Measurement of Optic Nerve Blood Flow During Dissection of Parasellar Tumors

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Abstract The authors describe direct measurement of optic nerve blood flow and examine application of such monitoring to detect optic nerve ischemia during parasellar tumor surgery. Twenty-six patients requiring surgery for parasellar tumors were evaluated prospectively. Ophthalmologic examination was performed before and after surgery. The optic nerve blood flow was measured using a laser Doppler flowmeter before tumor dissection (initial ONBF) and after tumor removal (final ONBF). The waveform was analyzed by a data acquisition system. In 16 patients, initial ONBF could be measured (22 nerves; 8.9±0.9 ml/100 g/min). Final ONBF could be determined in all 26 patients (42 nerves; 10.8±0.7 ml/100 g/min). In the 22 nerves with initial measurements, final ONBF (11.3±0.6 ml/100 g/min) was significantly increased ($p<0.01$). In 6 patients whose optic canal was unroofed, the optic nerve blood flow did not change immediately; nonetheless, an increase was prominent in the final phase ($p<0.05$). In another 6 patients, a small vessel adjacent to the optic nerve was temporarily occluded. The optic nerve blood flow was reduced demonstrably in 3 and recovered quickly after reperfusion. Intraoperative optic nerve blood flow measurement may be useful as a real-time monitoring for prediction and prevention of intraoperative optic nerve ischemia.

Key words: parasellar tumor, optic nerve blood flow, laser Doppler, optic canal unroofing

Introduction

Parasellar tumors include pituitary adenomas, craniopharyngiomas, and other suprasellar tumors, as well as meningiomas originating from the planum sphenoidale, tuberculum sellae, diaphragma sellae, and anterior clinoid process. Frontobasal, olfactory groove, and medial sphenoid wing meningiomas also enter this group when they extend to the parasellar region [12]. As parasellar tumors commonly grow in close proximity to the optic nerve, a major concern during surgery in this area is damage to the visual system that may result in postoperative blindness. Even in the microsurgical era, risk of postoperative visual impairment remains high in patients whose optic nerve is compressed by the tumor or densely adherent. Many reports have addressed visual outcome after parasellar tumor surgery; occurrence of visual worsening has ranged from 0% to 36.8% [2, 4, 5, 9, 11, 12, 14, 17, 22, 24, 26, 27, 36, 38, 39].

Al-Mefty et al [2]., Fahlbusch and Schott [12] considered ischemia from interruption of the blood supply to the visual system to be a main cause of postoperative visual loss. They proposed that the mechanism of postoperative visual deterioration involved an ischemic insult from injury to small vessels perforating the optic apparatus rather than direct mechanical damage from manipulations ~~near optic structures~~. However, no previous clinical report has quantified intracranial optic nerve blood flow. We set out to make such measurements to detect intraoperative changes of optic nerve blood flow.

Riva et al [34, 35]. reported changes in velocity, volume, and blood flow in the ocular fundus as measured with a laser Doppler camera. Laurikainen et al [23]. and Yavuz et al [43]. used a laser Doppler flowmeter and a small contact probe to measure cochlear nerve blood flow in animals. Several authors have reported clinical usefulness of a laser Doppler flowmeter for detecting changes in nerve root blood flow during lumbar discectomy ~~performed to treat lumbar disc herniation~~ [16, 20]. In the present study we examined use of a laser Doppler flowmeter to directly measure intracranial optic nerve blood flow (ONBF) and analyzed changes detected during resection of parasellar tumors.

Clinical Material and Methods

Patient Population

Between December 2005 and June 2007, 26 consecutive patients harboring parasellar tumors underwent radical surgery at our institutions by the senior author (K. S.). Patients included 16 females and 10 males, ranging in age from 5 to 77 years (mean, 51.8). The most common symptom was visual disturbance (18 patients). Seven patients complained of headache. Three ~~patients~~ had exophthalmos. Clinical examination disclosed cognitive disorder in 2 patients, endocrinological dysfunction in 2, and ataxia in 1. Intervals from initial symptom to surgery ranged from 2 months to 7 years (mean, 12 mo).

Of 26 tumors, 3 were recurrent. Tumors included 3 craniopharyngiomas, 2 pituitary adenomas, 1 suprasellar teratoma, 1 medial sphenoid wing tuberculoma, and 19 meningiomas. Locations of meningiomas were tuberculum sellae in 7, medial sphenoid wing in 4, spheno-orbital in 2, olfactory groove in 2, diaphragma sellae in 1, clinoidal in 1, planum sphenoidale in 1, and petroclival region in 1. For all tumors the diagnosis was established pathologically.

Operative approaches to tumors included pterional (n=15), supraorbital-pterional [3] (n=2), orbitozygomatic (n=2), anterior petrosal (n=1), and bifrontal basal interhemispheric [37] (n=6). During dissection of tumor from optic structures, meticulous care was taken to avoid injury to small perforating arteries, and to preserve the arachnoid plane between the tumor and normal structures.

Ophthalmologic Examination and Evaluation

Visual assessment was performed in all patients by an ophthalmologist before surgery, including best-corrected visual acuity, fundus appearance, intraocular pressure, and visual fields. In 25 of 26 patients, postoperative visual function was assessed 10 to 20 days after surgery. In one pediatric patient, postoperative examination could not be completed because of restlessness; however, she did not note any visual disturbance postoperatively. All patients with

visual impairment maintained regular ophthalmologic follow-up. Patients with normal vision underwent only clinical and radiologic follow-up after the first postoperative assessment.

Patient data were evaluated according to pre- and postoperative ophthalmologic findings. Visual impairment score was determined according to the guidelines of the German Ophthalmological Society [8, 12]. In this study ONBF was determined separately in each eye. Scores for visual acuity and visual field defects were calculated for each eye, providing a monocular visual impairment score (VIS). Any change of the VIS was considered to represent improvement or deterioration of visual function.

ONBF Measurement

ONBF was measured using a laser Doppler flowmeter (TBF-LN1, Unique Medical, Tokyo, Japan) [25, 30]. The contact probe (10 mm in major axis; LP-UCS, Unique Medical, Fig. 1A) was placed directly and centrally upon the superior surface of the optic nerve after the nerve was adequately exposed (Fig. 1B). A data acquisition system (UAS-108S, Unique Medical) was used to analyze the blood flow waveform and to obtain a mean value. The Japanese Pharmaceutical Council approved clinical use of this equipment.

