International Journal of Biomedicine 12(2) (2022) 303-307
http://dx.doi.org/10.21103/Article12(2)_OA19

INTERNATIONAL JOURNAL OF BIOMEDICINE

ORIGINAL ARTICLE

Novel Technology and Devices

Program Development for Choosing a Surgical Treatment Option and Mathematical Prediction of Findings in Patients with Postoperative Median Abdominal Hernias

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Abstract

Background: The aim of the study was to develop a mobile program for choosing a method of surgical treatment and mathematical prediction of findings in patients with postoperative median abdominal hernias, sized small to large, using a complex of non-linear mathematical models to help a practicing surgeon.

Methods and Results: The level of intra-abdominal pressure was determined indirectly, based on SpO_2. The total electrical activity (TEA) and the degree of fatigue (DF) of the abdominal muscles were determined by electromyography. The experimental data were processed using non-linear programming methods. There has been detected a non-linear dependence of the parameters of the DE and the TEA of the abdominal muscles six months after surgery, based on their preoperative values compared to SpO_2 values on the preoperative day and on the postoperative Day 7, and compared to SpO_2 values under physical simulation of hernia repair and the selected treatment option.

Conclusion: A mobile program has been developed for smartphones that implements the recommended choice of hernioplasty technique and predicts typical features of the patient's postoperative condition.(**International Journal of Biomedicine. 2022;12(2):303-307.**)

Key Words: postoperative median abdominal hernia • hernioplasty • mathematical model • predictive software • iPhone

For citation: Arapov DV, Cherednikov EF, Skorobogatov SA, Polubkova GV, Belozertsev AS, Gladkich TV, Korobova LA, Borodina EA, Chikunov SV, Kuritsyn VA. Program Development for Choosing a Surgical Treatment Option and Mathematical Prediction of Findings in Patients with Postoperative Median Abdominal Hernias. International Journal of Biomedicine. 2022;12(2):303-307. doi:10.21103/Article12(2)_OA19

Abbreviations

DF, the degree of fatigue; **HO**, hernial orifice; **MM**, mathematical models; **SpO_2**, oxygen saturation; **TEA**, total electrical activity.

Introduction

Currently, surgical interventions due to postoperative median hernias of the anterior abdominal wall are common in medical practice.[1] However, the issue of surgical treatment of these hernias is still challenging. These surgeries are quite complicated and dangerous: about every fourth one of them results in complications and, on average, 4% of surgeries are fatal.[2] Pathology is common in older patients suffering from chronic diseases that complicate the choice of treatment tactics. For example, almost 50% of elderly and geriatric patients undergo relapses during plastic surgery with their own tissues.[3] On the other hand, the number of postoperative hernias of small sizes, which are repaired by local tissue plastic, is increasing;[4] this is due to the development of laparoscopic technologies in hernia surgery. Currently, mesh endoprostheses providing a "tension-free" technique of treating abdominal wall hernias are actively used in the treatment of postoperative median hernias.[5] However, the recurrence rate for these interventions is 30% or more due to the rejection of the endoprosthesis.[6] For large-sized hernia treatment, separation techniques are currently being introduced. Drawbacks of these types of plastic surgery are the lack of knowledge about long-term consequences, high trauma and a long duration of surgical intervention. In patients with ventral hernias, the problem of reconstruction of the anterior abdominal wall is still relevant.[7] However, where feasible, the self-tissue repair is probably the best option for surgical treatment of postoperative median hernias. The disadvantage of this technique is that the immersion of hernia components into the abdominal cavity and the reduction of the hernial orifice (HO) contribute to a sharp increase in intra-abdominal pressure, especially with extensive dimensions of the orifice. The main factors for successful surgical treatment of large postoperative ventral hernias are as follows: 1) a decrease in the intra-abdominal pressure, up to its complete elimination; 2) a decrease in the degree of tension of proper tissues.

