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Lacrimal drainage anatomy in the Japanese population☆

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ABSTRACT

Purpose: The aim of this study is to provide a comprehensive and clinically relevant review of the lacrimal drainage anatomy in the Japanese population.
Methods: A thorough search on the lacrimal drainage anatomy in the Japanese population was performed using PubMed and Ichushi Web, which is managed by the Japan Medical Abstracts Society, for related studies up to December 2018. Published books on the same topic were also reviewed. Data from all articles and book chapters were reviewed, analyzed, and incorporated in this review.
Results: This review presents the subparts of the lacrimal drainage anatomy in a chronological manner, from proximal to distal. The location, dimensions, position or angle, histology (with some reference to the essential clinical functions and physiology of the lacrimal drainage system) are described in this review.
Conclusions: Understanding lacrimal drainage anatomy in the Japanese population is essential to provide insight as to how it is important to consider patients as individuals, with unique and specific anatomies, and uphold a patient-specific approach.

Contents

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1. Introduction

A thorough understanding of the lacrimal drainage anatomy is necessary in order to perform the appropriate lacrimal surgery with a successful outcome. Through the years, various anatomists and lacrimal surgeons have published their reports in order to establish the foundation of lacrimal anatomy. Subsequently, certain variations that are of clinical significance have also been reported for advancement of our understanding of lacrimal anatomy. However, while knowledge on basic anatomy is of utmost importance for a lacrimal surgeon, updating this knowledge with regard to paradigm shifts and race-specific findings can elevate one's clinical practice to a patient-specific approach. The aim of this study is to provide a comprehensive review of the lacrimal drainage anatomy in the Japanese population.

2. Materials and methods

This is a review article on the lacrimal drainage anatomy in the Japanese population. A thorough search on the lacrimal drainage anatomy was performed using PubMed and Ichushi Web, which is managed by the Japan Medical Abstracts Society for related studies up to December 2018. This yielded numerous studies from various anatomists and lacrimal surgeons. For this review, the authors included all relevant studies on the Japanese population that were written in either English or Japanese. However, a few studies that where not focused specifically on the Japanese population but were thought of as relevant by the authors (as they were written by authorities in lacrimal anatomy) were also included. Published books on the same topic were also reviewed. Data from all articles and book chapters were reviewed, analyzed, and incorporated in this review.

3. A review of Japanese lacrimal drainage anatomy

3.1. Lacrimal caruncle, lacus lacrimalis, and lacrimal punctum

The lacrimal caruncle is a soft, ovoid, pinkish tissue, measuring 1.5–3.0 mm in height, 2.3–5.0 mm in vertical length, and 1.1–2.5 mm in transverse length (Mori, 1965) (Fig. 1). Its epithelium is well-developed and similar to the skin, rather than the conjunctiva. It is composed of stratified squamous epithelium, hair follicles, sebaceous glands, and goblet cells (Mori, 1965). Sometimes, accessory lacrimal glands have also been observed (Mori, 1965). It is located in the lacus lacrimalis and is medial to the plica semilunaris (Kamiyama et al., 2004; Kakizaki and Valenzuela, 2011). Its lateral margin continues to the lower eyelid margin and has a direct connection to the lower eyelid retractors (Fig. 1) (Kakizaki et al., 2010b; Kakizaki and Valenzuela, 2011). Adjacent to the caruncle, the lacus lacrimalis (lacrimal lake) is located and is seen as a triangular space that is vertically aligned with the lacrimal papilla (Kakizaki and Valenzuela, 2011), allowing accumulation of tears.

The lacrimal punctum is situated on top of a fibrous mound known as the lacrimal papilla. The punctum has a funnel-form (Kamiyama et al., 2004) and the shape of its orifice varies from oval, linear, and fish-mouth according to age (Yoshihashi and Ishio, 2008; Miyakubo, 2013; Kakizaki, 2016). The punctal opening measures around 0.2–0.7 mm, which varies widely among individuals; furthermore, the lower punctum tends to be larger than the upper punctum (Yoshihashi and Ishio, 2008; Shigeta et al., 2009; Kakizaki, 2016).The inner wall of the punctum is covered by nonkeratinized stratified squamous epithelium (Kominami et al., 2000).

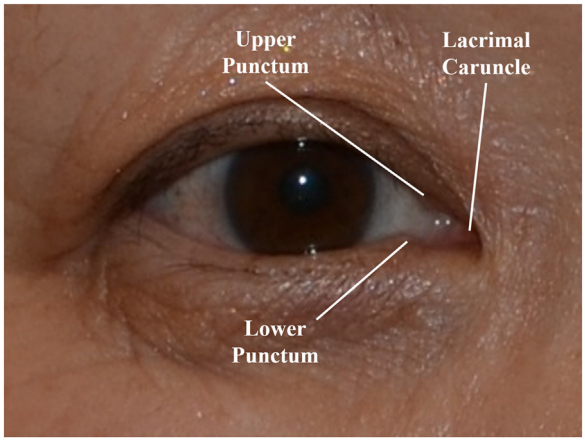

Fig. 1. The lacrimal caruncle and puncti.
The lacrimal caruncle is located in the medial canthus and its lateral margin continues to the lower eyelid margin. The inferior lacrimal punctum is situated temporal to the superior punctum.

The inferior punctum is situated 0.5–3.0 mm temporal to the superior punctum due to embryology, as the maxillary process grows faster compared to the lateral nasal process (Fig. 1) (Kominami et al., 2000; Kakizaki, 2016). Moreover, the other postulated reason as to the more temporal location of the lower punctum is because the lateral margin of the caruncle is directed inferolaterally (Kakizaki and Valenzuela, 2011).

The punctum courses posteriorly towards the lacrimal lake (Kakizaki and Valenzuela, 2011; Kakizaki, 2016). The positioning of this triad (punctum, caruncle, and lacus lacrimalis) is essential for a fully functioning lacrimal system (Kakizaki, 2015). Any disturbance of some sort, such as when the lacrimal papilla is not aligned with the lacus lacrimalis, may result in epiphora (Kakizaki, 2015).

3.2. Vertical canaliculus

The vertical canaliculus is the part of the lacrimal canaliculus, lying between the lacrimal punctum and horizontal canaliculus (Kominami et al., 2000). The course of the vertical canaliculus is not "truly" vertical as there is usually an inclination of 5° laterally during eye opening (Fig. 2A) (Kakizaki et al., 2008b). The transition from vertical to horizontal portion of the canaliculus is referred to as the ampulla, and this is observed in 1/3 of the Japanese population (Fig. 2A) (Kakizaki et al., 2008c). The inner wall of the vertical canaliculus is also lined with nonkeratinized stratified squamous epithelium (Kominami et al., 2000).

