TIBBIYOT
TA'LIMI & INNOVATSIYALARI

O'ZBEKISTON RESPUBLIKASI
19 20
TOSHKENT TIBBIYOT AKADEMIYASI

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- 14.00.00 - Tibbiyot fanlari;
- 14.00.01 - Akusherlik va ginekologiya;
- 14.00.02 - Morfologiya;
- 14.00.03 - Endokrinologiya;
- 14.00.04 - Otorinolaringologiya;
- 14.00.05 - Ichki kasalliklar;
- 14.00.06 - Kardiologiya;
- 14.00.07 - Gigiena;
- 14.00.08 - Oftal'mologiya;
- 14.00.09 - Pediatriya;
- 14.00.10 - Yuqumli kasalliklar;
- 14.00.11 - Dermatologiya va venerologiya;
- 14.00.12 - Tibbiy reabilitologiya;
- 14.00.13 - Nevrologiya;
- 14.00.14 - Onkologiya;
- 14.00.15 - Patologik anatomiya;
- 14.00.16 - Normal va patologik fiziologiya;
- 14.00.17 - Farmakologiya va klinik farmakologiya;
- 14.00.18 - Psixiatriya va narkologiya;
- 14.00.19 - Klinik radiologiya;
- 14.00.20 - Tibbiy genetika;
- 14.00.21 - Stomatologiya;
- 14.00.22 - Travmatologiya va ortopediya;
- 14.00.23 - Hamshiralik ishini tashkil etish;
- 14.00.24 - Sud tibbiyoti;
- 14.00.27 - Xirurgiya;
- 14.00.28 - Neyroxirurgiya;
- 14.00.41 - Xalq tabobati;
- 14.00.35 - Bolalar xirurgiyasi;
- 14.00.34 - Yurak-qon tomir xirurgiyasi

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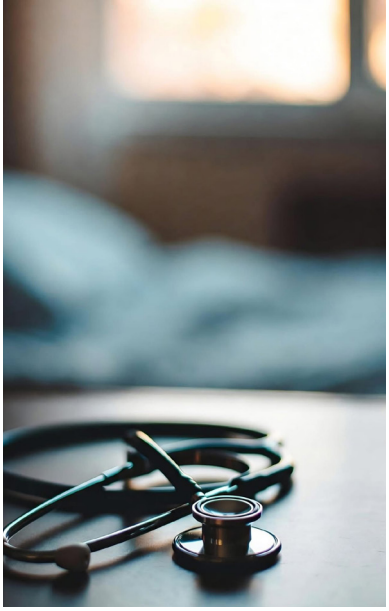
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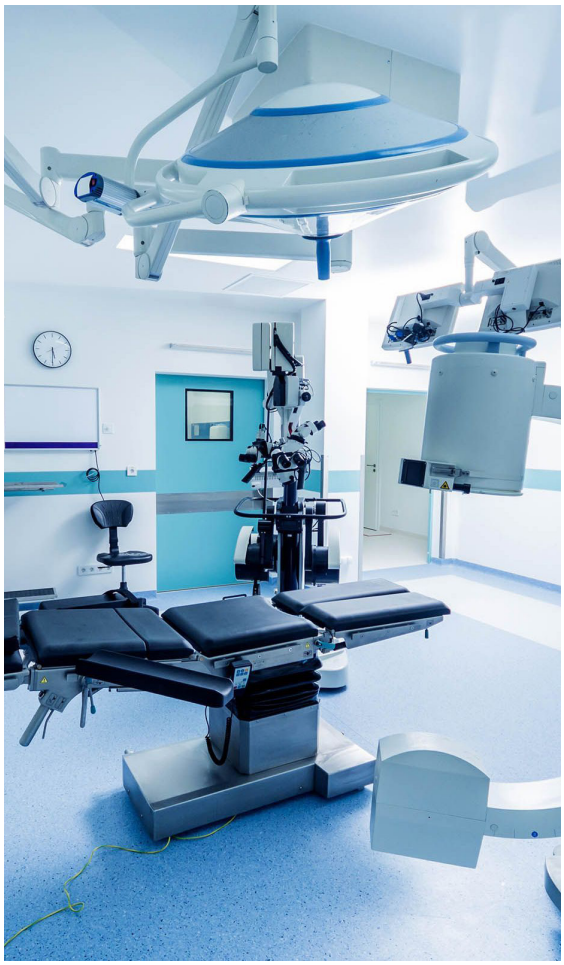
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ilmiy elektron jurnali O‘zbekiston Respublikasi Axborot va ommaviy kommunikatsiyalar agentligi (AOKA) tomonidan 2024-yil 9-oktabrdan boshlab c-5669651 raqami ostida rasmiy ro‘yxatdan o‘tkazilgan.

