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NEW ALGORITHMS OF HIGH-FREQUENCY WELDING OF BIOLOGICAL TISSUES*

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Studies of the influence of new algorithms for welding biological tissues on the temperature parameters of the process in the weld zone and the biophysical and structural characteristics of the tissues being welded using the advanced control system of EKVZ-300 series apparatuses have been carried out. The effect of new experimental algorithms for high-frequency welding of biological tissues on the temperature parameters of the process and the characteristics of tissues of various types in the seam area was studied. 9 Ref., 6 Figures.

Keywords: *high-frequency welding, biological tissues, EKVZ-300 «PATONMED» apparatus, welding algorithms, process temperature values, structural and biophysical changes in tissues, research complex*

Beginning from 2002, the technology of high-frequency (HF) welding of biological tissues using the apparatuses developed at PWI has been extensively used in surgical practice in medical establishments of Ukraine. This technology offers significant advantages, compared to other processes during performance of even the most complicated operations [1–5].

At the same time, continuous improvement of the available and development of new algorithms of the process and appropriate equipment for their realization are required for further development, expanding the application areas and improvement of the effectiveness of high-frequency technology application in the surgical practice. In this connection, performance of integrated studies of structural and biophysical characteristics of the seam zone, as well as temperature values of the process of joining and treatment of biological tissues under the impact of high-frequency current supplied by different algorithms, is certainly timely.

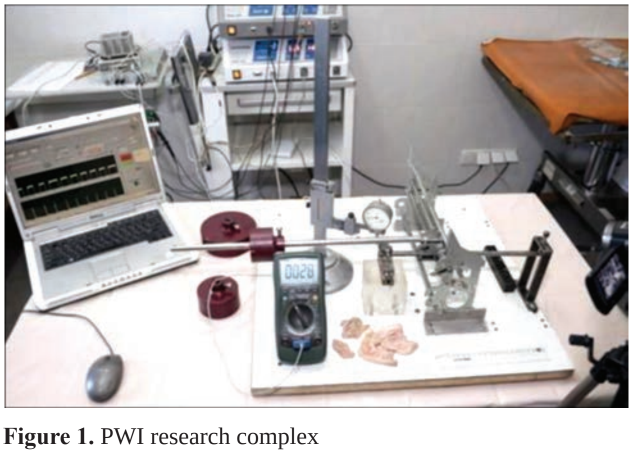

Figure 1. PWI research complex

The objective of this work is studying the influence of new experimental algorithms of HF welding of biological tissues on temperature values of the process, change of tissue characteristics in the seam zone, as well as documenting and analysis of the advantages of application of the developed algorithms, compared to those currently used.

The objects of study were removed pig organs, namely small and large intestine, stomach, bronchi, etc.

Experiments were conducted in an all-purpose research complex (Figure 1) [6–8], which consisted of:

- upgraded apparatuses of EKVZ-300 type with enhanced technological capabilities — special control system and software, ensuring realization of both standard welding algorithms, and new ones, making a special kind of energy impact on the object of study;
- specialized research stand, fitted with different basic and experimental electrodes (Figure 2);
- working bipolar tools and their mockups;
- measuring and recording equipment.

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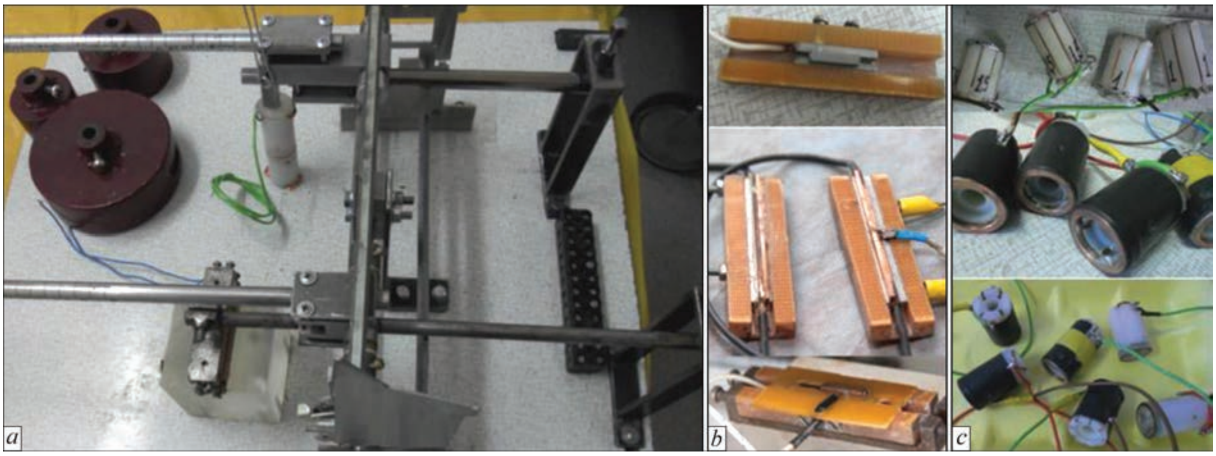

