# The Orbits—Anatomical Features in View of Innovative Surgical Methods

Carl-Peter Cornelius, MD, DDS<sup>1</sup> Peter Mayer, MD, DDS<sup>1</sup> Marc Christian Metzger, MD, DDS<sup>2</sup>

<sup>1</sup> Department of Oral and Maxillofacial Surgery, Ludwig Maximilians University, Munich, Germany

<sup>2</sup> Department of Oral and Maxillofacial Surgery, Albert Ludwigs University, Freiburg, Germany

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### Abstract

### **Keywords**

- anatomy of internal orbit
- osseous structures
- ► bony surface contours
- ► periorbita
- extraocular muscles
- connective tissue compartments
- nerve and vessel supply

The aim of this article is to update on anatomical key elements of the orbits in reference to surgical innovations. This is a selective literature review supplemented with the personal experience of the authors, using illustrations and photographs of anatomical dissections. The seven osseous components of the orbit can be conceptualized into a simple geometrical layout of a four-sided pyramid with the anterior aditus as a base and the posterior cone as apex. All neurovascular structures pass through bony openings in the sphenoid bone before diversification in the mid and anterior orbit. A set of landmarks such as the optic and maxillary strut comes into new focus. Within the topographical surfaces of the internal orbit the lazy S-shaped floor and the posteromedial bulge are principal determinants for the ocular globe position. The inferomedial orbital strut represents a discernible sagittal buttress. The periorbita and orbital soft tissue contents—extraocular muscles, septae, neurovasculature—are detailed and put into context with periorbital dissection.

The orbits are a pair of symmetrical mirror-imaged bony housings positioned in the craniofacial transition territory. They enclose and protect the ocular globes, complexly organized organs of vision collecting and converting light into electrochemical signals to enter the anterior gate of the visual pathway, which extends from the photoreceptors in the retina back to the occipital brain lobe next to the calcarine sulcus. The eyes, retinae, optic nerves, chiasma, and optic tracts are part of the central nervous system or more precisely anterior prolongations and constituents of the diencephalon. Binocular vision is based on the perception and fusion of information from either side. The actual visual organ, the eye or ocular globe, is surrounded by auxiliary structures maintaining or expanding its functionality such as the eyelids, the lacrimal apparatus, the extraocular muscles including the optomotor nerves (cranial nerves-CN III, IV, and VI), the blood vessels, and the orbital fat body partitioned by a

delicate system of connective tissue septa. With the exception of the eyelids, the globes and the auxiliary structures are accommodated within the bony orbital cavities.

The osseous orbital framework is connected by canals, fissures, and foramina to the middle cranial fossa as well as to the internal nose, the ethmoid sinuses, the pterygopalatine and infratemporal fossa, and the outer skeletal surfaces of the midface and anterior cranial vault.

Apart from the optic nerve (CN II), numerous neural and vascular structures pass through the openings in the orbital apex that is made up by the sphenoid which can be understood as kind of a backup structure for the whole midface.

It is pure coincidence that the orbit lends itself to a word play with its two last letters. Oddly enough, they are identical with the acronym for information technology. In fact, much of the ongoing revolution in craniofacial surgery started with IT applications to optimize the assessment of orbital trauma and

Issue Theme Reconstruction of the Orbit; Guest Editor, Rainer Schmelzeisen, MD, DDS, PhD, FRCS Copyright © 2014 by Thieme Medical Publishers, Inc., 333 Seventh Avenue, New York, NY 10001, USA. Tel: +1(212) 584-4662. DOI http://dx.doi.org/ 10.1055/s-0034-1394303. ISSN 0736-6825.

Michael Ehrenfeld, MD, DDS<sup>1</sup>

Address for correspondence Carl-Peter Cornelius, MD, DDS, Department of Oral and Maxillofacial Surgery, Ludwig Maximilians University, Lindwurmstr 2a, 80337 Munich, Germany (e-mail: Peter.Cornelius@med.uni-muenchen.de). its repair.<sup>1,2</sup> These technologies in conjunction with the tremendous capabilities of endoscopically assisted surgery of the paranasal sinuses and skull base<sup>3–6</sup> have given new insights into the details of orbital anatomy and have transformed the basic understanding of internal surface contours in relation to volume, ocular globe position, and binocular function.<sup>7–13</sup> Of course, fundamental anatomical facts and variations have not changed, but refined ways of description providing unfamiliar facets and a newly developing anatomical jargon among orbital surgeons make the difference nowadays.

### **Bony Orbits—Margin and Orbital Walls**

The bony orbit or orbital cavity is conceived as a threedimensional (3D) geometric assembly in form of a four-sided pyramid with a triangular tip or apex. The base of this pyramid corresponds to the wide aperture or aditus orbitae oriented frontolaterally to the face, whereas the narrowed apical end is pointing posteriorly toward the middle cranial fossa.<sup>14–16</sup>

The medial walls of the two orbital pyramids are arranged almost in parallel with a corridor of 2.5 cm width for the ethmoid in between. The angle between each lateral and medial wall is approximately 45degrees; hence, the extension lines along the lateral walls of both the orbits meet at right angles. The orbital axes which are imaginary bisecting lines between the medial and lateral walls converge toward the orbital apices.

The circumference of the orbital aperture is framed by a superficial orbital margin. The margin is formed by the maxilla, the zygoma, as well as the frontal and lacrimal bones. This marginal rim is thick, prominent, and well defined except for the medial side, which is discontinuous because of the interposition of the fossa for the lacrimal sac between its lower and upper part.<sup>17</sup> The medial rim or nasal orbital margin consists of the frontonasal process of the maxilla, the lacrimal bone, and the maxillary process of the frontal bone. The frontonasal process extends upward into the anterior lacrimal crest and makes up the lower medial margin leveling off toward the frontonasal suture line. The supraorbital rim continues into the posterior lacrimal crest in a more backward plane and creates a second parallel bone ridge and the fossa lacrimalis in between a fluted bevel.

The superior and inferior orbital margins curve distinctly posterior, so that the lateral rim is least projecting in the whole orbital circumference. The four walls of the human orbit or the internal orbit, respectively, are formed by the following seven bones: frontal, zygoma, maxilla, palatine, lacrimal, ethmoid, and sphenoid.

The roof of the orbit is composed largely of the orbital plate of the frontal bone anteriorly and of the lesser wing of the sphenoid (LWS) with a minor part in the posterior part. The triangular shape of the roof narrows toward the orbital apex. The anterior portion of the frontal bone contains the frontal sinuses, which can extend far up into the squamous part of the frontal bone and far back over the orbital roof when The fossa for the lacrimal gland is a shallow depression in the anterolateral aspect of the roof next to the zygomaticofrontal suture (ZFS). A small depression in the anteromedial portion of the roof, the trochlear fovea, is the site of attachment for the fibrocartilaginous ring (pulley) girdling the tendon of the superior oblique muscle.

The medial orbital wall is formed, again in the anterior posterior direction, by the frontonasal maxillary process, the lacrimal bone, the lamina papyracea of the ethmoid bone, which is quadrangular in shape, and the anterolateral surface of the sphenoid body. The anterior and posterior ethmoidal foramina (EF) are located superiorly along the frontoethmoidal junction and indicate the level of the cribriform plate.

The lateral orbital wall consists of the lateral orbital process of the zygoma constituting the anterior part and the greater wing of the sphenoid (GWS) posteriorly. The zygomaticosphenoid suture (ZSS) line is located in the thinnest portion of the lateral wall, which becomes obvious in axial cross sections. The axial cut through the GWS takes on a thickening triangular shape in transit to the middle cranial fossa floor. The posterolateral GWS surface contributes to the temporal and infratemporal fossa configuration. The ZSS is a pertinent landmark for realignment of the fractured zygoma from inside the orbit.<sup>18</sup> Whitnall's tubercle is situated on the orbital surface of the frontal process of the malar bone a few mm behind the orbital margin, 2-4 mm posterior to the rim and 11 mm below the ZFS.<sup>19</sup> The blunt eminence of 2 or 3 mm-in generic nomenclature the marginal orbital tubercle on the zygoma-is the common attachment for the components of the lateral retinacular suspension complex, that is, the lateral canthal tendon or palpebral ligament, lateral horn of the levator aponeurosis, the so-called lateral check ligament of the lateral rectus muscle, and Lockwood suspensory ligament of the ocular globe inferiorly. In the anterolateral intraorbital surface of the lateral wall, anterior to the inferior orbital fissure (IOF) the zygomatico orbital foramina are exiting either with separate orifices or as a common groove to the external bony surface of the zygoma. Within the bone, they continue as two canals to the zygomaticofacial and zygomaticotemporal foramina.

The "cranio-orbital" foramen also known by the names "lacrimal,"<sup>20,21</sup> "meningo-orbital," and "sphenofrontal" foramen<sup>22</sup> is located in the GWS anterolateral to the upper tip of the superior orbital fissure (SOF).

The floor of the orbit is shorter in its anteroposterior extent than the three other orbital walls and terminates in the IOF in front of the orbital apex that consequently turns into a triangular frontal cross section. For its most part, the floor consists of the orbital plate of the maxilla supplemented by the tiny orbital plate of the palatine bone posteriorly and by the inferior orbital process of the zygoma anterolaterally. As a portray image of the orbital roof the floor takes a triangular shape, it is thin-walled and forms the superior boundary of the maxillary sinus. The anteromedial corner where the floor is continuous with the medial wall is perforated by the nasolacrimal canal. The infraorbital groove opens in the middle section of the anterior border of the IOF posteriorly and runs forward in the midline of the orbital floor to convert into the infraorbital canal anteriorly. This canal usually projects into the maxillary sinus as a marked bony molding that ends at the facial antral wall with the infraorbital foramen.

# Bony Openings: Canals, Fissures, Foramina, and Notches

### **Optic Canal**

The medial wall and the roof of the orbit extend posteriorly to the orbital end of the optic canal. The canal is 4 to 9.5 mm in diameter and 5.5 to 11.5 mm in length,<sup>6,23</sup> and it takes a path with 45 degrees inward and 15 degrees upward angulation through the junction of the sphenoid body and the LWS. The canal transmits the optic nerve, the ophthalmic artery, and accompanying sympathetic nerve fibers. The entrance or optic foramen opens in the superior most and medial most corner of the orbital apex.<sup>15</sup> The canal has an elliptical cross section whose major diameter lies in a horizontal plane, accordingly it is considered as built up from sections of an ovoid outline. The bony layer of the upper arc corresponds to the anterior root of the LWS which is contiguous with the planum sphenoidale in the anterior cranial fossa. The inferomedial canal circumference is commonly formed by the sphenoid body. However, this pattern is subject to variation by sphenoethmoidal air cells, named Onodi cells. The Onodi cell, the most posterior ethmoid cell, may extend posteriorly and laterally into the sphenoid sinus with intimate contact to the optic nerve due to excessive pneumatization and a missing bony protection. Laterally, the optic canal is separated from the SOF by the optic strut. This is a bony bridge linking the base of the anterior clinoid process to the sphenoid body. Sometimes, the optic strut is addressed as the posterior LWS root. Occasionally, the optic strut itself presents with an extra foramen, which transmits the ophthalmic artery having a low origin from the internal carotid artery. This is referred to as ophthalmic foramen.

