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Treatment of empty sella associated with visual impairment: a systematic review of chiasmapexy techniques

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Abstract
Purpose Chiasmapexy is a poorly described surgical procedure adopted to correct the downward displacement of suprasellar visual system (SVS) into an empty sella (ES) causing visual worsening. The aim of our study is to define the indications for extradural and intradural chiasmapexy.
Methods A systematic literature review has been performed on MEDLINE database (US National Library of Medicine), including only articles that depicted cases of surgically treated patients affected by ES and progressive delayed visual worsening. Moreover, we have reported three cases of secondary ES syndrome (SESS) with visual worsening treated in our Department with transsphenoidal (TS) microsurgical intradural approach. Finally, we have compared the results of extradural and intradural chiasmapexy described in literature.
Results The etiology of visual impairment is different in primary and secondary ESS. In primary ESS (PESS) the only predisposing factor is a dehiscence of diaphragma sellae, and the anatomical distortion caused by displacement of optic chiasm or traction of pituitary stalk and infundibulum may determine a direct injury of neural fibers and ischemic damage of SVS. In PESS the mechanical elevation of SVS performed through extradural approach is sufficient to resolve the main pathologic mechanism. In SESS, arachnoidal adhesions play an important role in addition to downward herniation of SVS. Consequently, the surgical technique should provide elevation of SVS combined to intradural release of scar tissue and arachnoidal adhesions. In treatment of SESS, the intradural approaches result to be more effective, guaranteeing the best visual outcomes with the lowest complications rates.
Conclusions The intradural chiasmapexy is indicated in treatment of SESS, instead the extradural approaches are suggested for surgical management of PESS.

Keywords Empty sella · Visual worsening · Transsphenoidal · Pituitary surgery · Intradural · Chiasmapexy

Introduction

The term "empty sella" (ES) was introduced in 1951 by Busch, who reported 5.5% of incidence after post-mortem examination of 788 patients with no known history of pituitary disease [1]. Since then, two types of empty sella syndrome (ESS) with different pathological characteristics have been described in the literature. Primary empty sella (PES) has been defined as an intrasellar cerebrospinal fluid (CSF) cistern herniation associated with variable enlargement of sella turcica and remodeling of pituitary gland [2]. The only known etiology is the congenital deficiency of diaphragma sellae. The diaphragmal opening for pituitary stalk is greater than 5 mm in 39–56% of specimens [3, 4] and the incidence of subarachnoidal space protruding within the sella turcica exceeds 20% [5]. It has been hypothesized that the deficiency of diaphragma sellae represents a "free pathway" between the chiasmatic cistern and the pituitary fossa, allowing the pulsatile movements of CSF to push down the cistern into the sella turcica. These pulsations slowly flatten the pituitary gland to the sellar floor and produce slight enlargement of sella turcica, reducing the thickness of bony walls. The displacement of pituitary gland to the sellar

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floor determines traction on pituitary stalk and suprasellar visual system (SVS). As result, optic nerve and chiasm are pulled down into the sella turcica. The PES is usually an incidental finding detected on cerebral MRI. Nevertheless, PES syndrome (PESS) may occur usually in females in association with multiparity and obesity and is characterized by endocrine disturbances, headache, visual impairment and rhinorrhea [3, 6–8]. Some Authors consider the chronically increased intracranial CSF pressure and the dehiscence of diaphragma sellae as the pathogenic factors of PESS [9, 10]. However, hydrocephalus and intracranial benign hypertension differ from PESS for infundibular recess persistence, decreased visual acuity and papilledema rather than visual field defects and descent of third ventricle, A1 segments and SVS.