ONBF was measured before tumor dissection from the optic nerve (initial phase) and again after completion of tumor resection (final phase). In 7 nerves of 6 patients with tuberculum sellae meningiomas, the optic canal was unroofed initially to decompress the optic nerve; then ONBF also was measured during unroofing of the canal. In another 6 patients, after completion of intradural procedures, a small artery adjacent to the optic nerve was occluded temporarily with a micro clip (Sugita AVM clip) and ONBF was measured. Before suturing the dura mater, cortical blood flow in the frontal or temporal lobe was measured. The possibility of visual worsening by some of procedures was explained to the patients before obtaining informed consent.

Statistical Analysis

Data are expressed as the mean ± standard error of the mean. ONBF values were compared between groups using the Mann-Whitney U test. Intraoperative change in ONBF was compared between phases of surgery using the Wilcoxon signed-rank and paired-t tests. Correlation between ONBF and visual function was assayed with Spearman's correlation coefficient. *P* values less than 0.05 were considered to indicate significance.

Results

Surgical Results

In 11 cases, including 8 with tumor invasion into the optic foramen, optic canal unroofing was required to decompress the strangulated nerve prior to tumor dissection. Gross total resection was achieved in 19 patients (73%). In 7 patients (2 with large pituitary adenomas, 1 with recurrent sphenoid wing meningioma, 1 with spheno-orbital meningioma, 1 with petroclival meningioma, 1 with craniopharyngioma, and 1 with tuberculoma), small portions of tumor remained because of dense tumor adhesion to vascular and neural structures.

Postoperative visual status (VIS) was examined after follow-up intervals ranging from 14 to 32 months (mean 22.2). Visual function was improved in 16 patients (62%); unchanged in 5 (19%); and worsened in 5(19%).

ONBF Before Tumor Dissection

Initial ONBF was measured in 16 patients (22 optic nerves). In 10 patients whose opticocarotid space was occupied by tumor, ONBF was measured only in the final phase. When ONBF could be measured before tumor dissection, it was 8.9±0.9 ml/100 g/min, representing 41.0% of cortical blood flow (21.7±1.6 ml/100 g/min). No significant correlation was evident between initial ONBF and preoperative VIS **(**Fig. 2A**)**.

ONBF With or Without Tumor Compression

ONBF was evaluated according to tumor compression. Patients were divided into groups with (group A) and without (group B) tumor compression of the optic nerve based upon preoperative magnetic resonance images and intraoperative findings. Two nerves exposed in the early phase and five nerves requiring tumor removal for exposure were assigned to group B, lacking evidence of tumor invasion or compression. Mean ONBF for group B was 13.2±1.3 ml/100 g/min. Another 20 optic nerves exposed before tumor manipulation showed obvious tumor compression, and were assigned to group A. Mean ONBF for group A was 8.5±1.0 ml/100 g/min, representing a significant difference between 2 groups ($p<0.05$).

ONBF After Tumor Removal

In the final phase, the ONBF was measured in 42 optic nerves of 26 patients, showing a mean final ONBF value of 10.8±0.7 ml/100 g/min. No significant correlation was demonstrated between final ONBF and postoperative follow-up VIS (Fig. 2B).

Change in ONBF During Surgery

Both initial and final ONBF were measured in 22 optic nerves of 16 patients, whose final ONBF (11.3±0.6 ml/100 g/min) was significantly greater than initial ONBF. Laser Doppler flow data provided us with real-time information accompanying each manipulation. In 6 patients, 7 optic nerves affected by tuberculum sellae meningiomas had continuous ONBF measurements. The probe was fixed at the optimal position in relation to the ipsilateral optic nerve throughout optic canal drilling and tumor debulking. Initial ONBF of these patients were relatively low (6.9 ± 2.0 ml/100 g/min). The mean value was unchanged immediately after unroofing the canal (6.9 ± 1.3 ml/100 g/min) but later demonstrated a significant increase (10.7 ± 1.4 ml/100 g/min) after complete removal of the tumor ($p<0.05$; Fig. 3A). Figure 3B compares ONBF change between the patients with and without optic canal

unroofing. In the former group, final ONBF increased prominently (55% of initial ONBF). The difference was statistically significant ($p<0.05$).

Change in ONBF with Test Occlusion of the Perforating Artery

After removal of the tumor, test occlusion of small perforating arteries adjacent to the optic nerve was performed by clipping in 6 patients. Three patients showed a significant decrease in ONBF with this test. After removing the clip, ONBF recovered to reach the previous flow. In other 3 cases, ONBF remained stable (Fig. 4A). In a representative waveform (Fig. 4B), ONBF promptly fell in response to vascular occlusion.

Discussion

Vasculature and Flow in the Optic Nerve

The optic nerve, chiasm, and optic tract are covered with complex vascular network. The ophthalmic artery rarely provides intracranial perforating branches distributed to the ventral aspect of the optic nerve and chiasm [32]. Feeding arteries to optic structures are classified mainly into two groups [6]. The superior group consists of tiny branches that arise from the lower wall of the A1 segment of the anterior cerebral artery and anterior communicating artery. They pass above the optic pathway to supply to the upper surface of the optic nerve, optic tract, and the lateral portion of the chiasm [6, 10, 21, 29, 32]. The inferior group, derived from the basilar, posterior communicating, posterior cerebral, and internal carotid arteries, supplies the inferior surface of the optic nerve, optic tract, and most of the optic chiasm [13, 32]. Bergland and Ray [6] stressed that the central portion of the chiasm has a blood supply limited to the inferior vessels, which makes the central portion of chiasm particularly vulnerable to vascular compression from beneath.

~~Measurement of cranial nerve blood flow has been reported previously, including changes of cochlear nerve blood flow related electrical stimulation [23] or hypoxic conditions [43].~~ Measurement of the intracranial ONBF by a

laser Doppler flowmeter~~, however,~~ has not been reported before. Orgül et al [28]. used microspheres to measure blood flow in rabbit optic nerve, finding ONBF among 17 rabbits to range between 3 and 37 ml/100 mg/min. We successfully obtained real-time, reproducible data in our present study, with ONBF in the absence of tumor compression found to be 13.2±1.3 ml/100 g/min, or 60.8% of cortical blood flow.

