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Acoustic Screening of Abnormal Scars in Maxillofacial Region

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ABSTRACT

BACKGROUND: Despite significant advances in the treatment of patients with inflammatory maxillofacial diseases, there have been cases of secondary cicatricial deformities in the face and neck area in patients with purulent and inflammatory diseases. The share of such cases in maxillofacial surgery hospitals is 77.5%–89.3% of total patients. The medical acoustic test used to diagnose abnormal scarring in patients with purulent and inflammatory maxillofacial and neck diseases allows for localizing the identified lesions based on anisotropic parameters, which is certainly relevant for treatment and prevention of soft tissue deformities in healthcare practices.

AIM: To substantiate the relevance of acoustic screening to improve diagnosis and prevention of secondary soft tissue deformities of the face and neck in patients with maxillofacial diseases.

METHODS: The clinical study included 30 patients undergoing inpatient and outpatient observation in the maxillofacial surgery department and rehabilitation office of a multidisciplinary clinical hospital. The patients were divided into two groups. Group 1 comprised 15 patients with maxillofacial phlegmon of various origin, location, and localization of the affected tissue plane; group 2 comprised 15 patients after scheduled surgeries without signs of inflammation.

The study included physical examination; interviews to identify complaints, anamnesis morbi, and anamnesis vitae; investigations; radiological imaging and functional tests, acoustometry, and examination by a physician and anesthesiologist.

Integumentary tissues were evaluated using an acoustometer on postoperative days 1, 14, and 60. The mechanical skin properties were assessed around the wound by measuring the velocity V_p in orthogonal directions, including V_y along the vertical axis of the face and V_x along the horizontal axis of the face. Based on the measured values, the anisotropy coefficient $K = V_y/V_x$ was calculated. V_n was simultaneously assessed in a similar region on the healthy side.

RESULTS: Group 1 velocity changes during the study were more than 2.5 times higher than those in group 2.

The study proved that the velocity measured by an acoustic device in patients with purulent and inflammatory maxillofacial diseases is 2.5 times higher than the wave velocity in patients without signs of inflammation.

CONCLUSION: Changes in acoustic parameters recorded at different stages of wound healing in maxillofacial surgery objectively reflect the regeneration progress and allow for studying the type of abnormal scarring. Early diagnosis helps prevent the abnormal scarring and determine the medical, physical, or radiation therapy strategies.

Keywords: purulent and inflammatory diseases; wound; scars; acoustic device; anisotropy; maxillofacial surgery; wound acoustometry.

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Акустический скрининг патологических рубцов челюстно-лицевой области

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АННОТАЦИЯ

Обоснование. Несмотря на значительный прогресс в лечении больных с воспалительными заболеваниями челюстно-лицевой области, отмечены факты вторичных рубцовых деформаций в области лица и шеи пациентов с гнойно-воспалительными заболеваниями. Эти пациенты составляют 77,5–89,3% всех больных стационаров челюстно-лицевой хирургии. Медицинский акустический метод диагностики формирования патологической рубцовой ткани у пациентов с гнойно-воспалительными заболеваниями челюстно-лицевой области и шеи позволяет локализовать выявленные патологические очаги на основании показателей анизотропии, что, безусловно, актуально для практического здравоохранения при лечении и профилактике деформаций мягких тканей.

Цель. Аргументация необходимости акустического скрининга для совершенствования диагностики и профилактики вторичных деформаций мягких тканей лица и шеи у пациентов с заболеваниями челюстно-лицевой области.

Методы. В клиническое исследование вошли 30 пациентов, находившихся на стационарно-амбулаторном наблюдении в отделении челюстно-лицевой хирургии и кабинете реабилитации многопрофильной клинической больницы, которых разделили на две группы: группу I составили 15 пациентов с флегмонами челюстно-лицевой области различного происхождения, расположения и локализации поражённых клетчаточных пространств; во II группу вошли также 15 пациентов после планового хирургического вмешательства без признаков воспаления.

Методы исследования включали в себя физикальное обследование; опрос с выявлением жалоб, анамнеза заболевания, анамнеза жизни; лабораторно-клинические исследования; лучевую и функциональную диагностику, акустометрию, осмотр терапевта и анестезиолога.

Исследование покровных тканей акустометром проводили на 1, 14 и 60-й день после операции. Механические свойства кожи оценивали вокруг раны путём измерения скорости $V_п$ во взаимно перпендикулярных направлениях: V_y — вдоль вертикальной оси лица, V_x — вдоль горизонтальной оси лица. По полученным значениям вычисляли коэффициент анизотропии $K=V_y/V_x$. Одновременно оценивали скорость $V_н$ на аналогичном участке здоровой стороны.