Secondary empty sella (SES) has been well described by Olson: tumors of long duration with large suprasellar extension determine development of adhesion between the enlarged diaphragma sellae and optic chiasm. After tumor removal the gradual postoperative retraction contributes to the downward displacement of diaphragma sellae and optic chiasm into the ES, stretching the optic nerves [11]. The presence of an intrasellar mass (i.e. pituitary tumor, abscess, lymphocytic hypophysitis, apoplexy) alters the normal anatomy, stretching, enlarging and thinning diaphragma sellae, and favors the development of arachnoidal adhesions with the SVS upward displaced. Surgery (trans-cranial or transsphenoidal), radiotherapy, medical therapy (i.e. dopaminergic agonist), traumas or spontaneous resolution (i.e. after tubercular meningoarachnoiditis, tumor apoplexy, lymphocytic hypophysitis) induce the sellar mass reduction and may produce a SES associated with the development of scar tissues. After several months, scar tissue retraction might cause displacement of diaphragma sellae and downward tethering of SVS into the ES, leading to visual disturbances [11–22].

Introduced in 1971 by Wealch and Stears, the term *chiasmapexy* literally means "*fixing the chiasm*" and refers to the surgical techniques adopted to elevate the SVS downward displaced into ES, when visual deterioration occurred [13]. To the best of our knowledge, we report the first systematic review of surgical techniques adopted to perform chiasmapexy. Factors that made difficult this review are the limited number of cases, the variety of surgical procedures described and the not clear distinction between PESS and SESS [3, 6, 8, 11, 14, 16–18, 23–36]. We also described three other cases of SESS treated in our Department.

Materials and methods

Literature review

A systematic literature review was performed on MEDLINE database (US National Library of Medicine), including only English-language publications from 1960 to 2016. The keywords used were "*chiasmapexy, empty sella, primary, secondary, visual deterioration, transsphenoidal, transcranial, pituitary surgery, suprasellar visual system, optic chiasm, herniation*". All titles, abstracts and full text articles have been reviewed by the first author. Only papers reporting cases of surgical treatment for progressive visual worsening in ESS were taken into consideration. Punctures of lamina terminalis were excluded. We have identified 26 papers reporting transcranial (Table 1) [3, 6, 11, 13, 14, 17, 18, 21, 23, 35, 37] and transsphenoidal (TS) approaches (Table 2) [11, 16, 24–34, 36, 38].

Then, we proceeded to quantitative analysis of literature data, collecting all the chiasmapexy performed in SESS, looking for surgical technique (trans-cranial or TS approaches, carried out extradurally or intradurally), complications and visual outcomes (Table 3).

Original series and surgical technique

We described three illustrative cases of SESS with visual worsening treated with microsurgical TS intradural chiasmapexy in our Department. Patients' clinical characteristics and postoperative outcomes are described in Table 4.

After standard general endotracheal anesthesia, a lumbar drain is placed to allow intraoperative CSF drainage [39]. The sellar floor is reached via a sublabial trans-septal TS microsurgical approach. The dura mater is incised in a "book page" shape. The downward herniation of suprasellar cistern is evident and the optic pathways appeared merged within the arachnoid (Fig. 1a–c). The sellar cavity has been explored with an H® Straight Forward Telescope 0°, enlarged view, diameter 4 mm, to better evaluate SVS herniation into the pituitary fossa (Fig. 1a, b). The optic pathways are released from the intrasellar tissues using a round dissector, as showed in Fig. 1c (bayonet-shaped, diameter 2 mm, straight, with round handle, working length 16 cm). The CSF subtraction through the lumbar drain decreases the pressure exerted on the suprasellar cisterns and then the downward displaced SVS moves upward (Fig. 1d). Three sleeves of bovine pericardium (Tutopach, Tutogen Medical Gmbh, Neukirchen, Germany) fixed with fibrin glue (Tissucol, Baxter Glendale, CA healthcare corporation) are put inside sella turcica to reconstruct the diaphragma sellae. After that, a fragment of septal bone is placed over the dural sleeves in order to keep in place the material used for dural reconstruction [40].

