Original article

Ukr Neurosurg J. 2022;28(1):
doi: 10.25305/unj.236139

Reconstructive plastic surgery in patients with complex defects and deformities of the head when removing extracerebral tumors extending beyond the cerebral skull

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Received: 30 June 2021
Accepted: 16 February 2022

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Objective: To improve the surgical results of neurosurgical patients with complex defects and deformities of the head based on modern innovative technologies.

Materials and methods. Based on the analysis of diagnosis and surgical treatment of 54 patients with common extracerebral tumors of the head the issues of optimizing their treatment were considered. The positive role of reconstructive-plastic operations in complex defects and deformities of the head on the basis of modern possibilities of computer modeling and use of arterial autografts is noted.

Results. Carrying out computer simulations before the operation, radical removal of the tumor with a single-stage reconstructive-plastic operations with the use of innovative technologies provides high efficiency of treatment, satisfactory quality of life of patients.

Conclusions. Reconstructive plastic surgery in patients with complex defects and deformities of the head when removing extracerebral tumors that extend beyond the cerebral skull, can provide a satisfactory functional and cosmetic effect of the operation. Radical removal of the tumor by a single-stage autologous tissue grafting using modern technologies promotes rapid wound healing and good quality of life. In patients with widespread cancer stages of the skull, for the plasty of complex soft tissue defects of the cranial vault, the optimal operation is the use of regional musculocutaneous flaps. The type, shape and required amount of the tissue depends on the size and location of the defect. It has been confirmed that the use of a horizontal D-shaped musculocutaneous flap is justified for temporal and parietal defect plasty, and the use of a vertical D-shaped musculocutaneous flap is required to close the occipital-parietal defect. The use of computer simulation is effective and appropriate in patients with large defects and deformities of the cerebral and facial skull when planning complex reconstructive plastic surgery. The use of modified surgical approaches, the latest innovative technologies has made it possible to significantly improve the quality of life of patients, contributed to their early rehabilitation and readaptation.

Keywords*: computer simulation; tumors; complex defects of head tissues; surgical treatment.*

Introduction

Development and improvement of reconstructive plastic surgeries in complex defects and deformities of the head is an urgent problem of modern neurosurgery and plastic surgery [1–5,7,8], owing to not only the high functional but also aesthetic significance of these anatomical areas [1,3,10]. Invasive widespread tumors of various head tissues affect both intracranial structures and bones of the neurocranium and facial skull, as well as integumentary tissues of the head. Resections of widespread extra-intracranial malignant tumors together with the affected surrounding tissues as a result of radiation therapy use with the occurence of degenerative-dystrophic changes, radiation dermatitis and necrosis, disruption of reparative processes lead to large and complex defects [1,4,6,9].

Patients with massive defects of the head, complicated by combined damage to anatomical functional and critical structures, are the most severe clinical group of patients whose treatment and rehabilitation using traditional methods is usually accompanied by a high rate of complications, making such interventions ineffective both functionally and cosmetically. [1,4,10]. Analysis of the literature has shown that plastic surgery of large soft tissue defects of the skull using free flaps with microvascular anastomosis is currently considered the optimal operation [2,4,8,10].

The methods of plastics of large combined defects of the head developed and improved by us in recent years by pedicled arterialized grafts, as well as using microsurgical anastomoses allow to single stage replacing destroyed tissues with a functional effect and perform plasty in areas with trophic disturbance that greatly expanded the possibilities of neurosurgery and plastic surgery [1,4]. Careful planning of surgical interventions is of great importantance [2,3,5,6].

One of the promising directions for solving this problem is the use of computer simulation (CS) methods. Modern computer technologies make it possible to create models of complex biological objects and provide the necessary accuracy of calculations and detailing [2]. There are a number of software systems (Materialise, Implant-assistant, 3D-DOCTOR, etc.) that allow you to move to 3D objects with the possibility of structural analysis of the system by its X-ray density. The capabilities of modern computed tomography (CT) have changed the approach to modeling biological objects and made it possible to introduce computer-aided design systems (CAD/CAM/CAE-technologies) in clinical practice [2,3]. Creating a virtual model of a biological object is no longer just a diagnostic procedure and turns into a powerful tool for planning surgical procedures and predicting their consequences, and can be used to create devices necessary for implementing an operation plan [2-6].

Objective: to improve the surgical results of neurosurgical patients with complex defects and deformities of the skull based on modern innovative technologies.

Materials and methods

The results of diagnosis and surgical treatment of 54 patients with complex head defects after removal of widespread (mainly large and giant) extra-intracranial malignant tumors, who from September 2013 to March 2018 were treated at the Department of Extracerebral Tumors of the Institute of Neurosurgery named after acad. A.P. Romodanov, Ukraine. There were 30 (55.6%) women and 24 (44.4%) men among the patients.

