

ОГЛЯД ЛІТЕРАТУРИDOI: 10.21802/artm.2020.3.15.203.
UDC 616.12-039-089.8:615.825**THEORETICAL MODEL OF STERNUM EXTERNAL FIXATION FUNCTIONING IN PHYSICAL THERAPY OF PATIENTS FOLLOWING CARDIAC SURGERY VIA STERNOTOMY**

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Abstract. The **purpose** is to develop and analyze a theoretical model of sternum external fixation functioning as sternal precaution after cardiac surgery via sternotomy.

Methods: theoretical modeling based on literature data.

Results. The literature data, measuring the impact of sternum external fixation on the development of complications after cardiac surgery via sternotomy, do not present a proper report of the functioning mechanism or mechanical model of the interaction between the sternum and sternum external fixation. The first stage of theoretical model development included selecting the criteria based on the sternum anatomy, physiology of respiration, results of scientific research, which enabled to define key aspects of the theoretical model. The second stage included studying interaction of non-elastic SEF and sternum during a deep breath and a cough acting as main elements of inspiratory muscle training after cardiac surgeries; performing a similar algorithm of studying elastic type of SEF, which enabled to investigate and analyze preventive potential of SEF in relation to sternal dehiscence in the lateral direction. The third stage included the analysis of SEF restricting potential for anteroposterior stabilisation of the sternum. Since the use of sternum external fixation should not impede pulmonary function recovery after cardiac surgery and cannot restrict chest circumference increase with inhalation, sternum external fixation cannot properly function as sternal precaution when chest circumference is increased due to sternal edge dehiscence as well. The restricting effect of inelastic sternum external fixation will be possible only in case of a large dehiscence, when its size is bigger than the chest circumference increase during normal and deep breathing. Only when the circumference of inelastic sternum external fixation corresponds to the chest circumference after a full exhalation, the effect restricting dehiscence development will be possible. However, this condition is not practically feasible and does not comply with the need for pulmonary function recovery. As an example a barrel with iron rings that prevent it from expanding and emerging of dehiscence between the boards. However, this is not practically possible and is inconsistent with physiology of respiration. The restricting effect of elastic sternum external fixation will be possible in case the force of compression is greater than the force expanding the sternum during a cough, which will completely restrict inhaling and disable its practical use. The use of sternum external fixation must be biomechanically justified. The fact that the sternum is covered with soft tissues (muscles, which are joined with the bones of the sternum, shoulder blade and humerus; subcutaneous fat, which increases with excessive body weight) also reduces sternum external fixation effectiveness, as the existence of a soft and movable layer between the fixing parts and fixing means is a negative factor. On the other hand, dehiscence is a rare case among patients who do not use SEF. This confirms the priority of the sternal closure stability after sternotomy and the factors affecting it: the strength of bone tissue, the diameter of the wire, used during sternotomy, and the number of sutures.

Conclusions. The theoretical model analyzed in this study confirms either the insignificant role of sternum external fixation or its complete absence in the prevention of sternal dehiscence in the lateral direction and anteroposterior displacement of sternum edges after sternotomy.

Keywords: sternal precautions, dehiscence, sternotomy, vest, bandage.

Introduction. Sternum external fixation (SEF) is one of the sternal precautions (SP) used in the mobilization and physical therapy (PT) of patients following operations on the heart and other organs of the chest. SEF can be divided into two groups: inelastic (vest, corset) and elastic (bandage).

Studies of SEF effectiveness are mainly focused on superficial wound infection (SWI), deep sternal complications (DSC), and sternal wound dehiscence (SWD). In particular, “vest – no vest” [5, 9], “vest – bandage” groups of patients are compared [10, 11, 17, 19]. One of the studies [19] reports on the ability of a corset to protect the sternum from dehiscence during a cough, the ease of use, functionality, preservation of lung function and aux-

iliary respiratory muscle movement, as well as simultaneous prevention from excessive thorax expansion, excessive movement of the rib cage in an anterior and a lateral directions. Another study [9] reports that sternum vest provides anteroposterior stabilization of the thorax, prevents intrinsic movement of the two sternum halves, and the straps stop the thorax support vest sliding to the abdominal region. Other studies [5, 10], describing similar characteristics of the analogous type of SEF, admitted also the use of cushions acting as shock absorbers when the patient coughs or breathes deeply, and supporting the sternum when turning the patient in bed.