Результаты. Выявлено, что в группе I изменения скоростей в процессе исследования более чем в 2,5 раза превышают таковые в группе II.

Проведённое исследование доказало, что значение показателей скорости акустического индикаторного прибора у больных с гнойно-воспалительными заболеваниями челюстно-лицевой области в 2,5 раза выше значения показателей скорости распространения волны у пациентов без признаков воспаления.

Заключение. Изменения акустических показателей, регистрируемых в различные сроки заживления ран в челюстно-лицевой хирургии, объективно отражают ход процесса регенерации, позволяют изучить тип патологического рубцевания. Ранняя диагностика помогает предотвратить развитие патологического рубца, определить тактику терапевтического, физиотерапевтического или лучевого лечения.

Ключевые слова: гнойно-воспалительные заболевания; рана; рубцы; акустический прибор; анизотропия; челюстно-лицевая хирургия; акустометрия раны.

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ЭКО • ВЕКТОР

BACKGROUND

Over the past decade, maxillofacial surgery has been undergoing substantial changes in diagnostics, treatment, patient rehabilitation, and disease-prevention methods for the head and neck. Contemporary approaches have been developed for surgical treatment and prevention of complications associated with pathological scarring of soft tissues in the maxillofacial region. Nevertheless, several questions remain unresolved and call for detailed analysis and refinement, particularly the early diagnosis and prevention of pathological scar deformities of the face and neck.

The most common nosological entities in the maxillofacial region remain purulent-inflammatory processes, accounting for 30%–40% of all surgical cases (2020 data). Due to their tendency for rapid progression and spread through fascia spaces, facial and cervical phlegmons pose a serious threat, often leading to life-threatening states such as sepsis, respiratory disorders, mediastinitis, venous thrombosis, and scar deformities of the face and neck [1]. The number of patients with odontogenic phlegmons increases annually. More than 50% of maxillofacial inpatient beds are occupied by such cases [2]. The treatment and postoperative management of the aforementioned patients inevitably involve therapy for long-lasting non-healing wounds, often leading to pathological scarring of soft tissues and, in some cases, the development of scar deformities in the facial and cervical regions. A substantial proportion of these patients are individuals of working age, between 30 and 59 years, both young women and men. This imposes specific aesthetic demands on the surgical intervention and underscores the need for a modern approach to medico-social rehabilitation and prevention of condition in this significant region. The formation of pathological scars in the facial and cervical regions results in profound psychological distress, undermining confidence in one's appearance and attractiveness, lowering self-esteem (in some cases leading to depressive states).

Despite notable progress in the treatment of inflammatory diseases of the maxillofacial region, there is no clear trend toward a reduced incidence of scar-related complications, and prevention of pathological scar formation in the facial and cervical regions remains an exceptionally difficult and not always solvable clinical problem [3–5].

Notably, according to scientific research, the presence of comorbidities may substantially affect the course of pathological scar formation. According to many authors, comorbid conditions such as connective tissue disorders, impairments of the endocrine and immune systems, cardiovascular disorders, chronic inflammatory diseases, gastrointestinal diseases, and a history of allergic reactions tend to adversely affect recovery outcomes [6]. The presence of severe inflammatory processes affects the duration of wound healing and disrupts collagen metabolism, thereby contributing to the formation of pathological scarring [7, 8].

In this article, particular interest for surgeons lies in the medical acoustic method for early diagnosis of pathological scar tissue formation, especially in patients with purulent-inflammatory diseases of the maxillofacial region and neck. Assessment of tissue anisotropy allows for early detection and localization of pathological foci, enabling timely therapeutic, physiotherapeutic, and other indicated interventions, which is unquestionably significant for clinical practice.

AIM

The work aimed to substantiate the use of acoustic screening for improving the diagnosis and prevention of secondary soft tissue deformities of the face and neck in patients with maxillofacial conditions.

METHODS

Study Design

A prospective, observational, single-center, sample-based, randomized, controlled study was conducted. The study was carried out in an inpatient setting on postoperative day 1, and in an outpatient setting on postoperative days 14 and 60. Following physical examination and measurement of acoustic parameters on postoperative day 14, an individualized treatment regimen was prescribed, with outcomes assessed on day 60.

Eligibility Criteria

Exclusion criteria: age under 18 or over 60 years, decompensated somatic condition, and severe or complicated disease course.