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MUNDARIJA

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ETIOLOGY-SPECIFIC PROTECTIVE FACIAL HEADGEAR FOR THE PREVENTION OF COMBINED MAXILLOFACIAL INJURY: CONCEPTUAL DESIGN OF FOUR PROTOTYPES DERIVED FROM BIOMECHANICAL ANALYSIS

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Abstract: Facial protectors are widely used in sport and at work, but most are designed for a single activity and protect a fixed set of structures. The mechanism of injury, however, determines which parts of the facial skeleton are loaded and where they fail, so protection that is not matched to the mechanism may leave the most vulnerable regions exposed.
Aim–To derive protection priorities for four common injury mechanisms from clinical, computed-tomographic, and finite element data and to translate them into conceptual designs for protective headgear.
Three sources were combined: the anatomical distribution of fractures in patients with combined maxillofacial trauma caused by road traffic accidents, falls from height, sports injuries, and multifactorial trauma; regional radiodensity in Hounsfield units, used as a computed-tomography surrogate for bone mineral density, and porosity of the facial skeleton; and finite element simulation of frontal, lateral, and oblique impacts at 5–10 m/s, with calculation of the Head Injury Criterion (HIC). For each mechanism, anatomical regions were ranked by fracture frequency, mechanical vulnerability, and contribution to head-injury risk, and the resulting priority zones were expressed as four conceptual three-dimensional designs.
Fracture distribution differed clearly between mechanisms: road traffic accidents produced predominantly midfacial injuries of Le Fort I–II type, with orbital floor and zygomatic fractures; falls from height produced nasal and orbital floor fractures; sports injuries produced isolated nasal and zygomatic fractures; and multifactorial trauma produced multiregional injuries involving the mandible, frontal bone, and midface. The orbital floor (590±65 HU) and nasal bones (510±60 HU) were the least dense and most porous regions, while the temporal region carried the highest head-injury risk on simulation (HIC 1620±260 for lateral impact versus 1380±210 for frontal, 1250±180 for parietal, and 1100±160 for occipital impacts). Four prototypes were designed accordingly: a closed design protecting the lower face and lateral region for road traffic use; a lightweight open frame protecting the nose, malar region, and temple for fall-prone settings; an open sports design protecting the nose, malar region, and jaw while preserving the visual field and ventilation; and a full design additionally covering the frontal and temporal regions for mixed high-energy exposure. The system has been registered (FAP20260186).
Injury mechanism can be used as the organising principle for facial protection. The four designs presented here translate measured fracture distribution, regional bone vulnerability, and simulated impact risk into distinct coverage patterns. They are conceptual: material selection, impact testing against recognised standards, and field evaluation of protective efficacy remain to be carried out.
Key words: facial protection; protective headgear; maxillofacial trauma; injury prevention; finite element analysis; Head Injury Criterion; facial fractures.