The mean length of the vertical canaliculus in Japanese varies from 1.4 to 2.4 mm, according to previous reports (Ashikaga, 1925; Kurihashi et al., 1991; Kominami et al., 2000; Miyakubo, 2013). In our previous report on the Japanese population, the mean length of the vertical portion of the lacrimal canaliculi is 2.82 mm (range, 2.3–3.0 mm) in the upper eyelid and 2.39 mm (range, 2.3–2.5 mm) in the lower eyelid (Takahashi et al., 2011b). The upper vertical canaliculus is noted to be significantly longer compared to the lower vertical canaliculus. The disparity is attributed to the difference between the upper and lower tarsal height (Takahashi et al., 2011b).

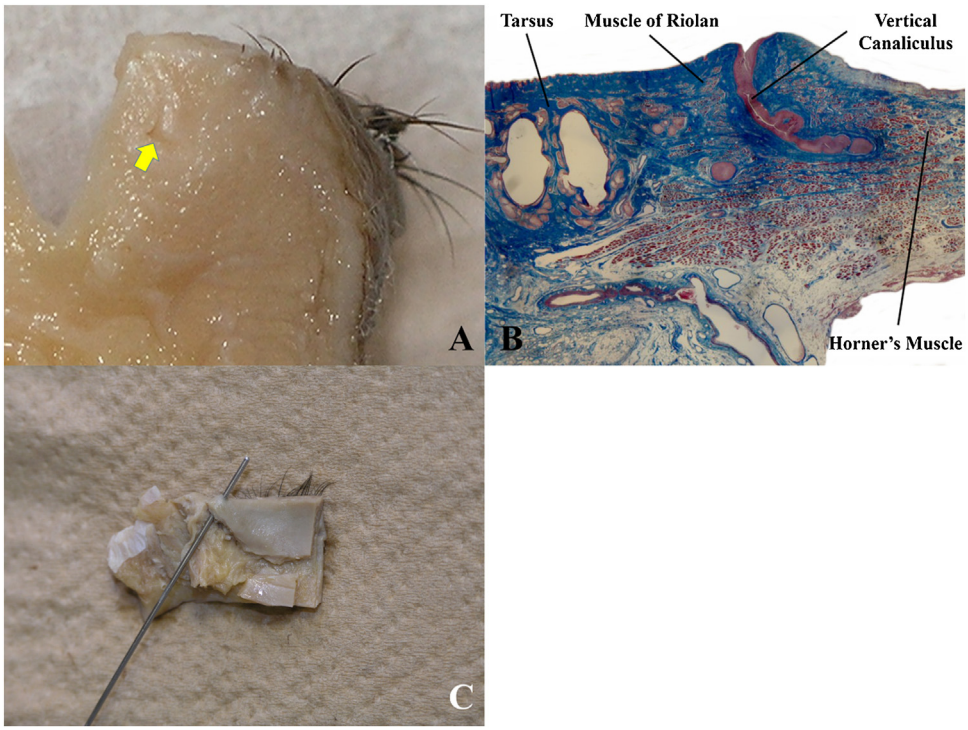

Fig. 2. The vertical canaliculus.
A. A cross-section of the lower eyelid incised at 5° of lateral inclination to the sagittal plane. The whole length of the vertical portion and the ampulla are presented in this plane.
B. The vertical canaliculus, as well as the lower punctum is surrounded by a hard and fibrous tissue, which includes the muscle of Riolan (Masson's trichome stain).
C. The upper vertical canaliculus runs into a fibrous tissue that is indistinguishable from the tarsus.

Since the whole length of the vertical lacrimal canaliculus, as well as the lacrimal punctum, are covered with a hard and fibrous tissue, they are considered to be tarsal components (Fig. 2B and C) (Takahashi et al., 2011b; Kakizaki et al., 2012b). The punctum and vertical canaliculus are, therefore, regarded as "intra-tarsal structures". This tissue, containing skeletal muscle fibers, is referred to as the muscle of Riolan (Fig. 2B) (Kakizaki et al., 2012b). This fibrous tissue acts like a "shape-memory" system and is usually the culprit for recurrence after punctal occlusion surgery (Takahashi et al., 2011b; Kakizaki et al., 2012b).

3.3. Horizontal canaliculus

At the distal end of the vertical canaliculus, the canaliculus turns medially and directs towards the lacrimal sac (Yoshihashi and Ishio, 2008). The course of the upper canaliculus is relatively straight, but the lower canaliculus curves 1 mm before joining the upper canaliculus and this curved point becomes narrow (Kurihashi et al., 1991). Thus, probing via the upper canaliculus is easier compared to the lower canaliculus.

The temporal 4/5 of the horizontal canaliculus is surrounded by the Horner's muscle and consequently, this is sometimes referred to as the lacrimal part of the orbicularis oculi muscle (Fig. 3A) (Shinohara et al., 2001a; Kakizaki et al., 2005, 2010a). In the nasal 1/5 of the canaliculus, the Horner's muscle separates from the horizontal canaliculus and diverts posteriorly while the canaliculus directs anteronasally (Fig. 3A) (Shinohara et al., 2001a; Kakizaki et al., 2005, 2010a). This arrangement largely contributes to how the lacrimal pump system functions (Kakizaki et al., 2005). On the other hand, in cases of proptosis, the canaliculus is observed to direct posteronasally (Kakizaki et al., 2010a). The epithelium of the horizontal canaliculus is nonkeratinized stratified squamous epithelium with some areas with goblet cells (Kakizaki et al., 2007, 2010a).

The canalicular wall, as well as Horner's muscle fascia, is composed of elastic fibers, allowing enlargement or shrinkage of the canalicular lumen (Kakizaki et al., 2014). In the temporal 4/5 of the horizontal canaliculus, the canalicular wall and Horner's muscle fascia contain many elastic fibers because this portion needs to endure mechanical stress from the Horner's muscle (Fig. 3B) (Kakizaki et al., 2014). On the contrary, there are fewer elastic fibers in the nasal 1/5 of the horizontal canaliculus, resulting in less contractility in this portion (Kakizaki et al., 2014).