Nevertheless, none of these studies provides sufficient information on the mechanism of SEF functioning.

Therefore, the development of a theoretical model is necessary for better understanding of SEF functioning for physical therapists, surgeons as well as the patients.

The **purpose** is to develop and analyze a theoretical model of SEF functioning after sternotomy.

Methods: theoretical modeling based on literature data. To achieve the aim of the research model-based approach was used (studying objects of cognition on their models; "model" is an artificially created image of a certain object which reflects and reproduces its structure and properties in a simpler form) on the grounds of scientific literature. Positive result (confirmation of the specified in the literature preventive and protective properties of SEF with those obtained during modelling) is assumed to create a biomechanical basis for the use of SEF, and the negative one vice versa.

Results. To construct a model and evaluate the mechanism of SEF functioning, it is necessary to determine a number of conditions (Cond.):

Cond.1. The shape of the sternum in most cases resembles a truncated cone with the bottom base or a cylinder. Anteroposterior size is smaller than the lateral one.

Cond.2. The use of SEF allows the patient to perform normal and deep breathing, coughing, as they are necessary for living and are key elements of postoperative physical therapy, including respiratory. At the same time, it does not contradict the description in the studies [5, 10, 19].

Cond.3. Chest circumference increases with normal and maximal inhalation.

Cond.4. Chest circumference decreases with maximal exhalation due to expiratory reserve volume (ERV) exhaled from the lungs.

Cond.5. For better understanding of the model and calculations, we can assume that cross-sectional view of the chest forms a ring.

Taking into account these conditions, we will consider the interaction model for *inelastic SEF*. We take as an example the cross section of the chest, as this will provide a good visualization of the chest excursion/expansion and anteroposterior movement of the two sternum halves.

Taking into account Cond. 5, chest circumference (C) is calculated according to the formula $C = \pi \times d$, where d is chest diameter (d_{max} – with maximal inhalation, d_{TV} – with normal inhalation, d_{min} – after ERV exhalation, d_0 – after calm exhalation).

Taking into account Cond. 3 and Cond. 4, C values may vary:

C_{MAX} – chest circumference with inhalation of inspiratory capacity (IC),

C_{TV} – chest circumference after inhalation of tidal volume (TV),

C_0 – chest circumference after exhalation of TV,

C_{MIN} – chest circumference after exhalation of ERV.

The modeling also requires C_{ESF} value – the circumference of SEF.

Based on the presented values, we can measure the value of respiratory chest circumference changes. With inhalation of TV chest circumference increases by $C_{\Delta TV}$, which is calculated according to the following formula:

$$C_{\Delta TV} = C_{TV} - C_0 \quad (1).$$

With inhalation of IC chest circumference increases by $C_{\Delta IC}$, which is calculated according to the following formula:

$$C_{\Delta IC} = C_{MAX} - C_0 \quad (2).$$

With exhalation of ERV chest circumference decreases by $C_{\Delta ERV}$, which is calculated according to the following formula:

$$C_{\Delta ERV} = C_0 - C_{ERV} \quad (3).$$

With exhalation/inhalation of vital capacity (VC) chest circumference increases/decreases by $C_{\Delta VC}$, which is calculated according to the following formula:

$$C_{\Delta VC} = C_{MAX} - C_{MIN} \quad (4).$$

According to some studies, $C_{\Delta VC}$ is named total chest excursion [21] and chest expansion [2]; $C_{\Delta IC}$ is named complementary chest movement [21], and $C_{\Delta ERV}$ is named reserve chest movement [21].

