O R I G I N A L   A R T I C L E

Anatomical study on branching pattern and variations of orbital segment of the oculomotor nerve

R. Haładaj, Ł. Olewnik, M. Polguj

Department of Normal and Clinical Anatomy, Interfaculty Chair of Anatomy and Histology, Medical University of Lodz, Poland

Background: This study aims to revisit the anatomy of orbital segment of the third cranial nerve (CN III). The study also involved morphometric measurements of CN III muscular branches. Detailed description of observed anatomical variations and their incidence was also included. The study supplements earlier findings with detailed observations of the neuromuscular relations.

Materials and methods: The study was conducted on 52 orbits taken from 26 cadaveric heads (10 males and 16 females; Central European population).

Results: Anatomical variations of the orbital segment of the CN III observed on the examined material involved both the superior and inferior branch of this nerve. The muscular branch innervating the levator palpebrae superioris muscle occasionally pierces the superior rectus muscle. The nerve to the inferior oblique muscle may pierce and innervate the inferior rectus muscle. In rare instances, duplication of the parasympathetic root of the ciliary ganglion may also occur. Among the muscular branches, the smallest diameter reached the branch to the levator palpebrae superioris muscle. Among the three muscular branches derived from the inferior branch of the CN III, the nerve to the inferior oblique was the longest one. Its length varied from 28.9 mm to 37.4 mm. The shortest was the muscular branch to the inferior rectus muscle. Its length varied from 0 mm (when muscular sub-branches arose directly from the nerve to the inferior oblique muscle) to 7.58 mm.

Conclusions: This study presented the characteristic of orbital segment of the CN III, including anatomical variations and morphometric measurements relevant to intraorbital procedures. (Folia Morphol 2021; 80, 1: 63–69)

Key words: anatomic variations, oculomotor nerve, orbit

INTRODUCTION

The oculomotor nerve is the third cranial nerve (CN III). It runs in the superior orbital fissure to enter the orbit. The CN III provides motor innervation to the levator palpebrae superioris and almost all extraocular muscles except the superior oblique and lateral rectus muscle. It also carries preganglionic parasympathetic fibres to the sphincter pupillae and the ciliary muscles of the eye [1, 10, 22, 24, 27]. Those fibres enter the ciliary ganglion through the motor (parasympathetic) root of the ganglion. The postganglionic fibres leave the ganglion and reach the eyeball through via the short ciliary nerves [11, 17, 25].

The CN III enters the orbit through the superior orbital fissure and from this point the orbital segment of the nerve begins [18, 21]. Just after reaching the

Address for correspondence: Dr. R. Haładaj, Department of Normal and Clinical Anatomy, Chair of Anatomy and Histology, Medical University of Lodz, ul. Żeligowskiego 7/9, 90–752 Łódź, Poland, e-mail: robert.haladaj@umed.lodz.pl

orbit, the CN III is divided into two main subdivisions, namely the superior and inferior branch. The superior branch rans on the lateral and then over the optic nerve and ophthalmic artery and innervates the superior rectus and levator palpebrae superioris muscle [1, 10, 22, 24]. The inferior branch, in turn, is thicker and gives off three muscular branches: the branch to the medial rectus muscle which runs under the optic nerve; the branch to the inferior rectus which is the shortest; and the branch to the inferior oblique muscle (also called the nerve to the inferior oblique muscle) which courses along the lateral side of the inferior rectus muscle. In most of cases the parasympathetic root of the oculomotor nerve branches off the muscular branch to the inferior oblique muscle [11, 17, 25].

When CN III is paralysed, drooping of the upper eyelid (ptosis) may occur. In those cases, the eyeball is directed laterally and downwards (divergent strabismus) [24]. If parasympathetic fibres are affected, the pupil dilates and the accommodation of the eye is also affected [5, 24]. Cases of selective damage of the CN III muscular branches were also described [4, 7].

Occasionally, some deviations from the typical anatomy of the CN III may be observed. Anatomical variations of the CN III may have significant clinical importance both during surgical procedures carried out inside the orbit, and when diagnosing clinical symptoms of damage to CN III or its branches [4, 7, 15, 23, 26]. Thus, the goal of this work was to describe the anatomy of orbital segment of the CN III. The study also involved morphometric measurements of CN III muscular branches. Detailed description of observed anatomical variations and their incidence was also included. The study supplements earlier findings with detailed observations of the neuromuscular relations.