Table 1 Trans-cranial procedures reported in literature to treat patients with ES and visual impairment

Author, year	N. of pts	Empty sella	Surgical technique
Lee et al. (1968) [6]	1	SES	Surgical exploration: ONs thin and white surrounded by arachnoidal adhesions
	1	SES	Surgical exploration: left ON downward displaced into ST; right ON non visualized
Mortara et al. (1970) [3]	2	PES	Surgical exploration
	2	SES	Lamina terminalis puncture
	1	PES	Sellar packing (muscle)
	1	SES	Tumor removal
	2	SES	Surgical exploration
	1	Normal	Sellar packing (muscle)
Welch et al. (1971) [13]	1	SES	Adhesions lysis and sellar packing (silicone sponge)
Olson et al. (1972) [11]	1	SES	Adhesions lysis
Wood et al. (1975) [35]	1	PES	Sellar packing (muscle)
Scott et al. (1977) [14]	1	SES	Adhesions lysis
Cupps et al. (1978) [23]	1	PES[a]	Surgical exploration: chronic arachnoiditis and compromised vascular supply; adhesions lysis and sellar packing
Fischer et al. (1994) [17]	1	SES	Adhesions lysis (OC bound to the DS by dense scar tissue and not displaced into ST)
Czech et al. (1999) [18]	1	SES	Adhesions lysis (GR and SVS tethered by dense scar tissue to downward displaced DS)
	2	SES	Adhesions lysis (GR, SVS and A1 herniation)
Thomè et al. (2004) [21]	1	SES	Adhesions lysis (A1 grooves the antero-dorsolateral aspect of the OC—no SVS herniation into ST)
Gkekas et al. (2013) [37]	1	SES	Adhesions lysis (ON and ACoA downward displaced)

A1 first segment of anterior cerebral artery, *ACoA* anterior communicating artery, *DS* diaphragma sellae, *GR* gyrus rectus, *OC* optic chiasm, *ON* optic nerve, *PES* primary empty sella, *SES* secondary empty sella, *ST* sella turcica, SVS suprasellar visual system

[a]ES probably caused by cyst rupture

Table 2 Transsphenoidal procedures reported in literature to treat patients with ES and visual impairment

Author, year	N. of pts	Empty sella	Surgical technique	EXD versus IND
Olson et al. (1972) [11]	1	SES	MS adhesions lysis and sellar packing (fascia, muscle and bone plaques)	IND
Decker et al. (1977) [25]	1	SES	MS adhesions lysis and sellar packing (fascia, muscle and bone plaques)	IND
Spaziante et al. (1985) [34]	7	NR	NR	Mixed
Nagao et al. (1987) [31]	1	PES	MS balloon placement filled with liquid silicone	EXD
Hamlyn et al. (1988) [29]	1	SES	MS sellar packing (muscle and septal cartilage)	NR
Cybulski et al. (1989) [24]	1	PES	MS balloon placement filled with HEMA	EXD
Barrow et al. (1990) [16]	2	SES	NR	NR
Gallardo et al. (1992) [26]	56	NR	MS sellar packing (lyophilized dura)	EXD
Polyzoidis et al. (1993) [32]	3	PES	MS sellar and sphenoid sinus packing (fat tissue)	EXD
Gazioglu et al. (1999) [27]	3	PES	MS balloon placement filled with HEMA	EXD
Guinto et al. 2002 [28]	2	PES	MS sellar packing (fascia, muscle and bone plaques)	EXD
Zona et al. (2003) [36]	2	SES	MS sellar packing (silastic coil) and reconstruction of sellar floor (bone and cartilage)	EXD
Kubo et al. (2005) [30]	1	SES	ES silicone block placement	EXD
	1	PES	ES silicone block placement	EXD
Rudnik et al. (2006) [33]	4	PES	ES sellar elevation (silicone spiral)	EXD
Alvarez Berastegui et al. (2016) [38]	1	SES	ES sellar elevation (HydroSet and AlloDerm)	EXD

ES endoscopic, *EXD* extradural, *IND* intradural, *MS* microsurgical, *NR* not reported, *PES* primary empty sella, *SES* secondary empty sella

Table 3 Literature review of intraoperative findings, surgical techniques and visual outcomes in patients with SES and delayed visual worsening