According to the results of literature analysis, we can affirm that C value changes significantly during respiration (table 1).

Table 1

Respiratory chest circumference changes

Studies	$C_{\Delta TV}$, cm	$C_{\Delta VC}$, cm
Wade O.L. [21] (male, age 24-36 years, weight 73±9.2 kg, height 1.75±0.08 m; C at rest 90.5±8.0 cm; the level of the xiphoid)	1.2±0.4 cm (TV 0.8 l)	7.4±1.8 cm (VC 4.86±0.84 l)
Ando T. et al. [2] (age 24.5±2.4 years, height 1.66±0.08 m, weight 56.5±8.3 kg, the level of the xiphisternum)	-	4.6±2.1 (without bio-feedback) 5.3±2.2 (with)
Olsen M.F. et al. [14] (age 33±13.9 years; body mass index within normal range, conventional instruction for deep breathing)	I - the level of the fourth costae	I - 5.5±1.5 II - 6.5±2.0
Olsen M.F. et al. [14] (age 38±11.1 years; body mass index within normal range, new instruction for deep breathing)	II - the level of the xiphoid	I - 6.9±2.5 II - 7.4±2.3
Carlson B. [3] (age 22.5±3.6)		8.48±0.64 (VC 98.7 %)

The study of Wade O.L. [21] also analyzed $C_{\Delta IC}$ value (5.9±1.5 cm, with IC 3.17±0.45 l) and $C_{\Delta ERV}$ value (1.5±0.6 cm, with ERV 1.68±0.52 l) near the level of the xiphoid. The correlation of these values is consistent with

the results of other studies [1]. Besides, the study of Herxheimer H. [12] presents evidence that C can increase up to 4 mm when inhaling every 100 cm³ of air, though it was the maximal value, whereas the average dynamic

comprised 2.4-3.5 mm per 100 cm³ of inhaled air. The study of Ando T. et al. [2] shows that thoracic excursion was increased by 17% when using the biofeedback system. Changing patient's instructions can also affect the increase of C with deep inhalation [14]. This proves important since we have Cond. 2 and the need for pulmo-

nary function recovery after surgery and stimulation of the patient to deep breathing.

Taking into account the above-mentioned information and Cond. 2, we can conclude that when using inelastic SEF, $C_{SEF}=C_{MAX}$ equality is undeniable, as shown in Figure 1(a).

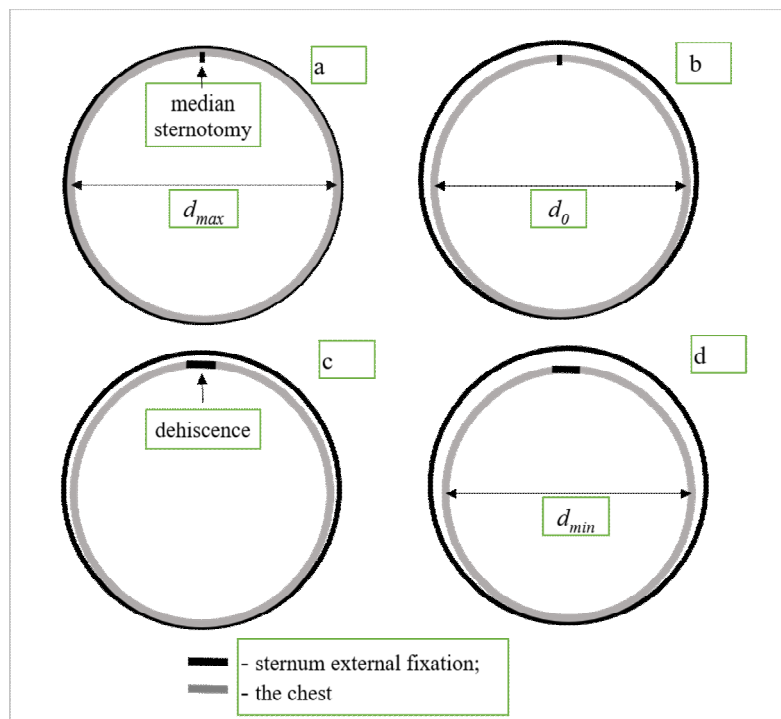


Fig. 1. The model of interaction of sternum external fixation (inelastic) and the sternum in the horizontal plane:

- a) maximal inhalation;
- b) in condition before normal inhalation;
- c) onset of the cough;
- d) exhalation of expiratory reserve volume during a cough.