Study Setting

The study was conducted at the Maxillofacial Hospital for War Veterans (a branch of City Clinical Hospital No. 1 named after N.I. Pirogov, Moscow Department of Health). This mono-specialty healthcare facility includes both inpatient and outpatient departments and specializes in the treatment of various diseases and traumatic injuries of the maxillofacial region. This specific feature of the healthcare facility allowed for the inclusion of patients receiving care under the Compulsory Health Insurance system at both the inpatient treatment stage and during the follow-up (outpatient rehabilitation) period. The hospital has its own radiology department and laboratory and is staffed with consulting physicians, internists, and anesthesiologists-intensivists.

Study Duration

The study duration was one year. Control points for measuring pathologically altered and intact tissues were scheduled at clearly defined intervals: postoperative day 1, day 14, and day 60. Further patient monitoring continued for up to one year until complete wound healing. No deviations from the scheduled follow-up time points were recorded.

Intervention

In patients with conditionally sterile wounds resulting from elective surgical procedures, acoustic measurements were performed immediately after soft tissue incision and again following wound closure. In cases involving a phlegmon of two anatomical spaces in the maxillofacial region, measurements were taken after drainage of the purulent focus and at the stage of wound regeneration and suture placement.

The mechanical properties of the skin surrounding the wound were assessed by measuring V_p velocity of acoustic waves in two perpendicular directions: V_y along the vertical axis of the face, and Vx along the horizontal axis. Based on obtained values, the anisotropy coefficient was calculated as $K = V_y/V_x$. Simultaneously, V_n was measured in an unaffected area of the skin.

Subgroup Analysis

Two study groups were formed. Group 1 (n = 15; 6 women and 9 men) included patients who underwent extraoral drainage of phlegmon involving two anatomical spaces of the maxillofacial region. Group 2 (n = 15; 2 women and 13 men) consisted of patients who underwent elective surgical interventions without clinical signs of inflammation.

Outcomes Registration

Outcome registration involved physical examination, detailed anamnesis and disease course assessment, laboratory and clinical diagnostics, and acoustic anisotropy analysis of both pathological and intact tissues.

Statistical Analysis

No preliminary sample size calculation was performed. The statistical analysis was conducted using Microsoft Excel (Microsoft, USA) and Statistica software (StatSoft Inc., USA).

RESULTS

Participants

The study included 30 patients (8 women and 22 men aged 18 to 60 years) with postoperative wounds in the maxillofacial region. All patients gave written consent to participate in the study. In group 1, 2 patients had a history of gastrointestinal disorders, 5 patients had stage I–II hypertension, and 5 patients were diagnosed with compensated type 2 non-insulin-dependent diabetes mellitus; in addition, 3 patients had a history of compensated type 2 non-insulin-dependent diabetes mellitus.

Primary Endpoint

A custom acoustic measurement algorithm was developed. For each of the five scanning points, the differences in wave propagation velocities (ΔV_y and ΔV_x) along both vertical and horizontal axes were calculated at each follow-up stage (Table 1).

Assessment of the velocity differentials (ΔV_y and ΔV_x) across the scanning points in the study groups over time demonstrated notable variation and statistical significance of the observed differences.

Changes in velocity throughout the study differed between groups 1 and 2: ΔV in group 1 ranged from 12.6 to 11.7 m/s; ΔV in group 2 ranged from 5.0 to 4.4 m/s. The mean differences were as follows: ΔV_{y_avg} = 2.52 m/s; ΔV_{x_avg} = 2.66 m/s.

The study found that the acoustic velocity values measured by the indicator device in patients with purulent-inflammatory diseases (group 1) were 2.5 times higher than the wave propagation velocities observed in patients without signs of inflammation (group 2). The analysis of the obtained data demonstrated that acoustic screening of soft tissue properties is a statistically significant method for functional monitoring of scar formation processes following surgical interventions:

- High wave velocity values and a decrease in the anisotropy coefficient correlate with pronounced inflammation in the wound area;

Table 1. Evaluation of ΔV_y and ΔV_x velocity parameters at each scanning point in patients from the study groups over time

Scanning point No.	Group 1				Group 2			
	Patient 1		Patient 2		Patient 3		Patient 4	
	ΔV_y	ΔV_x	ΔV_y	ΔV_x	ΔV_y	ΔV_x	ΔV_y	ΔV_x
1	10	11	15	11	6	5	3	4
2	13	11	16	12	6	6	2	4
3	10	13	13	11	8	4	3	4
4	10	12	14	12	6	5	6	3
5	12	12	13	12	6	5	4	4
Δ	11.0	11.8	14.2	11.6	6.4	5.0	3.6	3.8

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- The absence of inflammatory response is characterized by lower velocity values and a higher anisotropy coefficient.