Primary tumors were diagnosed in 15 (27.8%) patients, continued tumor growth - in 39 (72.2%).

Research methods were used in accordance with the standards: neuroimaging methods (CT (CT-MAX (GE, USA), CT-LX (Philips, Holland), magnetic resonance imaging (MRI)) (Magnetom 42 SP (Siemens, Germany), angiography), morphological and immunohistochemical. Surgical approach was determined based on MRI and CT data. In the early postoperative period, to control the radicality of surgery and identify possible postoperative complications, all patients underwent CT.

All patients gave written consent to the examination and use of data from the medical history in scientific research. The study was approved by the Committee on Ethics and Bioethics of the Institute of Neurosurgery named after acad. A. P. Romodanov, Ukraine (Minutes №1 dated January 29, 2019).

Description of the preparation and closure of large soft tissue defects of the head

Patients underwent spiral CT before surgery. Orientation of tomographic slices was based on the standard CT protocol of the facial skull and neurocranium. The slice thickness was 1 mm. The data obtained in the form of a series of DICOM files were imported into the software environment for analysis and subsequent processing of tomographic images. The software packages Minimics 12.3, SimPlant 11.0 (Materialise, Belgium) and eFilmLite (Merge Healthcare, USA, 2006) were used. After image conversion, the axial sections obtained by CT and the reconstruction of these images in the sagittal and frontal planes were studied. Depending on the objectives of the study, the bone window mode and the soft tissue visualization mode of the facial skull and neurocranium were used. Virtual repositioning of grafts and fragments was performed by moving and rotating models of individual bone defects and fragments. In the postoperative period, the results of surgical interventions were compared with the created virtual model [2,3].

To build a model of branches of the external carotid artery, PCad software package was used. After evaluating all the disadvantages and advantages of the work being done, there was the aim to automate and optimize the surgeon's efforts to predict the passage and search of vessels in the area of the operation. Purposeful topographic studies of the anatomy of the branches of the external and internal carotid arteries depending on the shape of the head and the defect were performed. A set of actual values was obtained as a result of measuring each main vessel and its main branches. The head area was divided into zones indicating the commonly used standard angiosome flaps and possible areas for graft harvesting. Based on the studies carried out, the software for modeling the occurrence and variable anatomic geometry of vessels and nerves of the head was developed, the priority stage of which is visualization ***(Fig. 1, 2)***.

In the developed software, the vessels of the head were displayed by drawing lines depending on the values of their projection in a linear coordinate system. Each of the lines is conventionally divided into three axial components: 1 and 2 are the outer boundaries of the projections, 3 is the central axis of the vessel. For each vessel, a separate linear coordinate system is used with reference point at the base of the axial line of the vessel. To construct the calculated axial lines, inflection points were found, the entire line was divided into arcs, and the curvature was calculated. Based on the values of the curvature of the obtained arcs, the radius of the arcs was calculated, which made it possible to draw using standard tools [5]. For practical implementation of the software it is possible to enter the calculated data after

This article contains some figures that are displayed in color online but in black and white in the print edition