ONBF With Tumor Compression

The manner of optic nerve compression varies in cases of tumor extension. Tuberculum sellae meningiomas usually grow beneath the optic chiasm and into the optic canal [14, 15, 17, 19, 27]. Canal invasion often causes severe visual disturbance from compression of the nerve [5]. Spheno-orbital meningiomas may directly involve the optic canal [33]. Clinoidal meningiomas encase the optic chiasm and the nerve while respecting the arachnoid plane of the chiasmatic cistern [4]. Medial sphenoid wing meningiomas often involve the anterior visual pathways and sometimes infiltrates into the optic canal [26]. In craniopharyngiomas and tuberculum sellae meningiomas, optic pathways are compressed by the underlying tumor and by stretched overlying A1 segments [42].

In our cases with tumor compression, ONBF was 8.5±1.0 ml/100 g/min, showing variation reflecting differences in vascular anatomy and degree of compression. After unroofing of the optic canal, ONBF showed a marked increase when tumor resection was completed. ONBF may be particularly impaired in cases where the tumor invades into the optic canal. We previously demonstrated the importance of optic canal unroofing under conditions requiring retraction of the optic nerve [1]. Optic nerve visual evoked potential (VEP) amplitude was reduced depending on intension of traction, while successful unroofing of the optic canal lengthened the duration of essentially intact VEP amplitude during traction. This indicated that optic canal unroofing enhances optic nerve mobility and functional durability despite retraction during surgery. Mathiesen and Kihlström [24] reported that early optic nerve decompression had improved visual outcome in resection of tuberculum sellae meningiomas. Widening of the space by unroofing facilitates identification of important vessels and the normal arachnoid plane, protecting the vascular

network greatly enhancing ONBF after tumor removal. Both unroofing of the optic canal and subsequent tumor removal appeared to contribute to improvement of circulation in the optic nerve.

We also found that temporary occlusion of small arteries adjacent to the optic nerve reduced ONBF, a result compatible with anatomic findings [6, 10, 21, 29, 32]. Intraoperative injury to these small arteries can produce optic nerve ischemia that leads to postoperative visual deterioration [2, 12].

Relevance to Visual Function

Most of the clinical reports of visual function monitoring during surgery of parasellar lesions have considered VEPs to be the logical choice of method. VEPs can help to predict the final effects of trauma on visual function, while changes in amplitude and latency appear to represent an early indication of reversible damage to the visual system [18, 41]. Our previous study supported the benefit of VEP monitoring during retraction of the optic nerve [1]. However, VEPs are susceptible to a variety of nonspecific influences, such as those of volatile anesthetics [1, 40], blood pressure, and body temperature [31]. VEPs also vary in amplitude and latency both between patients and for an individual patient. Adequate positioning of light-emitting diode goggles can be difficulty in patients who require a skull base approach including orbitotomy or frontobasal osteotomy. Correlation between intraoperative VEP changes and intraoperative procedures sometimes has been difficult to prove [7]. In addition, the surgeon is required to interrupt manipulation for at least for 100 seconds to allow the 200 VEP data acquisitions needed for waveform averaging.

We evaluated laser Doppler flowmetry as a way to avoid these problems. The equipment is simple and easy to operate, and provides real-time data. Volatile anesthetic agents are not known to influence ONBF. Under stable conditions of mean blood pressure, $PaCO_2$, and body temperature, ONBF data are considered to be reproducible. However, maintaining the probe in an informative position is difficult when the optic nerve underlies the tumor or the opticocarotid space is narrowed by tumor compression. Furthermore, whether or not ONBF measurements correlate

with visual function remains unclear. Indeed, we could not demonstrate a significant correlation between ONBF and visual function. Multiple factors such as status of various parts of the optic pathway or intracranial pressure contribute to visual outcome. The importance of ONBF lies in its ability to detect optic nerve ischemia immediately. Stable or improved ONBF can eliminate optic nerve ischemia as a cause of potential visual dysfunction, directing therapeutic intervention toward other factors.

In our patients with postoperative visual deterioration, tumors were densely adhered to optic structures and accompanying vessels, with partial absence of the arachnoid plane. Direct mechanical injury to the optic system could account for visual deterioration. Since ONBF measured focally in the optic nerve was well preserved after gross total tumor removal in these patients, visual worsening may have involved ischemia of another part of the optic pathway. Repetitive measurements of ONBF in various locations may be required to detect an abnormality threatening vision.

Sometimes the probe used currently cannot be maintained in the desired position during portions of the procedure. While debulking tumor around the optic nerve, measurement is impossible to continue without interruption. Development of a device with a smaller probe and a more pliable cable is necessary. Further investigation is required to clarify the role and reliability of ONBF monitoring as an indicator of visual function during parasellar tumor surgery.

Conclusion

Surgical treatment of a parasellar tumor still represents a difficult task for neurosurgeons. Using a laser Doppler flowmeter to monitor ONBF during these procedures, we demonstrated that ONBF increased significantly after completion of tumor resection, especially in cases with optic canal unroofing. Various perforating arteries around optic structures may give rise to optic nerve ischemia if injured. Our results indicate that measurement of intraoperative ONBF can provide real-time monitoring for prediction and prevention of intraoperative optic nerve

ischemia.

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Figure legends

Fig. 1. Intraoperative application of the contact probe. ~~After the optic nerve is adequately exposed, the contact probe, 10 mm in greatest dimension, is centered upon the nerve.~~ **A:** The contact probe is 10 mm in greater dimension. **B:** After the optic nerve is adequately exposed, the contact probe is centered upon the nerve. T; tumor, Rt ON; right optic nerve, Lt ON; left optic nerve, *; the contact probe

Fig.2. Correlation between visual impairment score (VIS; normal=0, blind=35) and optic nerve blood flow (ONBF). **A:** Scatter plot showing no correlation between preoperative VIS and initial ONBF. **B:** Scatter plot showing no correlation between postoperative VIS and final ONBF.

Fig. 3. Data concerning effects of optic canal unroofing. **A:** Linear plots show changes in ONBF for six patients (seven optic nerves) upon unroofing the optic canal. ONBF increases prominently after removal of the tumor ($p<0.05$). **B:** Columns compare ONBF changes between patients with optic canal unroofing and those without unroofing. Final ONBF shows significant increases (55% of initial ONBF) in unroofed cases ($p<0.05$).

Fig. 4. Changes with temporary occlusion of a small artery adjacent to the optic nerve. **A:** In three of six patients (filled triangles), ONBF decreases significantly (by 49.8%) during occlusion of the artery ($p<0.05$). When the decline is observed, the occlusive clip is removed immediately. ONBF then shows significant recovery up to 92.0% of baseline ($p<0.05$). In the other three patients (open circles), ONBF remains stable. **B:** Waveforms in a representative case. A 55-year-old man with a tuberculum sellae meningioma underwent left pterional craniotomy. After tumor removal, the right optic nerve was exposed. Soon after a small perforating artery adjacent to the optic nerve is

temporarily occluded, ONBF decreases to 50% of baseline. After occlusive clip removal 15 sec later, ONBF recovers immediately.

