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Kimmerle anomaly: history of discovery, classification, and evolution of clinical concepts

Kimmerle anomaliyasi: kashf etilish tarixi, tasnifi va klinik qarashlarning evolyutsiyasi

Аномалия Киммерле: история открытия, классификация и эволюция клинических представлений

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Abstract. Background. Kimmerle anomaly is an anatomical variant of the atlas characterized by formation of a partial or complete osseous bridge over the vertebral artery groove on the posterior arch of C1. Initially regarded predominantly as an anatomical and radiographic curiosity, the anomaly subsequently attracted clinical interest because of its close relationship with the V3 segment of the vertebral artery, the suboccipital nerve, and the surgical anatomy of the craniovertebral junction. Materials and Methods. A structured narrative review of classical and contemporary publications addressing the historical description, terminology, epidemiology, morphological classification, radiological evaluation, vascular relationships, and surgical relevance of Kimmerle anomaly was performed. Historical anatomical and radiographic studies were compared with modern CT, CT angiographic, morphometric, systematic-review, and meta-analytic evidence. Results. Concepts regarding Kimmerle anomaly evolved from recognition of an anatomical bony bridge to radiographic identification, epidemiological characterization, morphological classification, appreciation of C1 instrumentation-related risk, and, more recently, assessment of potential dynamic neurovascular conflict. Classification systems progressed from simple complete/incomplete forms to laterality-based, morphometric, and vascularly oriented phenotypes. Contemporary evidence emphasizes that morphological presence alone does not demonstrate symptom causality. Conclusion. The concept of Kimmerle anomaly has evolved from a simple atlas variant into a patient-specific craniovertebral phenotype with morphological, vascular, neurological, and surgical dimensions. Contemporary clinical interpretation requires separation of incidental anatomy from surgically significant morphology and dynamically verified symptomatic neurovascular conflict.

Keywords: Kimmerle anomaly; ponticulus posticus; arcuate foramen; atlas; vertebral artery; V3 segment; craniovertebral junction; classification; history

O'ZBEKCHA

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Annotatsiya. Dolzarblik. Kimmerle anomaliyasi atlasning posterior yoyida umurtqa arteriyasi egati ustidan o'tuvchi qisman yoki to'liq suyak ko'prigi shakllanishi bilan tavsiflanadigan kraniovertebral anatomik variantdir. Ushbu tuzilma XIX–XX asrlarda avvalo anatomik va rentgenologik topilma sifatida o'rganilgan bo'lsa, keyinchalik uning vertebral arteriyaning V3 segmenti, subokspital nerv va kraniovertebral jarrohlik anomaliyasi bilan munosabati klinik qiziqishni oshirdi. Zamonaviy tasvirlash usullari anomaliyani oddiy “bor yoki yo'q” shaklida baholashdan ko'p komponentli morfologik va funksional fenotiplashga o'tish imkonini berdi. Material va usullar. Kimmerle anomaliyasining anatomik tavsifi, terminologiyasi, epidemiologiyasi, morfologik klassifikatsiyasi, radiologik diagnostikasi, vertebral arteriya bilan o'zaro munosabati va jarrohlik ahamiyatiga bag'ishlangan klassik va zamonaviy ilmiy manbalar strukturaviy narrativ usulda tahlil qilindi. Tarixiy

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anatomik-rentgenologik ishlar zamonaviy KT, KT-angiografiya, morfometrik tadqiqotlar, sistematik sharhlar va meta-tahlillar bilan solishtirildi. Natijalar. Kimmerle anomaliyasi haqidagi ilmiy qarashlar bir necha bosqichda rivojlangan: anatomik variantni tavsiflash, rentgenologik identifikatsiya, populyatsion prevalensiyani o'rganish, complete va incomplete shakllarni tasniflash, C1 instrumental fiksatsiyasidagi jarrohlik xavfini anglash va nihoyat dinamik neyrovaskulyar konflikt konsepsiyasiga o'tish. Zamonaviy adabiyotlar morfologik mavjudlikning o'zi simptomlarning sababiyligini isbotlamasligini ko'rsatadi. Klinik ahamiyat morfologiya, vertebral arteriya anatomiyasi, simptomlarning reproduktivligi va funksional gemodinamik o'zgarishlar birgalikda mavjud bo'lganda oshadi. Xulosa. Kimmerle anomaliyasi haqidagi tushuncha oddiy atlas anatomik variantidan individual morfologik, vaskulyar va jarrohlik xususiyatlariga ega kraniovertebral fenotip konsepsiyasigacha evolyutsiya qilgan. Zamonaviy klinik yondashuvda terminologik aniqlik, morfologik klassifikatsiya va simptomatik holatlarni tasodifiy topilmalardan ajratish asosiy ahamiyatga ega.

Kalit so'zlar: Kimmerle anomaliyasi; orqa yoy; arcuate foramen; atlas; C1; vertebral arteriya; V3 segment; kraniovertebral birikma; tasnif; tarix

РУССКИЙ

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Аннотация. Актуальность. Аномалия Киммерле представляет собой анатомический вариант атланта, характеризующийся формированием частичного или полного костного мостика над бороздой позвоночной артерии на задней дуге C1. Первоначально данная особенность рассматривалась преимущественно как анатомическая и рентгенологическая находка. В дальнейшем изучение ее взаимоотношений с V3-сегментом позвоночной артерии, субокципитальным нервом и хирургической анатомией краниовертебрального перехода привело к существенному пересмотру клинического значения аномалии. Материалы и методы. Проведен структурированный нарративный анализ классических и современных публикаций, посвященных истории описания, терминологии, эпидемиологии, морфологической классификации, лучевой диагностике, сосудистым взаимоотношениям и хирургическому значению аномалии Киммерле. Исторические анатомические и рентгенологические исследования сопоставлены с современными КТ-, КТ-ангиографическими, морфометрическими исследованиями, систематическими обзорами и метаанализами. Результаты. Представления об аномалии Киммерле прошли последовательную эволюцию от описания костного мостика как анатомической вариации до современного понимания его как потенциально значимого элемента краниовертебральной нейроваскулярной анатомии. Были сформированы классификации по полноте костного моста, стороне поражения, морфологии канала и взаимоотношению с позвоночной артерией. Особое значение аномалия приобрела после широкого внедрения инструментальной фиксации C1–C2. Современный подход не допускает автоматического отождествления морфологической находки с симптоматическим синдромом. Заключение. Современная концепция аномалии Киммерле основана на разграничении случайного анатомического варианта, хирургически значимой морфологии и клинически значимого динамического нейроваскулярного конфликта.

Ключевые слова: аномалия Киммерле; ponticulus posticus; arcuate foramen; атлант; позвоночная артерия; V3-сегмент; краниовертебральный переход; классификация; история

1. KIRISH

Introduction

Kimmerle anomaliyasi atlasning yuqori yuzasidagi umurtqa arteriyasi egati ustida suyak ko'prigi shakllanishi bilan tavsiflanadigan kraniovertebral anatomik variant bo'lib, zamonaviy adabiyotlarda ko'pincha orqa yoy yoki yoysimon teshik terminlari bilan ifodalanadi [1–3]. Suyak ko'prigi atlasning yuqori bo'g'im o'simtasining orqa qismi bilan orqa yoyining yuqori-lateral qismi orasida hosil bo'lib, normal holatda ochiq bo'lgan umurtqa arteriyasi egatini qisman yoki to'liq suyak kanaliga aylantiradi. Ushbu kanalda umurtqa arteriyasining V3 segmenti, subokspital nerv va periarterial yumshoq to'qima komponentlari joylashadi [1, 10, 11].

