the hospital once a day, for 15 days. The duration of the procedure for the second, third and fourth groups of patients increased gradually every day, ranging from 5 minutes with a gradual increase to 15 minutes. All manipulations took place under the supervision of specialists. For treatment, small doses of ultrasound (up to 1.2 W/cm²) were used.

The first group of patients on the third day of therapy had a feeling of malaise. Disturbed headaches. Patients noted sleep disturbances and lack of appetite. This group discontinued ultrasound treatment immediately. Despite this, patients noted a significant analgesic effect and a decrease in edema at the site of the fracture on the first day of treatment.

The second group on the second day noted a decrease in swelling of the tissue at the site of the fracture, an analgesic effect. Due to the physico-chemical effects of ultrasound, experts noted the intensity of tissue redox processes, the increase in the formation of biologically active substances - heparin, histamine, serotonin. The nutrition of the tissues at the fracture site was improved, which allowed to avoid atrophy of the muscle tissue. Complete fusion of bones in this group of patients occurred in the interval from 20 to 28 days.

The third group achieved similar results. Anesthetizing effect patients of this group felt on the 5th-6th day of therapy. Edema was eliminated on day 5 of therapy. Improvement of blood circulation specialists noted on day 7. The period of complete bone fusion this group of patients achieved more than 45 days.

Patients of the fourth group did not complete the course of treatment with physiotherapy. The treatment was intermittent, due to the complexities of wearing the plaster bandage (crumbling of gypsum, the appearance of diaper rash). Those patients who completed the course fully noted the analgesic effect only after the 7-9 course of physiotherapy with ultrasound, puffiness passed after 10-12 courses. Complete fusion of the bone in the fracture site took more than 60 days.

Data on the results of the study are given in Table 1.

|                        | 1st group | 2nd group | 3rd group | 4th group |
|------------------------|-----------|-----------|-----------|-----------|
| Number of exposures per day | Unlimited | 3 times a day | 1 per day | 1 per day |
| Removing the pain syndrome (on what day) | 1st day | 2nd day | 5-6th day | 7-9th day |
| Reduction of swelling of the tissues (on what day) | 1st day | 2nd day | 5th day | 10-12th day |
| Increase in the formation of biologically active (on what day) | No | 4-5th day | 8-10th day | 20th day |
Improvement of blood circulation

|                  | No  | 3rd day | 7th day | 10th day |
|------------------|-----|---------|---------|----------|

Complete fusion of bone

|                  | No  | 20-28 days | >45 days | >60 days |
|------------------|-----|------------|----------|----------|

Side effects

|                  | Feeling of malaise, headaches, sleep disturbance and lack of appetite. | No | No | No |
|------------------|------------------------------------------------------------------------|----|----|----|

Table 1. Description of research results.

Thus, it can be concluded that the orthosis, in which the ultrasonic generator is built in, significantly alleviates the condition of patients after injuries and fractures. It gives an opportunity to conduct a course of treatment without leaving home. The period of wearing the latch is greatly reduced. This model of orthosis allows in the shortest time possible to reduce the swelling of the tissue, reduce the pain syndrome and improve blood circulation. The most optimal course of treatment was daily therapy with ultrasound 3 times a day for 15 days.

References

[1] Kashapov R N, Korobkina A I, Platonov E V, Saleeva G T 2014 The method of manufacture of nylon dental partially removable prosthesis using additive technologies *IOP Conference Series: Materials Science and Engineering* Volume 69 (1) 012026

[2] Kashapov L N, Rudyk A N, Kashapov R N 2014 Applying 3D-printing technology in planning operations of cancer patients *IOP Conference Series: Materials Science and Engineering* Volume 69 (1) 012016

[3] Kashapov L N, Kashapov N F, Kashapov R N, Pashaev B Y 2016 The application of additive technologies in creation a medical simulator-trainer of the human head operating field *IOP Conference Series: Materials Science and Engineering* Volume 134 012011

[4] Akhmetov I D, Kashapov N F, Kashapov R N 2014 Modernization of clamping unit of draft of endosurgical monopolar forceps *IOP Conference Series: Materials Science and Engineering* Volume 69 (1) 012002

[5] Kashapov R N, Khusaenova E L P, Faizrakhmanov I A, Kashapov L N 2016 Ion-Beam Treatment of Glass Substrates for Creation of Biomatrices *Indian Journal of Science and Technology* 9(18) 5

[6] Gavrilova V A, Kashapov N F, Kashapov R N 2011 Plasma application of protective polymer-powder coatings to ultrasonic sensors *Biomedical Engineering* Vol 45 Iss 5 pp 198–200