Figure 2. Specialized research stand (*a*), linear (*b*) and ring (*c*) electrodes

This complex, which is being continuously upgraded and improved, enables conducting extensive research of the process, in particular studying the impact of the following characteristics on its temperature values, biophysical and structural properties of different biological tissues in the seam zone:

- different welding algorithms;
- specific pressure of electrodes on the tissues being welded (in the range from 0 up to 4 N/mm^2);
- diverse tool designs with electrodes of different geometry (electrode area in the range from 2.0 to 270 mm^2).

During this series of experiments both the main electric and mechanical (specific pressure, etc.) characteristics of the process, and tissue temperatures directly in the seam zone, were recorded. Temperature measurement was performed by insulated thermocouples that were mounted into the electrode body and were in direct contact with the material being welded. At the same time, temperature was controlled by a contactless method with a thermovision camera.

Studies were conducted using both defined in previous work and new variants of the algorithms that should provide sound welded joints at shortening of the extent of the HAZ, lowering of process temperature, absence of charring in the seam zone and HAZ and absence of tissue «sticking» to the electrodes [9].

When testing the welding algorithms for evaluation of the joint quality and studying the biophysical and structural characteristics of the tissues, visual estimation, mechanical and hydraulic testing, as well as histological studies were performed. The results of experimental studies performed on removed small intestine and bronchi of a pig are partially presented below.

Testing of new welding algorithms was performed at linear welding of small intestine of a pig (0.6–0.8 mm wall thickness, 25–28 mm diameter) in an upgraded stand by an experimental bipolar clamp with electrodes of 45 mm^2 area; interelectrode gap of 0.05 mm, and specific pressure between the electrodes of 2.6 N/mm^2.

Given below are the results obtained when studying the impact of the developed new welding algorithms, according to which the set voltage was supplied as modulated pulses of a set duration, equal to 0.1 and 1.0 s. Here, the value of voltage and total duration of its feeding remained unchanged in both the cases.

During testing of both the variants of the algorithms a linear welded joint of small intestine formed between the bipolar electrodes without evolution of vapour or fumes, without «sticking» of tissues contacting the electrodes or of the tissues in the seam zone. By visual estimation and results of mechanical testing of the welded joints of studied tissues of small intestine, when using the above algorithms a sound, strong, elastic, continuous and sealed welded joint was produced. The tissue was of the same colour against the light over the entire area of the seam. There was no deformation, charring or spasm of the tissues in the seam zone and HAZ. The formed seam did not have any perforations, and consisted of a continuous homogeneous tissue.

The process of welding the experimental samples of small intestine using the above algorithms took place at temperature which was not higher than 60–70 °C under the experimental conditions and was significantly lower than that at application of earlier used algorithms.

Figure 3 gives the temperature values of the process at testing new experimental algorithms of small intestine welding (No.1 — duration of pulses and pauses of 0.1 s; No.2 — duration of pulses and pauses of 1.0 s) and standard (traditional) algorithms (No.3 —pulse duration of 1.0 s, pause duration of 0.2 s; No.4 — pulse and pause duration of 0.2 s).