Terminologik jihatdan ushbu anatomik variant tibbiy adabiyotlarda juda ko'p nomlar bilan tavsiflangan. Orqa yoy, atlasning orqa suyak ko'prigi, yoysimon teshik, atlasning orqa teshigi, retroartikulyar kanal, umurtqa arteriyasining retroartikulyar suyak halqasi, umurtqa arteriyasi kanali, atlas yoyining suyak ko'prigi va Kimmerle anomaliyasi bir xil yoki anatomik jihatdan bir-biriga juda yaqin holatlarni ifodalash uchun qo'llanilgan [1, 8–

10]. Zamonaviy anatomik nomenklaturada “orqa yoy” suyak ko'prigining o'zini, “yoysimon teshik” esa to'liq ko'priki hosil qilganda vujudga keladigan suyak teshigini ifodalash jihatidan aniqroq hisoblanadi [1, 10].

Anomaliyaning tarixi Kimmerle eponimidan ancha oldin boshlanadi. Zamonaviy tarixiy-anatomik sharhlarda atlas orqa yoyidagi bunday suyak ko'priklari XIX asr anatomik adabiyotlarida qayd etilgani, keyinchalik Louis Bolk tomonidan XX asr boshlarida batafsilroq morfologik tavsiflangani ko'rsatiladi [1, 27]. Biroq klinik va rentgenologik adabiyotlarda “Kimmerle anomaliyasi” atamasi 1930-yillardagi radiologik tavsiflardan keyin ommalashgan. Shu sababli Kimmerle tarixan muhim eponim bo'lsa-da, u mazkur anatomik strukturaning mutlaq birinchi kashfiyotchisi deb qaralishi terminologik jihatdan to'liq aniq emas [1, 26, 27].

XX asrning o'rtalariga kelib atlas orqa yoyidagi ushbu tuzilma sistematik rentgenologik tadqiqot obyekti bo'la boshladi. Selby, Garn va Kanareff 1955-yilda suyak ko'prigining populyatsion va oilaviy xususiyatlarini tahlil qildilar [3]. Pyo va Lowman 1959-yilda 300 ta normal rentgenogrammani o'rganib, orqa yoyning

rentgenologik morfologiyasi, uchrash chastotasi va klinik anatomiyasini batafsil bayon qildilar [2]. Ularning ishlari atlas orqa qismidagi umurtqa arteriyasi egati ustidagi suyak ko'prigini oddiy anatomik kazuistikadan ajratib, kengroq radiologik fenomen sifatida qarashga yordam berdi [2, 3].

Kendrick va Biggs bolalar va o'smirlarda bu anatomik variantni o'rganib, uning yosh populyatsiyada ham mavjudligini ko'rsatdilar [4]. Bu kuzatuv anomaliyani faqat qarilikda orqa atlanto-oksipital membrananing degenerativ ossifikatsiyasi natijasi deb tushuntiruvchi nazariyalarga qarshi muhim dalillardan biri bo'ldi. Radojević va Negovanović umurtqa arteriyasi egati hamda uning suyak halqalarini anatomik-rentgenologik tahlil qildilar [5]. Lamberty va Zivanovic esa "umurtqa arteriyasining retroartikulyar suyak halqasi" tushunchasini rivojlantirib, uning evolyutsion va anatomik xususiyatlariga e'tibor qaratdilar [6]. Saunders va Popovich atlas yoyining suyak ko'prigining oilaviy uchrashini o'rganib, rivojlanish va genetik komponent mavjud bo'lishi mumkinligini ko'rsatdilar [7]. Keyingi antropologik ishlarda Le Minor va Trost odamlarda va primatlarda umurtqa arteriyasi egati ustidagi suyak pontikullarni taqqoslab, ularni faqat patologik ossifikatsiya emas, balki evolyutsion va morfologik polimorfizm sifatida ham ko'rib chiqish kerakligini ta'kidladilar [10]. Shu tariqa anomaliya etiologiyasi bo'yicha "degenerativ ossifikatsiya" modeli asta-sekin tug'ma, rivojlanish va filogenetik komponentlarni ham o'z ichiga oluvchi ko'p faktorli konsepsiyaga aylandi.

Dugdale 1981-yilda ponticulus posteriorni radiologik nuqtai nazardan muhokama qildi [8], Stubbs esa 1992-yilda yoysimon teshik tarqalishining irq va jins bilan bog'liqligini o'rganib, populyatsiyalar o'rtasida sezilarli tafovutlar mavjudligini ko'rsatdi [9]. Bu bosqich Kimmerle anomaliyasining klinik kasallikdan ko'ra keng tarqalgan anatomik variant ekanligi haqidagi qarashlarni kuchaytirdi.

XX asr oxiri va XXI asr boshida morfologik tasniflash muhim yo'nalishga aylandi. Anomaliya dastlab to'liq va to'liq bo'lmagan shakllarga ajratilgan bo'lsa, Miki tomonidan taklif etilgan va keyingi radiologik ishlarda keng qo'llanilgan tasnif to'liq, to'liq bo'lmagan va kalsifikatsiyalangan tiplarni ajratdi [17, 20]. To'liq shaklda umurtqa arteriyasi egati ustida yopiq suyak halqasi hosil bo'ladi. To'liq bo'lmagan shaklda yuqori bo'g'im o'simtasi yoki orqa yoydan chiqqan suyak o'simtalari bir-biriga to'liq qo'shilmaydi. Kalsifikatsiyalangan shaklda esa ligamentar yo'nalish bo'ylab chiziqli yoki amorf mineralizatsiya kuzatiladi [17, 20].

Paraskevass va hammualliflarning morfologik anatomik tahlili atlasning umurtqa arteriyasi egati ustidagi ko'priklarini yanada batafsil tavsiflab, orqa va lateral variantlarning mavjudligini ko'rsatdi [11]. Tubbs va hammualliflar foramen arcuolening anatomiyasi va jarrohlik ahamiyatini tizimlashtirdilar [10]. Kim va hammualliflar esa oddiy rentgenogramma bilan uch o'lchamli KTni taqqoslab, orqa yoy morfologiyasini baholashda uch o'lchamli tasvirlashning ustunligini ko'rsatdilar [12].

Anomaliyaga klinik qiziqishning keskin ortishi C1–C2 instrumental fiksatsiya texnologiyalari rivojlanishi bilan bog'liq bo'ldi. Young va hammualliflar 2005-yilda orqa yoyning C1 lateral massaga vint o'rnatishdagi ahamiyatini ta'kidlab, suyak ko'prigi orqa yoyning qalin qismi sifatida noto'g'ri talqin qilinsa, vint umurtqa arteriyasi kanaliga yo'nalishi mumkinligini ko'rsatdilar [13]. Hong va hammualliflarning uch o'lchamli KT-angiografik ishi atlas orqa yoyi va V3 segment anatomiyasining yuqori darajada o'zgaruvchan ekanligini tasdiqladi [14]. Cho Koreya populyatsiyasida radiologik tahlil o'tkazib, to'liq va to'liq bo'lmagan shakllarning uchrash xususiyatlarini ko'rsatdi [15].