The optic strut is pneumatized from its inside, what creates the lateral opticocarotid recess in the posterior part of the sphenoid sinus. This is extending between the optic nerve superiorly and the intracavernous carotid artery inferiorly.

### **Superior Orbital Fissure**

The SOF separates the posterior part of the lateral orbital wall from the roof, more precisely, it is a gap interposed between the LWS and the GWS on the lateral side of the optic foramen. The fissure has a diagonal course sloping downward from the lateral apex to its medial base, where, it is bounded by the sphenoid body. Frequently, it is club-shaped<sup>24</sup> with a narrow lateral top end and a wide medial bottom portion. However, various subtypes can be distinguished.<sup>25</sup> The optic strut lies at the superomedial border of the fissure in an angle position between the upper and medial SOF edges. The orientation of the SOF deviates slightly from the coronal plane resulting

from a forward shift of the lateral apex. The SOF connects the orbit to the middle cranial fossa.

The annulus of Zinn<sup>26</sup> (synonyms: common tendinous ring, common annular tendon or Zinn's ring, tendon of Lockwood, and optic ring) is a circular array of connective tissue enfolding in the orbital apex. Zinn's ring is the origin of the four extraocular rectus muscles. The upper half of the ring, also named the superomedial foramen, consists of the superior rectus muscle which encompasses the optic foramen and the optic nerve. The laterally oriented half of the tendinous ring, the superolateral foramen, is formed by the lateral, inferior, and medial rectus muscles and loops over the bottom portion of the SOF to demarcate the confines of the optomotor foramen, a compartment that inter alia transmits the oculomotor (upper and lower division) and the abducens nerve. The medial side of the optomotor foramen is made up by the optic strut. A small rectangular and flat or a pointed bony spur protruding from the lateral SOF margin, the spina rectus lateralis serves as a site for the bony attachment of Zinn ring.<sup>27</sup> Inferiorly, the SOF terminates at a transverse bony confluence above the foramen rotundum, which is referred to as maxillary strut.<sup>20,21,28</sup> Its edges along the lower SOF end proceed forward like the verts of a superficial half-pipe which blends with the medial end of the IOF.

### **Inferior Orbital Fissure**

The IOF separates the floor from the lateral wall of the orbit in their posterior two-thirds. Its long axis is oriented in a posteromedial to anterolateral direction from the exocranial surface of the maxillary strut to the tip of a loop in between the anterior and the lateral orbital plate of the zygoma, the adjacent margins of the GWS, and the orbital plate of the maxilla. Posteromedially, the sphenoid body and the palatine bone contribute to the IOF formation. With the view from above, the IOF simply has the outline of a double-ended spoon with a narrow intermediate grip. In fact, it is a rather complex 3D space providing passageways and portals for vessels and nerves or fat pads to the pterygopalatine, infratemporal, and temporal fossae. The narrowing (isthmus) in the center of the orbital opening of the IOF results from a crescent-shaped promontory of the orbital floor lateral to the orbital plate of the palatine bone and medial to the infraorbital groove that is projecting posteriorly beyond the actual medial IOF rim (IOF isthmus promontory).

A smooth muscle going by several names such as, Müller's (vestigial) muscle, periorbital muscle, or musculus orbitalis (Müller),<sup>29</sup> is filling the IOF along the entire extent.<sup>28</sup> It is understood as part of the orbital connective tissue system and the periorbital lining. The orbital muscle of Müller yields a ceiling which spans over the bony margins of the entire IOF length and crosses over the maxillary strut to enter the SOF.

### **Ethmoidal Foramina**

The EF are arranged along the suture line between the ethmoid and frontal bone. The number of EF varies, ranging from a single foramen over the prevalent double up to a sextuple array.<sup>30</sup> The most anterior and most posterior EF are commonly defined as the anterior EF (AEF) and posterior EF

(PEF). The proximity of the PEF to the optic foramen is of critical significance in periorbital dissection to avoid optic nerve injury. The mean PEF–optic foramen distances reported in the literature ranges between 4.3 and 9.15 mm.<sup>30</sup>

### **Cranio-Orbital Foramen**

The cranio-orbital foramen COF is laying either in the GWS lateral to the narrow lateral end of the SOF or it is confluent with it. The size, frequency of accessory foramina, and precise transverse/vertical position of the COF has been analyzed quantitatively.<sup>31</sup> Several variations, also in the arterial branching pattern must be expected.

### **Supraorbital Notch**

The exit of the supraorbital neurovascular bundle, the supraorbital notch, or the foramen is located approximately on the borderline between the medial third and the lateral two thirds of the supraorbital rim. When a notch is present, a fascial band completing the ring is a common finding.<sup>32</sup>

With a coronal approach appreciation is needed, that the supraorbital nerve trunk beyond the orbital rim splits up to form two consistently present divisions: a superficial medial portion which pierces the frontalis muscle and fans out over its surface for sensory supply to the forehead and anterior margin of the scalp and a deep lateral division that runs a superolateral course across the forehead in a layer over the pericranium and deep to the galea aponeurotica plane to and in parallel to the superior temporal fusion line reach the frontoparietal scalp medially.<sup>33,34</sup> Only a subset of individuals receives a dual innervation of the frontoparietal scalp from both the superficial and the deep division. Preservation of the frontoparietal scalp sensation therefore requires a special coronal flap design to protect the deep division of the supraorbital nerve.<sup>33</sup>

### **Nasolacrimal Canal**

The nasolacrimal canal is formed by the maxilla, the lacrimal bone, and the lacrimal process of the inferior nasal concha. It surrounds the draining membranous lacrimal duct, is directed downwards, backward and laterally thus producing a ridge in the anteromedial recess of the maxillary sinus. The canal is approximately 12 to 15 mm long and has a diameter of 4 to 5 mm. The lower opening is into the inferior nasal meatus.

#### Infraorbital foramen

The infraorbital foramen and the infraorbital canal belong to the orbital part of the maxilla. Their spatial characteristics are abundantly documented in terms of distances of the foramen from the infraorbital rim, the facial midline, and the lateral rim of the piriform aperture but with a wide range of different values.<sup>35–37</sup> The foramen is located between 7 and 10 mm below the infraorbital rim. Supernumerary foramina may be present.

#### Foramen rotundum—Maxillary Strut—Pterygoid Canal

The foramen rotundum penetrates the pterygoid process of the sphenoid bone below the medial portion of the SOF and links the middle cranial fossa with the pterygopalatine fossa (PPF). The maxillary strut refers to the narrow bridge of bone separating the foramen rotundum from the SOF.

The pterygoid canal, also known as Vidian canal is located inferomedial to the foramen rotundum and opens into the PPF anteriorly. The canal runs above the medial pterygoid plate along the junction with the sphenoid body.

# Surface Contours, Topographical Shape, Dimensions, and Volume of the Internal Orbit

Detailed mapping of the complex bony surfaces of the orbit, in particular, the topography of the floor in transition to the medial wall including the so-called posterior medial bulge has been taken to a new level by automated analysis of computed tomographic (CT) data sets from routine examinations of patients with unaffected regional anatomy.<sup>12,13,38–43</sup> In comparison to this, "big data mining" studies based on traditional manual caliper measurements must appear anachronistic. The visual impression of the published 3D orbital shapes and forms, however, elude exact narrative description and will need direct inspection in the respective articles.

The orbital floor inclination on coronal plane, that is, the angle between the floor and a horizontal plane is steeper in males than in females and decreases with age independent of the measurement in the anterior, middle, or posterior frontal plane. With aging, the lowest point of the orbital floor moves into a posterior and inferior direction.<sup>38</sup> The latter parameter provides new estimates for the extent of the concavity right behind all orbital rims. This widening of the orbital cavity is best appreciated in the sagittal sections of the conical orbit, aptly, it is referred to as the "postentry zone" according to the sequence in periorbital dissection of the floor.<sup>15</sup> From the bottom of the postentry zone, the floor is continuously ascending posteriorly up to the convex top of the orbital plate of the palatine bone, which curves strongly downward into the rear end of the IOF. The term "lazy S-configuration" eventuates from the undulating shape of the orbital floor in paramedian sagittal planes medial to the infraorbital groove. The lazy S-shape revealed great variability with subtle to steep curvatures as a function of the anteroposterior floor inclination.<sup>13</sup> Along the maxillo-ethmoidal suture line, the orbital floor slopes medially upward and merges with the medial wall. The posterior terrain of this transition zone, which we identify as the IOF isthmus promontory may take several forms from a flat, almost seamless silhouette, over an intermediate soft-edged terrace arrangement to a sharp bent buckling.<sup>13</sup> In abstraction of these variations, the inferolateral-medial wall transition directly behind the globe is claimed to integrate a focal convex sinus bulging, which is considered the most essential support mechanism to maintain the vertical position and anterior projection of the ocular globe. It is called the "posteromedial bulge" or "the key area,"<sup>9</sup> as this region is a main issue in orbital reconstruction. CTdatabased 3D contour mapping and virtual molds of the orbital floor topography give some fundamental ideas where to figure it out.<sup>12</sup> It has become clear, however, that the posteromedial bulge remains a "fuzzy" surface structure, as its boundaries lack distinct anatomical criteria and are

difficult to capture in automated digital shape analysis.<sup>40</sup> As a consequence, the posteromedial bulge still needs to be outlined manually in shape modeling based on surgical expertise and to transform it into an "embedded" region of interest. In males, larger and higher bulges were demonstrated than in females, <sup>12,13</sup> but in the laterality evaluation, the topographical shapes were symmetrical between left and right sides.<sup>12,40</sup> The IOF isthmus promontory is the lateral offshoot of the posteromedial bulge. While the farended verge of the promontory is solid and coincides with the orbital process of the palatine bone for the most part, the IOF isthmus promontory itself corresponds to the posterior recess of the maxillary sinus and ergo is hollow. The size of the orbital floor in terms of the parameters' width and length showed a limited number of different gender-dependent patterns in general with smaller dimensions in females.<sup>12</sup> In traumatic defect-like conditions, the profile of the posteromedial bulge is commonly lost, but most of the time the orbital plate of the palatine bone remains intact and can serve as a "posterior ledge" in reconstruction.44 The zygomatic/sphenoidal centerpiece of the internal lateral orbit displays a straight and even surface plane from the anterior rim to the lateral edge of the SOF in an angle position of approximately 45 degrees to its respective medial wall. The length of the lateral orbital wall is approximately 1.0 cm shorter than the medial wall and it appears even shorter owing to its angulation and the backward position of its outer rim.