It should be noted that increase of pulse length from 0.1 s (algorithm No.1) to 1.0 s (algorithm No.2)

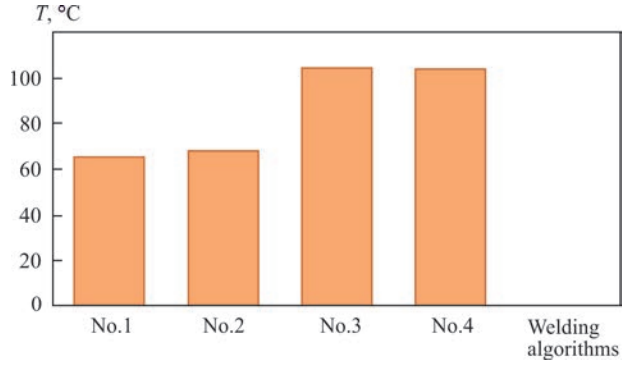

Figure 3. Average temperature values of the process of small intestine welding under the conditions of application of new experimental (Nos 1, 2) and traditional (Nos 3, 4) algorithms for small intestine welding

in experimental algorithms, at other conditions being equal, practically did not influence the temperature values under the experimental conditions.

Similar results were obtained at welding small intestine of a pig (wall thickness of 0.8–0.9 mm), using experimental algorithms with a standard bipolar clamp (electrode area of 70 mm^2 without interelectrode gap) at an essentially smaller (0.46 N/mm^2) specific pressure between the electrodes.

In this case a standard bipolar clamp, additionally fitted with an insulated thermocouple that was in direct contact with the tissue being welded, was used for experiments. Specified pressure was ensured using a system with a preset force.

Application of experimental algorithms, compared to standard ones, also allowed a significant lowering of the process temperature values. Temperature in the seam zone was not higher than 70 °C.

Based on visual estimate and mechanical testing results, against the background of lowering of temperature parameters of the process, the proposed algorithms provided sound and strong joints with improved biophysical characteristics of the tissue in the seam zone and reduced HAZ (Figure 4).

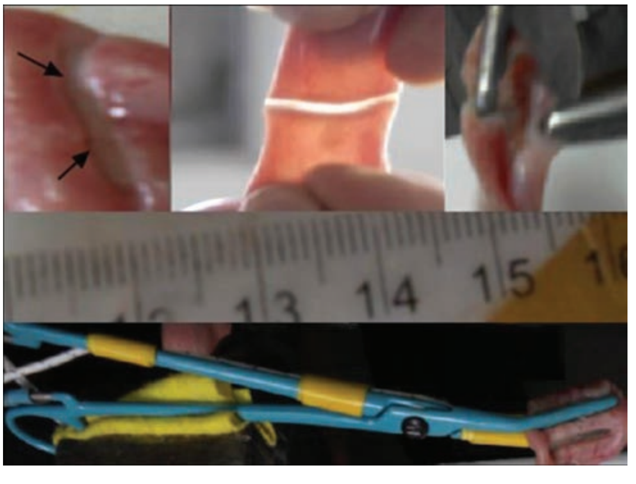

Figure 4. Welded joint of small intestine produced using modulated pulses. Welding was performed with standard bipolar clamp (electrode area of 70 mm^2, specific pressure between the electrodes of 0.46 N/mm^2, without electrode gap), additionally fitted with a thermocouple

Other experimental material used to conduct experimental work, were the removed bronchi of a pig (wall thickness of 0.5–0.7 mm, diameter of 6.0–6.5 mm). The area of stand electrodes and the clamp was 45 mm^2, interelectrode gap was 0.05 mm, and specific pressure between the electrodes was 2.6 N/mm^2.

The proposed algorithms allowed an essential shortening of the total time of HF current action on the tissue, obtaining sealed closure of the bronchi and lowering the temperature values of the process. Application of the new welding algorithms of the total duration from 0.1 to 2.0 s yielded better results of the process temperature values, compared with the results, obtained at application of earlier defined algorithms of a much greater duration (6–12 s). Temperature at the moment of bronchi closing at testing new algorithms did not exceed 40–70 °C that is almost two times smaller (Figure 5) than that recorded at application of the majority of earlier defined algorithms for bronchi welding.

Figure 5 shows the temperature values of the process with application of new algorithms of welding bronchi of the total duration of 0.1 s (No.1), 0.5 s (No.2), 0.8 s (No.3) and an algorithm of total duration of 8 s, that is currently used (No.4).