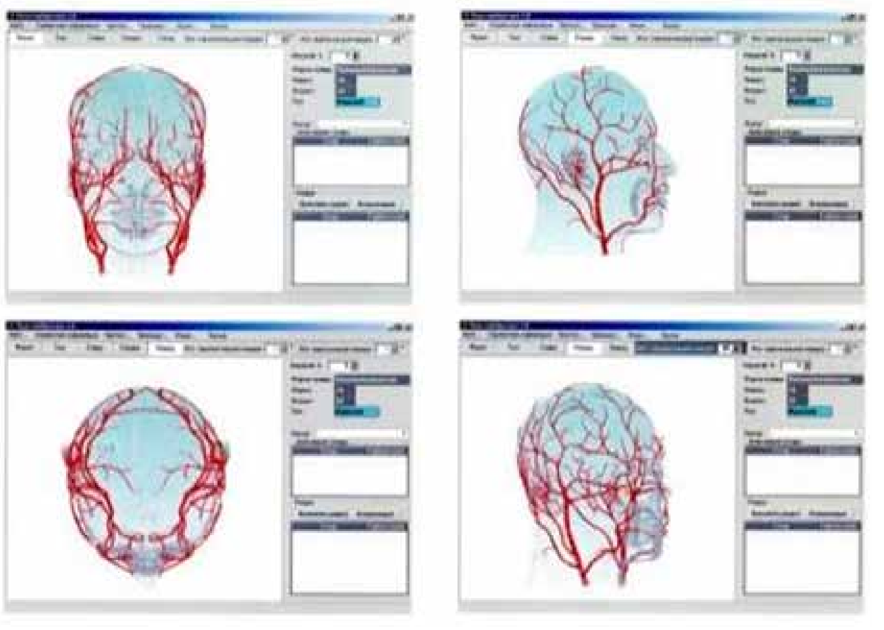

Fig. 1. Computer simulation interfaces

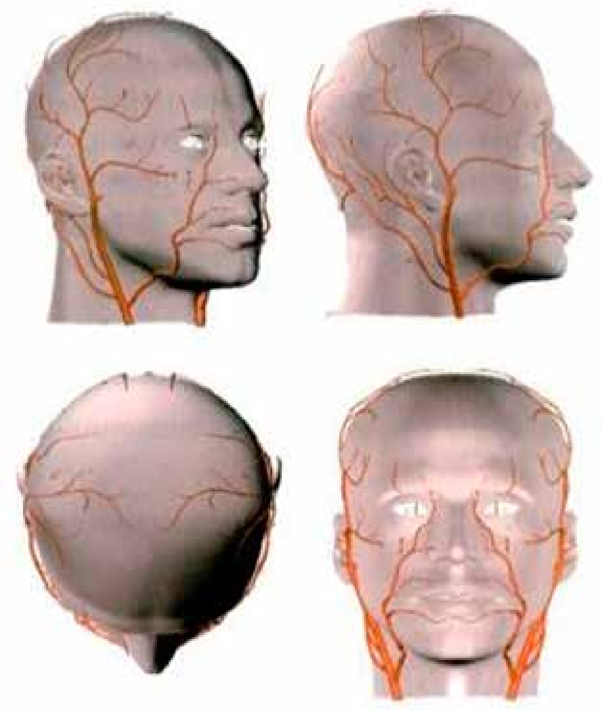

Fig. 2. Computer simulation of external carotid artery branching

forecasting into a standardized table, which reduced the margin of error in forecasting.

Regional and rotational tissue autografts are mainly used to close soft tissue defects of the head of large size and complex configuration, which have the following advantages: one-stage resection and reconstruction, short surgery duration, low complication rate and satisfactory functional results.

Standard methods of removing widespread head tumors involve the following stages: patient positioning; preoperative bathing of the surgical site in accordance with generally accepted principles; rigid fixation of the patient's head with a "Mayfield" frame; standard approach depending on the location of the tumor; layer-by-layer incision of the skin and subcutaneous tissue after previous anesthesia of soft tissues with 0.25% novocaine solution; hemostasis by applying Reni skin plastic clamps and monopolar coagulation; performing craniotomy and osteoperforation using a high-speed electric drill "Stryker". The size of the craniotomy window depended on the location and size of the tumor, as well as on surgical approach.

Hemostasis from diploic veins was performed by rubbing wax into the bone cut. A horseshoe and X-shaped incision of the dura mater (DM) was performed after preliminary electrocoagulation of blood vessels in it, usually moving back from the bone at a distance of 0,5 cm. In deep tumor spread taking into account the topography of the tumor according to CT and MRT data performed before the surgery, the trajectory of approach to the tumor outside the functional area of the cortex was calculated in accordance with the topography of functionally significant areas and neurovascular structures of the brain, in some cases – considering the data of ultrasound during surgery. The tumor was removed in stages by "pieces" under the control of the "Zeiss" magnifying technique. Hemostasis was performed using bipolar and monopolar coagulation, as well as hemostatic patches and special hemostatic sponges, as the final stage.

DM defects were closed by autoaponeurosis, femoral fascia and artificial DM. Sutures were sealed with the sealant DM "DuraSeal", using fibrin adhesives. Defects of skull bones were closed with modelled individualized bone cements or titanium meshes.

To improve the reliability of hemostasis, reduce trauma to the brain and the risk of occurrence or increase of neurological defect, new technologies and modern devices have been introduced into practice, which allow using ultrasound energy and plasma flow. To perform additional hemostasis, the bone cut was treated with argon plasma coagulation in the "Sprai" mode (power - 60 W, argon flow rate - 2 l/min) instead of rubbing with wax. The large number of rotations of the device made it possible to perform this stage of surgery almost bloodlessly. The incision of the DM was performed taking into account the location, size and direction of invasive tumor spread and providing the required examination of the surgical field.