Author, year	N. of pts	SVS herniation	Arachnoidal adhesions on intraoperative finding	Surgical technique		Postoperative visual function	
				TC versus TS	EXD versus IND	Complete recovery	Partial improvement
Extradural chiasmapexy							
Hamlyn et al. (1988) [29]	1	NR	NR	TS	NR	–	1
Zona et al. (2003) [36]	2	Yes	NR	TS	EXD	–	2
Kubo et al. (2005) [30]	1	Yes	Yes[a]	TS	EXD	–	1
Arachnoidal adhesions lysis							
Olson et al. (1972) [11]	1	Yes	Yes	TC	IND	–	1
Scott et al. (1977) [14]	1	No	Yes	TC	IND	–	1
Fischer et al. (1994) [17]	1	No	Yes	TC	IND	–	1
Czech et al. (1999) [18]	3	Yes	Yes	TC	IND	2	1
Thomé et al. (2004) [21]	1	No	Yes	TC	IND	–	1
Intradural chiasmapexy and arachnoidal adhesions lysis							
Welch et al. (1971) [13]	1	Yes	Yes	TC	IND	1	–
Olson et al. (1972) [11]	1	Yes	NR	TS	IND	–	1
Decker et al. (1977) [25]	1	Yes	Yes	TS	IND	1	–
Present series (2017)	3	Yes	Yes	TS	IND	–	3

EXD extradural, *IND* intradural, *NR* not reported, *SVS* suprasellar visual system, *TC* trans-cranial, *TS* transsphenoidal

[a]Visible on MRI

Table 4 Patients' clinical characteristics and visual outcomes after TS microsurgical intradural chiasmapexy: original series

Case	Sex, age (years)	Clinical picture		Neuro-ophthalmologic examination					FU (years)
		Initial presentation	MRI diagnosis + VW		Left eye		Right eye		
					Preop	At last FU	Preop	At last FU	
1	F, 45	– Pituitary apoplexy – RE: VW	2 months later SES + bilateral VW	VA CoP CPm	7/10 12/12 Normal	8/10 12/12 Unchanged	5/10 2/12 VFCN	6/10 12/12 Improvement	7
2	M, 41	– Macro-NFPA – LE: tHAP – RE: nHAP – Two surgical operations[b] (TS and TC) – RE: postoperative VFI	4 months later SES + bilateral VW	VA CoP CPm	1/10 10/12 tHAP	3/10 12/12 Unchanged	6/10 12/12 VFCN	8/10 12/12 Improvement	7
3	M, 34	– Macro-PRL – LE: visual loss[a] – RE: tHAP – After start of dopaminergic therapy ○ Tumor volume reduction ○ RE: VFI	6 month later SES + VW on RE[a] (despite dopaminergic therapy reduction)	VA CoP CPm	0/10 0/12 Absent	0/10 0/12 Unchanged	4/10 12/12 nHAP	5/10 12/12 Normalization	2

CoP color perception, *CPm* computed perimetry, *FU*, follow up, *LE* left eye, *Macro-NFPA* non functioning macroadenoma, *Macro-PRL* macroprolactinoma, *nHAP* nasal hemianopsia, *preop* preoperative, *RE* right eye, *tHAP* temporal hemianopsia, *VA* visual acuity, *VFCN* visual field concentric narrowing, *VFI* visual function improvement, *VW* visual worsening