According to formula 2: $C_{SEF} = C_{MAX} = C_0 + C_{AIC}$.

Thus, when the patient begins to exhale after maximal inhalation, the difference between C_{SEF} and C starts to increase and reaches C_{AIC} at the end of normal exhalation (Figure 1 (b)). It means that inelastic SEF provides a large degree of freedom, but this is necessary to restore external respiration function after surgery.

If the patient exhales ERV, the difference between C_{SEF} and C will become even greater and comprise C_{AVC} taking into account formulas 3 and 4.

Thus, C_{AIC} value is the exact extent of the dehiscence, which inelastic SEF will not be able to counteract.

Taking into account the results of the studies, C_{AVC} comprises 6.5 cm in average, and C_{AIC} comprises about 80% of C_{AVC} [1, 21]. Accordingly, C_{AIC} and the possible extent of dehiscence comprise about 5 cm, which is unacceptable taking into account the purpose of using SEF.

It should be noted that C_{AIC} and C_{AVC} decrease with age, as well as the pulmonary function decreases after surgery. Taking into account these two conditions, we reduce C_{AIC} by 70% from 5 cm to 1.5 cm. However, this extent of dehiscence is also unacceptable, since inelastic SEF will start functioning only after clinically significant dehiscence, which will require surgery. At the same time, the amount of young people undergoing cardiac surgery is increasing and pulmonary function is recovered during the use of SEF (3 months after surgery, sometimes even more), which makes our theoretical

reduction of C_{AIC} by 70% too large. This fact is not in favor of justifying the model of SEF mechanical functioning.

Since coughing is also an element of PT after cardiac surgery, which affects sternal closure, let us consider the impact of SEF during a cough.

The analysis of the force pressing the sternum during a cough revealed that this force comprises 555.3 N (56 kg) with a normal cough, and 1666 N (168 kg) – with a maximal cough [4]. Similar studies [7, 15, 20] showed that according to the Laplace law, the force pressing the sternum ranges from 160 N to 400 N when breathing, and from 550 N to 1650 N – when coughing.

We can also measure the pressure that occurs during a cough (P_{cough}). A normal cough reaches 100 mmHg, producing a force of 56 kg on the sternum, whereas maximal coughing can generate a pressure of 300 mmHg, producing a force of 168 kg [4].

Classically cough is considered to involve three phases: (I) an inspiration, (II) a compressive phase, where the muscles of expiration contract against a closed glottis and (III) an expulsive phase where the glottis suddenly opens and air is rapidly expelled [18]. Coughing may occur with initial inhalation of both IC or lower values [18], but this will not affect our model significantly.

Inelastic SEF functioning during a cough:

1. A cough is preceded by inhalation (phase I) – $C_{SEF}=C_{MAX}$ with inhalation of IC (Figure 1 (a)) or $C_{SEF}<C$ with inhalation of air volume less than IC.

2. Then phase II takes place, i.e. air in the lungs is compressed (C values decrease, the difference between C_{ESF} and C increases), the pressure in the lungs increases, which leads to the onset of the forces pressing the sternum [4, 7, 15, 20]. However, the protective effect of SEF cannot take place, because $C_{SEF} < C$ (Figure 1 (c)). Only in case the extent of dehiscence corresponds to the difference between C_{SEF} and C , SEF will have its restricting effect.

