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The enigma of underdrainage in shunting with hydrostatic valves and possible solutions

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Summary

Objective. Hydrostatic devices have considerable advantages compared to "conventional" differential-pressure-valves concerning overdrainage, but are thought to imply a tendency to underdrain or to clog. The aim of this study was to evaluate the ability of the hydrostatic gravitational Dual-Switch-Valve (DSV) to minimize overdrainage-related complications without increasing the danger of underdrainage.

Results. In a series of 202 adult patients with different etiologies treated with a ventriculo-peritoneal shunt including the hydrostatic Dual-Switch-valve (DSV), 21 cases were suspected of suffering from underdrainage. Using a new algorithm we were able to differentiate obstruction in 6 patients from functional underdrainage in 15 cases, thus we saw an indication to reimplant a DSV with a lower opening pressure in the latter.

Conclusion. The reasons for functional underdrainage were multifold in our series, especially the intraperitoneal pressure is still a "black box". Despite the ability of the DSV to avoid clogging and to minimize overdrainage by its high-pressure-chamber, it remains difficult to determine the optimal opening pressure of the low-pressure-chamber of the DSV for ideal clinical improvement. Therefore a new hydrostatic gravitational "programmable" valve (proGAV), entitled on avoiding the disadvantages of other adjustable devices, has been developed and implanted in 16 patients with promising results.

Keywords: Hydrocephalus; ventriculo-peritoneal shunt; underdrainage; hydrostatic valve; programmable shunt.

Introduction

The first reports about mechanical complications after shunting were dealing mainly with overdrainage-related problems. But especially since the introduction of hydrostatic valves, complications related to underdrainage gain increasing attention. However, an unequivocal evaluation of underdrainage is hindered by discrepancies in the definition of this entity, because in most series "functional" underdrainage is mixed with obstruction due to misplacement or kinking of catheters, disconnection of the shunt or blocking of the valve (Table 1). But if it is desired to evaluate the capability of a valve to avoid the two most important complications of shunting, over- and underdrainage, complications must be differentiated depending on the valve and those which are not directly related to the function of the device itself. For example, infection and surgical problems which include malpositioning of the ventricular or peritoneal catheter. As expected by the construction principle of a hydrostatic device like the DSV, the incidence of overdrainage-related complications was very low. However the question arose as to whether the decrease of overdrainage is counterbalanced by an increase of the rate of underdrainage.

By using our definition of functional underdrainage given in Table 1 we followed a new algorithm (Table 2) to differentiate between obstruction of different causes and functional underdrainage. Furthermore we think it is manditory to introduce a more objective grading system to determine the reduction of ventricular size for correlation with clinical outcome. We also wish to stress the importance of the intraperitoneal pressure for the function of a shunt and possible underdrainage. Therefore in every case of revision of the DSV implanted in the thoracic region we measured the intraabdominal pressure via the peritoneal catheter. Despite meticulous preoperative tests including: pressure measurements while performing a lumbar Tap-test before shunting; taking into account the etiology of hydrocephalus; radiological features and length of history, we could not avoid functional underdrainage due to the choice of a high pressure setting of the primarily implanted DSV. The incidence of functional

Table 1. *Discrepancies in definition and incidence of under- and overdrainage in different series in literature*

Author	Year	Patients and etiology	No. of cases	Type of valve	(functional) Underdrainage	Overdrainage	Under-drainage %	Over-drainage %	% related to
Saint-Rose [15, 16]	1991 1993	mainly children	1719 2062	DP-valves Orbis-S,	"underdrainage" different from obstr.	subdural eff. slit-ventricles isolated ventr.	69.7 (1.7)	12.3	all mechanic. complications
Di Rocco [3]	1994	mainly children	773	DP-valves + Orbis-S,	obstruction differ. from "insufficient drainage"	"excessive drainage"	70 (11)	2.3	all complications
Drake [4]	1996	children	344	DP- + Delta + Orbis-S,	assessed together with obstruction	subdural eff. slit-ventricles isolated ventr.	31.4	3.5	all patients
Boon [2]	1998	adults NPH	96	DP-valves	disconnect. displacem.	subdural effusions	19.8	53.1	all patients
Pollack [13]	1999	children and adults	377	adjust. Medos, DP-Delta-, Orbis-S, valves,	persistent ventriculomegaly	slit-like ventricles, extra-axial collections	7	6	all patients
Zemack [21]	2000	children and adults	583	adjust. Medos	based on symptoms or CT/MR	subdural eff., or signs and symptoms	39.1	35.4	adjustments of valves
UK-Shunt-Reg. [14]	2000	children and adults	10910	various valves	"shunt still functioning on removal"	subdural eff. craniostenosis slit-ventricles	52	3	all revisions
Hanlo *et al.* [5]	2003	children and adults	557	Orbis-sigma II	"valve hydrodynamics"	symptomatic overdrainage with slit-ventricles	22.6 (5)	1.8	all patients
Sprung	2004	adults different etiology	202	DSV	persistent ventr. size ass. with no clinical improving, despite functioning shunt	subdural eff., slit-ventricles clinical symptoms during orthostasis	11.9 (7.4)	5.0	all patients