The orbital cone angle characterizes the average medial/ lateral wall angulation in the mid and posterior orbit, which has been evaluated in a 3D-based geometric measurement approach using planes fitting the two walls. In stark contrast to the 45 degrees angulation just mentioned, the values for an European white ethnicity ranged between 41 degrees and 63 degrees.<sup>41</sup> The dimensions and volumes of the orbit vary greatly because of ethnic, gender, and age differences, and escape from normative quantification.<sup>39</sup> Although some values typically found in adults may serve as initial orientation: the anterior opening measures 4 cm horizontally and 3.5 cm vertically, the depth anteroposteriorly is approximately 4.5 to 5 cm-the overall orbital volume amounts to 30 mL, of which 7 mL go to the ocular globe volume.<sup>15</sup> For instance, the interindividual variation of orbital volumes for an European white ethnic group was lying between 20 to 29 mL (mean, 24.4 mL) in females and 22 to 32 mL (mean, 26.8 mL) in males. The globe volume ranged from 6.5 to 9.3 mL in females and from 6.7 to 9.7 mL in males.<sup>41</sup> The sagittal orbital rim position and angulation in relation to the medial rim (anterior lacrimal crest) has been assessed in a two-dimensional and 3D fashion again showing considerable gender-specific interindividual variations.42

#### Inferomedial Orbital Strut

The inferomedial orbital strut (IOS) is rather a conceptual than a discrete anatomic structure along the maxillo–eth-moid junction.<sup>45</sup> In biomechanical terms and clinical parlance, it is referred to as internal orbital buttress, a bone formation in sagittal direction, reinforcing the brinks of the

suture lines in the transition between the inferior and medial orbital wall. The IOS can be considered as one constituent of a set of three stabilizing sagittal ridges crossing the orbital floor in parallel—the reinforced medial bony IOF edge laterally, the bony surround of the infraorbital groove/canal intermediary and the IOS medially.

### Anterior Orbit—Midorbit—Posterior Orbit

It is a frequent practice to divide the orbit into three thirds along its anteroposterior extension ( > Fig. 1). This threefold division is arbitrary after all and has no precise relationships or metric distances between acknowledged reference points or planes. The conical apex with its triangular cross section is usually considered the posterior third of the orbit so that the floor extends over the remaining two thirds of the orbital depth. Regardless of any metric measurements and a correctly scaled ratio of three, it appears a meaningful approach to implement the IOF as indicator to partition an anterior, a mid, and a posterior orbit. A frontal plane at the level of a tangent to the tip of the anterior loop of the IOF forms the boundary between the anterior and the midorbit, whereas a second frontal plane passing through the maxillary strut separates the midorbit from the posterior or apical orbit.

### Soft Tissue Contents

### Periorbita

The periorbita is the periosteal lining of the internal orbit and covers the four orbital walls from the anterior aperture of the orbital cavity back to the conical apex with the optic canal and the SOF (**-Fig. 2**). The periorbital envelope provides protection for the orbital soft tissue contents, in particular, it holds the orbital fat. The periorbita is not very adherent to the bony surfaces except for some firm attachments to the suture lines, the trochlea, and the Whitnall tubercle. The inner side of the periorbita facing toward the orbital cavity does not have a smooth surface, as the radiating septae of internal connective tissue system attach there.

Anteriorly, the periorbita is continuous with the periosteum over the orbital rims and the orbital septum in the upper and lower lids as well as the canthal structures (**~ Fig. 3**). The fusion zone between periorbita and periosteum is thickened, making up the arcus marginalis. This is the origin of the orbital septum, which corresponds to the deepest layer of the aponeurotic galea.<sup>33,46,47</sup> Posteriorly in the orbital apex, the periorbita communicates with the dura mater of the middle cranial fossa and the cavernous sinus walls through the optic canal and the SOF. The periorbita covering the apex contributes to the formation of Zinn's ring in conjunction with fibrous components of the dura lining the SOF and optic canal, the optic sheath,<sup>20,21</sup> and the periosteum of the sphenoid body.<sup>48</sup>

In the superolateral quadrant of the anterior orbit, the inferolateral surface of the orbital lobe of the lacrimal gland may be invested by a fascia emanating from the adjacent periorbita.<sup>47</sup> Inferolaterally, the periorbita invaginates the IOF and bonds with the fibers of Müller's orbital smooth muscle,



Fig. 1 Anterior Orbit, Midorbit, and Orbital Apex. (A) Upper left: Orbital apex-spatial overview with Zinn's ring, extraocular muscles, and optic nerve. The optic canal, the SOF, and the posterior IOF represent the passageways between the middle cranial fossa and the orbit via the apex. (B) Upper right: Orbital apex-anterior coronal section breaking down the triangular bony cross section. The density of the orbital connective tissue septa is less pronounced than in the midorbit. (C) Middle left: Midorbit-spatial overview with posterior sphere segment of ocular globe covered by the according segments of the four rectus, the levator, and inferior oblique muscles. Superior oblique muscle segment adjacent to superomedial bony walls. Several bony landmarks determine this level: infraorbital groove, zygomaticosphenoid suture at the anterolateral circumference, ethmoidal foramina, lamina papyracea, and IOS/IOB. (D) Middle right: Midorbit-anterior aspect of coronal section just in front of the IOF. Throughout the midorbit the cross section is four-sided with a convex shifting of the inferomedial walls to the inside of the cavity. The floor and the lateral wall are separated with the beginning of the anterior IOF loop. The posterior end of the midorbit concurs with the orbital process of the palatine bone. The thickness of the lateral wall varies considerably. The GWS makes up the major part of the lateral wall. It has a thick axial cross section at the trigone over the temporal lobe extension of the middle cranial fossa and is thinned near the zygomaticosphenoid suture line. The orbital connective tissue septa are most extensive and complex in the anterior orbit interconnecting the extraocular muscles and linking them to the orbital walls. (E) Lower left: The anterior orbit corresponds to the segment in front of anterior IOF loop. The concave "postentry zone" represents the largest orbital circumference in the frontal plane. The anterior orbital floor is contiguous with the zygomatic orbital plate laterally. The tarsal plates and the orbicularis oculi close the front of the anterior orbital aperture. The insertion of the superior oblique muscle and the rectus superior muscle is covered by the levator muscle which fans out. (F) Lower right: Anterior orbit frontal transview giving insight to the bony and soft tissue structures of this level: lacrimal fossa for the lacrimal sac, inferior oblique muscle and its insertion, globe and insertions of extraocular muscle, trochlear fossa and pulley for superior oblique tendon, tarsal plates, medial and lateral canthi, and Whitnall's tubercle. Whole set of illustrations originates from Fig. 4 of Jacquiéry C, Leiggener C, Cornelius CP, Kunz C. Aktuelle Behandlungsstrategien von knöchernen Verletzungen der Orbitae. OP Journal 2013;29 (2):136–146;Abb.1, c1–c6. Slightly modified and corrected. Redrawn and modified from Fig. 3A (Atlas of orbital surgery) of Rootman J, Stewart B, Goldberg R. Orbital Surgery: A Conceptual Approach. Philadelphia, PA/New York, NY: Lippincott Raven; 1995:148.<sup>15</sup> GWS, greater wing of sphenoid; IOB, internal orbital buttress; IOF, inferior orbital fissure; IOS, inferomedial orbital strut; SOF, superior orbital fissure.

before its sheath duplication continues into the periosteal coating of the pterygopalatine and infratemporal fossae.

At the posterior lacrimal crest, the periorbita splits into two layers. A thin layer intervenes between the lacrimal fossa and a thicker extension, the fascia lacrimalis, invests the lacrimal sac between the posterior and anterior lacrimal crest.<sup>49,50</sup> Along the frontoethmoidal junction, the exiting ethmoidal neurovascular bundles are covered by sleeve-like



**Fig. 2** Periorbita after removal of the lateral wall and roof of left orbit. Trigeminal ganglion and divisions with the anteromedial and anterolateral triangle in between exposed in medial cranial fossa. The ophthalmic nerve (CN V1), the smallest of the three trigeminal divisions, courses forward in the lower portion of the lateral wall of the cavernous sinus to reach the SOF.

periorbital extensions following them into their respective foramina.

Small orbital vessel branches given off from the infraorbital artery are penetrating the periorbita in the orbital floor to set up anastomotic connections with the muscular branches of the ophthalmic artery at the level of the inferior oblique and rectus muscles.<sup>51,52</sup> The branches are encountered posterior to the postentry zone arising from the infraorbital groove, when the periorbita is lifted from the orbital floor (**Fig. 4**).

While the inferior aspect of the periorbital envelope extends gently upward into the medial side just like the underlying bone formation, laterally it turns abruptly over the medial border of the IOF. There can be tight adhesions between the periorbita covering the infraorbital groove and the epineurium of the nerve underneath it.

### Intraorbital—Extraocular Muscles

There are six extraocular muscles (**Fig. 1A, C, E** and **Figs. 5–7**), which are involved in coordinated voluntary ocular



**Fig. 4** Exposure of infraorbital neurovascular bundle from the medial side of the orbit. Several small arterial branches connecting to the periorbita and inferior rectus muscle arise from the open upside of the former infraorbital groove. These branches must be ligatured by bipolar cauterization and divided to achieve a clear plane of dissection when the periorbita is raised from the orbital floor.

motility, the four rectus muscles (superior, lateral, medial, and inferior), and the two oblique muscles (superior and inferior).<sup>53</sup> The levator palpebrae superioris muscle acts a retractor of the upper lid. The four recti and the superior oblique muscles originate from or around the common annular tendon (Zinn's ring) (**- Fig. 5**). The levator palpebrae arises from the orbital apex above the superior rectus. Its origin from the LWS is not considered a part of Zinn's ring, albeit it proceeds forward together with the superior rectus and has a fused medial fascial sheath.

The superior oblique muscle arises from the periorbita on the body of the sphenoid superomedial to the optic foramen and courses anteriorly and superiorly in close juxtaposition to the superior medial bony walls. As it approaches the orbital rim, the muscle narrows and becomes tendinous. The round tendon passes through the trochlea, a fibrocartilaginous pulley that is secured to the trochlear fovea of the frontal bone. The trochlea redirects the tendon at an acute angle backward, outward, and downward toward its insertion on the posterosuperior surface of the sclera lateral to the



**Fig. 3** Periorbit turning inside out into periosteum and orbital septum around the orbital entrance (aditus ad orbitae). Supraorbital and infraorbital nerve bundles marked with yellow spacers.



**Fig. 5** Dorsomedial view of extraocular muscles after removal of the orbital walls (right orbit). The superior oblique muscle ends in a round tendon that runs through the trochlea where it is redirected posteriorly and laterally coursing underneath the superior rectus muscle to attach to the sclera.



**Fig. 6** Dorsolateral view of extraocular muscles and globe (left orbit). Zinn's ring (*light green*) and its two foraminal subcomponents around the SOF and the anterior end of the optic canal are a funnel-structured connective tissue assembly in the orbital apex formed by the periorbita, the dural SOF lining and the optic nerve sheath. Detail (*upper right corner*): Anterior view of Zinn's ring featuring the funnel structure. The lateral rectus muscle has a vertical attachment line to the sclera and globe. The insertion of the superior oblique muscle on the sclera lies lateral to the vertical globe axis between the superior and lateral rectus muscles. The inferior oblique muscle traverses underneath the lateral rectus muscle and also inserts on the sclera between the superior and lateral rectus muscles. The nerves running outside Zinn's ring (CN IV, frontal, and lacrimal nerve) appear shining on its lateral surface. Source: produced with ipad app-3D4medical Eye-Practical-3D4Medical.com, LLC. SOF, superior orbital fissure.

longitudinal axis of the globe. On its way there, the tendon fans out and passes below the superior rectus muscle. The inferior oblique muscle is unique in that it originates from a spot just posterior to the infraorbital rim and lateral to the entrance into the nasolacrimal canal. It runs laterally and posteriorly following underneath the curvature of the globe passing between the inferior rectus muscle and the orbital floor toward its insertion on the posterolateral surface of the sclera underneath the lateral rectus muscle. The rectus muscles follow the curvature of the globe posteriorly and their terminal tendons finally attach to the superior temporal, nasal, and inferior sclera anterior to the equator of the globe (**-Fig. 6**).