Fig. 1A

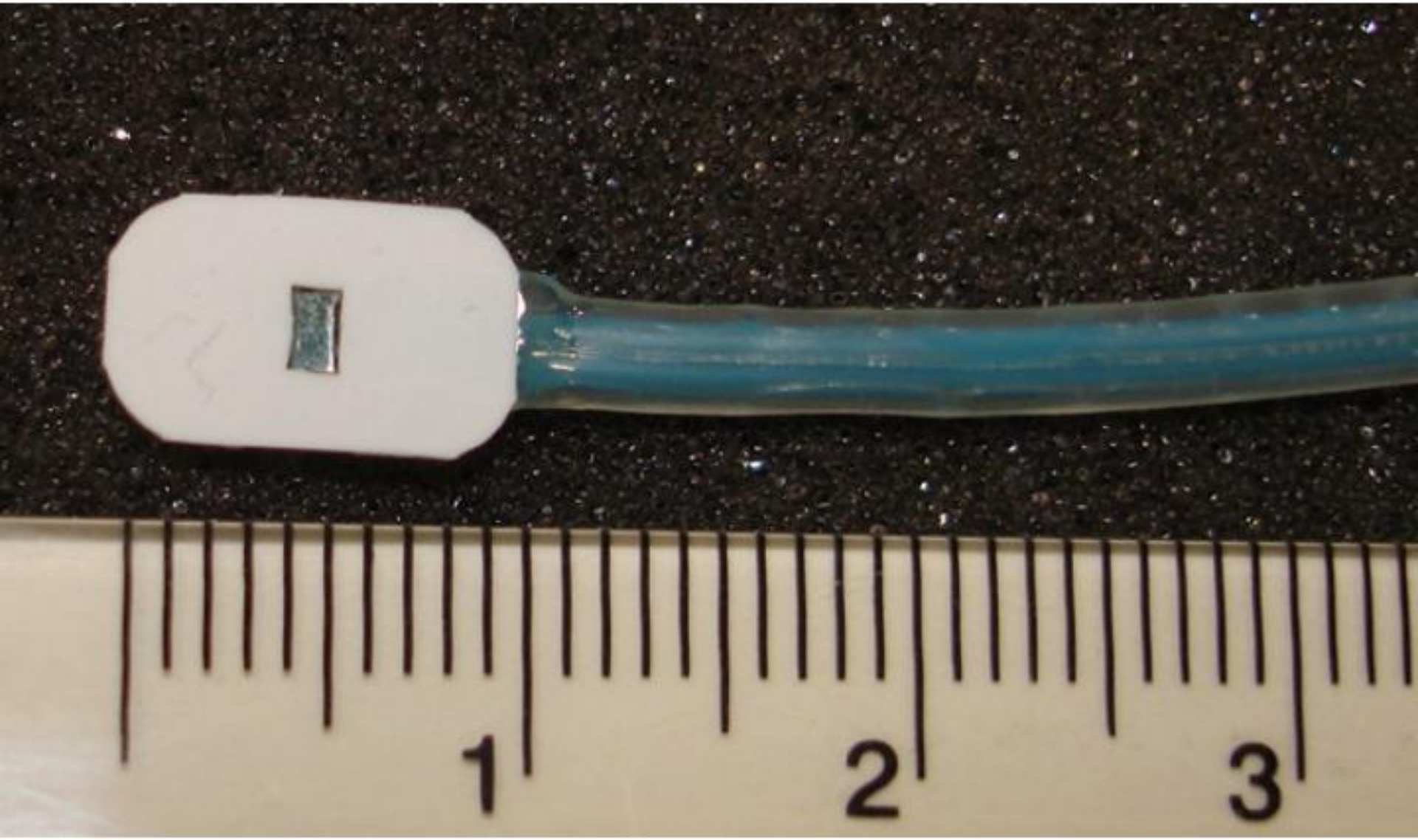


Fig. 1B

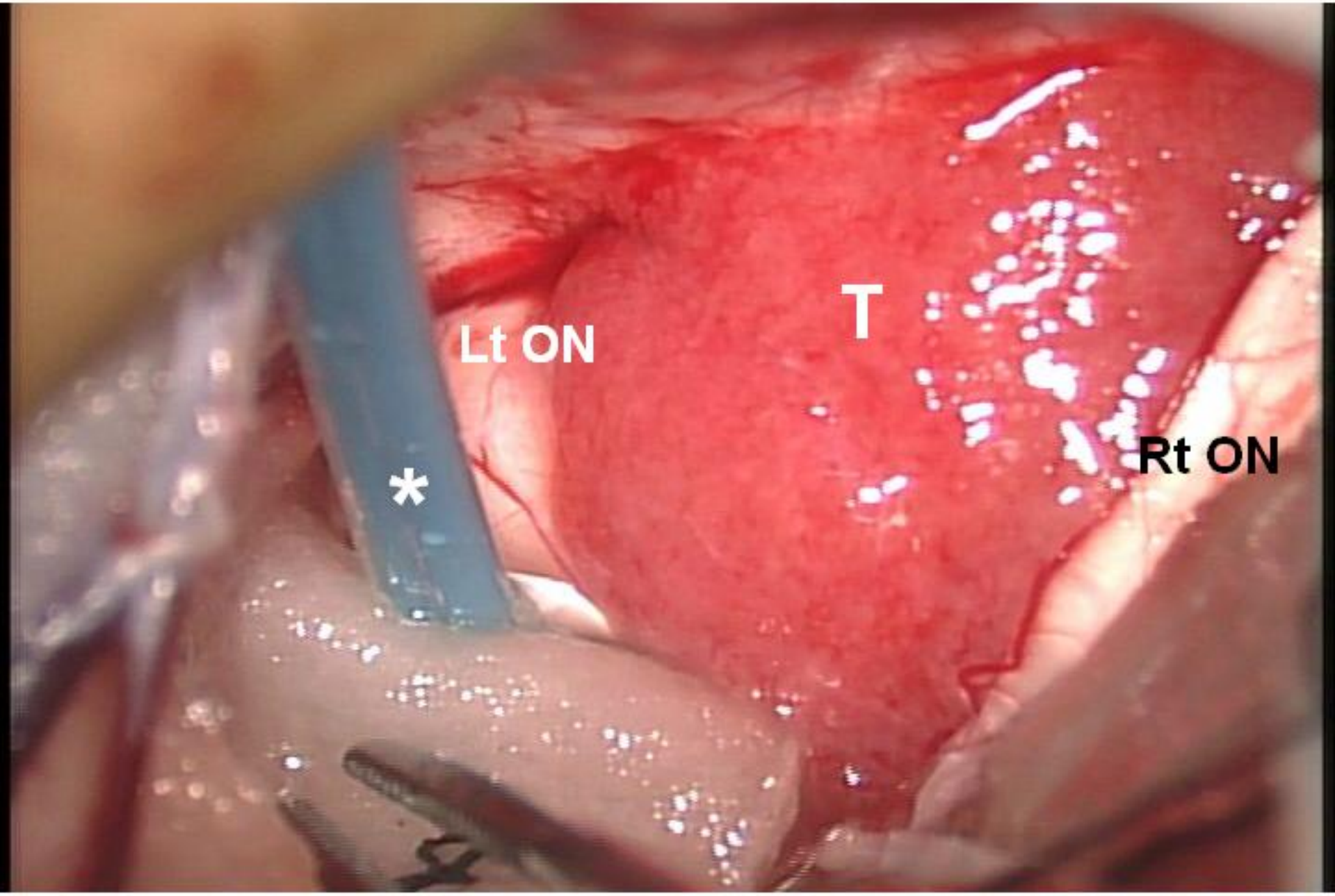


Fig. 2A