Annotatsiya: Yuzni himoya qiluvchi vositalar sportda va ish faoliyatida keng qo‘llaniladi, biroq ularning aksariyati ma’lum bir faoliyat turi uchun mo‘ljallangan bo‘lib, anatomik tuzilmalarning cheklangan majmuini himoya qiladi. Shu bilan birga, jarohatlanish mexanizmi yuz skeletining qaysi qismlariga yuklama tushishini va qaysi sohalarda shikastlanish yuz berishini belgilaydi. Shu sababli jarohatlanish mexanizmiga moslashtirilmagan himoya vositasi eng zaif sohalarni himoyasiz qoldirishi mumkin.
Tadqiqot maqsadi– to‘rtta keng tarqalgan jarohatlanish mexanizmi uchun klinik, kompyuter-tomografik va chekli elementlar tahlili ma’lumotlari asosida himoya ustuvorliklarini aniqlash hamda ularni himoya bosh kiyimlarining konseptual konstruksiyalariga aylantirish.
Uchta ma’lumot manbasi birlashtirildi: yo‘l-transport hodisalari, balandlikdan yiqilish, sport jarohatlari va ko‘p omilli jarohatlar natijasida yuzaga kelgan qo‘shma jag‘-yuz jarohatlari bo‘lgan bemorlarda sinishlarning anatomik taqsimoti; kompyuter tomografiyasi yordamida o‘lchangan yuz skeleti suyaklarining hududiy rentgen zichligi (Hounsfield birliklarida, suyak mineral zichligining kompyuter-tomografik ko‘rsatkichi) va g‘ovakligi; shuningdek, 5–10 m/s tezlikdagi frontal, lateral va qiyshiq zarbalarning chekli elementlar yordamida modellashtirilishi hamda bosh jarohati mezoni (Head Injury Criterion, HIC) hisoblanishi. Har bir jarohatlanish mexanizmi uchun anatomik sohalar sinishlar chastotasi, mexanik zaiflik va bosh jarohati xavfiga qo‘shadigan hissasi bo‘yicha tartiblandi, natijada aniqlangan ustuvor himoya zonalari to‘rtta konseptual uch o‘lchamli konstruksiya ko‘rinishida ifodalandi.
Sinishlarning taqsimlanishi jarohatlanish mexanizmlariga qarab aniq farq qildi: yo‘l-transport hodisalari asosan Le Fort I–II tipidagi o‘rta yuz sohasi jarohatlari, orbita tubi va yonoq suyagi sinishlariga olib kelgan; balandlikdan yiqilish burun suyaklari va orbita tubi sinishlari bilan kechgan; sport jarohatlarida burun va yonoq suyaklarining izolyatsiyalangan sinishlari kuzatilgan; ko‘p omilli jarohatlarda esa pastki jag‘, peshona suyagi va yuzning o‘rta sohasi ishtirokidagi ko‘p sohali shikastlanishlar kuzatilgan. Orbita tubi (590±65 HU) va burun suyaklari (510±60 HU) eng past zichlik va eng yuqori g‘ovaklikka ega sohalar bo‘lgan, temporal sohada esa modellashtirish natijalariga ko‘ra bosh jarohati xavfi eng yuqori bo‘lgan (HIC lateral zarba uchun 1620±260, frontal zarba uchun 1380±210, parietal zarba uchun 1250±180 va oksipital zarba uchun 1100±160). Shunga muvofiq, to‘rtta prototip ishlab chiqildi: yo‘l-transport sharoitida foydalanish uchun yuzning pastki qismi va lateral sohani himoya qiluvchi yopiq konstruksiya; yiqilish xavfi yuqori bo‘lgan sharoitlar uchun burun, malyar soha va chakka sohasini himoya qiluvchi yengil ochiq karkas; ko‘rish maydoni va ventilyatsiyani saqlagan holda burun, malyar soha va jag‘ni himoya qiluvchi ochiq sport konstruksiyasi; hamda yuqori energiyali aralash ta’sirlar uchun peshona va temporal sohalarni qo‘shimcha ravishda qamrab oluvchi to‘liq konstruksiya. Tizim ro‘yxatdan o‘tkazilgan (FAP20260186).
Jarohatlanish mexanizmidan yuzni himoya qilishni tashkil etishning asosiy prinsipi sifatida foydalanish mumkin. Taqdim etilgan to‘rtta konstruksiya o‘lchangan sinishlar taqsimoti, suyaklarning hududiy zaifligi va modellashtirilgan zarba xavfi to‘g‘risidagi ma’lumotlarni turli himoya qoplamasi sxemalariga aylantiradi. Ular konseptual xususiyatga ega: materiallarni tanlash, tan olingan standartlarga muvofiq zarbaga chidamlilik sinovlarini o‘tkazish va himoya samaradorligini real sharoitlarda baholash hali amalga oshirilishi kerak.
Kalit so‘zlar: yuzni himoya qilish; himoya bosh kiyimi; jag‘-yuz jarohati; jarohatlarning oldini olish; chekli elementlar tahlili; bosh jarohati mezoni; yuz skeleti sinishlari.