The tumor was removed with maximum radicality within physiological permissibility. The "CUSA-Excel" device was used. Using an ultrasonic cavitation disintegrator, the tumor removal was started from its outer margin towards the main tumor mass, which was treated last. In the tumor removal stages, large vessels were ligated or permanent clips were applied, small and medium-sized vessels were coagulated using micro-, mono-, and bipolar coagulations. In basal and parasagittal tumors, if brain traction was necessary, the "Aesculap" retractor system was used, which allowed for conservative traction, creating an optimal view of the surgical wound. D. Simpson scale was used to formalize the degree of radicality of operations. Almost all patients (52 (97%)) underwent radical sugery in accordance with the highest (first and second) type according to D. Simpson scale. In isolated cases, after visually complete removal of the tumor (type 2 on D. Simpson scale), coagulation of the tumor growth site was performed using an argon-plasma coagulator in the "Sprai" mode (power - 60 W, argon flow rate - 1.0-1.5 l/min). After removal of the tumor, the site of derivative growth of which was the wall of the superior saggital sinus, in order to prevent perforation of this wall, the matrix was treated only in the mode "Sprai" (power - 60 W, argon flow rate – 0.5 l/min). With macroscopic complete removal of the tumor, hemostasis was performed in 50% of cases, using a cold plasma coagulation device "SORING-CPC 3000" (power - from 10 to 25 W). The operation was completed by stitching and welding tightly by DM device "EKVZ-300" ("PATONMED").

In case of bone lesion, it was resected with a single-stage replacement of the defect with a titanium mesh implant or bone cement.

Results and discussion

Large (5–8 cm in diameter) tumors predominated (57.7%), while medium-sized (3–5 cm), giant (≥8 cm), and small (<3 cm) tumors were less common ***(Fig. 3)***.

Treatment outcomes of patients with complex defects of the skull vault were studied in the immediate and long-term period. The main criteria for assessing the immediate results of treatment were engraftment of the flap and the absence of cerebrospinal fluid. A good result with complete engraftment of the flap was observed in 49 (90.74%) cases. Necrosis of the distal horizontal flap and suture line disruption in the donor site, which required additional treatment, occurred in 5 (9.26%) patients ***(Table 1)***.

Clinical case №1

Patient R., aged 50 ***(Fig. 4)***. In 2014, the diagnosis was made: basal cell carcinoma of the occipital region. Two courses of radiation therapy and 4 times a year the surgery for the tumor were performed. The result is negative - rapid tumor growth. According to CT data of August 17, 2015, a tumor of the soft tissues of the occipital region with extra-intracranial spread and destruction of the occipital bone was detected. Clinical

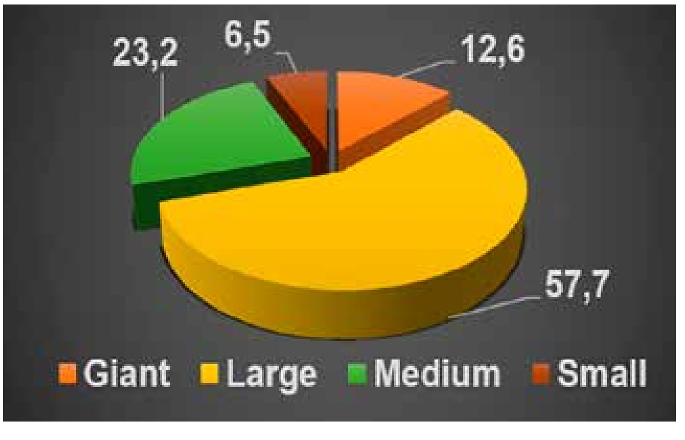

Fig. 3. Distribution of tumors by size,%

Table 1. The results of plasty of large defects of the neurocranium and facial skull by different types of tissue flaps

Defect localization	Plasty outcomes					
	Complete engraftment		Marginal necrosis		Partial necrosis	
	Abs.	%	Abs.	%	Abs.	%
Cerebral cranium structures	37	68,52	2	3,70	1	1,85
Facial skull structures	12	22,22	1	1,85	1	1,85
Total	49	90,74	3	5,55	2	3,70

diagnosis: squamous cell carcinoma of the occipital region with the occipital bone invasion and extra-intracranial spread. Condition after radiation therapy is secondary radiation dermatitis. There is large soft tissue defect of the occipital region. Systemic lupus erythematosus.

On September 10, 2015, the surgery was performed in the clinic: removal of the occipital tumor, tangential osteonecrectomy, soft tissue defect plasty with a vertical D-shaped musculocutaneous flap. The wound healed by primary intention healing.

Pain syndrome regressed in the neurological status. According to the control CT scan, there are no tumor remnants.

Clinical case №2

Patient R., 63 years old ***(Fig. 5)*** suffers from basal cell carcinoma of the parietal region of the skull since 2007. Two courses of radiation therapy were conducted. In 2016, he underwent surgery for tumor recurrence. According to CT data from February 27, 2017, after radiation therapy, recurrence of a tumor of the soft tissues of the parietal region with extra-intracranial spread and destruction of the parietal bone was detected. On March 2, 2017, the removal of the tumor, epidural inflammatory granulations, osteomyelitic bony sequestrum of the left temporoparietal region, plastic surgery of the soft tissue defect of the left temporoparietal region with a horizontal D-shaped musculocutaneous flap was performed. The wound healed by primary intention healing.