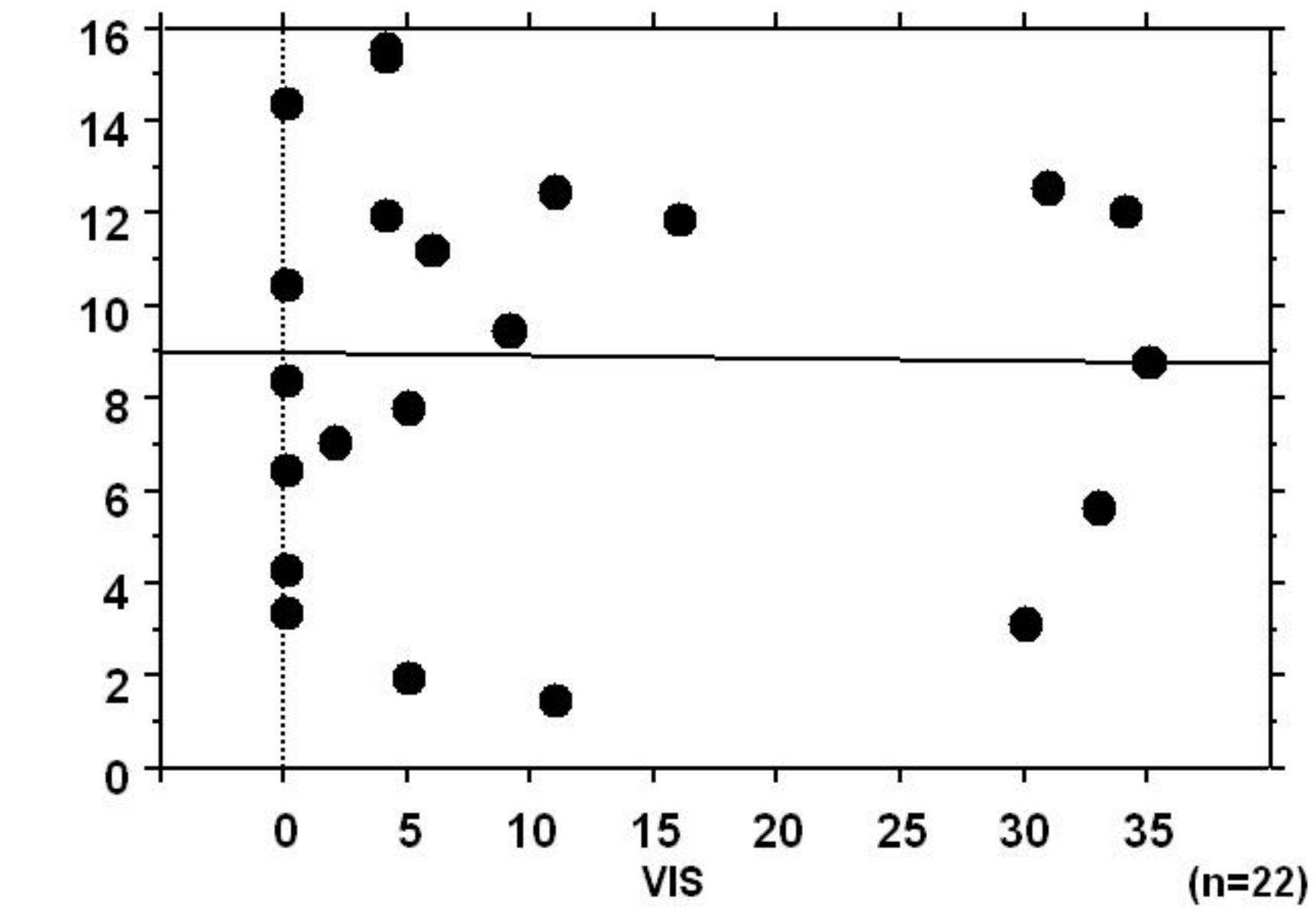

Inital ONBF
(ml/100 g/min)
16
14
12
10
8
6
4
2
0
0
5
10
15
20
25
30
35
VIS
(n=22)