3. Then the air is exhaled (phase III) and C keeps decreasing to the level of C_0 or less, approaching C_{MIN} value (Figure 1 (d)). However, the protective effect of SEF cannot take place, since the difference between C_{ESF} and C has increased. Accordingly, the theoretically possible extent of dehiscence has also increased. Therefore, only wire-based sternal closure restrains sternum edge displacement.

Thus, only in case $C_{ESF} = C_0$ or preferably $C_{ESF} = C_{MIN}$, we can talk about the restricting effect of inelastic SEF. We can take as an example a barrel with iron rings that prevent it from expanding and emerging of dehiscence between the boards. However, this is not practically possible and is inconsistent with physiology of respiration.

When analyzing the functioning of *elastic SEF*, we should add the following conditions:

- C_{ESF} is a variable value here, because SEF can stretch during a breath;
- there is a pressure that affects the sternum at the state of rest (P_{SEF}) and depends on the extent SEF was tightened when put on a patient;
- this pressure increases slightly in direct proportion of the depth of inhalation to P_{SEFmax} value at maximum deep inhalation.

Taking into account Cond. 2, inspiratory muscle force should be sufficient to increase SEF circumference by C_{ATV} and C_{AIC} . This force should be much less than the maximal force that develops when achieving maximum inspiratory pressures (MIP), since we have Cond. 2, as well as the problem of patient's comfort (constant respiratory muscle fatigue and damaging effect of SEF pressure on soft tissues covering the sternum will not stimulate the patient to use SEF properly). In particular, there is evidence that fatigue develops at 40% of maximum pressures that respiratory muscles can produce [8]. MIP value slightly decreases in patients following cardiac surgery and comprises about 70 cmH₂O in the early postoperative period [6, 13, 16], or it can increase as compared to preoperative values when using respiratory PT techniques and comprise about 95 cmH₂O [16]. To calculate working inspiratory pressure (IP), produced by inspiratory muscles, we will take 30% of MIP value at the level of 80cmH₂O, i.e. 24cmH₂O or 17.6 mmHg. This pressure/force must be enough to increase C by C_{ATV} and C_{AIC} . Accordingly $IP > P_{SEFmax}$.

Proceeding from these data, we can conclude that when using elastic SEF, almost all the pressure that occurs during a cough will affect wire-based sternal clo-

sure. Under the best of circumstances, when the patient attaches elastic SEF with or without help using reasonably large force, only a small amount of the forces expanding the sternum during a cough (less than $P_{SEFmax}/P_{cough} * 100\% = 17.6\text{mmHg}/100\text{mmHg} * 100\% = 17.6\%$ with a normal cough; less than $17.6\text{mmHg}/300\text{mmHg} * 100\% = 5.9\%$ with a strong cough) will be compensated by elastic SEF stretched by C_{AIC} . However, C_{AIC} value is not acceptable for the extent of the dehiscence. Therefore, clinically significant dehiscence will be possible.

In case the dehiscence has C_{ATV} size, the restricting effect of inelastic SEF will approach 0 since C_{ATV} is much smaller than C_{AIC} .

Analyzing SEF functioning model, we can take a slightly different approach and answer the question: "How much force or pressure is necessary for SEF to let chest circumference increase or cause dehiscence the size of 5 mm, for example?"

Answers:

- none for inelastic SEF, since according to Cond. 2 - $C_{ESF} = C_{MAX}$, and $C_{ATV} > 5\text{mm}$ and $C_{AIC} > 5\text{mm}$ [12, 21];

- for elastic SEF such force or pressure will be less than those generated by inspiratory muscles during normal inhalation, since $C_{ATV} > 5\text{mm}$, i.e. too small to hold 56-168 kg.

Therefore, we come to the same conclusion that all the pressure will affect wire-based sternal closure. The restrictive effect of SEF will take place only in case of a very large dehiscence.