The length of the horizontal canaliculus measures 8–10 mm (Shigeta et al., 2009). The lower horizontal canaliculus tends to be longer than the upper (Kurihashi et al., 1991). The diameter of the canaliculus is around 0.3–0.6 mm (Kakizaki et al., 2010a) but can expand to over 1.0 mm due to its elasticity (Kakizaki et al., 2015b; Kakizaki, 2016).

3.4. Common canaliculus

In general, in 95% of cases, the superior and inferior canaliculi merge to form the common canaliculus. This reaches the common internal ostium and pours into the sac (Kakizaki, 2016). However, in a previous study on the Japanese population, 6 out of 6 cadavers were noted to have the merging of the upper and lower canaliculus (Kurihashi et al., 1991). Another study on the common canaliculus in a Japanese cadaver revealed that the common canaliculus continued into the lacrimal sac in an almost perpendicular manner (Fig. 3A) (Kakizaki et al., 2007). The length of the common canaliculus ranged from 2.5 to 3.0 mm (Kurihashi et al., 1991; Kominami et al., 2000). A considerable portion of the common canaliculus (mean length, 1.345 mm) passes through the lacrimal sac wall (intra-sac portion) (Fig. 4A) (Kakizaki et al., 2010a, 2013b), and the

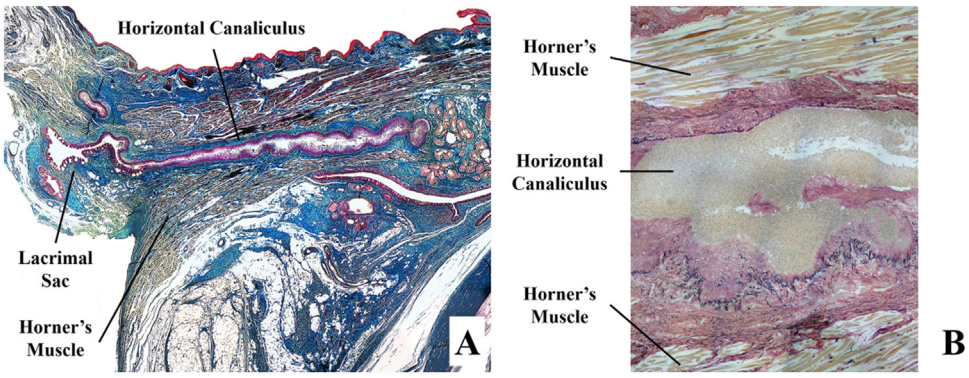

Fig. 3. The horizontal and common canaliculi.
A. The temporal 4/5 of the horizontal canaliculus is surrounded by the Horner's muscle, whereas the nasal 1/5 of the horizontal canaliculus separates from the Horner's muscle. The common canaliculus continues into the lacrimal sac in an almost perpendicular manner (Masson's trichome stain).
B. In the temporal 4/5 of the horizontal canaliculus, the canalicular wall and Horner's muscle fascia contain many elastic fibers (Elastic van Gieson stain).