Fig. 2B

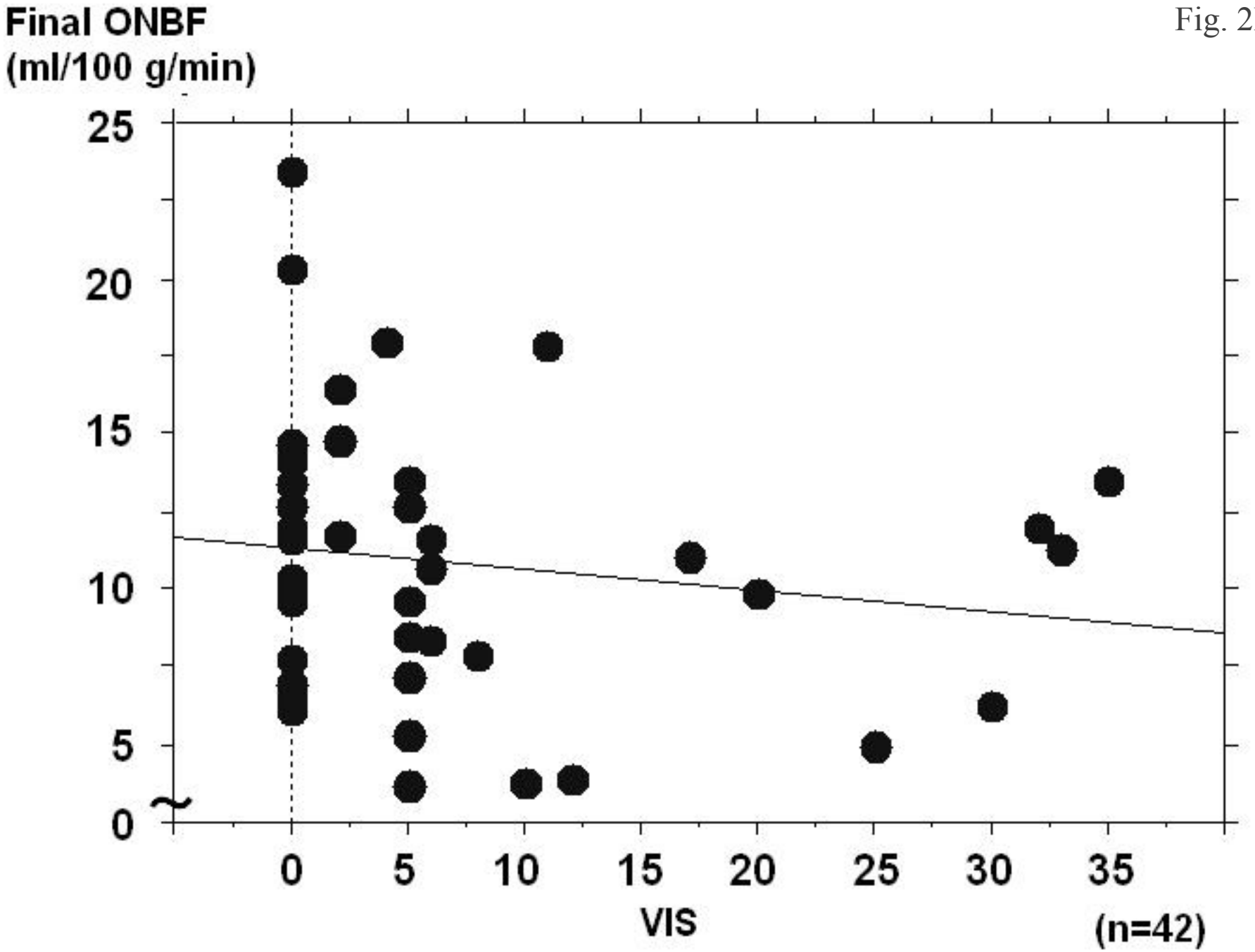


Fig. 3A

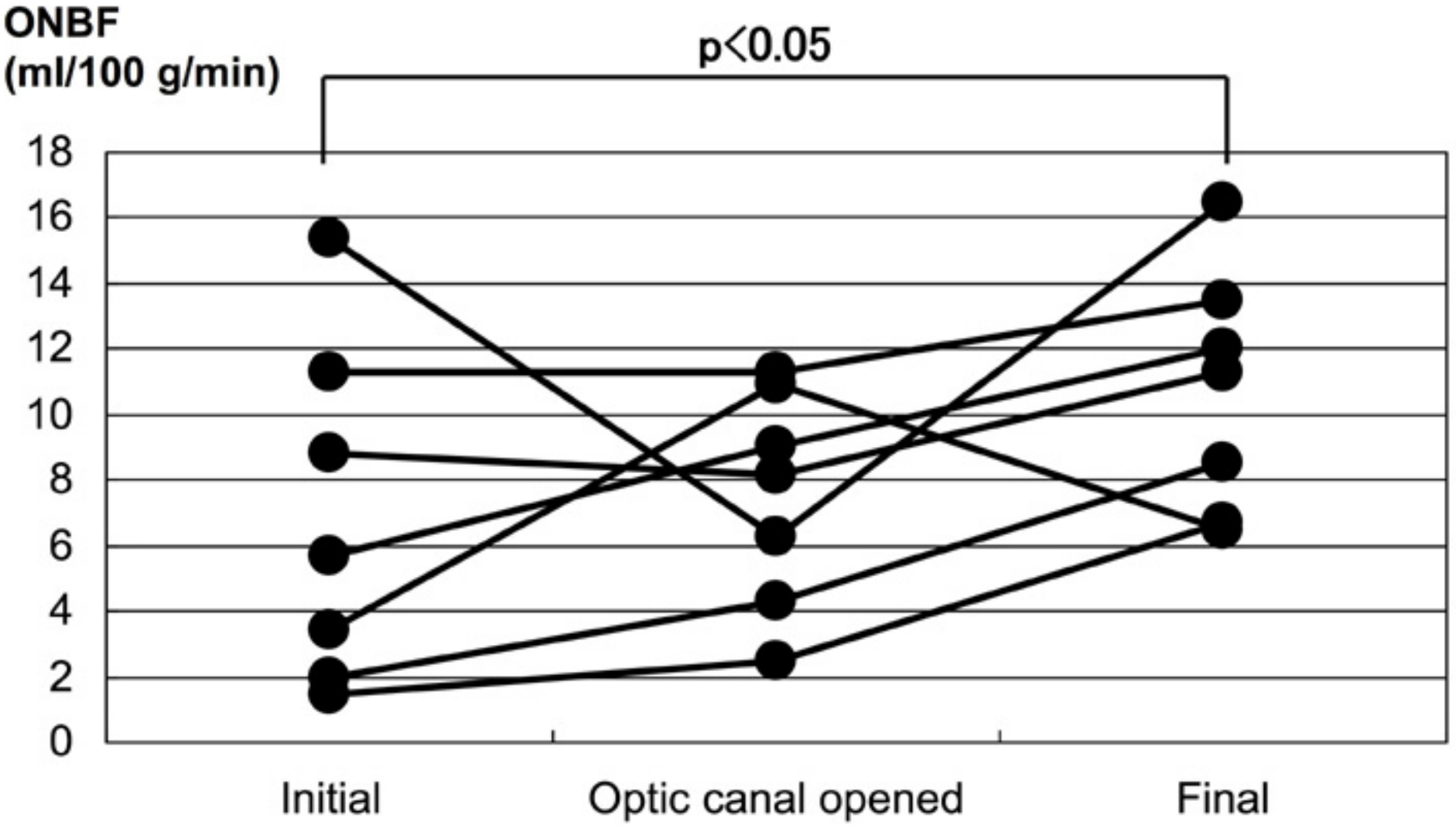

ONBF
(ml/100 g/min)
p<0.05
18
16
14
12
10
8
6
4
2
0
Initial
Optic canal opened
Final