Note the variations in patient material, different etiologies and valves and to what total number the incidence is related. The incidence of underdrainage in total is including obstruction and functional insufficiencies. The incidence of functional underdrainage in % is shown within brackets.

Table 2. *Algorithm to differentiate obstruction from functional underdrainage and to assess the necessity to revise the shunt/valve*

Diagnostic procedure	Result			Consequence
X-ray of Shunt: ↙	negative	/	Kinking Disconnection Misplacement PK →	Revision of Complication
CT-/MR-control: Shuntogram: ↙	negative	/	Increase ventricles Misplacement VC Shuntogram pos. →	Revision
ICP-measurement via reservoir recumbent + upright: ↙	negative	/	ICP significant higher than opening pressure ICP-drop in upright pos. inadequate →	Exchange of valve
Tap–test (50 ml): ↙	negative	/	Clinical improvement →	
No operation				Exchange of valve

Table 3. *Clinical data of patients with DSV*

Etiology	n	Sex		Age	Opening pressure horiz./vertical [cmH_2O]	n	Replace-ments	Follow-up
		f	m					
Idiopathic NPH	59				13/40	117		
Typ. secondary NPH > 3 mos	44				10/40	72		
Acute/subacute NPH < 3 mos	72			17–85 yrs	8/40	5		6–84 mos
Hypertensive hydrocephalus	13	106	96	∅ 60.8 yrs	5/40	6	21	∅ 33.2 mos
Pseudotumor cerebri	3				16/50	2		
Pat. not to wean from ext. drainage/narrow ventricles	11							

underdrainage in our DSV-series was one of the main reasons to look for a solution by adding the principle of adjustability to the advantages of gravitation-assisted hydrostatic devices. Therefore we saw an indication to construct a new adjustable valve (proGAV) avoiding the well known disadvantages of the "programmable" devices currently available.

Material and methods

From the beginning of 1995 to the end of 2002 we conducted a consecutive series of 202 adult patients, in whom we saw an indication for shunting, by implanting a frontal ventricular-peritoneal shunt including a burr-hole reservoir and a Dual-Switch-Valve. The collective comprised a majority of 76 cases with idiopathic and secondary Normal-Pressure-Hydrocephalus (NPH). 65 patients with development of subacute hydrocephalus (HC) within 3 months after the causative incident were differentiated, according to the Dutch NPH-Study [2], from typical secondary NPH (Table 3) with a time-gap of more than 3 months.

To avoid only subjective assessment of the ventricular regression postoperatively, we introduced an objective scale by grading the reduction of the Evans' Index (Fig. 1). The postoperative complications were differentiated in valve-related and those independent of valve-function.

A standarized assessment of clinical outcome was difficult due to the variety of etiologies in our series. We used different grading systems including the Stein and Langfitt-Scale and the Black-outcome-scale. The clinical outcome was determined not earlier than 6 months after shunting.

The proGAV comprises an adjustable unit in series with a gravitational hydrostatic unit, the Shunt-Assistant (Fig. 2). The adjustable unit consists of a differential-pressure-valve with a "brake" to avoid unintended changes of pressure-setting like in other adjustable devices. The brake working by friction of the rotor on the housing can be decoupled transcutaneously by an adjustment-pin to change the opening pressure of the valve. There is a wide pressure range from 0 to 20 cm H_2O. In the lying position the opening pressure is dependent only on the adjustable unit because the gravitational unit is not activated. If the patient moves into the upright position, the heavy tantalum-ball of the gravitational unit gradually closes the outlet of the valve. Thus in the upright position it remains closed until the intraventricular pressure plus the hydrostatic pressure is higher than the sum of the opening pressure of both units. By this mechanism the proGAV is counterbalancing the hydrostatic pressure in the vertical position of the shunted patient.