Аннотация: Защитные средства для лица широко используются в спорте и на производстве, однако большинство из них предназначено для одного вида деятельности и обеспечивает защиту фиксированного набора анатомических структур. Вместе с тем механизм травмы определяет, какие участки лицевого скелета подвергаются нагрузке и в каких областях происходит их повреждение, поэтому защита, не соответствующая механизму травмы, может оставлять наиболее уязвимые области незащищёнными.
Цель: определить приоритетные зоны защиты при четырёх распространённых механизмах травмы на основе клинических, компьютерно-томографических данных и данных конечно-элементного моделирования, а также трансформировать полученные результаты в концептуальные конструкции защитного головного снаряжения.
Были объединены три источника данных: анатомическое распределение переломов у пациентов с сочетанной челюстно-лицевой травмой, вызванной дорожно-транспортными происшествиями, падениями с высоты, спортивными травмами и многофакторной травмой; региональная рентгеновская плотность в единицах Хаунсфилда, используемая как компьютерно-томографический суррогат минеральной плотности кости, и пористость костей лицевого скелета; а также конечно-элементное моделирование лобовых, боковых и косых ударов при скорости 5–10 м/с с расчётом критерия травмы головы (Head Injury Criterion, HIC). Для каждого механизма травмы анатомические области ранжировались по частоте переломов, механической уязвимости и вкладу в риск травмы головы, после чего полученные приоритетные зоны были представлены в виде четырёх концептуальных трёхмерных конструкций.
Распределение переломов существенно различалось в зависимости от механизма травмы: дорожно-транспортные происшествия преимущественно приводили к травмам средней зоны лица типа Le Fort I–II, переломам дна орбиты и скуловой кости; падения с высоты — к переломам костей носа и дна орбиты; спортивные травмы — к изолированным переломам костей носа и скуловой кости; многофакторная травма — к многообластным повреждениям с вовлечением нижней челюсти, лобной кости и средней зоны лица. Дно орбиты (590±65 HU) и кости носа (510±60 HU) характеризовались наименьшей плотностью и наибольшей пористостью, тогда как височная область имела наиболее высокий риск травмы головы при моделировании (HIC 1620±260 при боковом ударе против 1380±210 при лобовом, 1250±180 при теменном и 1100±160 при затылочном ударах). В соответствии с полученными данными были разработаны четыре прототипа: закрытая конструкция, защищающая нижнюю часть

лица и латеральную область при использовании в условиях дорожного движения; лёгкая открытая конструкция, защищающая нос, скуловую область и висок в условиях повышенного риска падения; открытая спортивная конструкция, защищающая нос, скуловую область и нижнюю челюсть при сохранении поля зрения и вентиляции; и полная конструкция с дополнительной защитой лобной и височной областей при смешанном воздействии высокой энергии. Система зарегистрирована (FAP20260186).
Механизм травмы может использоваться в качестве основного принципа организации защиты лица. Представленные четыре конструкции преобразуют данные о распределении переломов, региональной уязвимости костей и смоделированном риске ударной травмы в различные схемы защитного покрытия. Они являются концептуальными: выбор материалов, испытания на ударную нагрузку в соответствии с признанными стандартами и оценка эффективности защиты в реальных условиях ещё должны быть проведены.
Ключевые слова: защита лица; защитное головное снаряжение; челюстно-лицевая травма; профилактика травм; конечно-элементный анализ; критерий травмы головы; переломы лицевого скелета.