Elliott va Tanweer tomonidan bajarilgan katta meta-tahlil anomaliya haqidagi epidemiologik qarashlarni sezilarli darajada standartlashtirdi [16]. 21 mingdan ortiq subyekt ma'lumotlarini umumlashtirgan tahlilda orqa yoy umumiy prevalensiyasi 16,7%

atrofida baholandi. Bu natija Kimmerle anomaliyasini "kam uchraydigan tug'ma nuqson" sifatida emas, nisbatan keng tarqalgan anatomik variant sifatida ko'rish kerakligini mustahkamladi [16].

Konus-nurli kompyuter tomografiyasi va ko'p detektorli kompyuter tomografiyasining keng tarqalishi morfologik tasnifni yangi bosqichga olib chiqdi. Bayrakdar va hammualliflar 730 bemor konus-nurli KT ma'lumotlarida orqa yoyning to'liq/to'liq bo'lmagan va tomonlama variantlarini yuqori aniqlikda baholadilar [17]. Geist va hammualliflar bolalar va o'smirlarda PP hamda ponticulus lateralisni konus-nurli KT bilan o'rgandilar [18]. Chen va hammualliflar dental konus-nurli KT tekshiruvlarida anomaliya prevalensiyasini baholadilar [19], Sekerci va hammualliflar esa to'liq, qisman, bir tomonlama va ikki tomonlama konfiguratsiyalarning sezilarli variabelligini ko'rsatdilar [20].

Tambawala va hammualliflar orqa yoy bilan servikogen bosh og'rig'i o'rtasidagi ehtimoliy bog'liqlikni o'rgandilar [21]. Giri va hammualliflar lateral tsefalogrammalarda anomaliyani aniqlash chastotasini baholab, dental va ortodontik tasvirlarda bu topilma tasodifan ko'p uchrashini yana bir bor ko'rsatdilar [22]. Saleh va hammualliflarning 2917 bemorni qamrab olgan KT tadqiqoti PPning prevalensiyasi va demografik xususiyatlariga katta klinik tasvirlash bazasida baho berdi [23]. Klinik simptomlar bilan bog'liqlik masalasi uzoq vaqt davomida bahsli bo'lib keldi. Pqkala va hammualliflarning 2018-yilgi sistematik sharh va meta-tahlilida yoysimon teshik mavjud bemorlarda bosh og'rig'i chastotasi yuqoriroq ekan ko'rsatildi [24]. Biroq epidemiologik assotsiatsiya individual bemorda sababiy munosabatni isbotlamaydi. Shu sababli zamonaviy klinik paradigma morfologik anomaliyaning o'zini "Kimmerle sindromi" deb baholashdan voz kechib, simptom, anatomik konflikt va gemodinamik dalilni birgalikda talab qiladigan yondashuvga o'tmoqda [24, 26].

Arslan va hammualliflar orqa yoyi C1 lateral massaga vint kiritilishida umurtqa arteriyasi uchun xavf omili sifatida yana bir bor tasdiqladilar [25]. Xu va hammualliflarning 2022-yilgi katta narrativ sharhi epidemiologiya, etiologiya, klinik simptomlar, tasvirlash va jarrohlik ahamiyatini birlashtirib, PP haqidagi zamonaviy bilimlarni tizimlashtirdi [26]. Olszewski va hammualliflar 2023-yilda to'liq orqa yoyi "yupqa" va "qalin" morfometrik tiplarga ajratishga asoslangan yangi konus-nurli KT klassifikatsiyasini taklif qildilar [27]. Bu ish Kimmerle anomaliyasi klassifikatsiyasi oddiy to'liq/to'liq bo'lmagan dixotomiyadan miqdoriy morfometriyaga o'tayotganini ko'rsatadi. Gul va Atik 2024-yilda orqa yoy bilan umurtqa arteriyasi diametri munosabatini bevosita radiologik baholab, morfologik tasnifni vaskulyar fenotiplash bilan birlashtirish zarurligini ko'rsatdilar [28]. 2025-yilgi faqat KT ma'lumotlariga asoslangan meta-tahlilda Ordoñez-Cure va hammualliflar 31 mingdan ortiq bemorda orqa yoyning umumiy tarqalishini taxminan 21% deb baholadilar, to'liq bo'lmagan shakl to'liq shakldan ko'proq uchrashini qayd etdilar [29]. 2026-yilda Valenzuela-Fuenzalida va hammualliflarning sistematik sharh va meta-tahlili yoysimon teshikni kraniovertebral klinik ahamiyat kontekstida qayta baholab, morfologik variantning to'liq, to'liq bo'lmagan, bir tomonlama va ikki tomonlama fenotiplarini klinik va jarrohlik xavf bilan bog'lash zarurligini ta'kidladi [30].

Shu bilan birga, umurtqa arteriyasi anatomiyasi zamonaviy klinik tasnifning muhim komponentiga aylandi. Wakao va hammualliflarning uch o'lchamli KT-angiografik tadqiqoti C1–C2 darajasida persistirlovchi birinchi intersegmentar arteriya, fenestratsiya, anomal PICA va yuqori joylashgan umurtqa arteriyasi kabi variantlar orqa yoy bilan birga yoki undan mustaqil ravishda mavjud bo'lishi mumkinligini ko'rsatdi [31]. Elgafy va hammualliflar yoysimon teshikning shu tomondagi yuqori joylashgan umurtqa arteriyasi bilan birga kelishi instrumental fiksatsiya xavfini yanada murakkablashtirishini ko'rsatdilar [32]. Natsis va hammualliflar atlas orqa yoyi hamda umurtqa arteriyasi egati variantlarini kengroq morfometrik klassifikatsiya qilib,

anomaliyani faqat suyak ko'prigiga emas, butun V3 segment anatomik koridoriga bog'liq holda baholashni taklif qildilar [33]. Zhang va hammualliflar orqa yoy mavjud bemorlarda C1 pedikulyar vintini o'rnatish imkoniyatini individual uch o'lchamli anatomik rejalashtirish asosida baholadilar [34]. Song va hammualliflar esa oksipitoservikal spondilodez uchun PPning morfometrik ahamiyatini tahlil qildilar [35]. Nihoyat, Lukianchikov va hammualliflarning klinik ishi orqa yoy va ponticulus lateralis kombinatsiyasida umurtqa arteriyasining simptomatik kompressiyasi yuzaga kelishi va mikrojarrohlik dekompressiyasi bilan tuzatilishi mumkinligini ko'rsatdi [36].

Bu kabi kuzatuvlar zamonaviy klinik qarashni yangi bosqichga olib chiqdi: Kimmerle anomaliasi endi nafaqat anatomik variant va nafaqat jarrohlik xavf omili, balki juda tanlangan bemorlarda dinamik kraniovertebral neyrovaskulyar konfliktning anatomik substrati sifatida ko'rilishi mumkin [28–36].