[a]Left optic atrophy

[b]Operations performed at another institution

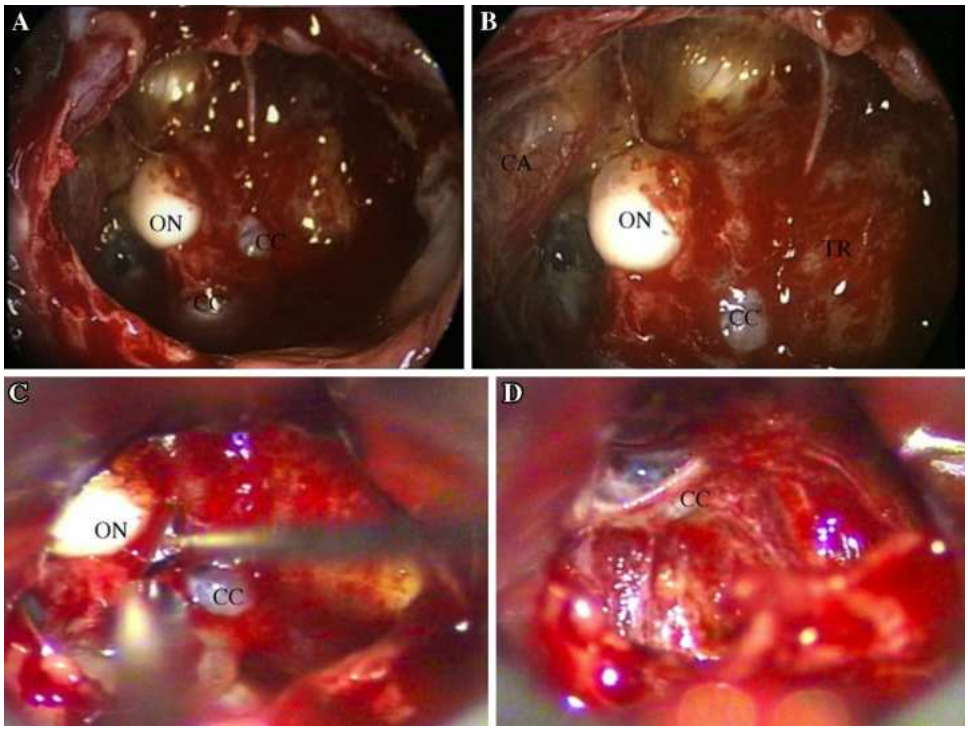

Fig. 1 **a, b** Endoscopic view before CSF drainage showed right optic nerve (ON) and chiasmatic cisterns (CC) downward displaced into the sella turcica (case 3 reported in Table 4); **c** microscopic view before CSF drainage and scars lysis around optic nerve; **d** microscopic view after CSF drainage and adhesions releasing, demonstrating CC and SVS moving upward. *CA* carotid artery, *CC* chiasmatic cistern, *CSF* cerebrospinal fluid, *ON* optic nerve, *ST* sella turcica, *TR* tumor remnants

Results

Trans-cranial and transsphenoidal chiasmapexy

Welch and Stears firstly reported a trans-cranial chiasmapexy in 1971 [13]. They described a 54 years old woman, operated through a left frontal craniotomy for pituitary adenoma. After 8 months the patient complained about progressive visual acuity decrease and left temporal hemianopsia and was re-operated through the same route. The diaphragma sellae "was found to be depressed into the sella and the left optic nerve was tethered down by the left anterior cerebral artery which was densely adherent to the diaphragm". The diaphragma sellae was incised to insert "many small pieces of silicone sponge" below it in order to replace the optic nerves in their position. The patient recovered completely from the previous visual impairment.

In 1972 Olson et al. reported one cases of SESS with visual defect after previous TS surgical removal of a large cystic pituitary adenoma. Trans-cranial exploration revealed "empty sella with downward migration of the optic chiasm; the left optic tract was observed to be impaled upon the posterior clinoid". The authors described "relaxation of the stretched optic chiasm accomplished by lysis of adhesions" and following visual acuity improvement [11].

The other cases of trans-cranial approach reported in literature are not precisely described (Table 1). The technique basically consisted in exploring the chiasmatic region with or without adhesions lysis and with or without sellar packing [6, 11, 13, 14, 17, 18, 21, 23, 35, 37].

Olson et al. reported the first chiasmapexy performed through the TS route, elevating the SVS and the diaphragma sellae using fascia, muscle and bone plaques from the nasal septum. They concluded that the SVS herniation must be prevented during the first operation. So, they suggested to pack sella turcica with bone plaques to elevate diaphragma sellae when it was not observed a "rapid free downward movement of the diaphragm following tumor removal". This occurrence was thought to be indicative of adhesions between diaphragma sellae and optic chiasm [11]. After this paper, many technical variants have been described for TS chiasmapexy, distinguished in intradural sellar packing, intradural arachnoidal adhesions lysis and optic chiasm elevation, and extradural sellar packing (Table 2). The two main topics are: (1) the materials adopted to elevate the optic chiasm, (2) the choice of extradural or intradural approach.