MATERIALS AND METHODS

The study was performed on 52 orbits taken from 26 cadaveric heads (10 males and 16 females; Central European population), fixed in 10% formalin solution. Cadavers used for the study did not show any craniofacial deformities, scars or traces of previous surgical interventions within the head. The study was approved by the Bioethics Committee (consent no. RNN/338/17/KE).

Dissection procedure was performed based on previously developed protocols [3, 9]. The superior and lateral walls (and upper part of the medial wall)

of the orbit were removed with a Luer bone rongeur and chisel. Opening of the superior orbital fissure and optic canal was also performed. The periorbita was bluntly separated from the remaining orbital walls, the nerves and vessels were cut at the level of the superior orbital fissure (and the optic canal), and then all orbital content was carefully removed. Subsequent section steps included the removal of the lateral rectus muscle which allowed the exposure of the intraconal space, removal of the fatty tissue and visualisation of the oculomotor nerve with its branches. Ciliary ganglion with its parasympathetic roof was also preserved. At this step anatomical variations involving CN III were recorded.

The measurements were taken with an electronic calliper (Mitutoyo Corporation, Kawasaki-shi, Kanagawa, Japan). Each measurement was taken independently by all authors with accuracy of 0.01 mm and included: the diameter of the CN III, diameters of its superior and inferior branch as well as diameters of all muscular branches. Furthermore, the lengths of all CN III branches were measured (from the origin of a given branch to the place of its division). The length of the superior and inferior branch of the CN III was measured from the level of the superior orbital fissure to the place of subsequent division into muscular branches. The lengths of the muscular branches were measured between their origins and the places of their division into muscular sub-branches, i.e. small divisions that reached the internal, global surface of individual muscles (the lengths of the muscular sub-branches defined in this way were also measured). Basic descriptive statistics (minimal and maximal values, mean, median and standard deviation) were calculated for the collected measurements.

RESULTS

The measurements of the CN III and its branches are given in Tables 1 and 2. Variability in size of certain CN III branches was observed on the examined material. The length of the superior branch of the CN III ranged from 5.88 mm to 12.96 mm. The length of the inferior branch of the CN III ranged from 6.49 mm to 9.98 mm. In all examined cases the inferior branch was thicker (taking into account all cases examined, the mean diameter of the superior branch was 1.17 mm, while the mean diameter of the inferior branch was 1.61 mm). Among the muscular branches, the smallest diameter reached the branch to the levator palpebrae superioris muscle. Its diameter measured

Table 1. Diameters of third cranial nerve (CN III) superior and inferior branch as well as diameters of all muscular branches

Variable	Minimum [mm]	Maximum [mm]	Mean [mm]	Median [mm]	SD [mm]
1	1.96	3.04	2.47	2.34	0.35
2	0.88	1.46	1.17	1.21	0.16
3	0.19	0.37	0.27	0.26	0.06
4	1.27	1.9	1.61	1.68	0.18
5	0.77	1.44	1.04	0.98	0.22
6	0.57	0.96	0.75	0.68	0.15
7	0.51	1.04	0.8	0.83	0.14

1 — diameter of the CN III; 2 — diameter of superior branch of CN III; 3 — diameter of muscular branch to the levator palpebrae superioris; 4 — diameter of inferior branch of CN III; 5 — diameter of muscular branch to the medial rectus muscle; 6 — diameter of muscular branch to the inferior rectus muscle; 7 — diameter of the nerve to the inferior oblique muscle; SD — standard deviation
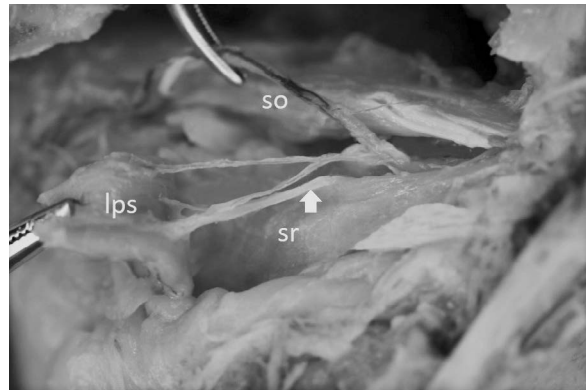
Table 2. Lengths of all branches of the third cranial nerve (CN III)