Pain syndrome regressed in the neurological status. Control CT showed no tumor recurrence.

Reconstruction of complex skull defects after removal of large and giant tumors and radiation therapy is a difficult problem primarily due to soft tissue deficiency. Cranial vault tissues are used directly for plasty of defects, but numerous previous interventions that turn these tissues into scars make their use impossible.

Alternatively, flaps from nearby areas were used to close large and complex soft tissue defects of the head in the absence of local tissue. Given the long purulent-necrotic process and degenerative-dystrophic changes in the tissues around the defect, there is a need for revascularization of the affected area. The use of regional musculocutaneous flaps has advantages over others, provides a sufficient amount of plastic material with its own blood supply, and tissue transfer on pedicle

Fig. 4. Patient R.: A - appearance of the patient before surgery; B - transposition of the vertical flap, suturing of the donor site

Fig. 5. Patient R.: A - appearance of the patient before surgery; B - the result of treatment after 1 month

muscle flap significantly reduces the risk of thrombosis of nutrient vessel.

Postoperative CT, MRI, and X-ray confirmed the viability of musculocutaneous grafts. In the long term period, the functional results and appearance of the reconstructed area were assessed by patients and neurosurgeons as good.

Clinical case №3

Patient V., 50 years old ***(Fig. 6)***. According to CT data of February 12, 2014, a giant tumor of the parieto-occipital region measuring 42.0×42.0×116.0 mm with extra-intracranial spread and destruction of the parietal and occipital bones, spreading to the superior sagittal sinus with its complete occlusion. On February 15, 2014, surgery was performed – gross total tumor resection (Sa) with a single-stage plasty of DM defect, skull bones and soft tissues with local tissues. Wound healing is without complications. Complete regression of neurological symptoms.

Clinical case №4

Patient S., 60 years old ***(Fig. 7)***. According to CT data of June 15, 2013, a bilateral defect of the frontal and parietal bones was detected after surgery for the removal of a giant bilateral meningioma of the anterior and middle third of the falx. Clinical diagnosis: defect of frontal and parietal bones after surgery for removal a bilateral meningioma of the anterior and middle third of the falx, continued tumor growth, trephine syndrome, external cerebrospinal fluid, secondary episyndrome, tetraparesis. On June 18, 2013, surgery was performed: postoperative wound exploration, tumor resection, plasty of DM defect and skull bones with titanium meshes and soft tissues with local tissues. Wound healing is without complications. Complete regression of neurological symptoms.

Clinical case №5

Patient M., 29 years old ***(Figs. 8, 9)***. Clinical diagnosis: a giant bilateral extra-intracranial tumor of the parietal-temporal-occipital region, a giant bilateral defect of the temporal, parietal, occipital bones and scalp, tetraparesis, episyndrome. On May 25, 2015, surgery was performed: gross total resection of a giant extra-intracranial tumor, plasty of the DM defect and skull bones with titanium meshes and scalp. Wound healing is without complications. Complete regression of neurological symptoms.

Clinical case №6

Patient L., 70 years old ***(Fig. 10, 11)***. Clinical diagnosis: bilateral extra-intracranial tumor of the frontal sinus, osteomyelitis of the frontal bone. On October 26, 2017, surgery was performed: extranasal surgical approach to the frontal sinus, resection trepanation of the frontal bone, gross total tumor resection, debridement of wound, plasty of the defect of the anterior wall of the frontal sinus and skull bones with bone cement ("Simplex") and scalp. Wound healing is without complications. Regression of symptoms.

Clinical case №7

Patient K., 42 years old ***(Fig. 12, 13)***. Clinical diagnosis: a giant bilateral extra-intracranial tumor (Sa) of fronto-parietal region. On January 15, 2018, a surgical intervention was performed: gross total resection of

Fig. 6. Patient V.: A - appearance of the patient before surgery; B - fixation of the patient on the operating table; C – gross total tumor resection; D- giant tumor (weight - 1.4 kg); E- appearance of the patient on the 7th day after surgery; F - appearance of the patient 1 month after surgery