2. MATERIAL VA USULLAR

Materials and methods

Mazkur ish strukturaviy narrativ sharh shaklida bajarildi. Kimmerle anomaliasiga oid tarixiy anatomiya, rentgenologiya, antropologiya, epidemiologiya, klinik nevrologiya, vertebral arteriya anatomiyasi va kraniovertebral jarrohlik bo'yicha klassik hamda zamonaviy ilmiy manbalar tahlil qilindi. Tahlilga orqa yoy, yoysimon teshik, yoysimon teshik, Kimmerle anomaliasi, atlas yoyining suyak ko'prigi, umurtqa arteriyasi egati, C1 lateral massasiga vint o'rnatish, kraniovertebral birikma, umurtqa arteriyasi kompressiyasi va tegishli anatomik tasnif tushunchalarini yorituvchi nashrlar kiritildi. Tarixiy evolyutsiya shartli ravishda anatomik kuzatuv davri, rentgenologik identifikatsiya davri, epidemiologik-morfologik davr, jarrohlik xavfi konsepsiyasi va zamonaviy neyrovaskulyar fenotiplash davrlariga ajratildi. Klassifikatsiyalarni taqqoslashda uchta asosiy mezon ishlatildi: suyak ko'prigining to'liqligi, lateralizatsiyasi va morfometriyasi.

Zamonaviy klinik yondashuvni baholashda esa morfologik topilma, umurtqa arteriyasi bilan topografik munosabat, klinik simptomatiklik va jarrohlik ahamiyati alohida tahlil qilindi. Natijalar bo'limida berilgan "evolyutsion klinik fenotip" modeli mualliflik konseptual sintezi bo'lib, xalqaro validatsiyalangan klassifikatsiya sifatida talqin qilinmaydi.

3. NATIJALAR

Results

Tarixiy rivojlanishning asosiy bosqichlari. Kimmerle anomaliasi tarixini tahlil qilish mazkur anatomik variantning ilmiy talqini tasvirlash texnologiyalari va kraniovertebral jarrohlik rivoji bilan birga o'zgarganini ko'rsatadi. Dastlabki anatomik davrda asosiy savol atlas posterior yoyidagi qo'shimcha suyak strukturasining mavjudligi va uning kelib chiqishi bo'lgan. XIX asr oxiri va XX asr boshidagi anatomik kuzatuvlar suyak ko'prigi odam skeletida muntazam uchrab turishini ko'rsatdi. Rentgenografiya rivojlangandan so'ng anomalisa tirik bemorlarda aniqlana boshlandi. Kimmerle eponimi aynan shu radiologik davrda klinik terminologiyada kengroq o'rin oldi. XX asr o'rtalarida rentgenografik prevalensiya, jins, yosh va tomonlama farqlar o'rganildi. Shu davrning o'zida bolalarda ham anomalisa mavjudligi tug'ma yoki rivojlanish komponenti haqidagi nazariyalarni kuchaytirdi. XX asr oxirida anomalisa antropologiya, evolyutsion morfologiya va klinik radiologiya nuqtai nazaridan o'rganildi. Complete va incomplete shakllar, unilateral va bilateral holatlar klassifikatsiyaning asosini tashkil qildi. XXI asr boshida anomalisaning ilmiy ahamiyati keskin o'zgardi. C1 lateral mass va posterior arch orqali vint o'rnatish texnikalarining rivojlanishi orqa yoyini potensial vertebral artery injury risk factor darajasiga olib chiqdi.

So'nggi bosqichda CT, CTA va 3D rekonstruksiya rivojlanishi bilan anomalisa morfometriya, vertebral arteriya anatomiyasi va dinamik klinik sindrom bilan bog'liq holda talqin qilina boshladi.

1-jadval

Kimmerle anomaliasi haqidagi ilmiy qarashlarning tarixiy evolyutsiyasi / Table 1. Historical evolution of scientific concepts of Kimmerle anomaly

Davr	Asosiy ilmiy qarash	Yetakchi metod	Klinika uchun ahamiyati
XIX asr oxiri – 1930	Anatomik suyak varianti	Skelet/anatomik preparat	Asosan morfologik qiziqish
1930–1960	Rentgenologik variant	Oddiy rentgenografiya	Tirik bemorda identifikatsiya
1960–1990	Populyatsion va antropologik polimorfizm	Rentgen, osteologiya	Prevalensiya va etiologiya
1990–2005	Complete/incomplete morfologik fenotip	Rentgen + dastlabki CT	Standartlashtirilgan an tasnif
2005–2015	C1–C2 jarrohlik xavf omili	3D CT/CTA	Vertebral artery injury profilaktikasi
2015–2024	Morfometrik va vaskulyar fenotiplash	CBCT, MSKT-A	Individual operativ planning
2025–2026	Dinamik kraniovertebral neurovascular konsepsiya	CT/CTA + funksional tekshiruv	Incidental va klinik ahamiyatli variantni ajratish

Terminologiyaning evolyutsiyasi. Tarix davomida terminlarning ko'pligi ma'lum metodologik muammolar yaratgan. "Kimmerle anomaly" eponimik nom bo'lib, klinik adabiyotda mashhur bo'lsa-da, strukturani morfologik jihatdan to'liq ifodalamaydi. "Orqa yoy" lotinchada "kichik posterior ko'priki" ma'nosini bildiradi va suyak strukturasining o'zini tavsiflaydi. "Foramen arcuale" yoki "arcuate foramen" complete suyak ko'prigi hosil qilib, vertebral artery groove yopiq kanalga aylanganda anatomik jihatdan aniqroq termin hisoblanadi.

"Retroarticular canal" atamasi suyak kanalining superior articular mass orqasida joylashuviga urg'u beradi. Shu sababli ilmiy maqolalarda "Kimmerle anomaly (orqa yoy/arcuate foramen)" shaklidagi birlashtirilgan nomenklatura terminologik noaniqlikni kamaytiradi.

Klassik morfologik tasnif. Eng sodda va amaliy klassifikatsiya anomalisaning complete va incomplete shakllarga ajratadi. Complete variantda superior articular process va posterior arch o'rtasidagi suyak ko'prigi to'liq birikib, arcuate foramen hosil qiladi. Incomplete variantda bir yoki ikkala tomondan suyak o'simtasi mavjud bo'ladi, biroq yopiq kanal shakllanmaydi. Keyinchalik radiologik tasnifga calcified variant ham qo'shilgan. Bunda posterior atlanto-occipital membrane yo'nalishida linear yoki amorf mineralizatsiya ko'riladi, ammo yetilgan suyak ko'prigi hali shakllanmagan bo'ladi.

2-jadval

Kimmerle anomaliyasi tasniflarining rivojlanishi / **Table 2.** Development of the classifications of Kimmerle anomaly

Tasnif mezon	Variantlar	Asosiy afzallik	Asosiy cheklov
To'liqlik	Complete / incomplete	Oddiy va reproduktiv	Kanal morfometriyasini bermaydi
Radiologik rivojlanish	Complete / incomplete / calcified	Ossifikatsiya bosqichini hisobga oladi	CT davrida qisman subyektiv
Laterallik	Unilateral / bilateral	Jarrohlik planning uchun muhim	Funksional ahamiyatni bermaydi
Lokalizatsiya	Posterior / lateral / combined	V3 yo'nalishini yaxshiroq tavsiflaydi	Kam qo'llanadi
Morfometriya	Thin / thick complete PP	Kanal geometrik xususiyatini beradi	Klinik validatsiya cheklangan
Vaskulyar fenotip	PP + VA normal / kinking / stenoz / variant	Klinik va jarrohlik jihatdan informativ	Universal standart mavjud emas

Complete va incomplete shakllarning klinik talqini. Tarixan complete ponticulus ko'proq klinik ahamiyatga ega deb qaralgan, chunki arteriya to'liq suyak tunnel ichida qoladi. Biroq bu taxmin individual darajada doimo to'g'ri emas. Katta diametrlilik complete arcuate foramen ichidagi arteriya erkin harakatlanishi mumkin. Aksincha, qalin incomplete suyak spiculum bosh rotatsiyasi vaqtida V3 segment bilan fokal konflikt hosil qilishi mumkin. Shuning uchun zamonaviy yondashuvda complete/incomplete klassifikatsiya boshlang'ich morfologik tavsif bo'lib qoladi, biroq klinik riskni yakka o'zi aniqlamaydi.