If the difference between pathological and normal tissue values is $(V_p/V_n) \times 100\% = 9\%–16\%$, the scar is classified as normotrophic. If the difference between pathological and normal tissue values is $(V_p/V_n) \times 100\% = 30\%–40\%$, the scar is classified as hypertrophic. If the difference between pathological and normal tissue values is $(V_p/V_n) \times 100\% = 98\%–128\%$, the scar is classified as a keloid scar.

As clinical examples, early results are presented for patients M. (55 years) and V. (45 years).

Patient M. was admitted electively with a diagnosis of fracture of the right mandibular angle. Clinical, laboratory, and radiographic examinations were performed. Under endotracheal anesthesia, osteosynthesis was performed in the right mandibular angle with placement of mini-plates and mini-screws. The wound was closed with continuous sutures. Postoperative acoustic velocity measurements were: V_x ±21.9 m/s; V_y ± 22.7 m/s. On postoperative day 14, pathological changes were noted in the form of induration and hyperemia of the skin (Fig. 1). The patient reported a sensation of skin tightness, tenderness on palpation, swelling, and itching. Acoustic measurements of the affected area were: V_x ± 14.4 m/s; V_y ± 15.8 m/s. The patient was advised to avoid physical manipulation in the surgical area and to apply local antiseptic treatment to the wound surface. Two months after treatment (Fig. 2), acoustic parameters approached values typical of healthy skin: V_x ± 9.8 m/s; V_y ± 10.2 m/s. For postoperative care, application of a cosmetic gel containing a complex of collagenolytic proteases and a silicone adhesive dressing was recommended.

Diagnostic data obtained using the acoustic assessment method demonstrated a marked decrease in velocity parameters along the x- and y-axes toward the end of the observation period. Two months after treatment, the acoustic anisotropy indices approached values consistent with normal tissue.

Patient V. was admitted with a diagnosis of phlegmon of the right submandibular, pterygomandibular, parapharyngeal, submental spaces, and the right sublingual sulcus. The medical history included severe diabetes mellitus. Under endotracheal anesthesia, classical incision and drainage of the phlegmon of the right submandibular region and sublingual sulcus were performed. Approximately 10 mL of purulent exudate was evacuated. The material was collected for bacterial culture and antibiotic susceptibility testing. The wound was irrigated with a 0.05% chlorhexidine solution and drained. The patient's general condition remained severe after incision and drainage of the phlegmon, due to systemic intoxication, underlying somatic disease, and the extensive scope of the surgical procedure performed for a diffuse purulent-inflammatory process involving two fascial spaces. Postoperatively, the patient reported pain at the surgical site, tissue induration, edema, erythema of the soft tissues, and seropurulent discharge (Fig. 3). Acoustic measurements at that time revealed the following values: V_x ±44.5 m/s; V_y ±43.3 m/s. After 14 days (Fig. 4) and 2 months (Fig. 5) of treatment, a noticeable reduction in inflammatory signs, decreased tenderness, and absence of purulent discharge were observed. Acoustic diagnostics on postoperative day 14 revealed a continued gradual decline in velocities along both perpendicular axes: V_x ±33.1 m/s; V_y ±34.5 m/s. Two months after treatment, the acoustic anisotropy values remained markedly deviated

Fig. 1. Patient M. (55 years). Wound appearance on postoperative day 14 following elective surgical treatment.

Fig. 2. Patient M. (55 years). Normotrophic scar on postoperative day 60 following elective surgical treatment.

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Fig. 3. Patient V. (45 years). Wound appearance on postoperative day 3 after surgical treatment for a purulent-inflammatory disease.

Fig. 4. Patient V. (45 years). Wound appearance on postoperative day 14 after surgical treatment for a purulent-inflammatory disease.

Fig. 5. Patient V. (45 years). Wound appearance on postoperative day 60 after surgical treatment for a purulent-inflammatory disease.

from normal: V_x ±28.8 m/s; V_y ±29.6 m/s, which was associated with the severe form of the disease, pronounced systemic intoxication, and the presence of comorbid pathology.