### Trochlea

The trochlea is a complex structure consisting of four main components, a grooved cartilaginous flange, a bursa-like synovial space lining, the inner surface of the cartilaginous trochlea that is created by a fibrillar highly vascular sheath and an outer dense fibrous condensation fixing the trochlea firmly to the fovea.<sup>54</sup>

### Zinn's Ring—Common Annular Tendon

Zinn's ring or the common annular tendon is composed of two tendinous portions, the inferior and superior tendon, which form a superolateral and superomedial annular foramen. Zinn's original description<sup>55</sup> referred to the lower ring portion, which he named "de ligamento communi" or the common tendon. This inferior tendon is located inferior to the optic foramen and serves as the origin for the lateral, inferior, and medial rectus muscles. These muscle form a gutter-like



**Fig. 7** Relationship of inferior rectus and inferior oblique muscles, posterior spherical segment of the globe preserved to show the insertion of the inferior oblique to the sclera. Superior oblique and remaining rectus muscles reflected or removed. Optic nerve resected. The inferior oblique muscle originates from the orbital floor area immediately lateral to the nasolacrimal canal. The muscle is directed laterally and posteriorly, passing underneath the inferior rectus muscle. The branch of the inferior division of CN III to the inferior oblique muscle. The zygomatic nerve (CN V2) enters the orbit by passing through the IOF. The zygomatic nerve courses along the lateral orbital wall and bifurcates into the zygomaticofacial and zygomaticotemporal nerves. IOF, inferior orbital fissure.

track,<sup>48</sup> which acts as a guide rail for the oculomotor nerve divisions (CN III), the nasociliary, and the abducens nerves (CN VI). The upper ring portion, the Lockwood tendon, inserts on the superior margin of the optic foramen and gives rise to the superior rectus and a variable superior head of the lateral rectus muscle. If the latter is present, it joins the main lateral rectus across the SOF. The upper ring tendon is fused with the dural sheath of the optic nerve in this region. At their posterior extension, the two tendons or foraminal tubes commingle into a fibrous cone that reaches intracranially through the SOF before insertion at the infraoptic tubercle or inside an infraoptic canal. These alternating structures are located in the body of the sphenoid beneath the optic strut.<sup>48</sup> The optic strut lies inside Zinn's ring.

### **Oculomotor Foramen**

The oculomotor foramen is identical with the superolateral annular foramen within Zinn's ring and represents the central sector of the SOF.<sup>20,21,47</sup> Besides CN III, CN VI, and the nasociliary nerve, it transmits the sensory and sympathetic roots of the ciliary ganglion.

### **Connective Tissue System—Orbital Septae**

An intimately linked web of extensive connective tissue septa surrounds the ocular globe and all other orbital structures, including the extraocular muscles and the orbital vascular and neural elements connecting them to the periorbita. This extremely complicated connective tissue framework consists of the membranes, fascias, sheets, and ligaments which unite to form chambers or pocket-like boundaries that are filled with fat lobules of low viscosity (**~Fig. 1B, D**).<sup>56–59</sup>

The mechanical properties of the connective tissue strands are necessary to maintain the spatial relationships, limit excursions, and resist displacement with the purpose to support the coordination of the globe position during ocular movements. For instance, a sideslip of the rectus muscles over the globe with extreme gaze shifts is prevented.

The connective tissue septa system within the orbit has been extensively investigated and described by Koornneef. Although the system can be regarded as a functional unit, each eye muscle complex is embedded by a peculiar connective tissue system with a special three-dimensional architecture.<sup>56–60</sup>

In the anterior orbit and particularly in the midorbit (**Fig. 1D**), the connective tissue system is most developed, whereas it is less dense in the orbital apex (**Fig. 1B**), where it fuses with Zinn's ring. Detailed descriptions, serial histologic slides, and illustrations can be found online at www.visible-orbit.org.

### Tenon's Capsule—Bulbar Sheath—Vagina Bulbi

The ocular globe and the insertions of the extraocular muscles are enveloped by a dense and elastic connective tissue membrane, known as Tenon's capsule, bulbar sheath or vagina bulbi. The capsule begins shortly behind the sclero-corneal junction and extends over the globe to the optic nerve. The fluid-filled episcleral space separates the inner smooth surface of the bulbar sheath from outer surface of the sclera and is traversed by multiple fine trabeculae. Tenon's capsule partitions the globe posteriorly from the intraconal and extraconal fat pads.<sup>61</sup>

# Whitnall's Superior Suspensory Ligament

Whitnall's superior transverse ligament represents a fibrous condensation of the fascial sheath of the levator palpebrae muscle. It extends from the fascial layers investing the trochlea and the tendon of the superior oblique muscle to the superolateral orbital corner next to the orbital lobe of the lacrimal gland. Whitnall ligament crosses the levator palpebrae muscle posterior to the musculoaponeurotic junction.<sup>62,63</sup> The ligament converts the posterior vector of the levator into a superior vector and prevents the upper lid from pulling away from the globe during elevation.

# **Medial Check Ligament**

The medial check ligament is a fascial extension from the sheath of the medial rectus muscle and the Tenon capsule. In conjunction with the medial horn of the levator palpebrae muscle it attaches behind the posterior lacrimal crest, to the orbital septum medially and to the caruncle and plica semilunaris.

# Lateral Check Ligament

The lateral check ligament is a fascial connection from the lateral rectus sheath to Whitnall tubercle inside the lateral orbital rim. There are additional attachments to the orbital septum and the fornix of the conjunctiva.

The function of the check ligament is to limit the actions of the extraocular muscle in longitudinal direction and to prevent the eyeball from posterior or anterior displacement by contraction of the rectus or oblique muscles, respectively.<sup>47</sup>

# Lockwood's Inferior Ligament

Lockwood ligament stretches across the inferior orbit directly anterior to the inferior oblique muscle extending from Whitnall tubercle laterally to the medial canthal tendon. It is formed by the capsulopalpebral fascia originating from the inferior rectus muscle. The fascia splits to encompass the inferior oblique muscle and its two heads fuse anteriorly to give rise to the Lockwood's ligament. Lockwood's ligament functions as sling support for the globe. The strip-like arcuate extension attaches to the inferolateral orbital rim and merges with the interpad septum separating the lateral and central fat compartments of the lower lid.<sup>61</sup> The capsulopalpebral fascia continues anteriorly getting involved in Tenon's capsule and the inferior conjunctival fornix as well as the septal connective tissue system at the bottom of the orbit.<sup>61</sup>

More anteriorly, the fascia fuses with the orbital septum 4 to 5 mm below the inferior tarsal border and extends through the orbicularis oculi into the eyelid skin. The inferior tarsal muscle, a smooth muscle lies posterior to the capsulopalpebral fascia and attaches at the base of the lower tarsus. The capsulopalpebral fascia and the tarsal muscle are acting as lower eyelid retractors.

# **Orbital fat**

Fat is omnipresent within the confines of the orbital cavity. It occupies all spaces left by the periorbita, connective tissue septa system, globe, muscles, neurovasculature, and glandular structures. In correspondence to the interstices of the septal framework, the consistency of the fat changes from more dense and fibrous in the anterior orbit to larger lobules posteriorly. The fat cushions the ocular globe and facilitates its wide range of movements. Distinct orbital fat pads lie posterior to the orbital septum, two fat pads in the upper and three in the lower eyelid. The two upper lid fat pads, the central, and the medial or nasal fat pad are located in the preaponeurotic space anterior of the levator. They are separated by a fascial extension, the interpad septum, from the trochlea. The lateral compartment is filled with the lacrimal gland.

In the lower eyelid, the inferior oblique muscle divides the nasal and the central fat pad. The arcuate expansion of

Lockwood inferior ligament spreads in between the central and the lateral or temporal fat compartment.

### **Orbital Septum**

The orbital septum is a distinct, multilayered though delicate connective tissue membrane which expands from the arcus marginalis, and the condensed periorbita around the bony margins. It fuses with the levator aponeurosis in the upper eyelid and with the capsulopalpebral fascia below the tarsal plate in the lower eyelid. At the medial canthus it is discontinuous. The upper septal half originates from the posterior lacrimal crest opposed to the lower portion, which arises from the anterior lacrimal crest. The orbital septum represents a barrier at the anterior base or the aditus of the orbit and separates facial from orbital structures. It is perforated by multiple terminal vessel and nerve branches exiting the orbital cavity. The intraorbital part of the lacrimal drainage system is located in a space left by the diverging septal attachments to the superior and inferior lacrimal crest.

# **Nerves of the Orbit**

Five of the twelve cranial nerves supply the orbit (**Fig. 8**): optic nerve (CN II), optomotor nerves to the extraocular muscles—oculomotor (CN III), trochlear (CN IV), abducens (CN VI)—and the sensory nerves—first and second trigeminal division (CN V1 and CN V2).<sup>65</sup> These nerves are complemented by secretomotor fibers from the facial nerve (CN VII) via the pterygopalatine ganglion and sympathetic fibers from



**Fig. 8** Lateral view of right middle cranial fossa. Part of the dural lining stripped off to reveal trigeminal ganglion, internal carotid artery and to open cavernous sinus. The cavernous sinus is located medial to the trigeminal ganglion and extends downward to the lower border of the ophthalmic nerve (CN V1). The optic nerve and ophthalmic artery pass through the optic canal and the medial part of the annular tendon. The oculomotor, trochlear, and ophthalmic nerves course in the lateral wall of the cavernous sinus. CN III is located superiorly in the posterior cavernous sinus and shifts inferiorly then. The intracranial course of CN IV is approximately 25-mm long before penetrating the dura and entering the cavernous sinus. In the cavernous sinus wall, CN IV passes forward between CN III and the ophthalmic nerve branches. At the level of the SOF, it turns medially to cross above Zinn's ring and continue on the levator muscle.

the paravertebral sympathetic chain and the superior cervical ganglion.

### **Optic Nerve**

The optic nerve is composed of retinal ganglion cell axons and support cells. It passes from the globe and the orbit via the optic canal to the optic chiasm with a total length of 45 to 50 mm. Accordingly, it can be divided into four zones: intraocular, intraorbital, intracanalicular and intracranial. The retrobulbar part of the adult optic nerve was reported to contain a mean of 1.16 million fibers (range: 777,000-1,679,000).<sup>66</sup> This number decreased with advancing age with a mean loss of approximately 4,000 per annum. CN II carries special somatic afferent (SSA) fibers, what means it conveys information from the special senses of vision. The optic nerve is invested within the three pachy- and leptomeningeal layers. The subarachnoidal space along the intraorbital and intracanalicular zones contains cerebrospinal fluid and communicates with the subarachnoidal space around the intracranial part and the brain stem.<sup>67</sup>

The dural sheath around the optic nerve binds with the periorbita at the optic foramen and with the sclera. The intraocular or scleral component of CN II is only 1 mm in length and corresponds to the thickness of the sclera around the optic disc. The perforations in the sclera (lamina cribrosa) are the passageway for the unmyelinated axons leaving the retina to form the optic nerve, where they are myelinated by oligodendrocytes. The intraorbital CN II portion is 4 mm in diameter and 25 to 30 mm long. It runs a serpentine course to cover the 20 mm spatial distance from the optic foramen to the posterior pole of the globe. This reserve length allows for movement and a certain limit of distension. The central retinal artery and an accompanying vein enter the nerve from inferomedially some 5 to 15 mm posterior to the globe.<sup>68</sup> In general, the intracanalicular CN II is 5 to 8 mm long and supplied with pial branches of the ophthalmic artery which runs along the inferolateral surface of the nerve. In continuation from the anterior end of the canal, the nerve passes through the superomedial annular foramen of Zinn's ring.