Fig. 3B

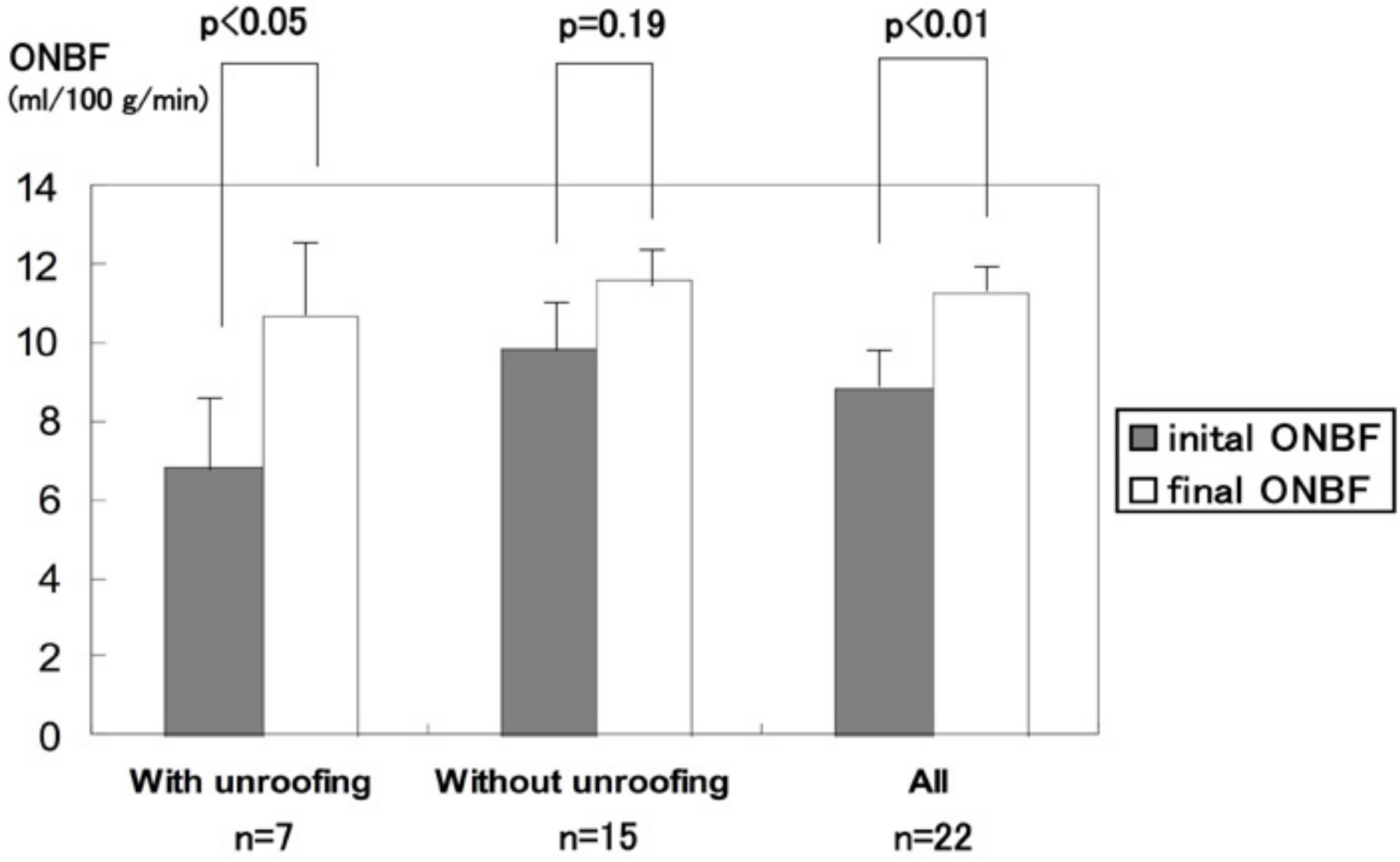

p<0.05
p=0.19
p<0.01
ONBF
(ml/100 g/min)
14
12
10
8
6
4
2
0
inital ONBF
final ONBF
With unroofing
n=7
Without unroofing
n=15
All
n=22