When considering the possibility of anteroposterior stabilization of the thorax with the help of SEF, we find the same inconsistencies as in the study of sternal dehiscence in the lateral direction, but in a slightly different interpretation (Fig. 2). Accordingly, if breathing and C increase are possible, then the variation of anteroposterior movement is possible as well (Fig. 2 (b)). To perform the movement shown in Fig. 2 (c), no conditions in terms of SEF are required at all. It is shown that SEF cannot perform anteroposterior stabilization. This is the task of surgical closure or metal osteosynthesis. Therefore, when a patient falls or is hit, an anteroposterior displacement, if any, will take place with or without SEF.

Discussion. Taking into account that this is a theoretical and quite simple model, as it is aimed only to form a basic idea of SEF functioning, we tried to stay impartial in terms of the considered issue. For this purpose, we slightly exaggerated the reduction of C_{AIC} by 70%, which should have been in favor of confirming the effect of inelastic SEF, but this did not happen. The analysis conducted in this study neither confirms the theoretical impact of SEF as sternal precaution after sternotomy nor attaches strategic significance to the use of SEF in the management of patients following median sternotomy or in activation of cardiac surgery patients by physical therapists.

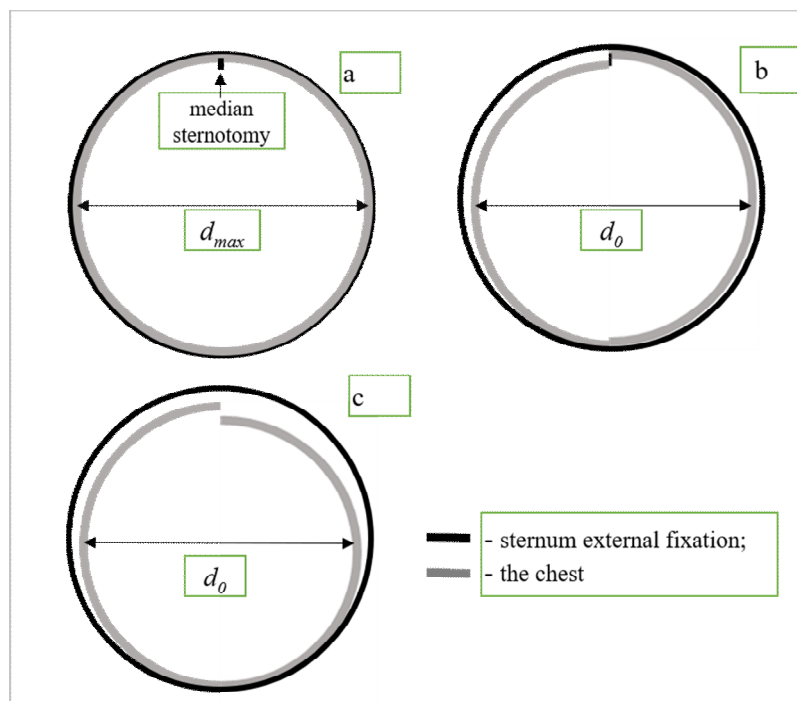


Fig. 2. The model of interaction of sternum external fixation and the sternum at anteroposterior stabilization:

- a) maximal inhalation;
b) movement of one part of the sternum forwards after normal exhalation;
c) movement of one part of the sternum backwards after normal exhalation.

For SEF to start significantly counteracting sternal dehiscence, C increase during normal and deep breathing must be impossible. However, this contradicts Cond.2. The fact that the sternum is covered with soft tissues also reduces SEF effectiveness, as the existence of a soft and movable layer between the fixing parts and fixing means is a negative factor. At the same time, the amount of soft tissue is quite large: muscles, which are joined with the bones of the sternum, shoulder blade and humerus; subcutaneous fat, which increases with excessive body weight.

On the other hand, dehiscence is a rare case among patients who do not use SEF [9, 5]. This confirms the priority of the sternal closure stability after sternotomy and the factors affecting it: the strength of bone tissue, the diameter of the wire, used during sternotomy, and the number of sutures (5-9 in general).