INTRODUCTION

Fractures of the facial skeleton are caused mainly by road traffic crashes, falls, sport, and assault [1–4], and a substantial proportion of them would be preventable with adequate protection of the face. Mouthguards and facial protectors have been shown to reduce the frequency and severity of orofacial injury in sport [5], and helmets are mandatory in many occupational and traffic settings. Most of these devices, however, are designed around one activity and one impact direction. They protect a fixed set of structures — usually the cranial vault, the dentition, or the eyes — while the middle third of the face, the orbital floor, and the lateral region often remain exposed. Injury mechanism determines both where the facial skeleton is loaded and where it fails. High-energy frontal loading in a traffic crash, a fall onto the central face, a tangential blow in sport, and a combination of these produce different fracture patterns, as large clinical series [1–4] and our own analysis of combined maxillofacial trauma [6] show. Regional differences in radiodensity and microarchitecture add a second layer: thin, porous regions such as the orbital floor and the nasal bones fail at lower loads than the frontal or zygomatic bone [7]. Finite element modelling of the craniofacial skeleton [8–11] makes it possible to add a third layer — the contribution of each impact site to the risk of brain injury.

Combining these three sources of information should make it possible to say, for a given mechanism, which facial regions deserve priority in a protective device. The aim of this work was to derive such priorities for four common injury mechanisms and to translate them into conceptual designs for protective facial headgear.

RESEARCH METHODOLOGY

The design was based on a cohort of 566 patients with combined maxillofacial injuries treated in 2015–2025 at the Republican Research Center of Emergency Medicine and the clinical bases of Tashkent State Medical University. Patients were grouped by mechanism: road traffic accidents (n = 186), falls from height (n = 139), sports injury (n = 124), and multifactorial trauma (n = 117). The epidemiology, fracture distribution, and severity of this cohort are reported in detail elsewhere [6]; the present work uses the anatomical distribution of fractures within each mechanism group as the first design input. Radiodensity in Hounsfield units (HU), porosity, and trabecular morphometry of the frontal, zygomatic, maxillary, mandibular, orbital, and nasal regions were measured on multislice and cone-beam computed tomography of the same cohort and are reported separately [7]. No dual-energy X-ray absorptiometry was performed: all density values given in this article are computed-tomography attenuation values in Hounsfield units, used as a surrogate for bone mineral density. These values were used as the second design input, identifying regions that fail at comparatively low load.

Three-dimensional models reconstructed from computed tomography were subjected to finite element simulation of frontal, lateral (temporal), parietal, and occipital impacts at velocities of 5–10 m/s. Von Mises stress, intracranial pressure, and the Head Injury Criterion (HIC) were computed for each impact site [7]. HIC ranking provided the third design input, indicating which impact directions carry the greatest risk of concurrent brain injury. For each mechanism, anatomical regions were ranked by three criteria: frequency of fracture in that group, low density and high porosity on computed tomography, and association with high HIC values on simulation. Regions meeting two or three criteria were designated priority zones, and regions meeting one were designated secondary zones. Each set of zones was then expressed as a conceptual three-dimensional model of a protective helmet or mask, balancing coverage against the visual field, ventilation, mandibular movement, and weight. The resulting system of differentiated protective helmets has been registered under No. FAP20260186 [12]. The designs are conceptual: no prototype has yet undergone mechanical impact testing or certification.