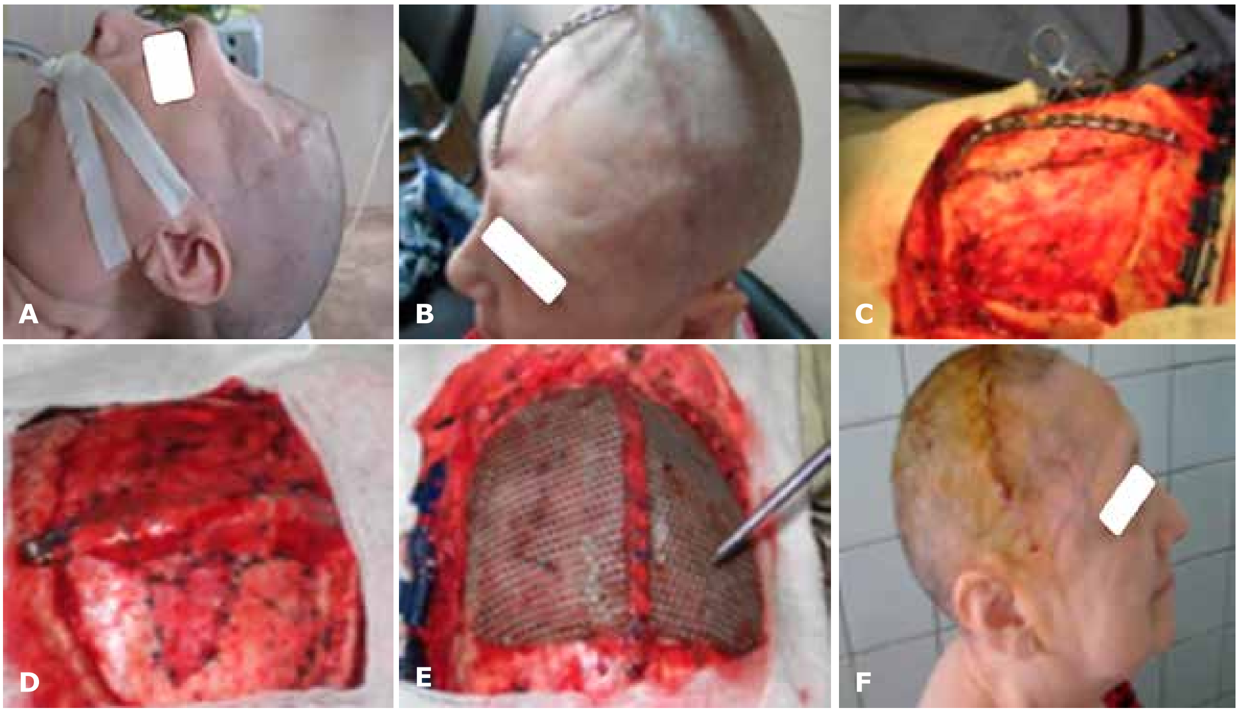

Fig. 7. Patient S.: A - appearance of the patient before surgery; B,C- giant defect of DM, skull bones and skin; D- plasty defect of DM; E - frame plasty defect of the skull bones with titanium mesh; F - appearance of the patient before discharge from the department

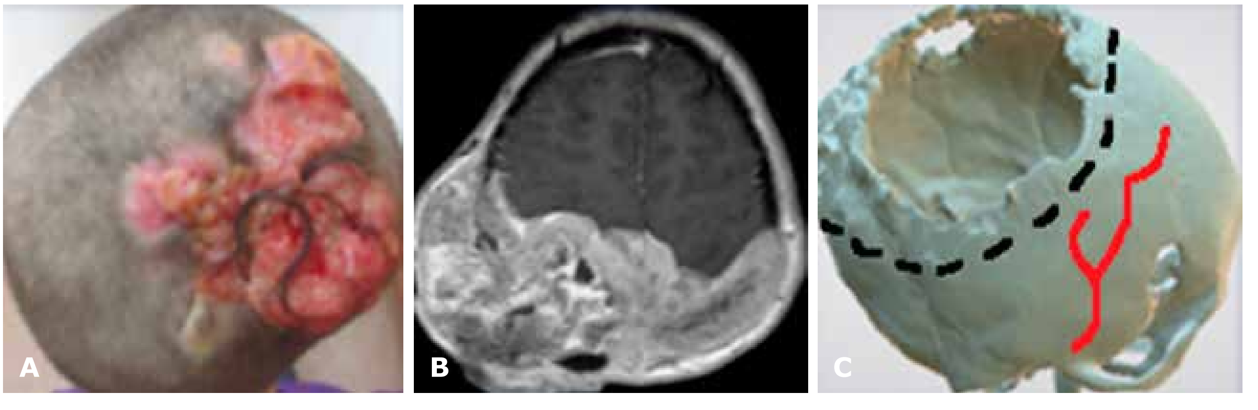

Fig. 8. Patient M.: A - appearance of the patient before surgery; B - CT data before surgery; C - 3D modeling data and CS before surgery. Giant defect of dura mater, skull bones and skin

Fig. 9. Patient M.: A - total resection of poorly differentiated carcinoma of the skin (weight - 0.96 kg) with plasty defects of DM and skull bones (titanium meshes) and scalp; B, C - appearance of the patient before and after surgery