Surgical interventions for postoperative ventral hernias, especially large ones, should be accompanied by control of the magnitude and dynamics of changes in intra-abdominal pressure. For this purpose, intra-abdominal pressure is monitored at various stages of treatment by measuring the pressure in the bladder.[8,9] However, this option is painful, poorly tolerated, and is frequently accompanied by complications. Measurement of blood SpO_2 at various stages of patients' treatment to control their intra-abdominal pressure is a more promising non-invasive, mediated technique.[10,11] In the treatment of patients with postoperative ventral hernias, it is important to restore the function of the abdominal wall muscles after hernioplasty.[9]

A common drawback of most publications on statistical modeling in medical research, for example, the condition of patients with burns[12] and peritonitis,[13] and a number of others, is that they have not explored the possibility of creating non-linear mathematical models (MM) to predict the patients' condition. However, non-linear modeling under a wide range of parameter changes appears to be the most important tool for creating adequate predictive models of the behavior of various objects, including the vital signs of patients.[14-17] Importantly for patients with hernias, neural network models have been developed,[17] which allow predicting their vital signs depending on input parameters, including a treatment option. In this regard, the development of an algorithm and a mobile program for the iPhone smartphone, which selects the method of surgical treatment and predicts the vital signs of patients using a complex of non-linear MMs, is relevant.

The aim of the study was to develop a mobile program for choosing a method of surgical treatment and mathematical prediction of findings in patients with postoperative median abdominal hernias, sized small to large, using a complex of non-linear MM to help a practicing surgeon.

Materials and Methods

The study included 55 patients with postoperative median reducible abdominal hernias who were examined and treated in the surgical departments of emergency hospitals No. 1 and No. 10, Voronezh, Russia. All patients were divided into three main groups depending on the width of the hernia orifice and the size of the hernia: 1) 16(29%) patients had small hernias with an HO width up to 5 cm; 2) 20(36%) people had medium-sized hernias with an HO width 5-9 cm; 3) 19(35%) patients had large hernias with an HO width 10 cm to 16 cm. The patients were comparable in gender, age, and comorbidity. In MM, data on gender, age, and concomitant chronic diseases were not taken into account.

The level of intra-abdominal pressure was determined indirectly, based on SpO_2.[9,11] Pulse oximeters OP-31.1 Triton T-31, Bitmos Sat 816, and Armed were used to measure blood saturation. No significant differences were detected in the assessment of SpO_2 values when measured with these devices. Blood SpO_2 level was determined several times – prior to surgery at rest and during physical modeling of the postoperative condition. Physical modeling was implemented by contracting the abdomen and bringing the hernia orifice closer together with the simultaneous immersion of the hernia components into the abdominal cavity by the pelota. A decrease in SpO_2 was recorded on Days 1, 2, and 7 after surgery.[8,9] The total electrical activity (TEA) and the degree of fatigue (DF) of the abdominal muscles were determined before surgery and six months after surgery according to EMG data using the "Neuro-MVP" Neurosoft device. During static loads, the TEA parameters of the muscles of the anterior abdominal wall were recorded first, and then the DF muscle values were calculated.[18] The following surgical treatment options were used for patients with postoperative median reducible hernias of the abdomen: 1) duplication plasty using local tissues (according to Sapezhko); 2) surgical bridge plasty with surgical wound immobilization; 3) instrumental 2-stage technique according to E. N. Lyubykh; 4) posterior separation plasty with retromuscular endoprosthesis; 5) flap endoprosthetics (correction) of the anterior abdominal wall (intramuscular mesh prosthesis).

Statistical data processing and computational experiments were conducted at the Department of Higher Mathematics and Information Technology, Voronezh University of Engineering Technologies. The experimental data were processed using non-linear programming methods: a genetic algorithm and the Hooke-Jeeves configuration technique implemented in the author's interactive identification MM system.[19] Because the developed MMs have a significant nonlinearity of the internal structure, the significance of the coefficients was estimated by the relative error achieved by the model in accordance with the special criterion.(1) In addition, the adequacy of the developed regression models was tested using the Fisher criterion in the absence of parallel experiments.

Results

Table 1 demonstrates the experimental data obtained in patients with large hernias who underwent an instrumental 2-stage technique surgery, endoprosthetics and posterior separation plasty. The HO size was 10-16 cm. The structure of the MM was detected in the process of computational experiments in an interactive mode. When searching for MM coefficients, the sum of root-mean-square deviations of the calculated patients' findings from the measured ones was minimized:

$$R=\sum_{i=1}^{L_p}\left(1-\frac{P_i^{рас}(\mathbf{A})}{P_i^{экс}}\right)^2 \xrightarrow[\mathbf{A}]{} \min, \qquad (1)$$

where L_p - the amount of processed experimental data when modeling the P value;

$P_i^{рас}, P_i^{экс}$ -calculated and experimental P value of the state of the i-th patient with similar plastic surgery;

A – vector of nonlinear MM coefficients.