The study did not confirm protective properties of SEF, presented in the literature, namely to protect the sternum from dehiscence during a cough [19]; anteroposterior stabilization of the thorax, to prevent intrinsic movement of the two sternum halves [5, 9, 10].

At the same time, these studies do not substantiate protective properties of SEF in terms of biomechanics, being of more descriptive or advertising nature. A possible reason for these differences may be authors' interest in exaggerating SEF efficacy. This can be confirmed by the existence of duplicate articles [9, 22], as well as statistical differences in favor of SEF use, which are not quantitatively large and are achieved by comparing the samples with a large number of patients [10, 11].

Conclusions:

1. The literature data, measuring the impact of SEF on the development of complications, do not present a proper report of the functioning mechanism or mechanical model of interaction between the sternum and SEF.

2. The first stage of theoretical model development included selecting the criteria based on the sternum anatomy, physiology of respiration, results of scientific research, which enabled to define key aspects of the theoretical model. The second stage included studying interaction of non-elastic SEF and sternum during a deep breath and a cough acting as main elements of inspiratory muscle training after cardiac surgeries; performing a similar algorithm of studying elastic type of SEF, which enabled to investigate and analyze preventive potential of SEF in relation to sternal dehiscence in the lateral direction. The third stage included the analysis of SEF restricting potential for anteroposterior stabilisation of the sternum.

3. The theoretical model analyzed in this study confirms either the insignificant role of SEF or its complete absence in the prevention of complications after sternotomy. The restricting effect of inelastic SEF will be possible only in case of a large dehiscence, when its size is bigger than the chest circumference increase during normal and deep breathing. The restricting effect of elastic SEF will be possible in case the force of compression is greater than the force expanding the sternum during a cough, which will completely restrict inhaling and disable its practical use.

4. The results obtained emphasize the necessity to reconsider the views on prescribing SEF for all patients after sternotomy.

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ТЕОРЕТИЧНА МОДЕЛЬ ДІЇ ЗАСОБІВ ЗОВНІШНЬОЇ ФІКСАЦІЇ ГРУДИНИ ПРИ ФІЗИЧНІЙ ТЕРАПІЇ ПАЦІЄНТІВ ПІСЛЯ КАРДІОХІРУРГІЧНОГО ВТРУЧАННЯ З СТЕРНОТОМІЄЮ

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Резюме. Мета – розробити та проаналізувати теоретичну модель дії засобів зовнішньої фіксації груднини як запобіжного заходу після кардіохірургічних втручань з стернотомією.

Методи: теоретичне моделювання на основі даних літератури.

Результати. На першому етапі розробки було прийнято ряд умов, котрі базувалися на анатомії грудної клітки, фізіології дихання, результатах наукових досліджень, що дозволило сформулювати ключові положення теоретичної моделі. На другому етапі розглянуто модель взаємодії нееластичного SEF та грудної клітки при глибокому диханні та кашлі як основних елементів респіраторної фізичної терапії після кардіохірургічних втручань; виконано аналогічний алгоритм для еластичного типу засобів зовнішньої фіксації груднини, що дозволило дослідити та проаналізувати профілактичні можливості щодо розходження частин груднини у бічному напрямку. На третьому етапі були проаналізовані обмежуючі можливості засобів зовнішньої фіксації для передньо-задньої стабілізації груднини. Оскільки використання засобів зовнішньої фіксації груднини не має заважати відновленню легеневої функції після кардіохірургічних втручань і не може обмежити збільшення окружності грудної клітки при вдиху, то