Unilateral va bilateral shakllar. Laterallik klinik va jarrohlik planning uchun alohida ahamiyatga ega. Unilateral complete PP mavjudligida aynan shu tomondagi vertebral artery dominant bo'lsa, anatomik topilmaning klinik og'irligi potensial ravishda

3-jadval

Kimmerle anomaliyasining taklif etilayotgan zamonaviy klinik fenotiplari / **Table 3.** Proposed contemporary clinical phenotypes of Kimmerle anomaly

Fenotip	Anatomik topilma	Klinik holat	Vaskulyar dalil	Talqin
KA-A	PP mavjud	Simptomsiz	Yo'q	Incidental anatomik variant
KA-S	PP mavjud	Nospetsifik simptom	Yo'q	Sababiylik isbotlanmagan
KA-V	PP + V3 yaqin konflikt	Mos vertebro bazilyar simptom	Statik vaskulyar o'zgarish	Potensial klinik ahamiyat
KA-D	PP + V3 konflikt	Pozitsion reproduktiv simptom	Dinamik flow reduction	Klinik ahamiyatli dinamik fenotip
KA-O	PP mavjud	Simptom bo'lishi shart emas	—	C1–C2 operatsiyasi uchun anatomik risk

Ushbu model validatsiyalangan xalqaro klassifikatsiya emas, balki morfologik va klinik tushunchalarni birlashtirishga qaratilgan konseptual taklifdir.

4. MUHOKAMA

Discussion

Kimmerle anomaliyasining ilmiy tarixini tahlil qilish bir anatomik strukturaning tibbiyotdagi ahamiyati diagnostik va jarrohlik texnologiyalariga qarab qanday o'zgarishini yaqqol ko'rsatadi. Ahn va hammualliflarning nomenklatura va embriologiyaga bag'ishlangan sharhi [1] hamda zamonaviy tarixiy-morfologik tadqiqotlar [26, 27] bu struktura Kimmerle eponimidan avval ham anatomik adabiyotlarda ma'lum bo'lganini ko'rsatadi. Shu sababli "Kimmerle anomaliyasi" tarixiy jihatdan qulay, lekin "orqa yoy" anatomik jihatdan ko'proq neytral termin hisoblanadi. Pyo va Lowmanning 1959-yildagi klassik rentgenologik tadqiqoti [2] ushbu strukturaning tibbiy tasvirlashdagi o'rnini mustahkamladi. Selby va hammualliflar [3] oilaviy va populyatsion belgilarni, Kendrick va Biggs [4] bolalar va o'smirlardagi

oshadi. Bilateral PP ikki tomonlama suyak tunnel mavjudligini bildiradi, biroq ikkala vertebral arteriya uchun gemodinamik ta'sir teng bo'lishi shart emas. Shuning uchun zamonaviy CTA baholashida PP lateralligi bilan vertebral artery dominantligi birgalikda ko'rsatilishi maqsadga muvofiq.

Posterior va lateral ponticuluslar. Orqa yoy vertebral arteriyaning atlas posterior yoyi ustidagi qismiga tegishli bo'lsa, ponticulus lateralis lateral mass/transverse process yaqinida qo'shimcha suyak kanal hosil qilishi mumkin. Ularning kombinatsiyasi V3 segmentni ikki anatomik nuqtada cheklashi mumkin. Bunday "double osseous constraint" modeli juda kam uchraydi, biroq dinamik arterial kinking uchun biologik jihatdan kuchli substrat bo'lishi mumkin.

Zamonaviy morfometrik tasnif. CBCT va MSKT tasvirlari anomaliyani miqdoriy baholashga imkon berdi. Complete arcuate foramen uchun kraniokaudal balandlik, anteroposterior kenglik, ko'ndalang diametr, maydon, suyak ko'prigining qalinligi va posterior arch bilan birikish burchagi o'lchanishi mumkin. Olszewski tomonidan taklif etilgan "thin" va "thick" complete PP modellari aynan shu morfometrik yondashuvni aks ettiradi. Biroq morfometriyaning klinik ahamiyati hali to'liq validatsiyalanmagan. Kanal kichik bo'lishi avtomatik stenozni anglatmaydi, chunki vertebral artery diametri ham individualdir. Shu sababli eng mantiqiy kelajak yo'nalishi suyak kanal maydonini arterial tashqi diametr bilan nisbatda baholashdir.

Klinik qarashlarning evolyutsiyasi. Kimmerle anomaliyasiga klinik munosabatni shartli ravishda to'rtta paradigmaga ajratish mumkin. Birinchi paradigma anomaliyani simptomlarsiz anatomik variant deb ko'radi. Ikkinchi paradigma uni vertebro bazilyar yetishmovchilik, cervicogenic headache va vestibulyar simptomlarning potensial sababi sifatida baholadi. Uchinchi paradigma C1–C2 instrumentation davrida uni vertebral artery injury uchun muhim anatomik risk sifatida tan oldi. To'rtinchi, zamonaviy paradigma esa incidental morfologik variant bilan haqiqiy klinik neyrovaskulyar konfliktlarni ajratishga intiladi.

uchrashni, Radojević va Negovanović [5] esa umurtqa arteriyasi egati anatomiyasini o'rganish orqali uning faqat qarilkdagi ossifikatsiya bo'lishi haqidagi soddalashtirilgan qarashni zaiflashtirdilar.

Lamberty va Zivanovicning umurtqa arteriyasining retroartikulyar suyak halqasi haqidagi anatomik ishi [6] va Saunders hamda Popovichning oilaviy tadqiqoti [7] rivojlanish, irsiy va filogenetik komponentlarga e'tibor qaratdi. Dugdale [8] anomaliyani radiologik adabiyotda davom ettirdi, Stubbs [9] esa irq va jins bo'yicha tarqalish variabelligini ko'rsatdi. Ushbu tarixiy ishlar [2–9] zamonaviy meta-tahlillarda ko'riladigan yuqori heterogenlikning ildizlari yangi emasligini ko'rsatadi. Tubbs va hammualliflarning anatomik sharhi [10] hamda Paraskevas va hammualliflarning makromorfologik tadqiqoti [11] orqa yoyini butun umurtqa arteriyasi egati anatomiyasi doirasida baholash zarurligini ko'rsatdi. Kim va hammualliflarning rentgenografiya va uch o'lchamli KTni birlashtirgan tadqiqoti [12] esa tasvirlash metodining o'zi prevalensiya va morfologik klassifikatsiyaga ta'sir qilishini tasdiqladi. Young va hammualliflarning 2005-yildagi ishi

Kimmerle anomaliyasi tarixidagi klinik burilish nuqtalaridan biri hisoblanadi [13]. Anomaliya endi faqat rentgenologik topilma emas, C1 lateral massasiga vint o'rnatish paytida umurtqa arteriyasiga real zarar yetkazishi mumkin bo'lgan jarrohlik anatomiya elementi sifatida ko'rila boshlandi. Keyinchalik Hong va hammualliflarning uch o'lchamli KT-angiografik tahlili [14] bu qarashni yanada kengaytirib, orqa yoy va V3 segmentning birgalikdagi uch o'lchamli anatomiyasini operatsiyadan oldin baholash zarurligini ko'rsatdi. Cho tomonidan berilgan radiologik ma'lumotlar [15] va Elliott–Tanweer meta-tahlili [16] Kimmerle anomaliyasining “kam uchraydigan nuqson” emasligini aniq ko'rsatdi.