Fig. 4A

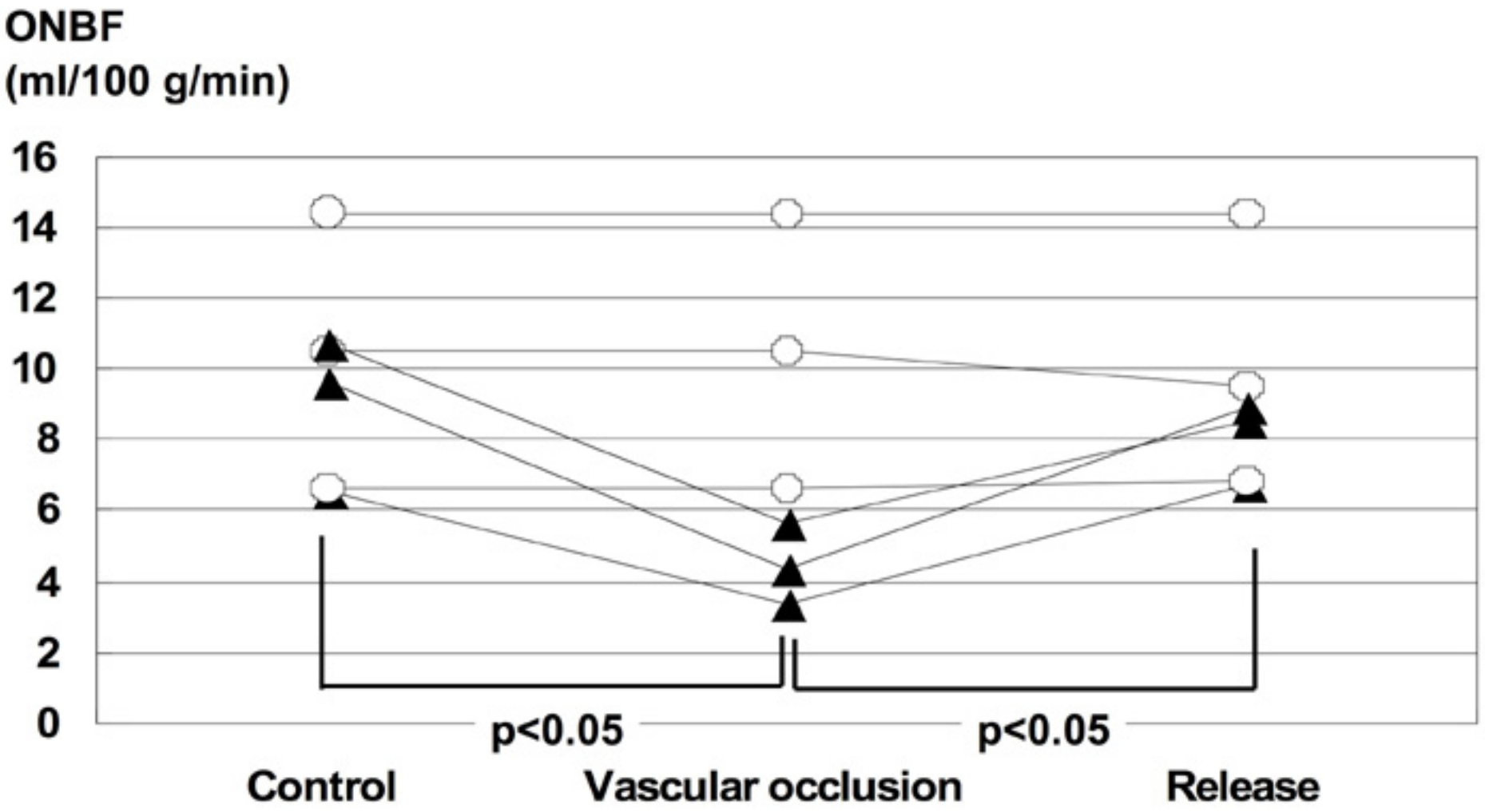
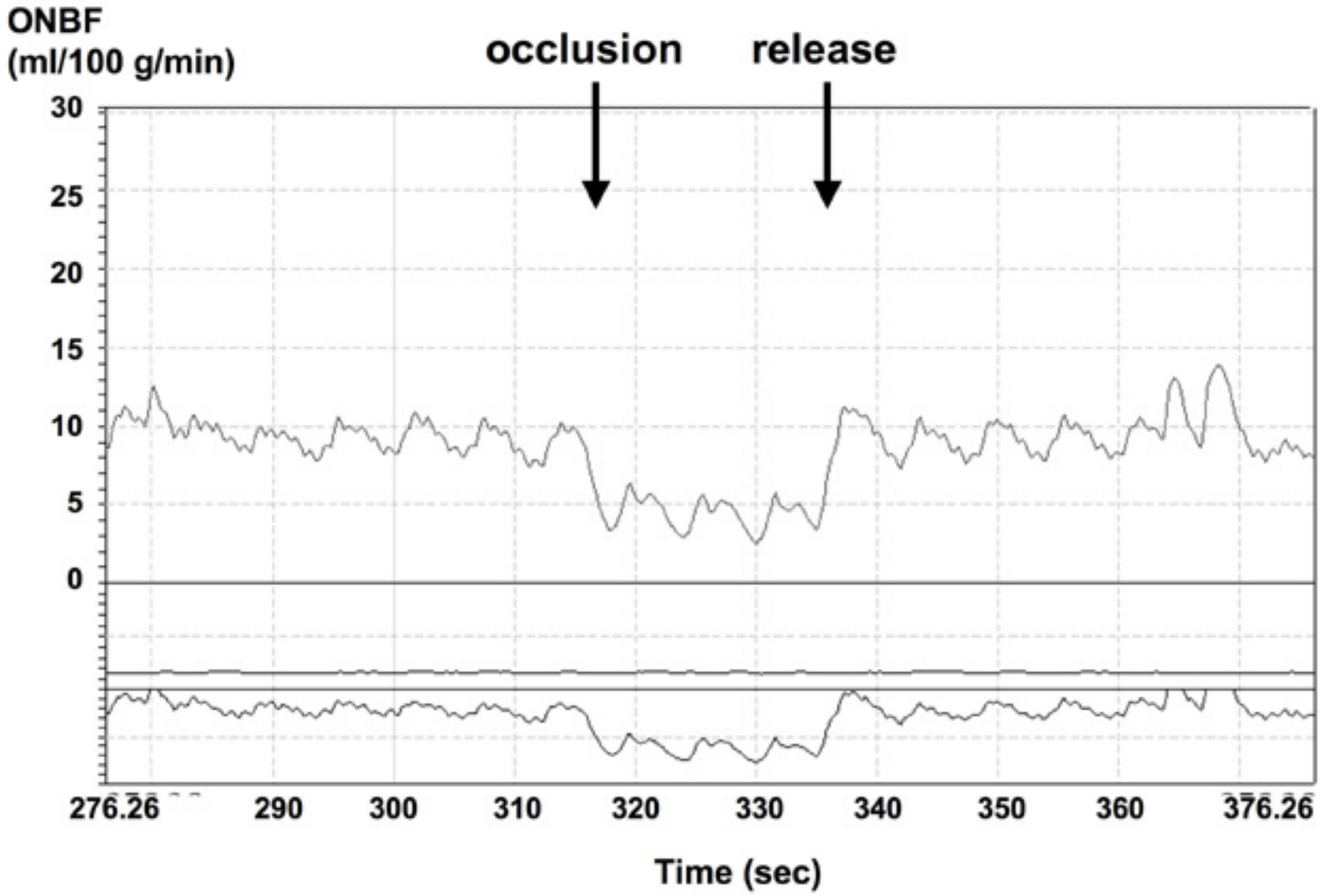

ONBF
(ml/100 g/min)
16
14
12
10
8
6
4
2
0
p<0.05
p<0.05
Control
Vascular occlusion
Release

Fig. 4B


ONBF
(ml/100 g/min)
occlusion
release
30
25
20
15
10
5
0
276.26
290
300
310
320
330
340
350
360
376.26
Time (sec)