In this way, the calculated formulas for SpO_2 of patients on Days 1, 2, and 7 after surgery were obtained, as well as DF and TEA six months after surgery.

1. Mathematical modeling of the dependence of saturation measured on Day 1after surgery on the preoperative parameters of the patient:

a) Large hernias, the treatment option is "two-stage instrumental technique": (2)

$$S_1=a_1\cdot S^M+a_2\cdot S^M\cdot 10^{11}\exp\left(-0{,}3\cdot S^M\right)+a_3\cdot S^M\cdot\ln S^M+a_4\cdot S^M\cdot 10^{-2}\cdot\sqrt{S^0-S^M}\cdot\ln A^0/U^0+$$
$$+a_5\cdot\ln U^0/\ln A^0+a_6\cdot\left(\sqrt{S^0-S^M}\cdot\ln A^0/U^0\right)^{a_7}+a_8\cdot\left(\sqrt{S^0-S^M}\cdot\ln A^0/U^0\right)^{a_9},$$

where S_1- SpO_2 on Day 1 after surgery, %; S^0 - SpO_2 prior to surgery at rest, %; S^M - SpO_2 under physical simulation, %; A^0, U^0 - TEA (mkV) and DF values prior to surgery at rest.

b) Large hernias, the treatment option is "endoprosthetics": (3)

$$S_1=a_1\cdot S^M+a_2\cdot S^M\cdot 10^{10}\exp\left(-0{,}28\cdot S^M\right)+a_3\cdot S^M\cdot\ln S^M+a_4\cdot S^M\cdot 10^{-2}\cdot\sqrt{S^0-S^M}\cdot\ln A^0/U^0+$$
$$+a_5\cdot\ln U^0/\ln A^0+a_6\cdot\left(\sqrt{S^0-S^M}\cdot\ln A^0/U^0\right)^2.$$

Table 1.
Experimental data of patients with large abdominal hernias (M W3-4 R0)

№№	S^0, %	S^M, %	U^0	A^0, mkV	S_1, %	S_2, %	S_7, %	$U_{0,5}$	$A_{0,5}$, mkV
Treatment option - two-stage instrumental technique									
1	97.0	86.2	2.29	506	84.0	86.3	96.5	1.8	527
…									
8	96.8	86.0	2.35	504	83.7	86.0	96.5	1.78	527
Treatment option - endoprosthetics									
9	96.5	87.3	2.7	421	90.0	91.5	95.3	2.89	414
…									
15	96.8	87.2	2.61	425	90.5	92.1	95.5	2.79	418
Treatment option – posterior separation									
16	97.5	89.5	2.14	507	84.7	85.6	96.0	1.95	518
…									
19	97.5	89.6	2.15	510	84.6	85.8	96.1	1.9	521

c) Large hernias, the treatment option is "posterior separation": (4)

$$S_1=a_1\cdot S^M+a_2\cdot S^M\cdot 10^{10}\exp\left(-0{,}28\cdot S^M\right)+a_3\cdot S^M\cdot\ln S^M$$

Table 2 demonstrates the MM coefficients (2), (3), (4).

Thus, MMs of saturations were obtained for three surgical techniques of large hernia repair depending on the preoperative parameters of the patient. The relative error of modeling SpO_2 was within ±0.2%.

Table 2.
Model coefficient values (2), (3), (4)

Treatment option - two-stage instrumental technique				
$a_1=-578.36351$	$a_2=2.010195$	$a_3=151.23776$	$a_4=-2452.898$	$a_5=-378.5249$
$a_6=141.52329$	$a_7=2.0$	$a_8=-0.12163317\cdot 10^{-2}$		$a_9=6.0$
Treatment option - endoprosthetics				
$a_1=49.346888$	$a_2=-2.072135$	$a_3=-10.958287$	$a_4=12.828297$	$a_5=269.95193$
$a_6=-0.41083574$				
Treatment option – posterior separation				
$a_1=-12.558293$	$a_2=0.58435778$	$a_3=2.9763028$		