The intracranial part approximately 10 mm long lies in the subarachnoid cistern of the optic chiasm directly beneath the frontal lobe and with the internal carotid at the lateral surface.

### Sensory Innervation of the Orbit

### Trigeminal Nerve (CN V)

The trigeminal nerve CN V represents the major sensory nerve of the face. Its sensory ganglion (synonym: Gasserian or semilunar ganglion) is seated in an impression near the apex of the petrous bone in the middle cranial fossa (**- Fig. 8**).

"Meckel's cave" is a dural pocket that contains the sensory and motor roots of the trigeminal nerve, the trigeminal ganglion, and the trigeminal cistern.

The sensory nerves of the orbit come from the ophthalmic trigeminal division (V1) for the main part. The maxillary division (V2) contributes the zygomatic nerve and the

infraorbital nerve, which pass through the inferolateral orbit. The functional category of nerve fibers in these two divisions is general sensory afferent (GSA).<sup>67</sup>

# Ophthalmic Nerve—Trigeminal Ophthalmic Division

Trigeminal ophthalmic division (CN V1) is the smallest of the three peripheral trigeminal divisions. In the lateral wall of the cavernous sinus CN V1 gives off the lacrimal, frontal and nasociliary nerves which pass through the SOF (**Fig. 9**). The lacrimal nerve is the smallest branch of CN V1 and runs outside Zinn's ring, lateral to the frontal nerve, and above the superior ophthalmic vein. In the superolateral orbital quadrant, it courses along the superior border of the lateral rectus muscle toward the lacrimal fossa, through the gland and the orbital septum to the skin of the lateral upper eyelid. The lacrimal nerve provides the end of the pathway for postganglionic secretomotor (parasympathetic) fibers from the pterygopalatine ganglion. They travel with the zygomatic and zygomaticotemporal nerve (CN V2) to join the lacrimal sensory nerve across a communicating ramus along the lateral orbital wall and are distributed to the lacrimal gland. The frontal nerve is the largest branch of CN V1. It runs outside Zinn's ring, medial to the lacrimal nerve and below the trochlear nerve (CN IV), and passes anteriorly between the superior surface of the levator palpebrae and the periorbita. At the level of the posterior eyeball, the frontal nerve subdivides into two branches, the supraorbital and supratrochlear. The supraorbital nerve continues forward on top of the levator muscle together with the homonymous artery and exits the orbit at the supraorbital notch or foramen. Its terminal superficial and deep branches collect fibers from the upper eyelid, eyebrow, forehead, and scalp far beyond the vertex.<sup>33,34</sup>

The supratrochlear nerve passes anteromedially with the supratrochlear artery above the trochlea and exits the orbit through a small frontal notch. It receives fibers from the



**Fig. 9** View of the SOF focusing on the oculomotor foramen. The frontal nerve (CN V1) and CN IV are displaced superomedially on top of the optic strut. The ophthalmic nerve has been retracted to show the nasociliary nerve arising from its medial side and passing amid the lateral side of the oculomotor foramen. CN VI passes through the foramen below the nasociliary nerve to enter the ocular (medial) surface of the lateral rectus muscle. The superior and inferior divisions of CN III run on the medial side of the nasociliary and abducens nerves. SOF, superior orbital fissure.

medial upper evelid and brow, the lateral glabellar region and the medial forehead. The nasociliary nerve (CN V1) passes through the superolateral foramen of Zinn's ring to the medial side. Conceptually, it can be subdivided into a ciliary portion along the lateral aspect of the optic nerve in a row with a nasal portion in the superomedial orbit.<sup>69</sup> The ciliary portion keeps laterally in the orbital apex and provides a sensory root as well as sympathetic fibers to the ciliary ganglion ( $\succ$  Fig. 10). The fibers of both modalities pass the ciliary ganglion without synapsing. These fibers and the parasympathetic fibers leave the ganglion within the short ciliary nerves, which run to the eyeball and distribute to the cornea, the ciliary body, and the iris.<sup>53</sup> The two or three long ciliary nerves arise as the nasociliary nerve crosses over the optic nerve medially. They bypass the ciliary ganglion and enter the sclera around the optic nerve intermingled with the short ciliary nerves and convey sympathetic fibers to the globe and the pupillary dilator. Moreover, they collect sensory fibers from the cornea and the iris. The sympathetic fibers within the short ciliary nerves are vasomotoric in contrast to the pupillodilator fibers in the long ciliary fibers.

The nasal portion represents the continuation of the nasociliary nerve in the medial part of the orbit between the superior oblique and medial rectus muscle. In association with branches of the ophthalmic artery, it gives off the posterior and anterior ethmoidal nerve to the ethmoidal air cells, sphenoid sinuses, anterior nasal septum, and skin at the



Fig. 10 Lateral view of the orbital contents of Fig. 9 after opening the oculomotor foramen between the origin of the superior rectus and lateral rectus muscle. The lateral rectus has been reflected to expose the ciliary ganglion inferolateral to the optic nerve. The inferior and superior CN III divisions course on top of each other as they pass through the SOF and the oculomotor foramen on the medial side of the branches of CN V1. The ciliary ganglion has parasympathetic (motor), sympathetic and sensory roots. The short ciliary nerves carry the fibers of each of these roots to the globe. The preganglionic parasympathetic fibers from the branch of the inferior oculomotor division to the inferior oblique muscle synapse within the ciliary ganglion, whereas the postganglionic sympathetic and the sensory fibers, which convey corneal sensation, transverse it. The long ciliary nerves bypass the ciliary ganglion, they also convey sympathetic fibers (see the text for details). The inferior CN III division splits into three branches supplying the inferior rectus, medial rectus and inferior oblique muscles. CN VI enters the lateral rectus muscle from the ocular (medial) surface. At the level of the ciliary ganglion the nasociliary nerve, the ophthalmic artery, the superior ophthalmic vein pass between CN II, and the superior rectus muscle to approach the medial side of the orbit.

dorsum of the nose. The infratrochlear nerve is the anterior termination that traverses the orbital septum below the trochlea and receives fibers from the side of the nose, medial canthus region, the lacrimal sac, and the caruncle.

### Maxillary Nerve—Trigeminal Maxillary Division (CN V2)

The maxillary nerve derives from the middle of the trigeminal ganglion and enters the pterygopalatine fossa (PPF) through the foramen rotundum. The zygomatic and infraorbital branches of CNV2 ascend into the orbit through the IOF. The zygomatic nerve divides into the zygomaticofacial and zygomaticotemporal branches on the inside of the lateral orbital wall. The zygomaticotemporal nerve delivers secretomotor fibers to the lacrimal nerve before the departure of both branches from the orbit through the zygomatico-orbital foramina. On the external surface of the zygoma, the branches receive sensory fibers from the skin of the cheek and temple.

The infraorbital nerve courses in the sagittal midplane of the orbital floor within the infraorbital groove and the canal ultimately exiting at the infraorbital foramen. The terminal branches draw fibers from the skin of the lower eyelid, conjunctiva, cheek, lateral side of the nose, and the upper lip.

# Optomotor Innervation of the Orbit—Nerves to Extraocular Muscles

The oculomotor (CN III), trochlear (CN IV), and abducens (CN VI) collectively innervate the extraocular muscles. CN III also contributes a motor (parasympathetic) supply to the intraocular muscles (pupillary constrictor and ciliary muscle) via synapses in the ciliary ganglion. The optomotor nerves carry general somatic efferent (GSE) fibers, CN III carries general visceral efferent (GVE) fibers in addition.<sup>67</sup>

### **Oculomotor Nerve (CN III)**

The oculomotor nerve supplies all the extraocular muscles with the exception of the lateral rectus and superior oblique. The superior division sends branches to the superior rectus and levator palpebrae, the inferior division innervates the inferior and medial recti and the inferior oblique. CN III exits ventrally from the brain stem in front of the pons (interpeduncular space) and runs through the lateral wall of the cavernous sinus lateral to the intracavernous ICA. It enters the orbit through the medial part of the SOF and the superomedial or oculomotor foramen. The nerve splits into its two divisions within the SOF already. The superior division passes the oculomotor foramen next to the tendinous attachment of the superior rectus and sends branches to the ocular (inferior) surfaces in the posterior third of the superior rectus and levator muscles. The inferior division divides into the following three roots: medial, central, and lateral. The medial root crosses beneath the optic nerve to reach the ocular (lateral) surface of the rectus medialis muscle in its posterior third. The central root runs anteriorly to innervate the inferior rectus from its ocular (superior) surface, again posteriorly. The lateral root is the longest and travels anteriorly along the lateral

above the levator palpebrae and continues to the orbital (superolateral) surface of the superior oblique muscle. CN IV is the only nerve which does not enter its respective muscle from the ocular (intraconal) surface.<sup>17</sup>

#### Abducens Nerve (CN VI)

Trochlear Nerve (CN IV)

The abducens nerve exits the brain stem ventrally at the pontomedullary junction.

border of the inferior muscle to enter the ocular (superior)

surface of the inferior oblique muscle near the midpoint. Along

this course, the lateral root gives off the small motor (para-

sympathetic) twig which is ascending to the ciliary ganglion at the inferolateral side of the optic nerve. The preganglionic parasympathetic neurons are located in the Edinger–Westphal

nucleus in the midbrain. After synapsing in the ciliary ganglion,

the postganglionic fibers continue within the short ciliary

The trochlear nerve is the single cranial nerve that exits on the

dorsum of the brain stem from the inferior tectum. CN IV has

the smallest caliber of the cranial nerves and travels the

longest intracranial course of approximately 40 mm curving

around the cerebral peduncle above the pons and along the

free edge of the tentorium cerebelli. The dura is penetrated

inferior and lateral to the entry point of CN III into the

cavernous sinus. Within the lateral sinus wall, the trochlear

nerve moves superiorly until it crosses CN III before the

entrance into the SOF. The SOF is passed outside the annular

tendon, in classical terms through the superolateral narrow

portion, accompanied by the frontal and lacrimal branches

from the ophthalmic trigeminal division. These three nerves are the most superficial structures underneath the periorbita on the topside of the orbital apex with CN IV in a super-

omedial position. CN IV runs from temporal to nasal then

nerves to the pupillary constrictor and ciliary muscles.

After an ascending prepontine intracranial course, it pierces the dura of the posterior cranial fossa on the clivus. This portal is in line with the opening of CN III and is located 10 to 12 mm below it. After passing over the basilar plexus and the inferior petrosal sinus, it enters Dorello's canal at the petrous apex, an osteofibrous conduit inside the venous confluence in the petroclival area located below the petrosphenoid ligament. During the passage through the canal, the nerve makes an abrupt sharp angled bend before it finally arrives in the cavernous sinus. CN VI continues forward within the cavernous sinus and lateral to the posterior vertical segment of the internal carotid artery and medial to the ophthalmic nerve (CN V1).<sup>6,17,50,70</sup> Having passed the medial SOF portion and through the superolateral annular foramen CN VI arrives in the orbital apex, where it turns laterally to end up spreading at the innervation site on the ocular (medial) surface at the midpoint of the lateral rectus muscle.