Since February 2004, 16 of the new adjustable proGAVs have been integrated in V-P-shunts of adult patients with different types of hydrocephalus. In this preliminary series we were primarily interested in the question whether the construction of the new valve can be implanted without surgical difficulties and able to serve as a draining-device at least as good as other gravitation-assisted valves. Our secondary aim was to evaluate the security of different new tools to adjust the valve transcutaneously and the safety to determine the adjusted opening pressure avoiding the burden of multiple X-ray-controls. Furthermore we were interested in the capability of the new mechanism to avoid unintended adjustments.

Results

The outcome in our series of 202 patients with DSV was characterized by excellent and good clinical results accompanied by an only minimal reduction of ventricular size in the majority of cases. A total of 16 patients (7.9%) suffered from infections and 6 cases from minor surgical complications requiring revisions. The latter included 3 misplacements plus 1 kinking of the ventricular catheter, and 2 occlusions or malpositioning of the peritoneal catheter. We included 3 patients, in whom we primarily suspected functional underdrainage in this category of complications (not depending on valve-function), because the patients did not improve clinically despite operative change to a valve with a lower opening pressure. Probably this non-responsiveness was due to the severe damage done to the brain by the causative incidents pre-shunting (2 cases of ICB and 1 SAH), which could not be compensated by drainage of the hydrocephalic state.

The 17 cases of functional underdrainage could be subdivided in 15 with a wrong (too high) choice of pressure level, 1 change of pressure setting in vivo 2 years following implantation and 1 patient with abnor-

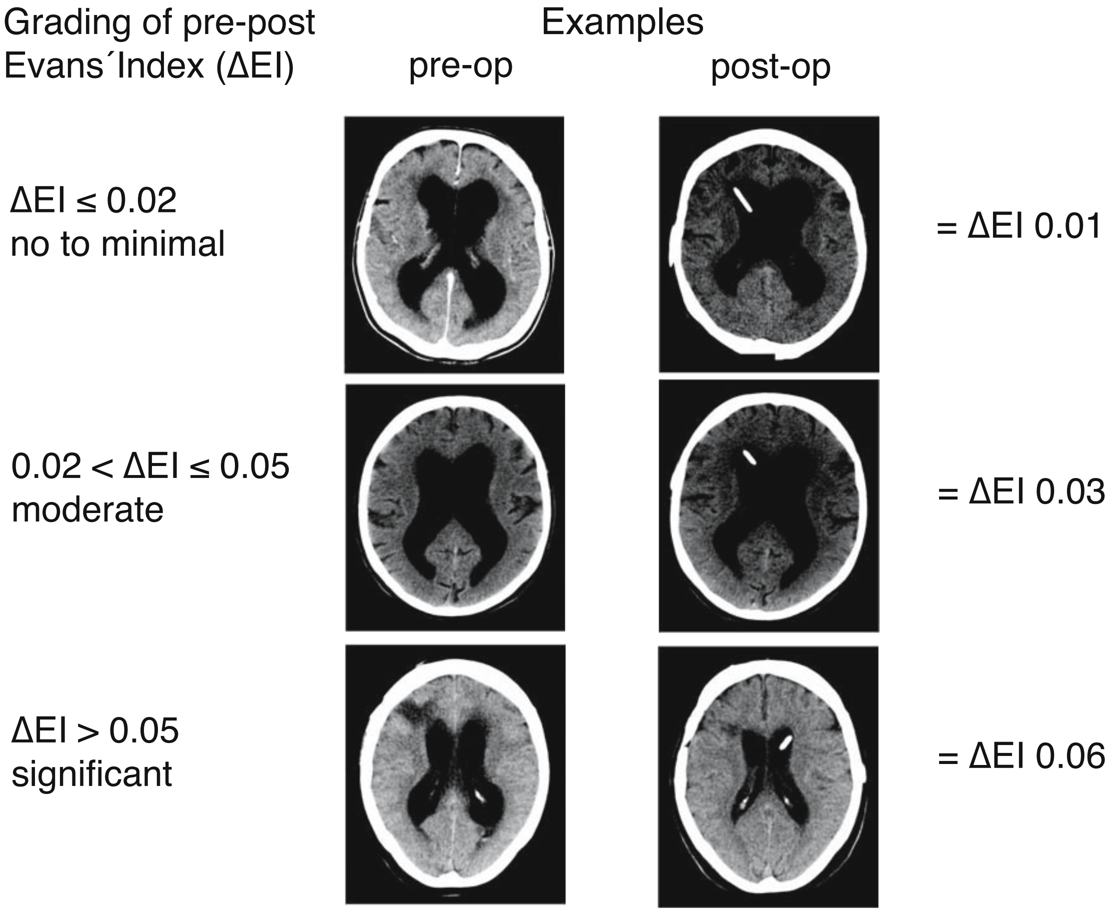

Fig. 1. Objective grading of the reduction of ventricular size by measuring the Evans-Index pre-/postoperatively