2. SpO_2 modeling on Days 2 and 7 after the operation was performed according to the general formula:

$$S_{2,7}=a_1+a_2\cdot\left(\sqrt{S^0-S^M}\cdot\ln A^0/U^0\right)+a_3\cdot\left(\sqrt{S^0-S^M}\cdot\ln A^0/U^0\right)\times \qquad (5)$$
$$\times\exp\left(-a_4\cdot\tau\right)+a_5\cdot S^M\cdot\ln A^0/U^0+a_6\cdot\left(S_1-S^M\right)+a_7\cdot\ln U^0/\ln A^0,$$

where S_2 и S_7 – SpO_2 of the patient on Days 2 and 7 after surgery, respectively; τ – is equal to Day 2 or Day 7.

Table 3 shows MM coefficients (5) for plastic surgery techniques: two-stage, endoprosthetics, and posterior separation. According to the formula (5), the average relative error of SpO_2 modeling was ±0.3%.

Table 3.
MM coefficient values (5)

Treatment option - two-stage instrumental technique				
$a_1=-77.76535$	$a_2=2.5291146$	$a_3=4.0145439$	$a_4=0.61454595$	$a_5=0.3327949$
$a_6=0.080563498$	$a_7=558.03233$			
Treatment option - endoprosthetics				
$a_1=-54.928943$	$a_2=-1.5786892$	$a_3=-0.9298535$	$a_4=-0.07855635$	$a_5=0.38088$
$a_6=0.78321156$	$a_7=446.24765$			
Treatment option – posterior separation				
$a_1=-118.95495$	$a_2=8.4055883$	$a_3=-0.52959447$	$a_4=-0.1922029$	$a_5=0.14555876$
$a_6=-3.303022$	$a_7=615.75785$			

According to formula (5) the average relative error of SpO_2 modeling is ±0.3%.

3. General models of the degree of fatigue of the patient's abdominal muscles and their electrical activity six months after surgery are:

$$U_{0,5}=U^0+a_1\cdot S_7+a_2\cdot S_7^2+a_3\cdot\sqrt{S^0-S^M}\cdot\ln A^0/U^0+a_4\cdot\left(S^0-S^M\right)+a_5\cdot\left(S_7-S^M\right)^2; \qquad (6)$$

$$A_{0,5}=A^0+a_1\cdot S_7+a_2\cdot S_7^2+a_3\cdot\sqrt{S^0-S^M}\cdot\ln A^0/U^0+a_4\cdot\left(S^0-S^M\right)+a_5\cdot\left(S_7-S^M\right)^2, \qquad (7)$$

where $U_{0,5}$ и $A_{0,5}$ – are DF and TEA values six months after surgery, respectively.

Table 4 demonstrates the coefficients of models (6) and (7) for the studied options of plastic surgery. The average relative error of the DF and TEA modeling calculated by formulas (6) and (7) was within ±2-3 %.

The algorithm for choosing the surgical treatment option is implemented as follows: The HO width determines further analysis of the patient's condition and, depending on the combination of values, the difference between the initial and simulated SpO_2, and terms of hernia, a certain plastic treatment option is selected. The algorithm uses the limiting values of TEA and DF equal to A=500μV and U=2.4, their combinations are crucial to conclude if the abdominal muscle functions are preserved. If $A^0 \geq 500$ mkV and $U^0 \leq 2.4$, then it is assumed that the functions of the abdominal muscles are preserved. Otherwise, if $A^0 < 500$ mkV and $U^0 > 2.4$, then it is assumed that the functions of the abdominal muscles are lost. Variants with partial preservation of the anterior abdominal wall muscle functions are also considered. In cases of large hernias, when the functions of the muscles are not preserved and the term for which the hernia is carried is 5 years or more, corrective methods of surgical treatment (endoprosthetics) are recommended to the patient. Otherwise, a 2-stage instrumental technique or posterior separation plastic is proposed, depending on the difference between preoperative and simulated SpO_2.

To implement the algorithm, a mobile application for the iPhone smartphone running iOS version 14 and higher has been developed. Objective-C is a programming language, Xcode 12.5.1 is a development environment.

Table 4.