Variable	Minimum [mm]	Maximum [mm]	Mean [mm]	Median [mm]	SD [mm]
1	5.88	12.96	9.15	8.69	2.44
2	8.39	12.46	10.37	10.48	1.42
3	6.49	9.98	8.33	8.22	1.18
4	4.52	8.86	6.61	6,18	1.62
5	6.9	9.59	8.36	8.36	0.91
6	0	7.58	4.62	5.68	3.24
7	8.79	15.16	11.42	10.99	2.06
8	28.91	37.45	32.72	32.18	2.92

1 — length of superior branch of CN III; 2 — maximal length of the muscular sub-branches reaching the superior rectus muscle; 3 — length of inferior branch of CN III; 4 — length of muscular branch to the medial rectus muscle; 5 — maximal length of the muscular sub-branches reaching the medial rectus muscle; 6 — length of muscular branch to the inferior rectus muscle; 7 — maximal length of the muscular sub-branches reaching the inferior rectus muscle; 8 — length of the nerve to the inferior oblique muscle; SD — standard deviation
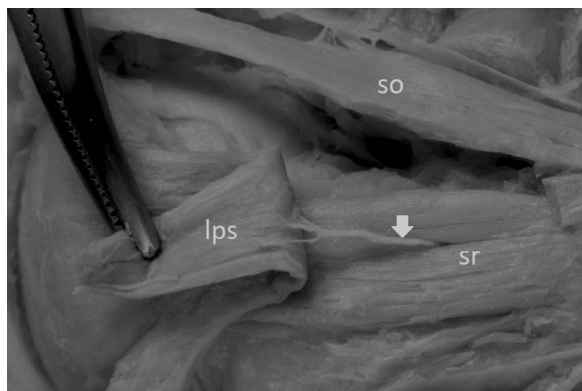

Figure 1. Typical variant in which muscular branch to the levator palpebrae superioris (marked by white arrow) wraps around the medial border of the superior rectus muscle (sr) to reach its target muscle. Superior view to the left orbit; lps — levator palpebrae superioris muscle (cut from its origin and reflected); so — superior oblique muscle.

from 0.19 mm to 0.37 mm. Among the three muscular branches derived from the inferior branch of the CN III, the nerve to the inferior oblique was the longest one. Its length varied from 28.9 mm to 37.4 mm, its diameter ranged from 0.51 mm to 1.04 mm. The shortest was the muscular branch to the inferior rectus muscle. The length of this branch varied from 0 mm (when muscular sub-branches arose directly from the nerve to the inferior oblique muscle) to 7.58 mm. Its diameter ranged from 0.57 mm to 0.96 mm.

All muscular branches derived from CN III underwent subsequent divisions into sub-branches reaching the internal (global) surfaces of each muscle. The number of muscular sub-branches reaching the superior rectus muscle varied on the examined material from 4 to 7 (mean: 5.4, median: 5, SD: 0.8). The number of muscular sub-branches reaching the medial rectus muscle varied from 4 to 7 (mean: 5.7, median: 6, SD: 0.9). The number of muscular sub-branches reaching the inferior rectus muscle varied from 2 to 4 (mean: 3.5, median: 4, SD: 0.8). While the number of muscular sub-branches reaching the inferior oblique muscle varied from 3 to 4 (mean: 3.6, median: 4, SD: 0.5).

Anatomical variations of the orbital segment of the CN III observed on the examined material included both the superior and inferior branch of this nerve. Regarding the superior branch of the CN III, anatomical variability was related to the muscular branch innervating the levator palpebrae superioris muscle. In all cases this branch originated on the inferior surface of the superior rectus muscle as one among the terminal sub-branches of the superior branch of the CN III. In most of cases (47/52; 90.4%) the branch wrapped around the medial border of the superior rectus muscle to reach the levator palpebrae superioris muscle (Fig. 1). However, in the remaining 9.6% of cases (5/52; in 1 female head bilaterally, in 1 female head unilaterally and in 2 male heads unilaterally) this branch pierced the superior rectus muscle and then joined the levator palpebrae superioris (Fig. 2).