# **Ciliary Ganglion**

The ciliary ganglion is located between the lateral aspect of the optic nerve and the lateral rectus muscle close to the orbital apex (**-Fig. 10**). It is associated with roots from

oculomotor (CN III) and the nasociliary (CNV1) nerve, as well as with direct sympathetic rami from the internal carotid plexus. The ganglion receives the parasympathetic motor fibers from the inferior division of the oculomotor nerve (CN III) or more specifically from its longest branch supplying the inferior oblique muscle.<sup>15,71</sup> The sensory root is supplied by the nasociliary nerve (CN V1). The sympathetic fibers reach the ganglion from the intracavernous carotid artery plexus via the SOF. The parasympathetic motor fibers synapse in the ganglion, whereas the sensory and sympathetic fibers simply traverse it. Five to six short ciliary nerves convey the parasympathetic, the sensory, and the sympathetic fibers

### Sympathetic Pathways

from the ciliary ganglion to the globe.<sup>72</sup>

The sympathetic pathways are responsible for pupillary dilation and for the innervation of the smooth muscles (Müller's, superior tarsal muscle, Müller's orbital muscle, and inferior eyelid tarsal muscle). The sympathetic axons arising from the paravertebral chain synapse in the superior cervical ganglion. From there, postganglionic fibers ascend through the pericarotid plexus along the ICA until they reach their targets.

The final sympathetic pathways into the orbit are still under investigation. There is agreement that they follow the ICA through the foramen lacerum into the cavernous sinus, from where they pass through the SOF and the superolateral annular foramen to be carried on by the abducens (CN VI) intermittently and then by the ophthalmic/nasociliary nerve (CN V1).<sup>53,73</sup> Others follow the course of CN III and CN IV. Direct routes to the ciliary ganglion and the ocular globe along with the ophthalmic artery have been described.53 Some sympathetic fibers from the nasociliary and the oculomotor nerve course through the ciliary ganglion to enter the short ciliary nerves "en passant" to the globe, others bypass the ganglion in the long ciliary nerves. Although the sympathetic fibers within the short ciliary nerves provide vasoconstriction, the fibers within long ciliary nerves are the suppliers to the pupillary dilatator muscle. Sympathetic innervation to Müller's superior tarsal muscle follows the sensory nerves and the arterioles through the levator palpebrae. The sympathetic innervation to Müller's orbital muscle and to inferior eyelid tarsal muscle derives from the pterygopalatine ganglion via the infraorbital nerve.<sup>17</sup>

# **Arterial Supply of the Orbit**

The arterial system that supplies the ocular globe and its auxiliary structures receives input from multiple vessels and various anastomoses interconnecting the external carotid artery (ECA) with the various branches of the ophthalmic artery, which are contiguous with the internal carotid system (ICA).<sup>15,74–76</sup> Distinctive ECA/ICA collateralization exists between the superficial temporal artery, its frontal branches and the supraorbital and supratrochlear arteries. The maxillary artery makes contact with the anterior and posterior ethmoid arteries (PEA) via the sphenopalatine vessels and the

facial/angular arteries anastomose with the dorsal nasal and the palpebral arteries.<sup>74–76</sup> Other links are established between the transverse facial artery, the deep temporal artery, and the lacrimal artery. Some ECA contribution to the arterial orbital supply is accomplished via the infraorbital artery and inconsistently an orbital branch of the middle meningeal artery.

The infraorbital artery, a terminal branch of the maxillary artery arrives in the orbit through the IOF and passes along the infraorbital groove, before it enters the infraorbital canal to exit at the infraorbital foramen, where it meets with the angular artery and the inferior palpebral vessels. In the midorbit, close upon the infraorbital groove, small branches anastomose with branches from the inferior rectus and inferior oblique muscles and the orbital fat. During deep dissection of the periorbita away from the orbital floor it is important to watch out for these anastomoses to section them after bipolar cauterization. The middle meningeal artery, another branch of the maxillary artery, may anastomose with a recurrent meningeal branch of the lacrimal or of the adjacent ophthalmic artery.<sup>15,20,21,74–76</sup> These meningeal or meningolacrimal recurrent branches pass backward through the lateral SOF or a particular foramen in the GWS just anterior to the superolateral end of the SOF, named the meningo-orbital or cranio-orbital foramen (COF). A rare, but relevant variant is a singular OA origin from the middle meningeal artery.<sup>21,77,78</sup> During periorbital dissection deep in the lateral orbital, a meningeal branch traversing a GWS foramen may be encountered and should be preserved in case of doubt about its provenance (major source of blood supply?).

# **Internal Carotid Artery**

The intracranial ICA consists of an intracavernous and a supracavernous portion. The intracavernous ICA begins above the petrolingual ligament and ends in the anterior clinoid process or at the roof of the cavernous sinus. The supracavernous or cerebral part of the ICA extends subsequent to the anterior vertical segment above the roof of the cavernous sinus (upper dural ring/carotid collar).<sup>6,73,79–81</sup>

# **Ophthalmic Artery**

The OA is the primary source of arterial blood supply to the orbit. According to general layouts in textbooks and atlases, the OA is the first intracranial branch of the ICA, which is given off from the superomedial convexity of the supraclinoid ICA segment in the subarachnoid space just above the dural roof of the cavernous sinus and below the optic nerve. The OA traverses the optic canal within the dural sheath on the undersurface of the optic nerve and follows an inferolateral course to enter the orbit through the superomedial foramen of Zinn's ring. The OA may also follow a duplicate bony passage below the optic canal. As a rarity, the OA can also arise from the clinoid ICA segment or from the middle meningeal artery. In these instances, it preferentially passes through the lateral SOF portion or the COF. Infrequently, the OA may be duplicated with two vessels of equal size or one normal-sized branch and an additional hypoplastic collateral. The origins and pathways of the OA duplications toward and inside the orbit vary.<sup>21,74–76</sup>

During its intraorbital course, the OA crosses most times over and less frequently (approximately 15%–20%) under the optic nerve from the lateral to the medial part. Between the superior oblique and medial rectus muscle, it takes a convoluted course distributing numerous and widespread branches, often in association with the nasociliary nerve (CN V1), before it divides into the terminal ramifications supplying the skin of the medial eyelids, the forehead, and the nasolabial region. The OA branches also show an impressive variation in their order and site of origin.<sup>82</sup> A generalized over-optic-nerve pattern includes major intraconal vessels (central retinal, long and short posterior ciliary, branches to the extraocular muscles, and anterior ciliary branches) and extraconal vessels (lacrimal, supraorbital, posterior and anterior ethmoidal, supratrochlear, dorsal nasal branches, and medial palpebral branches) (**Fig. 11**).

The central retinal artery is the first ocular OA branch, given off near the apex medial to the ciliary ganglion. It runs inferiorly and enters the optic nerve on its medial aspect at a point 10 mm behind the ocular globe. The central retinal artery courses a short distance inside the dural sheath of the optic nerve before taking a central position within the nerve cross section and running forward to the optic disc in the retina.

The posterior ciliary arteries are the next ocular branches. Two or three arteries, the medial and lateral posterior ciliary arteries proceed anteriorly in a network of numerous small branches around the optic nerve. These rebundle into 15 to 20 short posterior ciliary arteries which pierce the sclera in a ring around the optic nerve to supply the optic nerve head and the choroidal coat. Two branches deriving from the network behind the globe, the medial, and lateral long posterior



**Fig. 11** Lateral view of the arteries of the orbit (left orbit). Superior and lateral rectus muscles resected, intraconal fat removed. Over-optic-nerve ophthalmic artery course pattern. The ophthalmic artery enters the orbit on the inferolateral aspect of the optic nerve and passes above CN II to the medial orbit, where it continues its course between the superior oblique and the medial rectus muscles.

arteries pierce the sclera axially and extend within the choroid to supply the ciliary body and iris.

The muscular branches supplying the extraocular muscles usually arise from a medial and a lateral trunk of the OA. Subdivisions of the two trunks then run forward along the ocular (medial) surfaces of the four rectus muscles or inside the substance of the muscle bellies. Anteriorly, they divide into pairs of anterior ciliary arteries except for the lateral rectus which carries only one artery. These vessels run forward along the tendinous insertions and enter the globe anastomosing with the long posterior ciliary arteries to form the greater arterial circle of the iris.

The lacrimal artery, a large and early orbital OA branch, accompanies the lacrimal nerve (CN V1) along the upper border of the lateral rectus and distributes to the lacrimal gland and the lateral eyelids and conjunctiva.

The lacrimal artery also gives rise to a recurrent meningeal artery that communicates with the middle meningeal artery via the SOF or the COF. In rare instances, the recurrent artery may represent the parent vessel for the arterial blood supply inside the orbit and replace the OA. Posterior to the lacrimal gland a descending branch from the lacrimal artery divides into the zygomaticotemporal and zygomaticofacial arteries along the lateral orbital wall. These exit the orbit conjoined to the homonymous nerves through the respective foramina within the orbital plate of the zygoma. Elevating the periorbita from the lateral wall can easily disrupt these nerves and vessels.<sup>83</sup> A terminal branch of the lacrimal artery continues across the lacrimal gland and divides into the lateral superior and inferior palpebral arteries.

The supraorbital artery arises from the OA part over the optic nerve and runs in the extraconal space between the levator palpebrae and the periorbita. It accompanies the supraorbital nerve to the supraorbital notch or foramen, where it exits the orbit to the eyebrows and forehead.

The posterior and anterior ethmoidal arteries penetrate the periorbita and enter their respective foramina/canals at the frontoethmoidal suture together with the homonymous branches of the nasociliary nerve (CN V1). The posterior ethmoidal artery (PEA) usually passes over the superior oblique muscle. It mainly supplies the mucosal lining of the air cells in the posterior ethmoid. The PEA may be absent.

The anterior ethmoid artery (AEA) is somewhat larger in caliber and crosses under the superior oblique and over the medial rectus. The AEA penetrates the roof of the ethmoid sinus and passes across the floor of the anterior cranial fossa near the cribriform plate. So, it provides an arterial supply to the dura, the anterior falx, and the walls of the superior sagittal sinus. Branches of both the AEA and PEA in conjunction with ECA anastomoses via the angular/facial artery cover a far-reaching area of blood supply including the entire ethmoidal sinuses, the infundibulum of the frontal sinus, the upper nasal cavity, and the skin over the cartilaginous nasal vault with additional descending branches.