With regard to the materials used to pack sella turcica, abdominal fat, fascia lata, muscle, septal bone or cartilage and dural substitutes have been used, but delayed resorption and displacement have been reported for all of them [25, 41]. In the most recent years, synthetic materials have been proposed in order to correct the abnormal downward displacement of SVS [24, 27, 30, 31, 36]. Some authors have described the use of detachable silicon balloon filled with HEMA or liquid silicone for extradural obliteration of sella turcica, performed through a 4 mm opening in the sellar floor [24, 27, 31]. Interestingly, the detection in three cases of

balloons' deflation with relapsed ES was not associated with delayed visual deficits [27]. Zona et al. described microsurgical TS extradural packing using a silastic tube "arranged in a spiral form by means of three transfixed sutures" [36]. Kubo et al. performed an endoscopic endonasal TS approach and achieved the elevation of the optic chiasm by extradural packing with "silicone blocks made of two or more pieces of silicone plate sutured at the center" [30]. The reported advantages of synthetic materials are: the biocompatibility, the malleability, the solidity to support SVS, and the not absorbable nature that reduce the risk of relapsed ES and subsequent recurrence of symptoms. Moreover, the extradural approach with intraoperative fluoroscopy excludes the risks of over packing the sella turcica and damage the suprasellar structures [24, 27, 30, 31, 36]. By contrast, the restrictions of synthetic materials are the impossibility to perform a second TS approach and the almost exclusive employment in cases of PESS. In fact, to date only three cases of SESS treated through extradural chiasmapexy with synthetic materials placement are described in literature [30, 36].

The second matter of debates is the intradural or extradural technique adopted to pack the sella turcica and to elevate diaphragma sellae and SVS. Regardless of the endoscopic or microsurgical approach used to reach the sella turcica, the most recent literature suggests a less invasive extradural approach [24, 27, 30–32, 36]. In addition to previous reported extradural approaches, Polyzoidis and Pylaktakis in 1993 described in 3 cases of PES the extradural insertion of adipose tissue to prevent the most frequent complications of TS intradural approach, in particular CSF leakage and meningitis [32]. Nevertheless, Gallardo et al. reported a complication rate of 7.1%, even adopting the extradural TS sellar packing, describing cases of meningitis, osteomyelitis and hematoma [26]. Some Authors criticized the minimally invasive extradural chiasmapexy, noting that basal dura could not be sufficiently elevated and bleeding from the cavernous sinuses could occur [27].

Extradural and intradural chiasmapexy

We analyzed the visual outcomes in SESS comparing extradural chiasmapexy, intradural chiasmapexy with arachnoidal lysis and arachnoidal lysis alone (Table 3). The SVS herniation was present in 13/16 (81.3%) cases of SESS and the arachnoidal adhesions in 13/13 (100%). In all surgically treated patients the visual function improved, but a complete recovery of visual defect was achieved only in 4 patients (23.5%). Among these, in two cases SVS and diaphragma sellae elevation was associated with intradural exploration and scar tissue lysis, whereas in the other two only intradural adhesion lysis was performed. In none case treated through extradural chiasmapexy, that consents only SVS elevation, complete recovery was achieved, confirming the importance of intradural scar dissection. No complications were reported.

Discussion

Chiasmapexy is a poorly described and technically demanding surgical procedure. The indication is based on visual worsening in presence of SVS downward displacement and ES. In order to lift up and restore the natural position, reducing traction on SVS, either trans-cranial or TS chiasmapexy have to be adopted. Despite commonly chiasmapexy is a re-operation in patients who had previously suffered from compressive neuropathy with tissues extremely sensitive to damage, the worsening of visual function was described in only one patient [6]. In that case no postoperative complications occurred, but rather surgery was unable to arrest the progression of visual impairment. In fact, in more than half of reported chiasmapexy, visual improvement or recovery occurred and in the others the visual deficit not deteriorated or remained stable [3, 6, 11, 13, 14, 16–18, 21, 23–38]. In our 3 cases, homogeneous for indications and technique (intradural TS chiasmapexy), visual improvement, confirmed after a long follow-up, was achieved in all patients and no complications occurred (Table 4). Probably the good selection of patients, the correct surgical planning and the experience of pituitary dedicated neurosurgeons explain the significant low rate of visual complication reported in literature. Alternatively, cases of visual worsening after chiasmapexy may not be described because of publication bias. The TS approach, especially if performed by experienced neurosurgeons, is effective and less invasive than the transcranial route [40, 42–45]. The outstanding issue is when to use intradural or extradural TS approach. Before answering this question, we must make a small digression on etiology of visual damage in PESS and SESS.