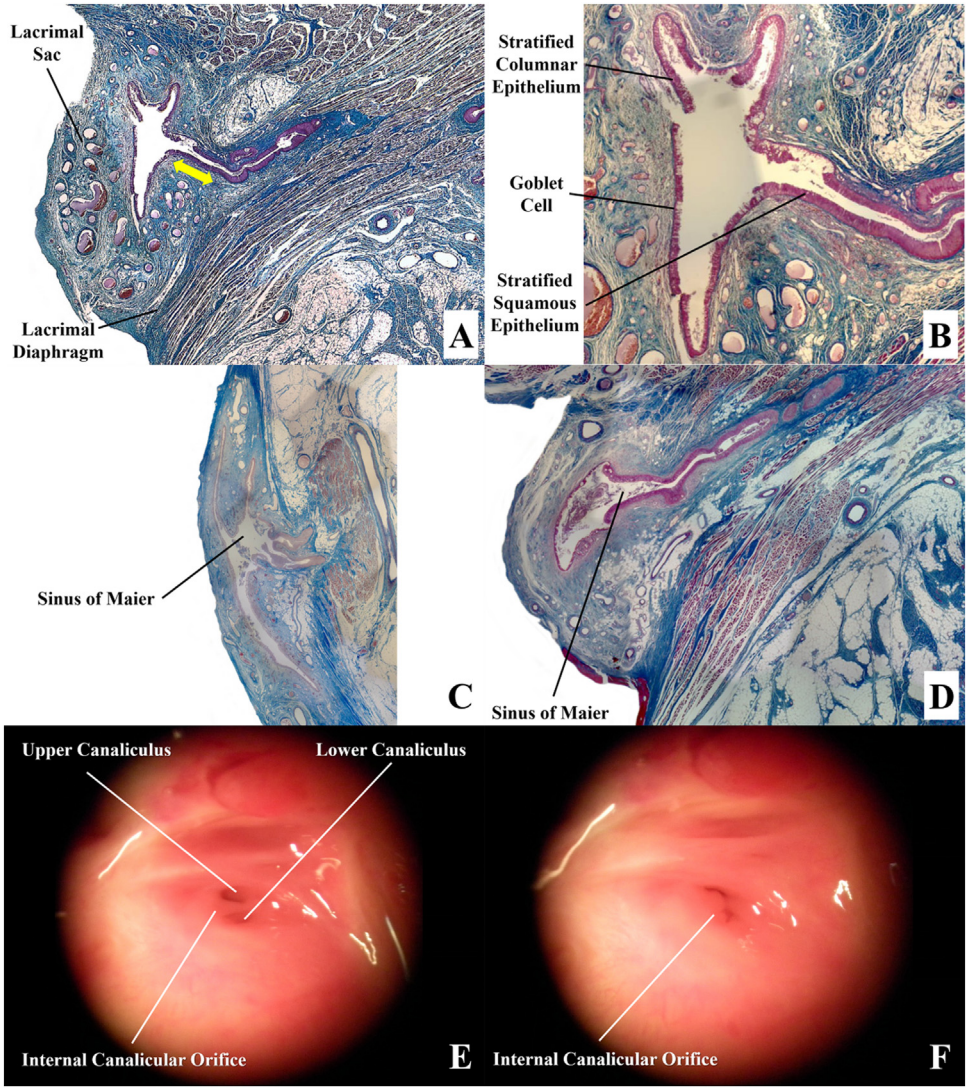

Fig. 4. The common canaliculus and lacrimal sac.
A. The common canaliculus passes through the lacrimal sac wall (the intra-sac portion; arrow). The extra-sac portion is also covered by solid fibrous tissue continuing the lacrimal diaphragm (Masson's trichome stain).
B. The common canaliculus and sac are covered by stratified squamous epithelium and stratified columnar epithelium with goblet cells, respectively (Masson's trichome stain).
C. A lacrimal sac diverticulum type of sinus of Maier (Masson's trichome stain).
D. A terminal dilatation of the common lacrimal canaliculus type of sinus of Maier (Masson's trichome stain).
E and F. A view of the internal canalicular orifice after endoscopic dacryocystorhinostomy using a 4 mm diameter rigid nasal endoscope with a 70° tip. **E.** During eyelid closure. The internal canalicular orifice opens and is pulled deeply in the lateral direction. **F.** During eyelid opening. The internal canalicular orifice closes.

extra-sac portion is also covered by solid fibrous tissue continuing the lacrimal diaphragm (Fig. 4A) (Kakizaki et al., 2010a). The lumen is 0.1 mm or less in diameter but can expand with support from elastic fibers (Kominami et al., 2000; Yoshihashi and Ishio, 2008; Kakizaki et al., 2014).

Although previous studies in the non-Japanese population (Ryan and Font, 1973; McCormick and Linberg, 1988; Olver, 2002) report that the epithelium transitions from squamous cell epithelium to columnar epithelium at the site where the distal common canaliculus opens into the sac, previous studies on Japanese cadavers (Kominami et al., 2000; Kakizaki et al., 2007) show that this does not always occur around the common internal ostium (Fig. 4B). In fact, there were superficial goblet cells, mucous secretory glands, and intraluminal debris in the distal part of the canaliculus, as well as the common canaliculus, where the lining consisted of columnar epithelium (Kakizaki et al., 2007; Kominami et al., 2000).

Around the common internal ostium, the sinus of Maier is occasionally found (Kakizaki et al., 2015a). However, the historical use of this term has been quite confusing. The sinus of Maier has been referred to as the following (Yazici and Yazici, 2000):

a a The common lacrimal canaliculus itself (Malik et al., 1969; Francisco et al., 2007),
b A terminal dilatation of the common lacrimal canaliculus; and,
c A lacrimal sac diverticulum into which the upper and lower canaliculi open separately (Jones et al., 1976; Yazici and Yazici, 2000).

Our study on Japanese cadavers, however, revealed only two types of sinus of Maier (Kakizaki et al., 2015a). First was the lacrimal sac diverticulum, which receives separate canalicular openings (Fig. 4C). The mucosa between both openings (0.282 mm in length) comprised of stratified squamous epithelia, which is characteristic of lacrimal canaliculi (Kakizaki et al., 2015a). The diverticulum was lined by a stratified columnar epithelium, and the diameter of the diverticulum emptying into the sac was 1.29 mm (Kakizaki et al., 2015a). The second type of sinus of Maier that we found was the terminal dilatation of the common lacrimal canaliculus, which had a diameter of 0.51 mm (Fig. 4D) (Kakizaki et al., 2015a). The dilated part was covered by stratified squamous epithelium (Kakizaki et al., 2015a).

The sinus of Maier becomes more noticeable during eyelid closure (Fig. 4E). When the internal canalicular orifice is closed, this folds or membranes are actually redundant and act as spare (Fig. 4F), allowing expansion of the diverticulum when necessary (Kakizaki et al., 2013a). As the lacrimal sac is a cavernous structure that may not withstand dynamic movements during repetitive blinking, the sinus of Maier acts as buffering structure.

The valve of Rosenmü¨ller is a protuberance or fold that can be seen at the junction between the common canaliculus and the sac in about 1/3 of the cases (Kurihashi et al., 1991). This so called "valve" is in fact, only a mucosal fold (Kakizaki et al., 2005). In truth, the valve-like mechanism comes from the movement of the common canaliculus during blinking. The internal canalicular orifice opens due to temporal movement of the Horner's muscle during eye closure (Kakizaki et al., 2005). On the other hand, the internal canalicular orifice closes due to nasal movement of the Horner's muscle during eye opening (Kakizaki et al., 2005). In addition, since the lacrimal sac wall has cavernous tissue (Paulsen et al., 2000; Mito et al., 2014), the lacrimal sac mucosa changes its thickness in response to the administration of sympathetic and parasympathetic agents (Narioka and Ohashi, 2006). The configuration of the lumen of the intra-sac portion may, therefore, change concurrently, acting as the functional valve mechanism at the common internal ostium (Kakizaki et al., 2010a, 2013b).

3.5. Lacrimal sac and its fossa

3.5.1. Lacrimal sac fossa

The lacrimal sac fossa is a conically-shaped concavity in the anteromedial orbital wall that contains the lacrimal sac (Fig. 5A) (Kakizaki et al., 2012a.). The fossa comprises the frontal process of the maxillary bone and the lacrimal bone. There are anterior and posterior ridges, called the anterior and posterior lacrimal crests, respectively, and the lacrimo-maxillary suture is located between the crests (Fig. 5A). The bone posterior to the suture is thinner and is easily punched out during dacryocystorhinostomy (DCR). The anteroposterior location of the lacrimo-maxillary suture is subject to anatomical variability (Sham et al., 2012). Our computed tomography (CT)-based study demonstrated that the proportion of lacrimal sac fossa that is comprised by the lacrimal bone was 38.2–42.1% (unpublished data). This indicates that the lacrimo-maxillary suture runs posterior to the center of the lacrimal sac fossa in most cases. The sutura notha is not a true suture but a vessel groove formed by a branch of the inferior orbital artery (Whitnall, 1932). This runs nasal and parallel to the anterior lacrimal crest. As the bone nasal to the groove is also thin, surgeons can easily start creating a bony window here during external DCR (Kakizaki et al., 2008a).