The OA continues in the superomedial extraconal space as the nasofrontal artery close to the medial orbital wall. Its terminal branches leave the orbit as supratrochlear and dorsal nasal arteries, which run above the trochlea or midway between the trochlea and the medial canthal tendon, respectively.<sup>53</sup>

### **Venous Orbital Outflow**

The outflow pathways of the valveless orbital veins lead through the SOF and empty into the cavernous sinus. The upstream orbital venous network has two distinct spatial distributions with two principal veins: the superomedial orbit drained by the superior ophthalmic vein and the inferolateral orbit drained by the inferior ophthalmic vein. The superior ophthalmic vein is a vein with a rather constant course originating from a confluence of the supraorbital, nasofrontal, and angular veins. The angular vein is a subunit of the facial vein. The superior ophthalmic vein courses backward alongside the trochlea and from medially to laterally in relation to the superior rectus muscle. In the midorbit, it crosses above the optic nerve to reach the lateral border of the superior rectus muscle and to enter into the orbital apex. It leaves the muscle cone between the heads of the superior and lateral rectus muscle and passes through the narrow lateral part of SOF above the Zinn's ring before it terminates below the ophthalmic nerve (CN V2) in the anteroinferior portion of the cavernous sinus. At the SOF level, the superior ophthalmic vein is usually joined by the inferior ophthalmic vein to form a common stem. This stem merges with the spaces of the cavernous sinus which are spreading forward across the lower and medial margins of the SOF. The inferior ophthalmic vein forms as a plexus in the anterior floor and lateral orbital wall region. The venous plexus is located in between the inferior rectus muscle and the optic nerve and can extend posteriorly close to the end of the muscle cone. Accordingly, the emerging inferior ophthalmic vein is of different length and runs in parallel to the branch of CN III supplying inferior oblique muscle.

The diameter of the superior ophthalmic vein ranges between 2 and 10 mm, while the caliber of the inferior ophthalmic vein is comparatively small. Apart from the outlet into the cavernous sinus via the superior ophthalmic vein, there also exist direct connections of the inferior ophthalmic vein through the inferior sector of the SOF below Zinn's ring and communicating branches with the pterygoid venous plexus through the IOF.

The intraorbital tributaries of the superior ophthalmic vein are originating from the lacrimal gland, the extraocular muscles in the vicinity (superior rectus, superior oblique, medial rectus, and lateral rectus), and the superior medial and lateral vortex veins (vena vorticosa) from the choroid and the central retinal vein. The inferior ophthalmic vein receives muscular branches (inferior rectus and oblique), medial and lateral collateral veins connecting from the superior venous system, and branches from the lacrimal sac and the inferior vortex veins.

Mostly, there are two ethmoidal veins. The anterior ethmoidal vein drains into the superior ophthalmic vein, whereas the posterior ethmoidal vein joins a venous webbing under the orbital roof. An infraorbital vein accompanying the infraorbital nerve and artery along the canal and groove in the orbital floor interconnects with multiple twigs to the inferior ophthalmic vein and passes through the IOF to end in the pterygoid venous plexus in the infratemporal fossa.

As opposed to the veins elsewhere in the body, the veins of the orbit are not as closely associated with the arterial system and show more independent pathways with the exception of the anterior section of the superior ophthalmic vein that coincides with the ophthalmic artery.<sup>82</sup> The orbital veins exhibit considerable variability following an increasing order: superior ophthalmic vein < inferior ophthalmic vein < collateral veins < muscular branches. One remarkable variant is the presence of a medial ophthalmic vein which corresponds to a semicircular vessel loop linking the anterior ethmoidal, the medial collateral, and the muscular vein from the medial rectus, which in this way indirectly drain into the superior ophthalmic vein.<sup>84</sup> The entire orbital venous network is suspended in the connective tissue septa interspersing the intraorbital contents, just like muscles and fat lobules.<sup>51,56–59</sup>

### **Lacrimal Apparatus**

The lacrimal apparatus consists of a secretory, a distributary, and a drainage or excretory system.<sup>46,85</sup> The function is to provide a continuous tear film that moistens the conjunctiva and cornea, which is composed of an inner mucin layer, an intermediate watery layer, and an outer lipid layer.

The eyelids with their particular arrangement of the orbicularis oculi fibers are responsible for the coordinated propulsion and distribution of the tear film. The eyelids contract progressively from temporal to nasal, propelling the tear fluid over the eye obliquely downward toward the superior and inferior puncta for collection and drainage.<sup>67</sup>

# **Lacrimal Gland**

The lateral horn of the levator aponeurosis partially separates the main lacrimal gland into a smaller inferior palpebral and a larger superior orbital lobe. Because of the parenchymal connection of the lobe behind the lateral palpebral horn of the levator aponeurosis this separation is incomplete. The gland is affixed to the anterolateral orbital roof by fibrous interlobular septa with the orbital lobe lodged in the lacrimal fossa of the frontal bone. The palpebral lobe extends into the lateral aspect of the superior conjunctival fornix. The suspension of the gland comes from attachments to the periorbita, the orbital septum, the conjunctiva, and the Whitnall ligament. All of the excretory ducts of the gland open into the superotemporal conjunctival fornix. Ducts from the orbital lobe join ducts from the palpebral part or traverse it independently.

The blood supply and innervation of the lacrimal gland are provided by the lacrimal artery and the nerve (CN V1). The lacrimal vein drains into the superior ophthalmic vein.

Postganglionic parasympathetic secretomotor neurons (GVE) from the pterygopalatine ganglion reach the lacrimal gland via the zygomatic/zygomaticotemporal (CN V2) and the lacrimal nerve (communicating ramus). The respective preganglionic parasympathetic neurons arise from the geniculate ganglion (CN VII—intermediate nerve) and approach the pterygopalatine ganglion as greater petrosal nerve and deep petrosal nerves. These nerves combine to the pterygoid or Vidian nerve, which enters the pterygopalatine ganglion.

Sympathetic fibers originate from the superior cervical ganglion and follow the course of the arteries to the lacrimal gland.

# Lacrimal Drainage System—Nasolacrimal Sac/Nasolacrimal Duct

The superior opening of the nasolacrimal canal is formed by indentations within the anteromedial orbital surface of the maxilla and the lacrimal bone. It is located next to the infraorbital rim in the medial lower corner of the orbit and is the frontal starting point of the sutural junction between the inferior and the medial orbital wall. The lacrimal drainage system consists of the lacrimal sac and its membranous downward continuation, the nasolacrimal duct, which runs through the intraosseous canal and opens into the inferior nasal meatus underneath the inferior concha. The tear fluid is collected by the lacrimal puncta and emptied into the lacrimal sac via the canaliculi.

The puncta are small round or transversely oval-shaped apertures at the margins of the eyelids near the medial canthus. Both puncta face backward and become only visible when the eyelids are everted. The puncta pass over into the upper and lower canaliculi. Each canaliculus has short vertical —ascending or descending—and a longer horizontal portion. The two horizontal portions run either separately or conjointly into the sidewall of the upper lacrimal sac. The sac is wrapped by the lacrimal fascia—an extension of the periorbita, which stretches between the anterior and the posterior lacrimal crests.

# **Medial Canthal Ligament**

The medial canthal ligament has an anterior and posterior fibrous reflection.<sup>86–88</sup> The anterior or superficial reflection attaches to the anterior lacrimal crest and is the fixation for the orbicularis muscle fibers. The posterior reflection is a fibrous extension arising from the rear side of the junction between the medial crura and the common tendon. It is deep to the lacrimal sac and inserts to the posterior reflection forms a tangential line with the curvature of the lids and supports their apposition against the globe.<sup>64</sup>

# **Lateral Canthal Ligament**

The lateral canthal ligament (LCL) is one of several structural elements of a complex connective tissue fixation ensemble at the lateral orbital rim.<sup>89</sup> The LCL extends from the lateral tarsal ends to Whitnall's lateral orbital. The precanthal ligament is a reinforced fibrous band of the orbital septum at the level of the canthus which runs from the tarsus to the outer periosteal sleeve of the lateral orbital rim. A small lobule of

preaponeurotic (capsulopalpebral) fat fills the triangular space between the septum anteriorly, the canthal ligament posteriorly, and the lateral zygomatic orbital plate. This adipose tissue extension is known as Eisler's fat pocket. Along its superior border, the LCL is adjacent to the lateral horn of the levator aponeurosis and the inferolateral pole of the lacrimal gland.<sup>53,64,86</sup> The posterior LCL portion is in close contact with the lateral rectus muscle check ligament. Inferiorly, the LCL is approximated by the lateral portion of Lockwood's inferior ligament. The inferolateral fibers of Whitnall's superior suspensory ligament connect to the LCL via interstitial fibrous septa in the lacrimal gland.

# Retinacula

The connective structures associated with canthal ligaments are summarized as retinacula. The medial retinaculum is located behind the posterior lacrimal crest. It encompasses Horner's muscle, the orbital septum, the medial horn of the levator aponeurosis, the check ligaments of the medial rectus muscle, and the medial portions of Whitnall's and Lockwood's ligament.<sup>64</sup> The lateral retinaculum, which attaches to Whitnall orbital tubercle, somewhat mirrors the medial retinaculum. It is composed of the LCL, the lateral horn of the levator aponeurosis, the lateral rectus check ligaments, and the lateral ends of Whitnall's and Lockwood's ligament.

# **Lid Retractors**

The levator palpebrae superioris, Müller's superior tarsal muscle and the retractor muscles of the lower eyelid function to open the eyelids and are antagonistic to the orbicularis oculi muscle (OOM), which is responsible for eyelid closure.

# **Levator Palpebrae Superioris**

The levator palpebrae superioris and Müller's superior muscle retract or elevate the upper eyelid. The levator palpebrae is a striated muscle, which is easily separable from the superior rectus muscle apart from their medial border, where they are both adherent to a common fascial sheath. The innervation of both muscles is by the superior CN III division. Whitnall's transverse ligament, the condensation of the fascial sheaths around the levator, is placed just posterior to the superior orbital rim or approximately 18 to 20 mm above the superior border of the tarsus (Fig. 12). Below the level of Whitnall's ligament, the levator is widening horizontally into a broad fibrous aponeurotic sheath arching over the globe with two tendinous extremities, the lateral and medial horns. The band-like lateral horn divides the lacrimal gland incompletely into the orbital and palpebral lobes before inserting on Whitnall's lateral orbital tubercle as a component of the lateral retinaculum. The medial horn passes over the superior oblique tendon, blends with the reflections of the medial canthal tendon, and joins the medial retinacular structures departing from the posterior lacrimal crest for osseous attachment. The cutaneous insertion of the aponeurosis is effected by terminal fibers traversing the orbicularis muscle



**Fig. 12** Supporting elements and retractor muscle in the upper eyelid (right orbit). Skin layers around the orbit have been removed. Suborbicular dissection in the upper lid and preaponeurotic fat removal is shown. Incisions at the midpupillary line into the preseptal orbicularis and through tarsus up to the musculoaponeurotic junction to expand them superiorly and in transverse direction, respectively. Superior rectus muscle sling hooked upward, levator palpebrae located laterally.

and forming a distinct supratarsal fold. A subset of deeper fibers attaches to the anterior surface of the upper tarsus.

However, the formation of a supratarsal eyelid fold is a matter of ethnic differences, and it depends on the vertical height of the fusion line between the orbital septum and the levator aponeurosis.<sup>90</sup> In Asian, single' eyelids without a fold or crease, the orbital septum fuses on the levator over the mid or inferior tarsal plate. A protrusion of the aponeurotic fat pad extending into the resulting pretarsal space prevents the terminal interdigitations of the aponeurotic fibers to anchor the skin and create a crease indentation.<sup>91</sup> In comparison to Caucasian upper, double eyelids are distinguished by dermal attachments of the aponeurotic fibers at or above the superior tarsal border demarcating the upper palpebral fold.