Visual damage in PESS and SESS

In PESS no underlying pathology is evident and the only predisposing factor is a dehiscence of diaphragma sellae. The SVS downward displacement rarely occurs, ranging from 1.6 to 16%, and has been considered the main determinant of visual worsening, while arachnoidal adherences are occasionally reported [3, 9, 28]. The SVS herniation into the sella turcica may cause: (1) mechanical traction on the optic-chiasmatic neural fibers (direct injury, interruption of axoplasmic transport); (2) kinking of optic nerves or chiasm (i.e. caused by A1 segment' compression); (3) traction or compression of SVS microvasculature (ischemic damage). The blood supply for the superior and central surfaces of the optic chiasm comes from inconstant branches of anterior communicating artery or anastomotic

network of infundibular plexus. Any anatomical distortion caused by displacement of optic chiasm or traction of pituitary stalk and infundibulum may lead to vascular insufficiency [28, 46].

At the contrary, SESS is a pathologic condition in which fibrotic adhesions and scar tissue development are common. In our review (Table 3) we evidenced that in all cases of SESS, in which the optic chiasm has been surgically explored, scar tissue and arachnoidal adhesions have been reported [11, 13, 14, 17, 18, 21, 25, 29, 30, 36]. Mortara and Norell described arachnoidal adhesions between sellar floor and SVS in all cases of SESS and only in one case of PESS [3]. Czech et al. reported 3 cases of SESS after pituitary surgery, describing "gyrus rectus, optic nerve and chiasm tethered to descended diaphragma sellae by dense scar tissues" [18]. Scars and arachnoidal adhesions have been described in association with delayed visual worsening after surgery or radiotherapy even without SVS downward displacement. Some authors have emphasized the role of arachnoiditis around optic nerves and chiasm in the genesis of ischemic chiasmatic syndrome [3, 15, 17, 21, 28]. In 1994 Fischer et al. described one case of delayed visual worsening after TS emptying of Rathke's cleft cyst. The MRI did not show displacement of SVS but an enhancing band of tissue extending from pituitary stalk to anterior portion of the optic chiasm. At re-operation, performed through trans-cranial approach, "the anterior border of the chiasm was bound to the diaphragm by dense scar tissue". The diaphragma sellae was incised and widely resected, leaving the scars attached to the anterior border of the optic chiasm and visual defect improved [17]. Similarly, the illustrative case of delayed visual worsening in SESS reported by Thomé and Zevgaridis highlighted two main topics: the nearly constant presence of dense scar tissue and the frequent vascular compression given by A1 segment [21]. In a case of SESS after surgical removal of hemorrhagic pituitary adenoma, the authors found the left optic nerve "thoroughly coated with scar tissue and tightly adhered to the frontobasal cortex". Freeing the optic nerve by sharp dissection they exposed its direct contact with the left sided A1, which grooves the anterior dorsolateral aspect of the optic chiasm. The visual defect improved after surgical adhesion lysis.

These evidences suggest that in SESS, contrary to PESS, the displacement of the optic chiasm into the sella turcica is not the only factor involved in visual function worsening. Scar tissue and arachnoidal adhesions contribute to visual damage causing anatomical distortion and microvascular damage. These different pathogenic mechanisms may explain: (1) the lack of correlation between the severity of visual impairment and the degree of SVS herniation [2]; (2) cases of delayed visual worsening and SES without SVS downward displacement [15, 17, 21, 28]; (3) the higher frequency of visual damage in SESS compared with PESS [6, 9, 12, 22, 28, 47, 48].