Regarding the inferior branch of the CN III, anatomical variations involved the nerve to the inferior oblique muscle, muscular sub-branches to the inferior rectus muscle, as well as parasympathetic root of the ciliary ganglion. In most cases (44/52 orbits; 84.6%) the nerve to the inferior oblique muscle ran along the
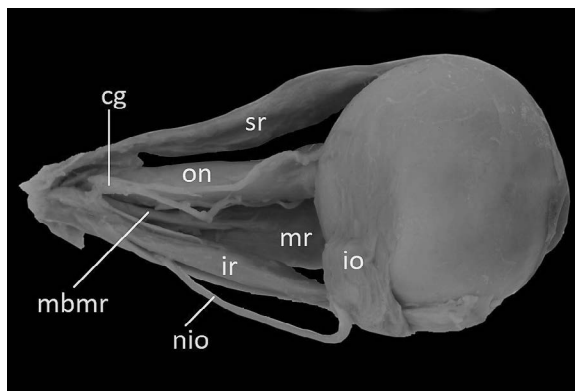
Figure 2. Variant in which muscular branch to the levator palpebrae superioris (marked by white arrow) pierces the superior rectus muscle (sr) to reach its target muscle. Superior view to the left orbit; lps — levator palpebrae superioris muscle (cut from its origin and reflected); so — superior oblique muscle.
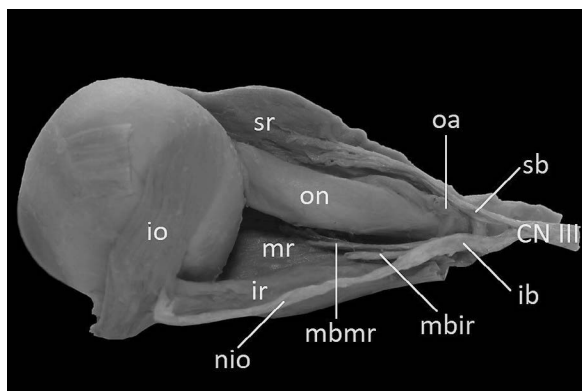

Figure 3. Typical anatomy of the third cranial nerve (CN III) and its branches. Lateral view to the left orbit. The lateral rectus muscle was removed to expose the intraconal space. Ciliary ganglion with its roots and short ciliary nerves was removed. The superior branch (sb) of CN III rans lateral and superior to the optic nerve (on) and ophthalmic artery (oa) and innervates the superior rectus (sr) and levator palpebrae superioris muscle (removed on this specimen). The inferior branch (ib) of CN III is thicker and gives off three muscular branches: muscular branch to the medial rectus muscle (mbmr) which runs under the optic nerve; muscular branch to the inferior rectus muscle (mbir) which is the shortest; and the nerve to the inferior oblique muscle (nio) which runs along the lateral border of the inferior rectus muscle (ir); io — inferior oblique muscle.
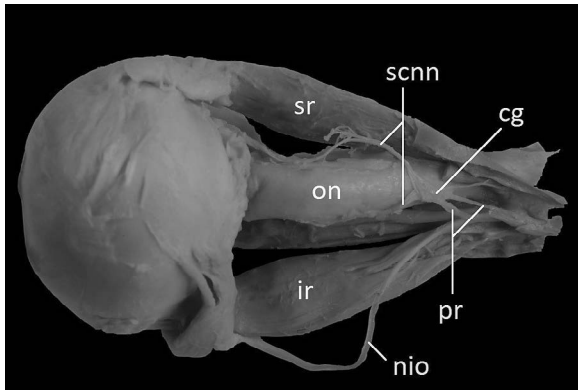