The lacrimal sac fossa inclines in the infero-postero-lateral direction. Narioka et al. (2007) studied the inclination of the lacrimal sac (without dissection of the sac from the fossa) in cadavers and reported the mean posterior (against the coronal plane) and lateral angles (against the sagittal plane) of 27.2° and 24.7° respectively, with a sex-related difference in only the lateral angle, and the dimension of the nose was correlated with the lateral angle. Their other study demonstrated that the inclination between the lacrimal sac and supero-medial orbital rim showed two types: anterior (more anteriorly inclined lacrimal sac, 46%) and posterior types (more posteriorly inclined lacrimal sac, 54%) (Narioka et al., 2008). The mean angles created by the lacrimal sac and supero-medial orbital rim were 6.5° in the anterior type and −7.6° in the posterior type, respectively (Narioka et al., 2008). Our previous studies in Japanese cadavers (with dissection of the sac from the fossa) showed the mean posterior (against the coronal plane) and lateral angles (against the sagittal plane) of 9.5° and 11.9°, respectively, with a sex-related difference in only the lateral angle (Fig. 5B–E) (Park et al., 2012; Takahashi et al., 2013a, b).

3.5.2. Lacrimal sac

Although the lacrimal sac and nasolacrimal duct are a continuous structure without a defined histological boundary (Fig. 6A), the part located in the lacrimal fossa is anatomically regarded as the lacrimal sac and the part inferior to the nasolacrimal canal entrance is the nasolacrimal duct. The lacrimal sac does not have a simple cylindrical shape, but is actually conical (Kakizaki et al., 2012a). The lateral aspect of the sac is covered by the lacrimal fascia while its posterior aspect is covered by common fascia with the Horner's muscle and sac (Shinohara et al., 2001b; Kakizaki et al., 2010a, 2012a,b; Shinohara et al., 2001b). These are components of the "lacrimal diaphragm" (Fig. 4A) (Ciftci et al., 2010).

The dimensions of the lacrimal sac are as follows: 9.8–11.0 mm in height, 7.5 mm in the anteroposterior diameter, and 3.0–4.9 mm in the horizontal diameter (Kurihashi et al., 1991; Yoshihashi and Ishio, 2008; Miyakubo, 2013). A part of the anterior surface is covered by the medial canthal tendon and the superior end above the medial canthal tendon is defined as the fundus of the lacrimal sac (Fig. 6B) (Russell et al., 1985). The mean height of the fundus in the Japanese population is 4.21 mm (Takahashi et al., 2014a). The horizontal diameter of the lacrimal sac lumen is 1–2 mm (Miyakubo, 2013), although this can be altered by intra-sac pressure changes (Takahashi et al., 2014c). The lacrimal sac is lined with stratified

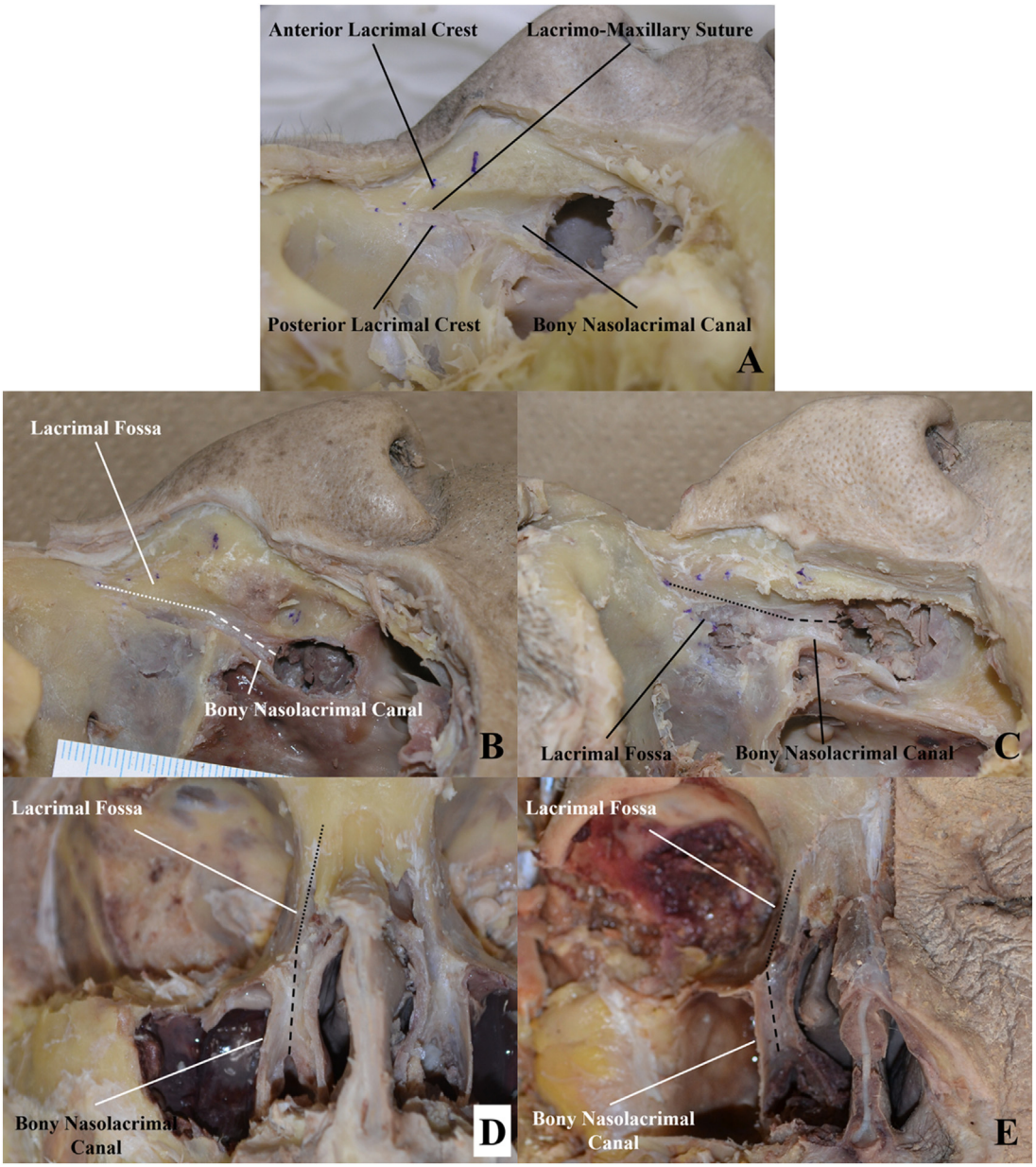

Fig. 5. The lacrimal fossa and bony nasolacrimal canal.
A. The lacrimal sac fossa is a conically-shaped concavity. The lacrimal fossa is located between the anterior and posterior lacrimal crests. The lacrimo-maxillary suture also runs between the crests.
B and C. The anteroposterior inclination of the lacrimal fossa and bony nasolacrimal canal. **B.** The posterior type. The lacrimal sac directs posteriorly (dotted line) and the bony nasolacrimal canal runs more posteriorly (broken line). **C.** The anterior type. The lacrimal sac inclines posteriorly (dotted line) and the bony nasolacrimal canal curves anteriorly (broken line) against the long axis of the lacrimal sac.
D and E. The horizontal inclination of the lacrimal fossa and bony nasolacrimal canal. **D.** The outward type. The lacrimal sac directs laterally (dotted line) and the bony nasolacrimal canal runs more laterally (broken line). **E.** The inward type. The lacrimal sac inclines laterally (dotted line) and the bony nasolacrimal canal curves medially (broken line) against the long axis of the lacrimal sac.