й при збільшенні окружності грудної клітки за рахунок дегісценції країв грудини засіб зовнішньої фіксації грудини не зможе належним чином відіграти роль запобіжного заходу. Обмежувальна дія нееластичних засобів зовнішньої фіксації грудини буде можливою лише за умови дуже великої дегісценції, коли її розмір буде більшим, ніж приріст окружності грудної клітки при звичайному та глибокому диханні. Лише коли окружність нееластичного засобу зовнішньої фіксації грудини відповідатиме окружності грудної клітки після повного видиху, буде можливою обмежуюча дія для розвитку дегісценції. Проте ця умова не відповідає практиці та необхідності відновлення функції легенів. Обмежувальна дія еластичних засобів зовнішньої фіксації грудини буде можливою при значній силі стискання, котра більша, ніж сила розтягу грудини при кашлі, що буде повністю обмежувати вдих і робити практичне використання неможливим. Використання засобів зовнішньої фіксації грудини має бути біомеханічно обґрунтованим.

Висновки. Розглянута теоретична модель підтверджує лише дуже незначну роль використання засобів зовнішньої фіксації грудини або взагалі її відсутність у профілактиці дегісценції країв грудини після стернотомії у боковому та передньо-задньому напрямках після стернотомії.

Ключові слова: запобіжний захід, дегісценція, стернотомія, корсет, бандаж.

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ТЕОРЕТИЧЕСКАЯ МОДЕЛЬ ДЕЙСТВИЯ СРЕДСТВ НАРУЖНОЙ ФИКСАЦИИ ГРУДИНЫ ПРИ ФИЗИЧЕСКОЙ ТЕРАПИИ ПАЦИЕНТОВ ПОСЛЕ КАРДИОХИРУРГИЧЕСКОГО ВМЕША- ТЕЛЬСТВА СО СТЕРНОТОМИЕЙ

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Резюме. Цель - разработать и проанализировать теоретическую модель действия средств внешней фиксации грудин в качестве меры профилактики после кардиохирургических вмешательств с стернотомией.

Методы: теоретическое моделирование на основе данных литературы.

Результаты. На первом этапе разработки было принято ряд условий, которые базировались на анатомии грудной клетки, физиологии дыхания, результатах научных исследований, что позволило сформировать ключевые положения теоретической модели. На втором этапе рассмотрена модель взаимодействия неэластичного средства внешней фиксации грудин и грудной клетки при глубоком дыхании и кашле как основных элементов респираторной физической терапии после кардиохирургических вмешательств; выполнено аналогичный алгоритм для эластичного типа средств внешней фиксации грудин, что позволило исследовать и проанализировать профилактические возможности относительно дегісценции половин грудин в боковом направлении после стернотомии. На третьем этапе были проанализированы ограничивающие возможности средств внешней фиксации для передне-задней стабилизации грудин. Поскольку использование средств внешней фиксации грудин не может мешать восстановлению легочной функции после кардиохирургических вмешательств и не может ограничить увеличение окружности грудной клетки при вдохе, так и при увеличении окружности грудной клетки за счет дегісценции краев грудин средство внешней фиксации грудин не сможет должным образом сыграть профилактическую роль. Ограничивающее действие неэластичных средств внешней фиксации грудин будет возможно только при условии очень большой дегісценции, когда ее размер будет больше, чем прирост окружности грудной клетки при обычном и глубоком дыхании. Только когда окружность неэластичного средства внешней фиксации грудин будет равна окружности грудной клетки после полного выдоха, ограничивающее действие для развития дегісценции будет возможно. Однако это условие не соответствует практике и необходимости восстановления функции легких. Ограничивающее действие эластичных средств внешней фиксации грудин будет возможно при значительной силе сжатия грудной клетки, которая больше, чем сила растяжения грудин при кашле, что будет полностью ограничивать вдох и делать невозможным практическое применение. Использование средств внешней фиксации грудин должно быть биомеханически обоснованным.

Выводы. Рассмотренная теоретическая модель подтверждает лишь очень незначительную роль использования средств внешней фиксации грудин или ее отсутствие в профилактике дегісценции краев грудин после стернотомии в боковом и передне-заднем направлениях после стернотомии.

Ключевые слова: мера профилактики, дегісценция, стернотомия, корсет, бандаж.

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