Figure 4. Variant in which the nerve to the inferior oblique muscle (nio) pierces the inferior rectus muscle (ir). Lateral view to the right orbit. In this variant, muscular branches to the inferior rectus muscle (ir) arise from the nerve to the inferior oblique instead of forming a separate muscular branch; cg — ciliary ganglion; io — inferior oblique muscle; mbmr — muscular branch to the medial rectus muscle; mr — medial rectus muscle; on — optic nerve; sr — superior rectus muscle.
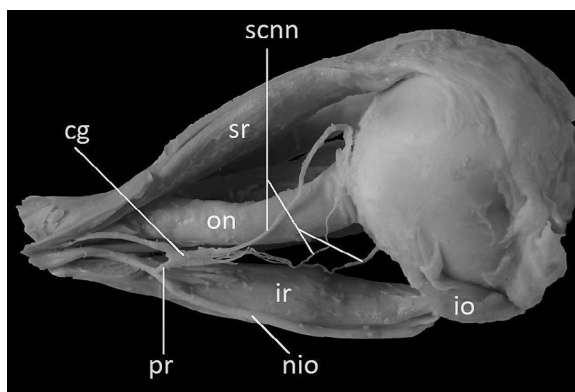
Figure 5. Variant with typical, single parasympathetic root (pr) of the ciliary ganglion. Lateral view to the right orbit; cg — ciliary ganglion; io — inferior oblique muscle; ir — inferior rectus muscle; nio — nerve to the inferior oblique muscle; on — optic nerve; scnn — short ciliary nerves; sr — superior rectus muscle.

inferior wall of the orbit, between the inferior and lateral rectus muscles (Fig. 3). However, in 15.4% of cases (8/52 orbits, bilaterally in 1 male and 1 female head, unilaterally in 1 male and 3 female heads), this nerve pierced the inferior rectus muscle; In all those cases, muscular branches to the inferior rectus muscle arose from the nerve to the inferior oblique rather than forming a separate branch (Fig. 4).

Anatomical variation was also observed regarding parasympathetic root of the ciliary ganglion.

The length of this root measured from 0.98 mm to 7.91 mm (mean: 4.41; median: 4.91 mm, SD: 2.6 mm). The mean diameter of the parasympathetic root was 0.41 mm (min: 0.15 mm, max: 0.59 mm, SD: 0.14). In majority of cases (47/52; 90.4%) the parasympathetic root was single and originated from the nerve to the inferior oblique muscle (Fig. 5). However, in 5 (9.6%) cases the single parasympathetic root took origin directly from the inferior division of the oculomotor nerve. In 5 cases the parasympathetic root of the ciliary ganglion was double (Fig. 6). In 4 out of those cases both roots emerged from the nerve to the inferior oblique muscle, while in one out of those cases the first root took origin from the inferior division of

Figure 6. Variant in which the parasympathetic root (pr) of the ciliary ganglion is duplicated. Lateral view to the left orbit. In this specimen one root is derived from the inferior branch of the third cranial nerve and the second root takes origin from the initial part of the nerve to the inferior oblique muscle (nio); cg — ciliary ganglion; ir — inferior rectus muscle; on — optic nerve; scnn — short ciliary nerves; sr — superior rectus muscle.

CN III and the second root originated from the nerve to the inferior oblique muscle.

DISCUSSION

According to Bergman et al. [3], anatomical variations of the CN III "may involve the occurrence of unusual branches or deviations in the course of its branches". In rare instances a branch from the CN III may replace the abducens nerve or may provide a branch to the superior oblique muscle [3]. However, this was not observed in our material.

The unexpected anatomical variations of CN III branches to the extraocular muscles may have significant meaning during orbital imaging or various surgical and reconstructive procedures performed within the orbit. Black et al. [4] suggest that the nerve to the inferior oblique muscle may be prone to damage due to its long intra-orbital course along the inferior orbital wall; this nerve is located along the lateral edge of the lateral rectus muscle and may be accidentally injured during surgical procedures or inferior orbital wall fractures. Occasionally, the nerve to the inferior oblique muscle or some of its branches may pierce the inferior rectus muscle [3, 4, 12, 20]. In our study an incidence of this variation was estimated at in 15.4% of specimens. In those cases, muscular branches that arise from the nerve to the inferior rectus muscle may cause strong connection between the two structures; Due to traction of the inferior rectus muscle the nerve to the inferior oblique muscle may be paralysed [4]. Since parasympathetic

fibres course most commonly with the nerve to the inferior oblique muscle, damage of this nerve may be accompanied by a tonically dilated pupil [4].