columnar epithelium with goblet cells, cilia, and serous glands (Yoshihashi and Ishio, 2008). Microvilli are arranged on each cell surface at regular intervals (Harada et al., 1983). The diameter and length are 0.05 μm and 0.25 μm, respectively (Harada et al., 1983). Some of the epithelial cells have a bundle of 20–30 microvilli with a diameter of 0.15 μm and a length of 0.25 μm (Harada et al., 1983). A septum is rarely observed in the lacrimal sac lumen (Fig. 6C) (Takahashi et al., 2012; Siapno et al., 2018). This can cause obstruction of the lacrimal drainage system.

The sac wall consists of a cavernous structure (Fig. 6D) (Paulsen et al.,2000; Mito et al., 2014). Regulation of blood flow causes thickening and thinning of the lacrimal mucosa via congestion in response to parasympathetic stimulation and decongestion in response to sympathetic stimulation to the cavernous body (Narioka and Ohashi, 2006; Kakizaki et al., 2013b). However, the cavernous structure in the lacrimal sac is apparently thin and less developed in comparison to the nasolacrimal duct (Fig. 6D) (Mito et al., 2014).

It is necessary for the lacrimal apparatus to have innate elasticity in order to perform its pump function of lacrimal drainage. Many elastic fibers in the lacrimal sac are distributed in the Lamina propria, with great density observed in the upper and middle lacrimal sac levels (Fig. 6E) (Kitaguchi et al., 2018).

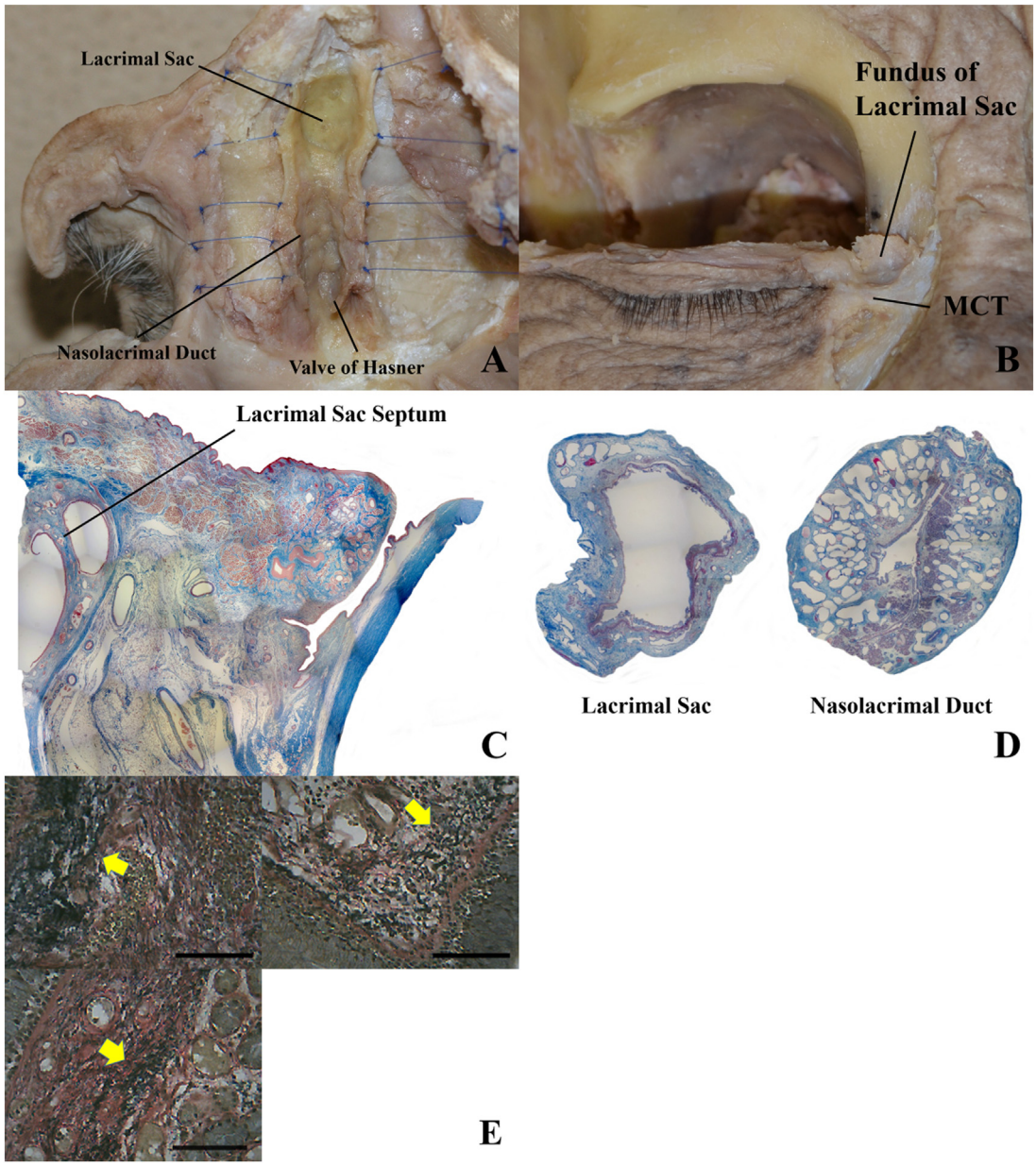

Fig. 6. The lacrimal sac and nasolacrimal duct.
A. The lacrimal sac and nasolacrimal duct are a continuous structure. The part where the nasolacrimal duct continues several millimeters beneath the nasal mucosa is called the valve of Hasner.
B. The medial canthal tendon (MCT) covers a part of the anterior surface of the lacrimal sac. The fundus of the lacrimal sac is the part superior to the MCT.
C. A lacrimal sac septum (Masson's trichome stain).
D. The cavernous structure that is seen in the lacrimal sac and nasolacrimal duct. The cavernous structure in the lacrimal sac is thin and less developed in comparison to that of the nasolacrimal duct (Masson's trichome stain).
E. Elastic fibers in the lacrimal sac and nasolacrimal duct. The elastic fibers are more distributed in the lacrimal sac (left-upper) and intrameatal portion of the nasolacrimal duct (left-lower) in comparison with the intraosseous portion (right-upper) (arrows).