Elliott va Tanweerning 16,7% umumiy tarqalish darajasi natijasi anomaliyaning klinik talqiniga fundamental ta'sir ko'rsatadi: populyatsiyaning taxminan har oltinchi kishisida morfologik variant mavjud bo'lishi mumkin bo'lsa, nospetsifik bosh og'rig'i yoki bosh aylanishining mavjudligi avtomatik sababiy bog'lanish sifatida talqin qilinishi mumkin emas [16]. Bu epidemiologik nuqta klinik ortiqcha tashxislash xavfini ko'rsatadi. Masalan, keng tarqalgan bosh og'rig'i bilan keng tarqalgan anatomik variant o'rtasida statistik assotsiatsiya mavjud bo'lishi mumkin, ammo individual bemorda patofiziologik sababiylik uchun qo'shimcha dalil talab qilinadi.

Konus-nurli kompyuter tomografiyasi davri ushbu masalani yanada aniqlashtirdi. Bayrakdar [17], Geist [18], Chen [19] va Sekerci [20] tomonidan bajarilgan tadqiqotlar rentgenografiyada ko'rilmagan qisman yoki tomonlama variantlarni uch o'lchamli tasvirlashda aniqroq identifikatsiya qilish mumkinligini ko'rsatdi. Shu sababli tarqalish darajasi faqat biologik populyatsion farq emas, diagnostik metodga bog'liq o'zgaruvchi ham hisoblanadi [17–20]. Tambawala va hammualliflar [21] servikogen bosh og'rig'i bilan assotsiatsiyani o'rgandilar, Giri va hammualliflar [22] lateral tsefalogrammalar orqali yuqori aniqlanish chastotasini ko'rsatdilar, Saleh va hammualliflar esa 2917 KT tekshiruviga asoslangan katta kohortda anomaliyaning zamonaviy epidemiologik ko'lamini aniqladilar [23]. Ushbu ishlarni birgalikda talqin qilish shuni ko'rsatadiki, Kimmerle anomaliyasi juda ko'p hollarda boshqa maqsadda olingan radiologik tasvirda tasodifan aniqlanadi.

Pekala va hammualliflarning bosh og'rig'i va migren bo'yicha meta-tahlili [24] klinik simptomlar masalasiga muhim dalil qo'shdi. Foramen arcuale mavjud guruhda bosh og'rig'i ko'proq uchragan. Biroq meta-tahlildagi assotsiatsiyaning o'zi mexanistik geterogenlikni hal qilmaydi. Bosh og'rig'i umurtqa arteriyasi kompressiyasi, C1 nervining ta'sirlanishi, periarterial simpatik chigalning ta'sirlanishi, servikal mushak-skelet disfunktsiyasi yoki boshqa birlamchi bosh og'rig'i buzilishi bilan bog'liq bo'lishi mumkin [24]. Shu sababli zamonaviy klinik qarash “to'liq PP simptomatik, to'liq bo'lmagan PP simptomatik emas” kabi soddalashtirilgan klassifikatsiyadan voz kechishi kerak. Arslan va hammualliflarning jarrohlik xavf bo'yicha tahlili [25] PPning klinik ahamiyati simptomatik bo'lmagan bemorda ham mavjud bo'lishini ko'rsatadi. Bemor hech qanday vertigo yoki bosh og'rig'iga ega bo'lmashligi mumkin, biroq C1–C2 instrumental fiksatsiya vaqtida PP uning umurtqa arteriyasi anatomiyasini o'zgartirganligi uchun juda muhim topilmaga aylanadi.

Xu va hammualliflarning 113 manbani qamrab olgan zamonaviy sharhi [26] aynan shu ko'p qirrali xususiyatni tasdiqlaydi. PP bir vaqtning o'zida anatomik variant, potensial klinik simptom substrati va jarrohlik xavfi ko'rsatkichi bo'lishi mumkin. Bu uch rolni bir-biridan ajratmaslik ilmiy va klinik noaniqlikka olib keladi. Olszewski va hammualliflarning yangi morfometrik klassifikatsiyasi [27] ham tasniflarning evolyutsiyasi haqida muhim xulosa beradi. Klassik to'liq/to'liq bo'lmagan tasnif klinik amaliyot uchun hali ham qulay, ammo zamonaviy yuqori fazoviy aniqlikdagi tasvirlash suyak ko'prigining qalinligini, kanal o'lchamini va shaklini qayd etish imkonini beradi. “Yupqa” va “qalin” to'liq PP

tiplari kelajakda vaskulyar xavf bilan bog'lanishi mumkin, biroq hozircha bunday sababiy korrelyatsiya yetarli klinik validatsiyaga ega emas [27]. Gul va Atikning umurtqa arteriyasi diametri bilan bog'liq zamonaviy tadqiqoti [28] muhim konseptual yo'nalishni belgilaydi: suyak kanalining o'lchami arteriya o'lchamidan alohida qaralmasligi kerak. Masalan, 5 mm yoysimon teshik 2,5 mm diametrlilik dominant bo'lmagan arteriya uchun keng bo'lishi mumkin, ammo 4,5 mm dominant V3 segment uchun nisbatan cheklovchi bo'lishi mumkin. Shuning uchun kelajakda “suyak kanali–arteriya nisbati” kabi individual indekslar klassik morfologik tasnifdan ko'ra ko'proq klinik axborot berishi mumkin.

Ordoñez-Cure va hammualliflarning 2025-yilgi faqat KT ma'lumotlariga asoslangan meta-tahlili [29] orqa yoyning umumiy tarqalish darajasini 21% atrofida qayd etib, to'liq bo'lmagan PPning ko'proq uchrashini ko'rsatdi. Bu natija tarixiy rentgenografik tadqiqotlardan yuqoriroq bo'lishi mumkin, chunki KT qisman suyak ko'priklarini yaxshiroq aniqlaydi. Demak, anomaliya tarqalish darajasining “o'sishi” biologik hodisa emas, kamida qisman diagnostik aniqlikning oshishi natijasidir [16, 17, 29]. Valenzuela-Fuenzalida va hammualliflarning 2026-yilgi sistematik meta-tahlili [30] bu masalani kranioservikal klinik ahamiyat bilan bog'ladi. Zamonaviy epidemiologik tadqiqotlarning eng katta xulosasi shuki, morfologik mavjudlik keng tarqalgan, ammo klinik ahamiyatli fenotip bundan ancha kam bo'lishi kerak. Shuning uchun prevalensiya va “Kimmerle sindromining tarqalish darajasi” bir xil tushuncha emas [29, 30].