ANALYSIS AND RESULTS

Road traffic accidents caused predominantly midfacial injury, with Le Fort I–II fractures combined with fractures of the orbital floor and the zygomatic bone, reflecting high-energy loading of the central and lateral midface. Falls from height caused mainly nasal bone and orbital floor fractures, with zygomatic and maxillary involvement in some patients, consistent with direct loading of the central face. Sports injury caused mainly isolated nasal and zygomatic fractures of lower severity. Multifactorial trauma produced the most complex pattern, with multiple fractures of the mandible, frontal bone, and midface affecting several anatomical zones at once [6].

The anatomical distribution of the fractures recorded in each group is given in Table 1; the totals quoted below are the sums of the site counts listed in that table. Road traffic accidents produced 144 fractures concentrated in the central and lateral midface: Le Fort I (n = 18) and Le Fort II (n = 14) fractures, orbital floor (n = 16), zygomatic bone (n = 16), nasal bones (n = 14), and frontal bone (n = 14). Falls from height produced 194 fractures, with the nasal bones (n = 28), orbital floor (n = 26), zygomatic bone (n = 26), and Le Fort I level (n = 22) most often affected. Sports injury produced 180 fractures dominated by the zygomatic bone (n = 34) and nasal bones (n = 30), with the zygomatic arch (n = 12) and dentoalveolar segment (n = 14) also involved. Multifactorial trauma produced 170 fractures spread more widely across the facial skeleton, involving the condylar process (n = 22), zygomatic bone (n = 19), frontal bone (n = 18), Le Fort I level (n = 18), mandibular angle (n = 13), and frontal sinus (n = 12).

Table 1. Anatomical distribution of facial fractures by injury mechanism (number of fractures).

Site	RTA	Falls	Sports	Multifactorial
Nasal bones	14	28	30	13
Le Fort I	18	22	14	18
Zygomatic bone	16	26	34	19
Condylar process	12	14	12	22
Frontal bone	14	10	6	18
Orbital floor	16	26	18	10
Le Fort II	14	16	10	15
Dentoalveolar	6	14	14	6
Anterior mandible	4	6	6	6
Frontal sinus	8	6	4	12
Zygomatic arch	4	8	12	4
Mandibular angle	6	8	8	13
Naso-orbito-ethmoidal complex	6	4	2	6
Le Fort III	4	2	0	6
Maxillary sinus wall	2	4	10	2

Regional bone vulnerability. Radiodensity declined from the frontal bone (1085 ± 92 HU) and zygomatic bone (955 ± 78 HU) through the mandibular body (825 ± 75 HU) and maxilla (695 HU) to the orbital floor (590 ± 65 HU) and nasal bones (510 ± 60 HU). Porosity followed the reverse order, from 18.5 ± 4.2% in the frontal bone to 41.2 ± 7.5% in the orbital complex and 45.6 ± 8.1% in the nasal bones [7]. The central midface is therefore the structurally weakest part of the facial skeleton and requires protection even against moderate impact energy. Impact direction and head-injury risk. HIC values were highest for lateral impact on the temporal region (1620 ± 260), followed by frontal (1380 ± 210), parietal (1250 ± 180), and occipital impact (1100 ± 160); maximum stress reached 105 ± 22 MPa in the temporal and frontal regions [7]. Lateral protection is therefore relevant not only to the facial skeleton but also to the risk of brain injury, and was treated as a priority zone whenever a mechanism involved lateral or oblique loading. Protection zones by mechanism. Applying the three criteria produced four distinct zone patterns (Table 2). The nose and the malar region appear in every pattern because they combine high fracture frequency with low radiodensity; the temporal region enters the pattern whenever lateral loading is expected; and the mandible and frontal region are added for mechanisms with multidirectional loading.

Table 2. Protection zones derived from fracture distribution, bone vulnerability, and simulated impact risk.