The most sound bronchi closure under the conditions of conducting this experimental stage, took place, by visual estimate, at process temperature of 47–65 °C with the total duration of impact of high-frequency current on the tissue of 0.5–1.5 s in the seam zone. No charring, spasm or «sticking» of the tissue to the electrodes under experimental conditions were observed. HAZ dimensions were within 0–0.1 mm. Selected samples with sound closure of the bronchi were used to conduct tightness testing (Figure 6, *a*) and mechanical and hydraulic tests (Figure 6, *b*).

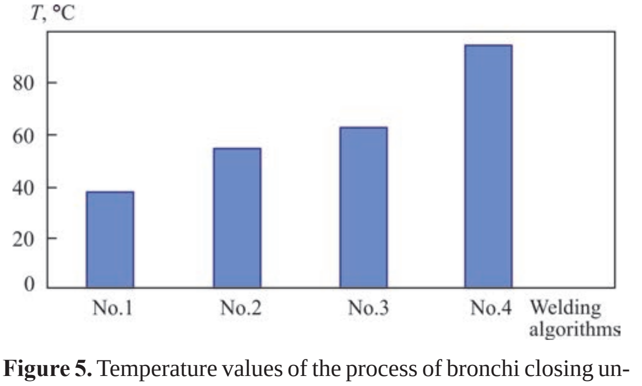

Figure 5. Temperature values of the process of bronchi closing under the conditions of application of new experimental (Nos 1–3) and currently available (No.4) welding algorithms

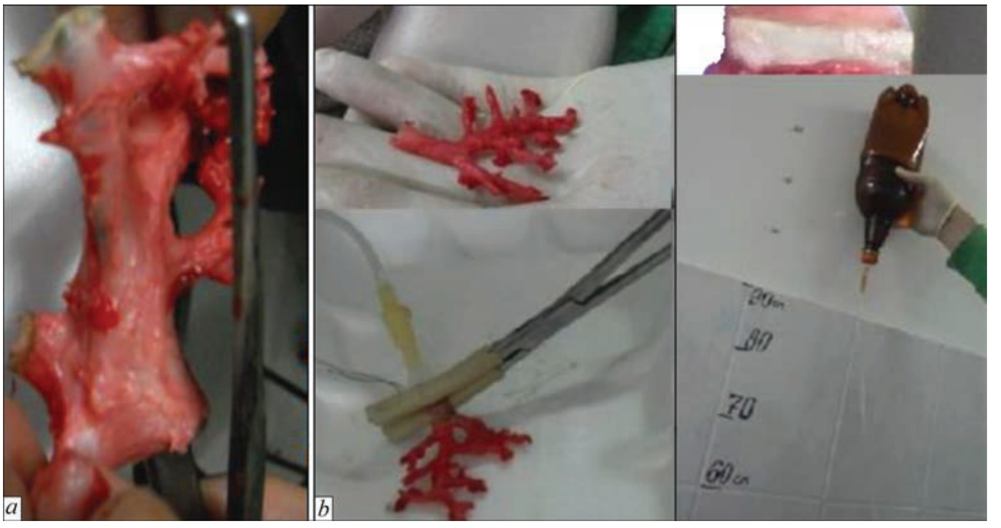

Figure 6. Testing of bronchi welds produced at application of special welding algorithms: *a* — vascular patency test; *b* — hydraulic testing

Visually determined sound closure of the bronchi obtained under the above-mentioned conditions, withstood 1000–1500 mm H_2O at hydraulic testing.

Results of studying the impact of new welding algorithms on the bronchi tissue demonstrated the good prospects for their application and the need to carry on the experimental work.

Conclusions

1. Results of the conducted experimental work showed that application of new experimental algorithms for welding biological tissues offers significant advantages, compared to earlier defined welding algorithms. These are producing sound seams at lower temperature values of the process and improvement of biophysical characteristics of the tissues in the seam zone and HAZ.

2. Based on visual estimate, mechanical and hydraulic testing of samples of different tissue type, it was established that new ingenious joining algorithms which can be realized at application of the developed control system of the apparatuses, allow producing sound joints of biological tissues at minimum specific pressure of electrodes, and ensure minimum temperature of heating of the tissues being joined and minimum length of the HAZ, that in its turn points to the good prospects for application of the proposed algorithms and continuation of experimental studies.

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