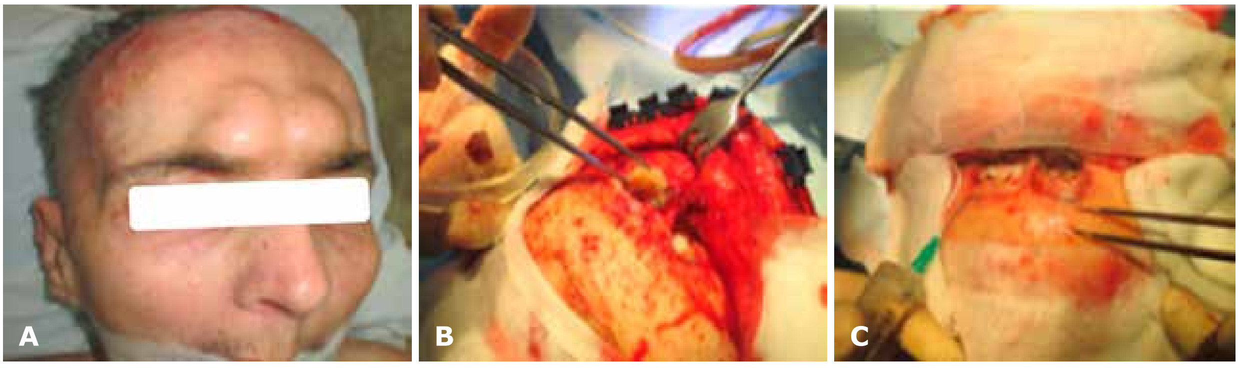

Fig. 10. Patient L.: A - appearance of the patient before surgery; B, C - sanitation of the frontal sinus

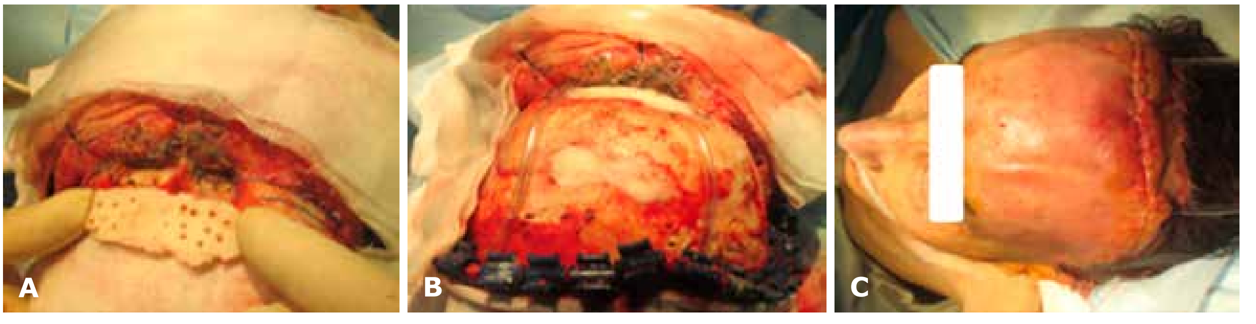

Fig. 11. Patient L.: A – closure of the defect of the anterior wall of the frontal sinus with bone cement; B - implantation of suction-irrigation system with antiseptics; C - appearance of the patient at the end of the operation

the tumor with a single-stage plasty of DM defect and skull bones and soft tissues with local tissues. Wound healing is without complications. Complete regression of neurological symptoms.

Surgical intervention in patients with this pathology requires careful planning. Special anatomical conditions and numerous preliminary palliative operations significantly complicate the situation.

The obtained results, confirming the effectiveness and expediency of computer simulation using modern computer technologies in neurosurgical patients, are the basis for further research on the possibilities of their use in patients with defects and deformities of the neurocranium and facial skull when planning complex reconstructive and restorative interventions in institutions of the appropriate level of providing professional medical care.

The use of modern software systems for the processing and analysis of CT data made it possible to individualize the shape of the grafts of neurocranium and facial skull transplants. Virtual simulation of surgical procedures contributed to a better understanding of the topographic and anatomical characteristics of defects and the condition of bone tissue, allowed determining the optimal parameters of grafts and significantly reduce the risk of complications of surgery as well as injury of important anatomical structures.

In patients with widespread stages of cranial vault cancer, scarring of the surrounding skin, severe degenerative-dystrophic processes and reduced skin regeneration capabilities, the operation of choice for the plasty of complex soft tissue defects of the cranial vault is the use regional musculocutaneous flaps.

The type, shape and required amount of tissue depend on the size and location of the defect. For the plasty of the skin of the temporal-parietal region, the formation of a horizontal D-shaped musculocutaneous flap is shown, for the closure of the occipital-parietal region - the formation of a vertical D-shaped musculocutaneous flap. After 4–6 months, the correction of the pedicle flap is necessary to obtain for a good cosmetic result.