# Müller's Superior Tarsal Muscle

The superior tarsal muscle of Müller's is an involuntary smooth muscle innervated by sympathetic fibers. It is incorporated in the undersurface of the levator palpebrae, is adherent to the conjunctiva posteriorly and inserts into the superior tarsal border. Additional smooth muscles fibers may arise from Tenon's capsule. The tarsal muscle is easily separable from the levator apart from the site of its origin near the musculoaponeurotic levator junction.

# **Lower Eyelid Retractors**

The lower eyelid retractors consist of two principal layers, the capsulopalpebral fascia and the inferior tarsal muscle. Fibrous extensions originate from the sheath of the inferior rectus muscle to compose the head of the capsulopalpebral fascia. This head transforms into an envelope around the inferior oblique muscle. Anterior to the muscle the inferior and superior fascial portions conjoin to form Lockwood's inferior suspensory ligament. The superior portion of the capsulopalpebral fascia then extends posteriorly into the inferior

conjunctival fornix and converts into Tenon's capsule. The inferior portion fuses with the orbital septum anteriorly, connects through the orbicularis oculi muscle (OOM) to the skin and inserts more upwardly on the inferior border of the lower tarsus.<sup>92</sup> The dermal attachments are the basis of the lower eyelid crease. A limited depression of the lower eyelid margin occurs in downgaze to enable an unimpaired visual field. This movement is essentially a synergic effect of the inferior rectus muscle contraction which is translated by the capsulopalpebral head and the inferior fascial portion. The sympathetic smooth inferior tarsal muscle is an accessory lower eyelid retractor. It originates and lies posterior to the capsulopalpebral fascia and inserts at the base of the inferior tarsus.

# **Orbicularis Oculi Muscle**

The OOM is a widespread array of muscle fibers that lies beneath the skin and over the orbital septum and the tarsoligamentous sling. It is innervated by multiple (buccal, zygomatic, and frontal) branches of CN VII. The motor supply of the levator palpebrae, its antagonist, is by the superior division of CN III.

The OOM is divided into three major concentric or ringshaped bands, the orbital, preseptal, and pretarsal portions. The orbital orbicularis arises medially from origins along the superior and inferior orbital rims as well as the medial canthal tendon and forms a wide loop around the lateral circumference of the orbital aperture. Superolaterally, the orbital portion covers the corrugator supercilii muscle and the anterior temporoparietal fascia. In the inferior temporal and cheek area, the orbital orbicularis extends to the origin of the masseter and the zygomaticus minor muscle at the surface of the zygomatic body. Along the infraorbital rim and the maxillary frontal process, the origins of the upper lip and nasal ala elevators are surrounded by the orbital orbicularis.<sup>86</sup> The preseptal portion and the pretarsal OOM overlie the orbital septum and the tarsal plates. At the medial canthal tendon and around the lacrimal canaliculi and lacrimal sac, both the portions divide into two components, anterior or superficial and posterior or deep heads. Both superficial heads connect to the medial canthal tendon and beyond to the anterior lacrimal crest and the nasofrontal maxillary process. The deep head of the preseptal OOM portion, or Jones' muscle, attaches posteriorly to the fascia of the lacrimal sac. The deep pretarsal orbicularis head, known as Horner's muscle, pars lacrimalis or tensor tarsi, passes posterior to the canaliculi and the lacrimal sac to attach to the posterior lacrimal crest<sup>64</sup> (►**Fig. 13**).

Laterally, the preseptal orbicularis from the lower and upper eyelid insert onto the horizontal lateral palpebral raphe which attaches to the zygoma. The pretarsal inferior and superior orbicularis parts join the LCL at Whitnall's tubercle. The integrity of the Horner's muscle connection to the posterior lacrimal crest determines the contact of the eyelid margins in the inner canthal area on the globe surface. The lid margins are pulled anteriorly away from the surface if the muscle is detached or disrupted.<sup>15</sup>



**Fig. 13** Lateral view of the medial part of the anterior orbit. Horner's muscle shown after combined transcaruncular lower fornix swinging eyelid approach. Plica semilunaris flap retracted medially.

# Lacrimal Caruncle

The lacrimal caruncle is a small pink bump (width 3 mm and height 5 mm) at the inner canthus nasally to the plica semilunaris. The superior border is in level with the lower eyelid margin. The caruncle is lined by a nonkeratinizing epithelium looking as if it were a formation of the palpebral conjunctiva. In fact, it is a modified part of the lower lid margin and contains cutaneous appendages such as fine colorless hairs, sebaceous glands, sweat glands, and modified lacrimal glands.<sup>49</sup>

### **Plica Semilunaris**

The plica semilunaris is a conjunctival fold along the curvature of the medial canthus, just lateral to the caruncle. It is important in the distribution of tear fluids, maintenance of the lacrimal lake and removal of ocular debris. Usually the plica is not very prominent, although it provides resiliency in rotational movements of the globe and still contributes some protection. Phylogenetically, it is a remnant of the so-called third eyelid or nictitating membrane, which can be horizontally closed across the entire eyeball.

### **Periorbital Dissection**

The periorbital dissection opens up the potential space between the connective tissue layers of the periorbita and the bony surfaces of the internal orbit. It is this essentially "subperiosteal" space that is commonly accessed in primary and secondary trauma management, in craniofacial corrective surgery and for bony decompression of the orbits. Commonly, it will be tried to keep the periorbita intact to prevent fat tissue prolapses obstructing the narrow visual field inside the orbit.

In severe trauma involving several orbital walls the periorbita may need to be separated from the bone in a 360 degrees sector encircling the anterior and the midorbit. The entry into the orbital cavity can be achieved by a variety of transcutaneous and/or transconjunctival access incisions either via a single or a combination of approaches.<sup>93,94</sup>

With the exception for surgical decompression in an acute optic neuropathy (visual loss/afferent pupil defect) or in a SOF syndrome, the dissection is usually stopped at the entrance into the posterior apex space. Outside the SOF and Zinn ring, the dissectible space under the periorbita is considered safe. The periorbital dissection for exposure in fracture repair advances starting from the anterior aperture at the rim level toward the apex posteriorly. The postentry concavities must be passed around stripping inferiorly (floor) or superiorly (roof) and backward.

In the anterior and the midorbit, the periorbital dissection should circumvent the origin of the inferior oblique muscle, the lacrimal duct, and the medial and lateral retinacular complexes to avoid any inadvertent disruption. Likewise, it is mandatory to be aware of the pertinent landmarks in every single orbital wall. The position, shape, and size of the IOF and SOF indicate a basic pattern for topographical orientation during the surgical exposure of the orbital walls.

In the roof, the trochlear fovea and the lacrimal gland fossa are passed proceeding toward the apex. Periorbital strands suspended from the top of the lateral SOF portion or even more laterally from the COF to the PEF as a tent-like folding delineate the horizontal termination for the dissection below the orbital roof. This periorbital fold will often contain the ophthalmic artery crossing the optic nerve superiorly and/or the recurrent meningeal artery.<sup>15</sup>

Although it is a basic principle to preserve the integrity of the periorbital sac in the case for an extended and deep exposure of the floor and the lower orbital circumference, it is a crucial maneuver to cut across the periorbital prolongations invaginating the IOF from the maxillary orbital plate and the lateral orbital (**-Figs. 14** and **15**).

The anterior part of the IOF does not contain important structures and the infraorbital nerve and zygomatic nerve in the posterior portion course below the usual level of dissection. The posterior limitation of the exposure along the orbital floor is the orbital process of the palatine bone, which



**Fig. 14** Exposure of lateral orbit with zygomatic rim removed. Bony bridge of orbital floor in front of anterior IOF loop left intact. Soft tissue contents of the IOF–temporal/buccal (Bichat) fat pad spreading through the fissure. IOF, inferior orbital fissure.



**Fig. 15** Another orbit—lateral orbital wall completely resected including SOF margin up to the periorbital/dural reflection. Contents of IOF fully exposed up into cavernous sinus/pterygoid plexus. Microscissors demonstrate periorbital dissection cutting through the contents of IOF. Note: triangular cross IOF section consisting of periorbital invagination with fat pad inside and Müller muscle outside. IOF, inferior orbital fissure.

becomes the "posterior ledge" of preserved bone beyond an extensive floor defect. A reliable way to end up there, but in the posterior maxillary recess, is to dissect along the lower margin of the GWS in the lateral wall, which is rarely fragmented. Once the posteromedial IOF has been reached, the periorbita is swept away medially over the posterior end of the infraorbital groove, the IOF isthmus promontory, and the posterior ledge. Raising the periorbita medially allows to visualize the infraorbital nerve and to release it in a controlled fashion.

The maxillary strut above the foramen rotundum would represent a salient bony landmark to terminate the floor dissection posteriorly; however, it lies adjacent to the venous connections through the inferior SOF and to the pterygoid plexus with no safety margin.

Coming along the lateral orbital wall the posterior boundary for the exposure is the dural/periorbital reflection at the lateral SOF margin. A few millimeters before the upper lateral arch of the SOF is approached a recurrent meningeal artery may be encountered passing through COF at the sphenofrontal suture line. On the medial wall, the maximal extent of the deep dissection is marked by the posterior ethmoidal vessels. They come into view at the vertically running sphenoethmoid suture line anterior to the optic foramen.

The pre/transcaruncular incision is often used to approach the medial orbital wall. It proceeds posteriorly inside the periorbita between the medial rectus muscle and Horner's muscle until the lamina papyracea behind the posterior lacrimal crest is reached (**-Fig. 13**). A vertical incision is made and the periorbita is elevated to continue the exposure straight below the frontoethmoid suture line to the AEF and PEF. The IOS in its full extent is best accessed via the pre/ transcaruncular incision combined with a transconjunctival lower fornix approach and temporary detachment of the inferior oblique muscle.

In the literature, oftentimes the safe distances for the periorbital dissection from the intact outside rim of the adult orbit to



**Fig. 16** Coronal section anterior to orbital apex. Spatula tip to elevate the periorbita rests on palatine bone (posterior ledge). Note the close approximation and potential compressional effects of the instrument on CN II.

vital interior structures are specified in millimeters.<sup>95</sup> Generally, a gauging depth of 25 mm along the lateral or inferior wall is regarded safe. A maximal distance of 30 mm from the supraorbital rim and from the anterior lacrimal crest is admitted for a safe exposure of the roof or the medial wall, respectively.

More detailed measurements at the medial wall refer to the position of the EF in relation to the anterior lacrimal crest and among each other. On the average the distance is 24 mm to the AEF, another 12 mm beyond this to PEF and 6 mm between the PEF and the optic foramen. The rule of halves, that is, 24–12–6 mm, is the aide-mémoire for these lengths.<sup>15,96</sup> In the heavily injured orbit or due to anatomic variations, the utility of these values is questionable.<sup>97</sup> Pushing the limits of dissection too far toward the optic foramen probably does not give the full picture of causative factors for CN II lesions. Indirect compression of CN II in its intraorbital course in the tight spatial relationships near the orbital apex may matter as much (**– Fig. 16**).

### Conclusion

The orbits are craniofacial building blocks containing critical ocular, neural, and vascular structures. This article intends to outline a ready-to-use survey of the anatomy of the orbits and their contents to facilitate comprehension of the most relevant surgical details. Certainly, it is a truism to conclude that there will be much more to discover, to figure out, and to learn with intensive immersion into the subject stimulated by the perspectives of technical innovations.

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The authors declare no conflicts of interest in relation to the content of this article.

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