Umurtqa arteriyasi variantlarini hisobga olmasdan Kimmerle anomaliyasini zamonaviy tasniflash to'liq bo'lmaydi. Wakao va hammualliflar [31] C1–C2 darajasidagi persistirlovchi birinchi intersegmentar arteriya, fenestratsiya, yuqori joylashgan umurtqa arteriyasi va anomal PICA kabi variantlarni uch o'lchamli KT-angiografiya yordamida ko'rsatdilar. Bu anomaliyalar orqa yoyning o'zi bilan bog'liq bo'lmashligi mumkin, ammo birgalikda operativ xavfni keskin o'zgartiradi. Elgafy va hammualliflarning shu tomondagi yoysimon teshik va yuqori joylashgan umurtqa arteriyasi kombinatsiyasi haqidagi ishi [32] aynan shu kompleks xavf modelini ko'rsatadi. Klinik anatomiyaning zamonaviy konsepsiyasida “PP bor” degan xulosa yetarli emas; “PP qaysi tomonda, qaysi arteriya uning ichidan o'tadi, arteriya dominantmi, yuqori joylashgan konfiguratsiya bormi va C2 pedikulasi xavfsizmi?” degan savollar birgalikda hal qilinishi kerak. Natsis va hammualliflarning keng morfometrik klassifikatsiyasi [33] atlasning orqa yoyi va umurtqa arteriyasi egatini bir butun anatomik koridor sifatida ko'rishga imkon beradi. Ushbu yondashuv kelajakdagi klassifikatsiya faqat ponticulus shakliga emas, balki “C1 orqa neyrovaskulyar koridor fenotipi”ga asoslanishi mumkinligini ko'rsatadi.

Zhang va hammualliflar [34] va Song va hammualliflar [35] PP mavjud holatlarda C1 vinti trayektoriyasi hamda oksipitoservikal spondilodez anatomiyasini morfometrik baholab, individual rejalashtirish konsepsiyasini mustahkamladilar. Ushbu jarrohlik ishlar shuni ko'rsatadiki, Kimmerle anomaliyasi simptomatik bo'lishi shart emas, biroq operatsion anatomiyada klinik jihatdan yuqori ahamiyatga ega bo'lishi mumkin. Lukianchikov va hammualliflarning simptomatik umurtqa arteriyasi kompressiyasi holati [36] esa evolyutsiyaning boshqa tomonini aks ettiradi. Tanlangan bemorda orqa yoy va ponticulus lateralising kombinatsiyasi V3 segmentning bosh holatiga bog'liq bukilishini yuzaga keltirgan va jarrohlik dekompressiyasi klinik yaxshilanish bilan bog'langan. Bunday ishlar morfologik variantning ayrim hollarda haqiqiy dinamik neyrovaskulyar sindrom substrati bo'lishi mumkinligini ko'rsatadi [36].

Ammo individual klinik holat bayonlarini keng populyatsiyaga ekstrapolyatsiya qilish noto'g'ri bo'ladi. Kimmerle anomaliyasi mavjud minglab simptomatsiz bemorlar borligi sababli simptomatik kasallikni aniqlashda yuqori diagnostik chegara talab qilinadi.

Zamonaviy klinik qarashda uch xil tushunchani ajratish maqsadga muvofiq.

Birinchisi — Kimmerle anatomik varianti, ya'ni tasodifiy topilgan orqa yoy.

Ikkinchisi — Kimmerlarning jarrohlik xavfi anatomiyasi, ya'ni simptom bo'lmasa ham C1–C2 instrumental jarrohlik uchun muhim bo'lgan suyak-tomir konfiguratsiyasi.

Uchinchisi — Kimmerle bilan bog'liq klinik ahamiyatli neyrovaskulyar konflikt, ya'ni morfologik tuzilma, mos simptom va vaskulyar-funksional dalil bir-biriga mos keladigan holat.

Bu semantik ajratish kelajakdagi ilmiy tadqiqotlarda ham muhimdir. “Kimmerle anomaliyasi bo'lgan bemorlar” nomi ostida faqat radiologik topilmaga ega bemorlarni haqiqiy gemodinamik sindromli bemorlar bilan bir guruhga qo'shish natijalarning katta heterogenligiga olib keladi.

4-jadval

Kelajakdagi Kimmerle anomaliyasi klassifikatsiyasiga kiritilishi maqsadga muvofiq bo'lgan komponentlar / **Table 4.** Components advisable for inclusion in a future classification of Kimmerle anomaly

Domen	Baholanadigan parametrlar
Morfologiya	To'liq, to'liq bo'lmagan, kalsifikatsiyalangan
Laterallik	O'ng, chap, ikki tomonlama
Lokalizatsiya	Orqa, lateral, kombinatsiyalangan
Morfometriya	Kanal balandligi, kengligi, maydoni, suyak ko'prigi qalinligi
Vaskulyar anatomiya	VA diametri, dominantlik, gipoplaziya, bukilish
Qo'shimcha variant	FIA, fenestratsiya, anomal PICA, yuqori joylashgan umurtqa arteriyasi
Klinik fenotip	Simptomsiz, bosh og'rig'i, vestibulyar, orqa qon aylanish havzasiga oid
Dinamik komponent	Bosh rotatsiyasida oqimning kamayishi mavjud/yo'q
Jarrohlik komponent	C1–C2 vint trayektoriyasi bilan konflikt mavjud/yo'q

Bunday ko'p domenli model klassik tasniflarni bekor qilmaydi. Aksincha, to'liq/to'liq bo'lmagan tasnif uning birinchi va eng sodda qatlami bo'lib qoladi. Maqolaning asosiy nazariy natijasi Kimmerle anomaliyasi konsepsiyasining uch bosqichli transformatsiyasidir:

morfologik variant → jarrohlik anatomik xavf → tanlangan dinamik neyrovaskulyar fenotip.

Aynan shu evolyutsiya anomaliyaga nisbatan qarama-qarshi qarashlarning nega mavjudligini tushuntiradi. Rentgenolog uchun u ko'pincha tasodifiy anatomik topilma. Umurtqa pog'onasi neyroxirurgi uchun u C1 fiksatsiyasi vaqtida potensial arterial xavf. Vaskulyar nevrolog uchun esa juda kam sonli tanlangan bemorlarda holatga bog'liq orqa qon aylanish havzasi sindromi substrati bo'lishi mumkin. Shuning uchun zamonaviy ilmiy terminologiyada “Kimmerle anomaliyasi klinik ahamiyatga ega” degan umumiy jumladan ko'ra, qaysi klinik kontekst nazarda tutilayotganini aniq ko'rsatish maqsadga muvofiq.

5. XULOSA

Conclusion

Kimmerle anomaliyasi haqidagi ilmiy qarashlar bir asrdan ortiq vaqt davomida sezilarli evolyutsiyani boshdan kechirdi. Dastlab atlas orqa yoyining anatomik varianti sifatida tasvirlangan suyak ko'prigi rentgenografiya rivojlanishi bilan klinik tasvirlash obyektiga aylandi, keyinchalik esa populyatsion, antropologik va evolyutsion nuqtai nazardan o'rganildi. Klassik to'liq va to'liq bo'lmagan tasniflari hozirgacha asosiy morfologik klassifikatsiya sifatida saqlanib qolgan bo'lsa-da, zamonaviy KT va konus-nurli KT morfometriyasi anomaliyaning kanal diametri, suyak ko'prigi qalinligi va fazoviy konfiguratsiyasini batafsil baholash imkonini yaratdi.