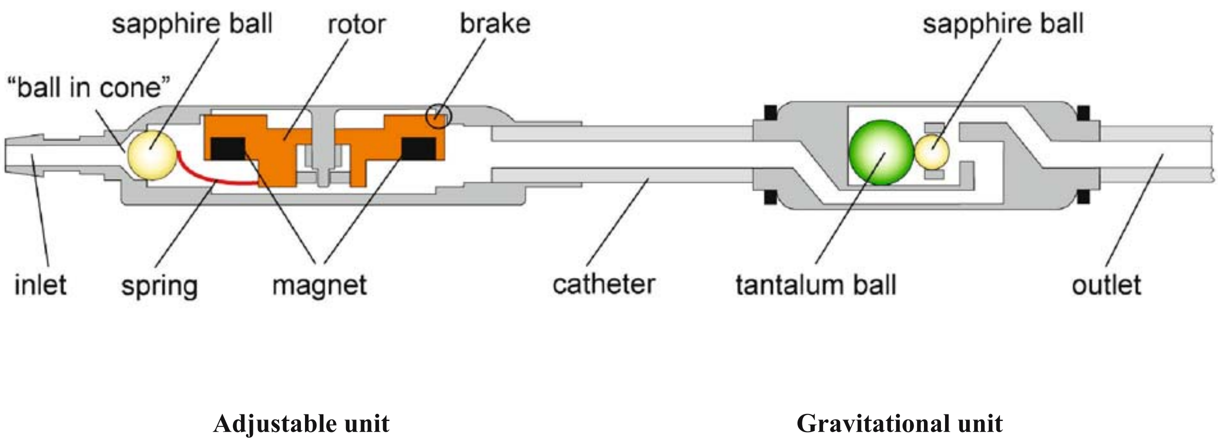

Fig. 2. Schematic depiction of proGAV

mal high intraperitoneal pressure. The 10 cases with overdrainage comprised 1 patient with slit-like ventricles five days postoperatively, 4 hygromas (3 transient and 1 persistent) and 5 subdural hematomas.

Of the patients with overdrainage related to the function of the DSV, all 10 presented clinical and radiological evidence of overdrainage. In only 7 cases, the overdrainage was persistent. Surprisingly one of

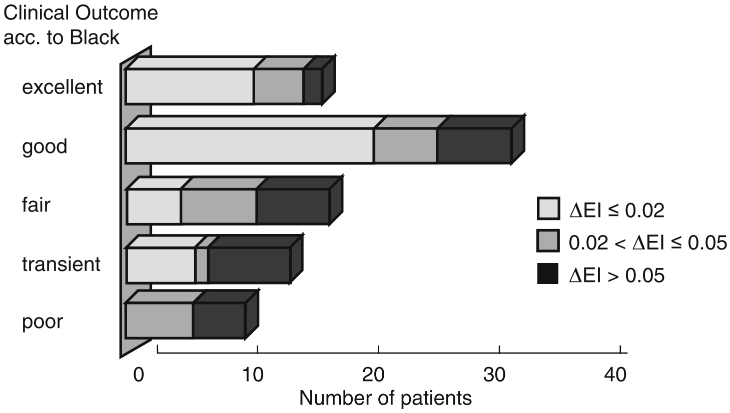

Fig. 3. Correlation of clinical outcome and reduction of ventricles

the cases with pseudotumor cerebri and narrow ventricles developed subdural hematoma. All other hydrocephalic cases with overdrainage – related complications necessitating revisions revealed predisposing factors like aqueductal stenosis due to isolated IV.ventricle, pre-shunt small subdural hematoma, too inclined implantation of the valve and one case with spontaneous fronto-basal fistula and pneumatocephalus. None of the patients with idiopathic or typical secondary NPH in our series developed persistent overdrainage-related complications. Thus, we believe the results of our collective concerning subdural effusions were superior to comparable series in the literature.