Typically, the muscular branch to the levator palpebrae superioris muscle courses along the medial border of the superior rectus muscle, wraps around this border and reaches its target muscle. The incidences of this typical variant reported by different authors vary between 78.6% and 87.5% [8, 10]. Occasionally, the muscular branch to the levator may pierce the superior rectus muscle and after that enters the inferior surface of the levator palpebrae. The incidence of this variant ranges between 12.5% and 21.4% [8, 10]. The same variation was also described by Bye et al. [6]. Isomura [19], reporting different variations in which two muscular branches to the levator palpebrae superioris united to form a common loop before supplying the muscle. In the presented study a branch to the levator palpebrae superioris muscle was characterised by the smallest diameter. It seems to be additionally fixed in cases where it pierces the superior rectus muscle, which may potentially increase the risk of damage of this branch to injury.

Regarding the parasympathetic root of the ciliary ganglion, variations in number, shape and diameter of this root were reported [11, 14, 17, 25]. Occasionally, duplication or triplication of the parasympathetic root may be observed [3, 11]. In one study the incidence of this variation was estimated at 10% of cases [11]. However, in the study of Tesapirat et al. [25] a single motor root was found in only 62.5% of cases. In the presented study duplication of the parasympathetic root was observed in per cent of specimens. When the parasympathetic root is duplicated one root may arise from the inferior division of the CN III while and another may take origin from the nerve to the inferior oblique muscle, both roots may also originate from those nerve [11]. Both the length of the parasympathetic root of the ciliary ganglion and its origin may also be variable, which was confirmed in the presented study. Knowledge of anatomical relations between the parasympathetic root of the ciliary ganglion and the inferior division of the oculomotor nerve (or the nerve to the inferior oblique muscle) may help with understanding risk to those structures that may occur during specific traumas or surgical procedures. For instance, Bayramlar et al. [2] described the mydriasis associated with the damage of the inferior division of the CN III resulting from complications of sinus surgery. Risk for the ciliary ganglion associated with

orbital floor fractures was stressed by Bodker et al. [5], He et al. [15] and Hornblass [16]. Those authors analysed association between fractures of inferior wall of the orbit and complications such as traumatic mydriasis.

From the practical point of view, the microsurgical anatomy of orbital segment of the CN III may be crucial in planning surgical accesses that allow extraocular muscles function to be preserved. It may also help to better understand the specific symptoms of damage to this nerve. The two main divisions of the CN III (namely superior and inferior branch) innervate most of the extraocular muscles. The superior branch of the CN III travels along the inferior surface of the superior rectus muscle and gives mean 5 (from 3 to 7) muscular sub-branches to this muscle [22, 27]. Those results are consistent with data provided in presented study, in which the mean number of muscular sub-branches reaching the superior rectus muscle was 5.4 (median: 5). As noted earlier in the discussion, the superior branch supplies also the levator palpebrae superioris muscle.

The inferior division of the CN III is typically divided into three muscular branches: a branch to the medial rectus muscle, muscular branch to the inferior rectus muscle and the nerve to the inferior oblique muscle [12]. According to Park et al. [22] and Zhang et al. [27] the range of muscular sub-branches that may reach the internal surface of the inferior rectus muscle is from 3 to 10. However, in the presented study the number of muscular sub-branches reaching the inferior rectus muscle varied from 2 to 4 (mean: 3.5, median: 4). This difference may be due to the fact that only primary divisions of the muscular branches reaching the inferior rectus muscle were included in this work. The last muscular branch of the inferior division of the oculomotor nerve reaches the medial rectus muscle. This branch may be divided into 3 to 8 sub-branches (mean: 5) innervating the medial rectus muscle. In the presented study the mean number of muscular sub-branches reaching the medial rectus muscle was 5.7 (median: 6). However, in one recent study based on Sihler's stain, the number of nervous branches reaching the medial rectus muscle from 4 to 8 (mean: 5.4, median: 5) [13].

CONCLUSIONS

This study presented the characteristic of orbital segment of the CN III, including anatomical variations and morphometric measurements relevant to intraor-

bital procedures. Anatomical variations of the orbital segment of the CN III involved both the superior and inferior branch of this nerve. The muscular branches innervating the levator palpebrae superioris muscle occasionally pierce the superior rectus muscle. The nerve to the inferior oblique muscle may pierce and innervate the inferior rectus muscle. The parasympathetic root of the ciliary ganglion may be duplicated. Knowledge of anatomical variations of the CN III orbital segment is important during surgical procedures conducted within the orbit and during diagnosing clinical symptoms of damage to CN III or its branches.

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