The subepithelial layer in the lacrimal passage contains the lacrimal drainage-associated lymphoid tissue (LDALT), which comprises the main immune mechanism of the lacrimal system (Knop and Knop, 2001; Ali et al., 2013). The LDALT forms a functional unit with the lacrimal gland, conjunctiva, and nasal mucosa to maintain ocular surface integrity through lymphocyte recirculation (Knop and Knop, 2001; Ali et al., 2013). Although autoimmune diseases occasionally occur in the lacrimal sac, inflammatory changes can be observed in the subepithelial layer (Takahashi et al., 2017, 2018; Ishikawa et al., 2019).

3.6. Nasolacrimal duct and canal

3.6.1. Nasolacrimal canal

The nasolacrimal canal is comprised of the lacrimal bone superonasally, the inferior turbinate bone inferonasally, and the maxillary bone temporally (Burkat and Lucarelli, 2006; Miyazaki and Sonoda, 2015). The canal entrance is medial to the junction between the lacrimal tubercle of the maxillary bone and the lacrimal hamulus of the lacrimal bone (Isloor, 2014; Miyazaki and Sonoda, 2015). The length of the bony canal is around 12 mm (Kakizaki, 2016).

There are several studies of the longitudinal axis of the nasolacrimal canal in Japanese. As for the anteroposterior inclination, Shigeta et al. (2007) reported the mean angle between the nasolacrimal canal and nasal floor measured on CT images was 78.3° and the angle was larger in males and elderly patients. Narioka et al. (2007) studied the inclination of the nasolacrimal duct (without dissection of the duct from the canal) in cadavers and reported that the mean posterior inclination of the nasolacrimal canal was 22.5°. There were two types of the anteroposterior course of the nasolacrimal duct: anterior (the course of the duct inclines more anteriorly than the sac, 80.4%) and posterior types (the course of the duct inclines more posteriorly than the sac, 19.6%) (Narioka et al., 2007). The mean angle between the lacrimal sac and nasolacrimal duct was 8.9° in the anterior type and −12.3° in the posterior type and this was correlated with the nasal depth (Narioka et al., 2007). They later examined the angle between the superomedial orbital rim and nasolacrimal duct and reported the angle of 7.9° in the anterior type (72%) and −7.5°in the posterior type (28%) (Narioka et al., 2008). However, our previous study in cadavers (with dissection of the duct from the canal) demonstrated a contrasting result, showing that the mean posterior inclination of the nasolacrimal canal and the mean angle between the lacrimal fossa and nasolacrimal canal were 19.8° and 10.3°, respectively, with only 2.4% of cadavers having the anterior type (Fig. 5B and C) (Park et al., 2012). There was no sex-related difference in the inclination of the nasolacrimal duct/canal (Narioka et al., 2007; Park et al., 2012).

As for the horizontal inclination, Narioka et al. (2007) also showed two types of the horizontal course of the nasolacrimal duct: outward (the course of the duct inclines laterally based on the sagittal line, 37.0%) and inward types (the course of the duct inclines medially based on the sagittal line, 63.0%), although all of the nasolacrimal duct runs more medially based on the long axis of the sac. The mean horizontal angle between the duct and sagittal line in the outward and inward types, and that between the sac and duct were 7.6°, 10.2°, and 28.3°, respectively (Narioka et al., 2007). The horizontal angle between the sac and duct was significantly influenced by the dimension of the nose (Narioka et al., 2007). Our previous study showed that the mean horizontal angle between the canal and sagittal line and that between the fossa and canal were 0.1° and 11.8°, respectively, and the ratio of cadavers with the outward or inward type was 1:1 (Fig. 5D and E) (Takahashi et al., 2013a).

The shape of the bony nasolacrimal canal entrance is an ellipse (Fig. 7A). The diameter of the bony nasolacrimal canal entrance in the Japanese was examined on CT images and the mean anteroposterior and transverse diameters of 5.6 mm and 5.0 mm, respectively (Shigeta et al., 2007). These were longer in males and elderly patients (Shigeta et al., 2007). Our previous study examined on CT images showed that the anteroposterior and transverse diameters ranged 6.34–6.48 mm and 5.32–5.43 mm, respectively, and there was no difference in the diameters between patients with or without nasolacrimal duct obstruction (NLDO) (Takahashi et al., 2014b). Another cadaveric study of ours demonstrated the mean anteroposterior and transverse diameters of 6.9 mm and 5.7 mm, respectively, and the transverse diameter was longer in males (Takahashi et al., 2011a).

The diameter of the nasolacrimal canal varies throughout its whole length, with some areas that are narrower while some areas are larger (Takahashi et al., 2013b). The anteroposterior and transverse diameters of the entrance was noted to be shortest in 3/4 and 2/3 of cases, respectively (Fig. 7B). However, others have reported that the narrowest area is usually 3.5 mm to 5.5 mm from the superior opening (Fig. 7C) (Takahashi et al., 2013b). Another study of ours reported that the shape of the nasolacrimal canal divided into 2 types: funnel (the narrowest point at the entrance) (Fig. 7B) and hourglass types (the narrowest point below the entrance) (Fig. 7C), and the funnel type was more frequently observed in patients with primary acquired NLDO (Takahashi et al., 2014b). These narrowed areas are thought to be the underlying reason as to how primary acquired NLDO develops (Takahashi et al., 2013b).