All patients received anti-inflammatory and antihistamine therapy during treatment, along with topical application of 0.05% chlorhexidine solution. Daily dressing changes and antiseptic wound care were performed, and patients were given medical instructions. Once the wound was clean, the use of a silicone patch dressing and a cosmetic gel containing a complex of collagenolytic proteases was recommended.

By the end of treatment, both patients had painless skin without signs of inflammation. Their condition was stable.

Adverse Events

No adverse events were observed during the study. The medical technique of acoustic anisotropy is minimally invasive and has no known contraindications for application.

DISCUSSION

It was established that, despite high-quality diagnostics and treatment, a patient's general somatic status has a substantial impact on the development of pathological scarring. Studies by Fedorova et al. [1, 2, 5] have demonstrated that the use of an acoustic device provides reliable assessment of the condition of underlying tissues based on skin acoustic parameters. In our study, we applied physical principles to evaluate the speed of acoustic perturbations in the near-field region of the generator. The obtained values of wound edge tension were found to correlate with the morphofunctional status of the soft tissues in the maxillofacial region. After incision of odontogenic phlegmons and cleansing of the wound, this approach enabled assessment of the scar formation features.

In 15 patients with odontogenic phlegmons (group 1), measurements of acoustic parameters after resolution of the purulent process and wound drainage, as well as during the regenerative stage and after secondary closure, showed differences in velocity parameters ranging from ΔV = 11.7 to 12.6 m/s. In patients with conditionally "clean" wounds resulting from planned surgical procedures (group 2), measurements of acoustic wave velocity immediately after tissue incision and after wound closure revealed values of ΔV = 4.4 to 5.0 m/s. We attribute this difference in acoustic amplitude to the persistently increased tissue density observed in the postoperative period among patients with facial and cervical purulent infections.

In the study by Kravets et al. [1], the authors reported a consistent pattern of in time changes in acoustic parameters across different phases of wound regeneration in all patient groups. Differences in the acoustic wave velocity profiles for wounds of different origins were evident only in the amplitude of the y values and their temporal changes.

In the study, which focused on the changes of acoustic measurements during scar formation, a difference between groups was noted: ΔV_y = 2.52–2.66 m/s. However, the high acoustic wave velocity values recorded in the presence of marked tissue inflammation (edema, infiltration, purulent wounds), and the low values observed in cases of minor inflammatory reactions, are numerically comparable to the findings of Kravets and other researchers.

In their study, Khelminskaya et al. [5] reported that in 64% of cases, a physiological type of tissue regeneration with normotrophic scar formation occurred in the postoperative wound area (purulent focus), whereas 32% of cases involved a pathological regeneration type characterized by hypertrophic scarring, with 4% of patients developing coarse keloid scars.

In the present study, normotrophic scars with minor hypertrophic areas were observed in 80% of cases following purulent-inflammatory diseases, whereas 20% of cases showed pathological hypertrophic scarring associated with severe comorbidities. After planned surgical procedures, normotrophic scarring was achieved in 100% of cases.

Thus, the findings of this study support the conclusion that acoustic diagnostics represent an informative method for functional monitoring of wound tissue regeneration. Based on these assessments, existing methods for the early prevention of pathological scarring in the soft tissues of the face and neck may be recommended.

CONCLUSIONS

Acoustic screening is considered an early diagnostic method for identifying the development of pathological scarring in the soft tissues of the face and neck following purulent-inflammatory diseases. This approach can be employed by surgeons to predict the type of tissue regeneration and to guide the use of preventive strategies and pharmacological interventions aimed at preventing coarse scarring and facial deformities during the patient's rehabilitation phase.

Differences in acoustic measurements obtained at various stages of the regeneration process indicate whether scar formation type is pathological or physiological.

Early acoustic diagnostics enables the identification of pathological scarring and facilitates the selection of therapeutic, physiotherapeutic, or radiation treatment strategies, depending on the type and timing of scar formation.

ADDITIONAL INFORMATION

Author contributions: E.V. Cherepanova: conceptualization, writing—original draft preparation; N.M. Khelminskaya, V.N. Fedorova: conceptualization, data curation, writing—review & editing, supervision; A.V. Posadskaya (Goncharova): conceptualization, writing—review & editing; E.E. Faustova, V.I. Kravets: conceptualization, project administration, writing—review & editing. All the authors approved the version of the manuscript to be published and agreed to be accountable for all aspects of the work, ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Ethics approval: The study was approved by the Local Ethics Committee of the Pirogov Russian National Research Medical University (Protocol No. 213 dated December 13, 2021). The study protocol was not published.

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