Mechanism	Priority zones	Secondary zones
Road traffic accident	Nose, malar region, mandible, temporal region	Lower face, chin
Fall from height	Nose, malar region, orbital rim	Temporal region
Sports injury	Nose, malar region, mandible	Orbital rim
Multifactorial trauma	Nose, malar region, mandible, frontal and temporal regions	Upper face, chin

The four prototypes. Design 1, for road traffic and similar high-energy use, is a closed construction giving maximum coverage of the lower face together with lateral protection of the temporal region, intended for impact, compression, and side loading. Design 2, for falls from height and comparable settings, is a light open frame covering the nose, malar region, and temple, shaped to distribute the load of a hard, flat impact on the central face while keeping weight low. Design 3, for sport, is an open lattice covering the nose, malar region, and jaw; the open construction preserves the visual field, ventilation, and speech during active movement, at the cost of protection against high-energy impact. Design 4, for mixed or unpredictable exposure, is the most complete construction, extending the coverage of Design 1 to the frontal and temporal regions and the upper face, and is intended for settings in which several loading directions are possible.

All four-share protection of the nose and the malar region, differ in the extent of lateral and frontal coverage, and use adjustable head fixation. The protective elements declared for each design are: Design 1 — nose, zygomatic bones, temporal region, lateral face, and lower face; Design 2 — nose, facial bones, and temporal region; Design 3 — nose, malar region, and jaw; Design 4 — nose, malar region, jaw, forehead and temples, and lower face. The conceptual three-dimensional models are shown in Figure 1.



Figure 1. Conceptual three-dimensional models of the four protective designs: top left — Design 1 (road traffic); top right — Design 2 (falls from height); bottom left — Design 3 (sport); bottom right — Design 4 (multifactorial exposure).

The value of facial protection is established: protective devices reduce the frequency and severity of orofacial injury where they are used consistently [5]. What has been missing is a principled way of deciding what a given device should cover. The approach taken here makes that decision explicit, using three measurable inputs — where fractures actually occur in each mechanism group, where bone is weakest, and which impact directions carry the highest risk of brain injury. Two findings have direct design consequences. First, the central midface is the weakest region of the facial skeleton in every group, so the nose and the malar region are protected in every design, while the orbital rim is a priority zone after falls from height and a secondary zone in the sports design (Table 2). Second, lateral impact carries the highest head-injury risk in the simulation, which argues for temporal coverage in any device intended for traffic or mixed exposure, even though the temporal region is not itself a frequent fracture site in the clinical data. The designs also illustrate the trade-off that limits facial protection in practice. Coverage competes with the visual field, ventilation, speech, mandibular movement, and weight, and a device that is uncomfortable is not worn. This is why the sports design is deliberately the most open of the four: it accepts reduced protection against high-energy impact in exchange for wearability during activity, while the traffic and multifactorial designs, intended for shorter and more predictable exposure, accept a heavier construction. The main limitation is that these are concepts. No prototype has been manufactured in a defined material, subjected to instrumented impact testing, or evaluated against recognised protective-

equipment standards, and no field data on injury rates with and without the devices exist. The underlying simulations also used idealised material properties and did not model soft tissue. The next steps are therefore material selection, laboratory impact testing of each design against the loading scenarios from which it was derived, and prospective evaluation in the settings each design targets.

CONCLUSIONS

The injury mechanism can serve as the organising principle for facial protection. Fracture distribution, regional radiodensity and porosity, and simulated impact risk together define distinct protection priorities for road traffic, fall-related, sports, and multifactorial trauma, and these priorities translate into four different coverage patterns. The nose and malar region require protection in all settings, while lateral coverage is important wherever lateral loading is possible, and the extent of frontal and mandibular coverage should correspond to the expected loading directions. The four conceptual designs presented in this study implement these principles and provide a basis for further material selection and impact testing. This research received no external funding. The author is a co-author of the registered design system described in this article (FAP20260186). The clinical data underlying this work were collected in accordance with the Declaration of Helsinki, and the data supporting the findings of this study are available from the author upon reasonable request.

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