3.6.2. Nasolacrimal duct

The nasolacrimal duct is divided into 2 parts: the intraosseous and intrameatal parts (Fig. 6A) (Miyakubo, 2013). The intraosseous part passes through the bony nasolacrimal canal and the intrameatal part runs in the inferior meatus. The valve of Krause is occasionally seen as mucosal folds of eminences in the nasolacrimal duct lumen (Kurihashi et al., 1991; Kakizaki, 2016). The valve of Hasner refers to the part where the nasolacrimal duct continues several millimeters beneath the nasal mucosa, after it leaves its osseous channel (Fig. 6A) (Shigeta et al., 2009; Kakizaki, 2016). Furthermore, this valve is essential in order to prevent air or fluid within the nose from going up into the nasolacrimal duct (Kakizaki, 2016). The shape of nasolacrimal duct opening into the inferior meatus is classified into 4 types: wide-open (12%), valve-like (8%), sleeve-like (14%), and adhesive type (66%) (Onogi, 2012).

The length of the nasolacrimal duct is 15–18 mm (Ashikaga, 1925; Kurihashi et al., 1991; Yoshihashi and Ishio, 2008), and the duct is 5–7 mm longer than the bony canal (Shigeta et al., 2009). The intrameatal part sometimes inclines anteriorly, which can cause a creation of false passage during probing (Miyakubo, 2013).

The nasolacrimal duct is lined with stratified columnar epithelium with goblet cells, cilia, and serous glands, similar to the lacrimal sac (Yoshihashi and Ishio, 2008). Goblet cells are distributed more inferiorly in the nasolacrimal duct (Mito et al., 2014). The nasolacrimal duct, having microvilli on the epithelial surface (Kurihashi, 1996), has more developed venous plexus and narrower cavity compared to the lacrimal sac (Fig. 6D) (Mito et al., 2014), enabling reabsorption of lacrimal fluid (Kurihashi, 1996; Mito et al., 2014).

The lower nasolacrimal duct area (intrameatal part) contains a dense amount of elastic fibers, similar to the lacrimal sac (Fig. 6E) (Kitaguchi et al., 2018). This prevents counterflow of tears and air (Kitaguchi et al., 2018). On the other hand, the intraosseous part has less elastic fibers since it is free from mechanical stress (Fig. 6E) (Kitaguchi et al., 2018).

4. Conclusion

To our knowledge, this is the first comprehensive review on the lacrimal drainage anatomy in the Japanese population. We believe that understanding the lacrimal drainage anatomy in the Japanese population is essential to provide insight as to how it is important to consider patients as individuals, with unique and specific anatomies. With this, application of the necessary treatment strategies that is patient-specific, can uphold the clinician's practice and provide the best possible patient care.

Informed consent

The authors obtained written informed consent from the person shown Fig. 1A.

All cadavers that were included in this study have given their written consent prior to their deaths, allowing their bodies to be donated to the university for the advancement of clinical science. The format of the approval was consistent with Japanese law involving "Act on Body Donation for Medical and Dental Education." All cadavers were donated and registered with the cadaveric service of Aichi Medical University. The methods used for securing human tissues were humane and complied with the tenets of the Declaration of Helsinki.

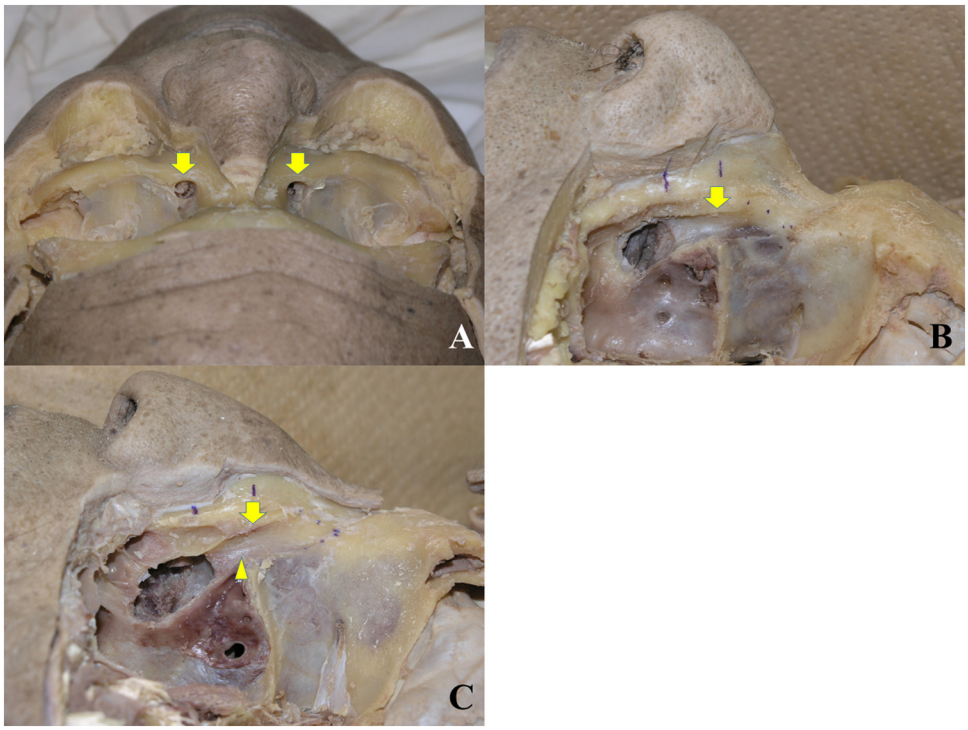

Fig. 7. The bony nasolacrimal canal entrance and the narrowest part of the bony nasolacrimal canal.
A. The entrance is ellipse-shaped.
B. The funnel type. The narrowest point of the nasolacrimal canal is at the entrance (arrow).
C. The hourglass type. The narrowest point (arrowhead) is below the entrance (arrow).

Originality and plagiarism

The authors ensure that they have written entirely original works, and if the authors have used the work and/or words of others, that this has been appropriately cited or quoted.

Multiple, redundant or concurrent publication

This article has not been submitted for publication nor has it been published in whole elsewhere.

Contributors

No one contributed to the work who did not meet our authorship criteria.

CRediT authorship contribution statement

Ma. Regina Paula Valencia: Writing - original draft. **Yasuhiro Takahashi:** Conceptualization, Investigation, Data curation, Writing - review & editing, Visualization, Project administration. **Munekazu Naito:** Investigation, Resources, Data curation, Writing - review & editing. **Takashi Nakano:** Investigation, Resources, Data curation, Writing - review & editing. **Hiroshi Ikeda:** Investigation, Resources, Data curation, Writing - review & editing. **Hirohiko Kakizaki:** Investigation, Data curation, Supervision, Writing - review & editing.

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