C1–C2 instrumental fiksatsiya texnologiyalarining rivojlanishi Kimmerle anomaliyasini spinal neyroxirurgiyada muhim umurtqa arteriyasi shikastlanishi xavfi omiliga aylantirdi. Zamonaviy KT-angiografiya va funksional gemodinamik diagnostika esa anomaliyaning klinik talqinini yanada chuqurlashtirib, morfologik topilmaning o'zi simptomlarning sababiyatini isbotlamasligini ko'rsatdi. Shuning uchun hozirgi bosqichda Kimmerle anomaliyasini uch xil klinik kontekstda baholash maqsadga muvofiq: tasodifiy anatomik variant, C1–C2 jarrohligi uchun muhim suyak-tomir anatomiyasi va juda tanlangan bemorlarda dinamik neyrovaskulyar konfliktning anatomik substrati. Kelajakdagi klassifikatsiyalar suyak ko'prigining to'liq yoki to'liq bo'lmagan ekanligi bilan cheklanmay, uning morfometriyasi, lateralligi, umurtqa arteriyasi dominantligi, qo'shimcha vaskulyar variantlar, simptomatik fenotip va dinamik gemodinamik ahamiyatini birlashtirishi kerak.

DECLARATIONS

Declarations

Author contributions *CRedit*

Conceptualization; Methodology; Investigation; Data curation; Writing – original draft; Writing – review & editing. All authors have read and agreed to the published version of the manuscript.

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The article is a review of published scientific literature. The work involved no experiments on animals and no human participants, and therefore required no separate ethics committee approval.

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All authors have read and approved the final version of the manuscript and have given their consent to its submission and publication. The study involved no human participants and no personal data.

Data availability statement

All data discussed in this review are taken from the publications listed in the reference list and are available from those sources.

Conflict of interest

The authors declare no conflict of interest.

Generative AI disclosure

Generative AI (Claude, Anthropic) was used in the editorial preparation of this article: for language editing, translation of the title, abstract and keywords between Uzbek, Russian and English, preparation of the extended English summary from the authors' text, and formatting of the reference list. No data, results or conclusions were generated by AI. The authors are responsible for the content of the publication.

EXTENDED SUMMARY IN ENGLISH

Kengaytirilgan inglizcha xulosa / Расширенный реферат на английском языке

Purpose and research problem

Kimmerle anomaly is an anatomical variant of the atlas in which a partial or complete bony bridge forms over the groove of the vertebral artery on the posterior arch of C1, converting the open groove into a partial or complete bony canal that contains the V3 segment of the vertebral artery, the suboccipital nerve and periarterial soft tissue. In the nineteenth and twentieth centuries the structure was studied mainly as an anatomical and radiographic finding, but its relationship with the V3 segment, the suboccipital nerve and the surgical anatomy of the craniovertebral junction later turned it into a clinically relevant entity. The literature describes the same variant under many names — ponticulus posticus, posterior bony bridge of the atlas, arcuate foramen, retroarticular canal, retroarticular vertebral artery ring and Kimmerle anomaly — which complicates comparison of studies. The aim of this review was to trace the history of the discovery of Kimmerle anomaly, the development of its classifications and the evolution of clinical concepts about its significance.

Materials and methods

The work was performed as a structured narrative review. Classical and contemporary publications on the historical anatomy, radiology, anthropology, epidemiology, clinical neurology, vertebral artery anatomy and craniovertebral surgery related to Kimmerle anomaly were analysed. The search covered the terms ponticulus posticus, arcuate foramen, Kimmerle anomaly, bony bridge of the atlas arch, vertebral artery groove, C1 lateral mass screw placement, craniovertebral junction, vertebral artery compression and related anatomical classifications. Historical anatomical and radiographic studies were compared with modern computed tomography, CT angiography, cone-beam CT, morphometric studies, systematic reviews and meta-analyses. The historical evolution was conditionally divided into the period of anatomical observation, the period of radiographic identification, the epidemiological and morphological period, the period of the surgical-risk concept and the current period of neurovascular phenotyping. Classifications were compared using three main criteria: completeness of the bony bridge, laterality and morphometry. When modern clinical approaches were evaluated, the morphological finding, its relationship with the vertebral artery, the reproducibility of symptoms and evidence of functional haemodynamic change were considered together.

Results and discussion

Scientific views of Kimmerle anomaly passed through several stages: description of the anatomical variant, radiographic identification, study of population prevalence, classification of complete and incomplete forms, recognition of the surgical risk associated with C1 instrumentation and, most recently, the concept of dynamic neurovascular conflict. With the development of CT, CT angiography and three-dimensional reconstruction, the anomaly became an object of morphometry and preoperative planning. Terminology evolved as well: the term ponticulus posticus is now considered more accurate for the bony bridge itself, whereas arcuate foramen designates the bony opening formed when the bridge is complete. The simplest and most practical classification divides the anomaly into complete and incomplete forms; later systems added unilateral and bilateral forms, posterior and lateral ponticuli, and quantitative morphometric parameters obtained with cone-beam CT and multislice CT, such as canal diameter, bridge thickness and spatial configuration. Large meta-analytic data cited in the review give an overall prevalence of 16.7%, which shows that the anomaly is common and that its presence alone cannot explain symptoms. The authors summarise the clinical evolution in a proposed set of phenotypes ranging from an asymptomatic incidental anatomical variant to a morphologically and haemodynamically confirmed symptomatic neurovascular conflict, and they stress that this model is a conceptual proposal rather than a validated international classification. The discussion shows that the development of C1–C2 instrumented fixation made the anomaly an important risk factor for vertebral artery injury during C1 lateral mass screw placement, and that individual case reports of symptomatic compression should not be extrapolated to the whole population. The authors therefore distinguish three concepts: the Kimmerle anatomical variant, the surgical-risk anatomy relevant to C1–C2 instrumentation even in the absence of symptoms, and a clinically significant Kimmerle-

related neurovascular conflict confirmed by morphology, symptoms and functional findings. A multi-domain model covering morphology, laterality, morphometry, vertebral artery anatomy and dominance, accompanying vascular variants, clinical phenotype and dynamic haemodynamic significance is proposed for future classifications.

Conclusion and contribution

Scientific concepts of Kimmerle anomaly have changed considerably over more than a century. The bony bridge, first described as an anatomical variant of the posterior arch of the atlas, became an object of clinical imaging with the development of radiography and was later studied from population, anthropological and evolutionary points of view. The classical division into complete and incomplete forms remains the basic morphological classification, while modern CT and cone-beam CT morphometry allow detailed assessment of canal diameter, bridge thickness and spatial configuration. The development of C1–C2 instrumented fixation turned the anomaly into an important risk factor for vertebral artery injury in spinal neurosurgery, and modern CT angiography and functional haemodynamic diagnostics showed that the morphological finding alone does not prove symptom causality. Kimmerle anomaly should therefore be evaluated in three clinical contexts: as an incidental anatomical variant, as bone-and-vessel anatomy important for C1–C2 surgery, and, in carefully selected patients, as the anatomical substrate of a dynamic neurovascular conflict. Future classifications should integrate morphometry, laterality, vertebral artery dominance, accompanying vascular variants, the symptomatic phenotype and dynamic haemodynamic significance.

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