The choice of surgical approach when removing a tumor depends on the primary localization of the tumor, the stage at the time of treatment, the nature and direction of invasive tumor spread, as well as blood supply sources, quality of life of patients - depends on the radical removal and histobiological properties of the tumor. Continued growth or recurrence of the tumor was influenced by the patient's age, radical intervention and histobiological features of the tumor.

Conclusions

1. Reconstructive plastic surgery in patients with complex defects and deformities of the head when removing extracerebral tumors that spread beyond the skull, provide a satisfactory functional and aesthetic effect of the operation.

2. Radical removal of the tumor by a single-stage autogenous tissues plasty using modern technologies promotes rapid wound healing and decent quality of life.

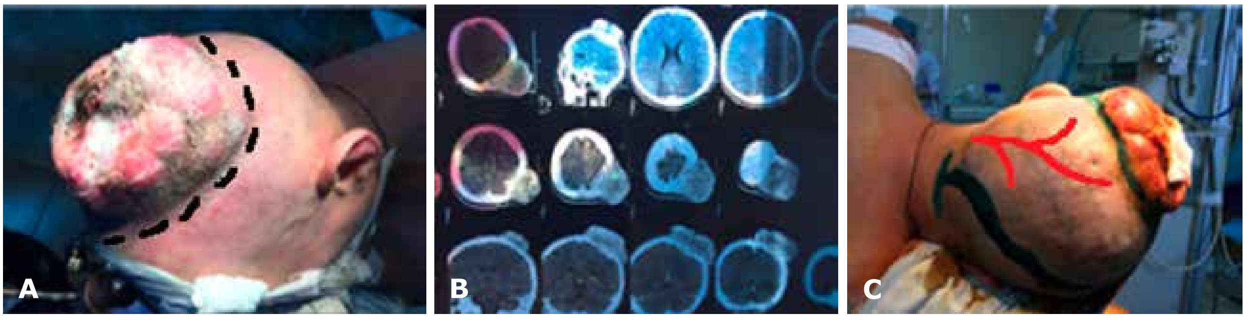

Fig. 12. Patient K.: A - appearance of the patient before surgery; B - MRI data before surgery; C - marking the operation plan on the operating table

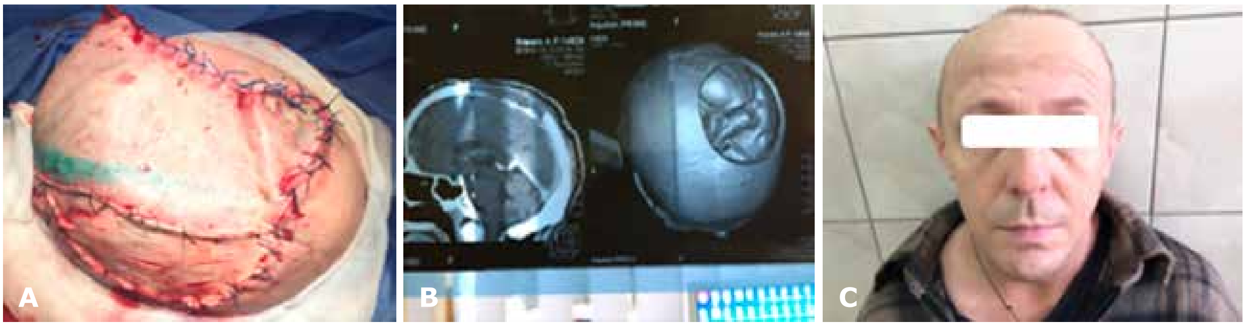

Fig. 13. Patient K.: A - combined closure of giant scalp defects with rotational occipital pedicle flaps and free skin graft from the right thigh; B - CT data after gross total tumor resection; C - appearance of the patient on the day of discharge from the department

3. In patients with widespread stages of cranial neoplasms the optimal operation for the plasty of complex soft tissue defects is the use of regional musculocutaneous flaps. The type, shape and required amount of tissue depend on the size and location of the defect. It has been confirmed that the horizontal D-shaped musculocutaneous flap is appropriate for the plasty of the temporal-parietal localization defect, and the vertical horizontal D-shaped musculocutaneous flap is used to close the defect of occipital-parietal localizaion.

4. Computer simulation is effective and appropriate in patients with complex defects and deformities of the neurocranium and facial skull when planning complex reconstructive and plastic interventions.

5. The use of modified surgical approaches and innovative technologies has improved the treatment outcomes of patients and facilitated their early rehabilitation and socialization.

Information disclosure

Conflict of interest

The authors declare no conflict of interest.

Ethical approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Funding

The research was conducted without sponsorship.

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