MM coefficient values (6) and (7)

Treatment option - two-stage instrumental technique, MM (6)				
$a_1 = 0.10638154$	$a_2 = -0.10995636 \cdot 10^{-2}$	$a_3 = 0.19294668$	$a_4 = -0.21550095$	
$a_5 = 0.6143278 \cdot 10^{-3}$				
Treatment option - two-stage instrumental technique, MM (7)				
$a_1 = 11.718234$	$a_2 = -0.13230293$	$a_3 = 30.811606$	$a_4 = -26.992092$	$a_5 = 1.3228408$
Treatment option - endoprosthetics, MM (6)				
$a_1 = -0.27254978$	$a_2 = 0.2896318 \cdot 10^{-2}$	$a_3 = -0.64509639$	$a_4 = 0.58871533$	
$a_5 = -0.018020586$				
Treatment option - endoprosthetics, MM (7)				
$a_1 = 81.043115$	$a_2 = -0.82771741$	$a_3 = 81.783149$	$a_4 = -141.50292$	$a_5 = 8.3268172$
Treatment option – posterior separation, MM (6)				
$a_1 = 0.09674961$	$a_2 = -0.11747287 \cdot 10^{-2}$	$a_3 = 0.15946951$	$a_4, a_5 = 0$	
Treatment option – posterior separation, MM (7)				
$a_1 = 0.22938094$	$a_2 = -0.11963044 \cdot 10^{-2}$	$a_3 = 0.56666165 \cdot 10^{-3}$	$a_4, a_5 = 0$	

Discussion

Figure 1 shows the results of the program for choosing the surgical treatment options for patients with large hernias and predicting their vital signs.

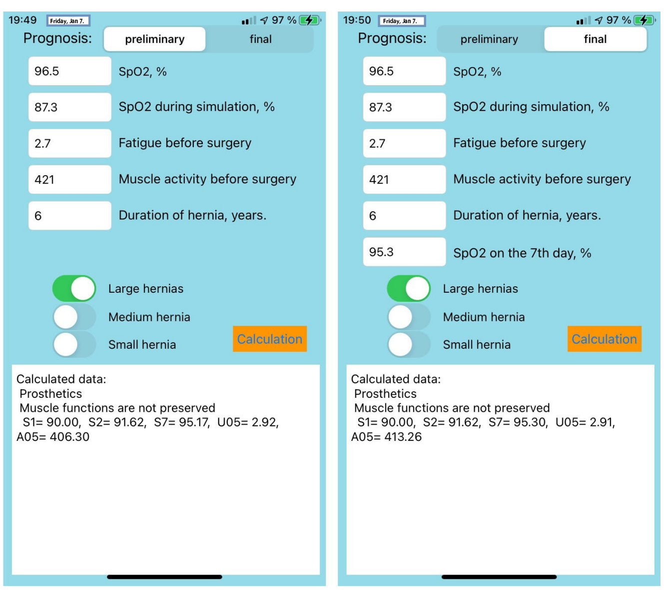

Fig. 1. *Program interface for the surgeon's mobile phone for choosing the plastic treatment option and predicting the patient's condition (a, b - "endoprosthetics")*

First, according to the patient's initial findings, the mobile program selects the plastic technique option in accordance with the programmed algorithm. Then, for the surgical technique selected by the program, a "preliminary" calculation of the patient's postoperative condition is carried out based on the preoperative findings of the patient's condition according to the models (2)-(7). The SpO_2 value is measured on Day 7 after the surgery; it is entered into the smartphone program and substituted into models (6) and (7). In such a way, the "final" calculation of the patient's DF and TEA vital signs is realized six months after the operation. Comparison of the data in Figure 1 and Table 1 (No. 9) evidences a high convergence of the results obtained and potential of the program's application in medical practice.

Conclusion

An algorithm has been developed for choosing the surgical treatment option and a complex of non-linear mathematical models to assess the vital signs of the patient's postoperative condition with median reducible abdominal hernias of various types and sizes. A mobile program that recommends a plastic surgery option and predicts typical features of the patient's postoperative condition has been developed to help the surgeon; it is installed and operates on an iPhone smartphone running iOS version 14 and higher. Objective-C is a programming language, Xcode 12.5.1 is a development environment.

Disclaimer

Views expressed in the submitted article belong to the authors and not to the university and funder.

Competing Interests

The authors declare that they have no competing interests.

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