Extradural and intradural chiasmapexy

The different pathogenic mechanisms of visual damage should be considered during surgical planning of chiasmapexy. In PESS the mechanical elevation of SVS performed through extradural or intradural approaches is sufficient, whereas in SESS arachnoidal scar tissue lysis in addition to chiasmapexy is indicate and requires necessarily an intradural approach. The analysis of literature data (Table 3) and our experience in cases of SESS documented arachnoidal adhesions almost in all cases [11, 13, 14, 17, 18, 21, 25, 29, 30, 36]. In the treatment of SESS, the intradural chiasmapexy with arachnoidal lysis or the arachnoidal lysis alone resulted to lead to the best visual outcomes without adjunctive complications in comparison to extradural approaches.

When visual function worsening occurs in patients previously treated for PAs, it is recommended to proceed to MRI and neuro-ophthalmologic tests to rule out tumor recurrence or any different neurologic or ophthalmologic causes of visual deterioration. If MRI shows SVS herniation in SES, it should be considered not only to fix up the optic chiasm but also to free it from adhesions. In these cases, performing intradural TS chiasmapexy could be more effective than extradural approaches, because it allows removing the real causative agents, arachnoidal adhesions tethering optic chiasm and its downward displacement. Even though on one hand extradural procedures are less invasive, on the other the surgeon cannot examine properly the anatomical status of the SVS, which is of paramount importance in SESS. By contrary, in PESS the TS extradural chiasmapexy could be most suitable, at least theoretically, because the main pathologic mechanism is traction and distortion of SVS anatomy.

Surgery may be not indicated as first line treatment when the visual worsening is due to SESS after prolactinoma shrinkage induced by dopaminergic therapy. In this setting, the correct treatment strategy is firstly to lower the dopamine-agonists dose, because it is usually sufficient to reduce the traction on SVS and revert the visual disturbances [20]. An alternative explanation is that dopaminergic drugs could cause direct toxicity, vasospasm-induced ischemia, or reversible perivascular fibrosis.

The last aspect to be considered is the choice of material used to restore the natural position of SVS. Usually abdominal fat tissue, muscle, fascia lata and dural substitute are used in different combination, but the most important step is to reconstruct the sellar floor with septal bone or cartilage to avoid long term resorption and to give support to the packing [11, 40]. We used a three layers of lyophilized bovine pericardium fixed by fibrin glue to reconstruct the

diaphragma sellae and to fit the sella turcica intradurally. A bone fragment is finally used to reconstruct the sellar floor. We think that lyophilized bovine pericardium is an excellent material both for its biological properties and for the possibility to be tailored according to the needs of the local anatomy. Moreover, the fibrin glue and the septal bone fragment are enough to prevent any eventual displacement or movement, as documented by our experience in pituitary TS surgery [40]. To avoid the risk of resorption or displacement after long time, some authors advised the use of synthetic materials [24, 27, 30, 31, 36], but this technique is indicated only in the treatment of PESS and long-term results are disappointing. The intradural placement of synthetic materials is not recommended [27].

Conclusions

Chiasmapexy is the surgical correction of the SVS displacement and is indicated when visual worsening occurs in ES. Our review showed two main surgical approaches to perform TS chiasmapexy. The minimally invasive extradural packing of sellar cavity and the intradural scar lysis associated with diaphragma sellae and sellar floor reconstruction. Resuming the literature evidence, we concluded that in PESS the SVS herniation into the sella turcica is the main condition associated with visual impairment and the extradural TS sellar packing is effective. In SESS the most constant finding is the arachnoidal adhesion between SVS and diaphragma sellae, frequently, but not always, associated with the SVS downward herniation. We evidenced that chiasmapexy in SESS should provide elevation of SVS combined to intradural release of scar tissue and arachnoidal adhesions to obtain good results. Comparing visual outcomes in SESS after extradural and intradural chiasmapexy associated or not with scar tissue dissection and arachnoidal lysis, the best results are reached when intradural chiasmapexy was adopted. Even though the small number of cases reported in literature makes it difficult to obtain guidelines or meaningful statistical results, our analysis confirms the importance of intradural SVS releasing in SESS, besides the diaphragma sellae and sellar floor reconstruction.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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