"Functional" underdrainage was suspected in 25 of our patients. Following the exclusion of obstruction due to other causes by the usual diagnostic procedures, all these cases underwent a continuous pressure-measurement in the recumbent as well as in the upright position via the Rickham-reservoir on a tilting-table, followed by a Tap-test. By this method we could clearly differentiate between obstruction and functional underdrainage in most cases (Table 2).

We did not find one obstruction of the valve itself neither by this pressure-measurement nor by re-examination of the explanted valves despite the fact that our series included several cases with high protein levels in the subgroup of cases with acute/subacute hydrocephalus. All explanted valves were re-evaluated by the manufacturer and with only one exception revealed the exact pressure-levels as stated before implantation.

After implanting a valve with a lower opening pressure for the recumbent position, 17 cases improved clinically but 3 did not. Thus in the latter cases the failure of shunting was judged as not depending on the valve-function.

A comparison of this complication to other series was not possible because other authors did not differentiate between obstruction and functional underdrainage (Table 1).

An only minimal or no reduction of ventricular size was documented on follow-up CTs in about 70% of our series with the hydrostatic DSV (Fig. 3). However, there were unequivocal differences concerning reduction of ventricles between the various forms of hydrocephalus in our patient group. Whereas hypertensive hydrocephalus revealed significant reduction of the ventricles in the majority of cases, the percentage of significant regressions was reduced in patients with sub-acute hydrocephalus and lowest in NPH-cases. Contrary to the radiological outcome a comparison of the clinical results depending on etiology did not reveal significant differences.

In agreement with the experience of the majority of authors reporting series with hydrostatic valves no correlation was found between the grade of regression of ventricles and overall clinical outcome (Fig. 3).

Despite numerous bench-tests in our 3-Tesla-MRT unit which provided evidence of the safety of pressure-level setting, the clinical series of 16 cases with proGAV is much too small and the follow-up is too short to assess one of the main theoretical advantages of the proGAV, the capability to avoid unintended adjustments by the "brake". There were no difficulties in releasing the brake for changing the opening pressure and we did not have to register an unintended adjustment in the clinical course of our 16 patients up to now.

Discussion

Since 1995 the hydrostatic gravitation-assisted Dual-switch-valve has been implanted for shunt-treatment of hydrocephalus [11, 17]. Since that time, the device has proven to be capable to decrease the rate of overdrainage in different forms of hydrocephalus [6, 8–10, 18, 19] without significantly increasing the complication of underdrainage. Nevertheless it remains difficult to define the ideal opening pressure of the valve for an optimal clinical result in the individual patient and in some cases it is unclear whether a better result could have been achieved with a lower opening pressure of the valve. The problem of underdrainage is multifold up to now and all efforts should be undertaken to solve the enigma for the successful shunting of hydrocephalic patients.

A prerequisite for a thoughtful comparison of shunt valves are corresponding definitions of the complications and similarity of the most important items of the series like patient inclusion, etiology of hydrocephalus and uniformity of implanted valves. However in the literature these criteria are not fulfilled in the vast majority of reports about shunt series. In some of the most important publications mostly children are included [3, 4, 15, 16], various groups comprise children and adults [13, 14, 21], whereas others exclusively adults with only one etiology [2] or with different types of hydrocephalus [17–19]. Whereas the definition of overdrainage is comparable in most of the series (Table 1), the complication of underdrainage is delineated differently by the various authors. While some reports differentiate clearly between obstruction and functional underdrainage [3, 16], others presume obstruction together with functional underdrainage [4], and do not mention the latter important complication at all [2, 13] or give equivocal definitions like "shunt still working on removal" [14] or "valve hydrodynamics" [5]. Another reason for the extremely divergent results concerning the incidence of these two most important complications after shunting is the different choice of the parameter under- and overdrainage is related to in these series (Table 1). In addition to the wrong choice of a too high pressure level by the surgeon, the intraperitoneal pressure remains a "black box" up to now necessitating the measurement of the patency of the peritoneal catheter and the intraperitoneal pressure during the revision. By this relatively simple manauver you can exclude or prove other possible reasons for non-responsiveness of shunts [20].

The grade of reduction of ventricular size with this type of valve depends on the etiology of hydrocephalus, but also on the pressure-setting. If there is a significant or moderate reduction, obstruction and functional underdrainage can be ruled out. On the other hand an only minimal or no reduction of ventricular size does not rule out good or even excellent clinical results. Apparently older brains of adults with more chronic forms of hydrocephalus and this type of hydrostatic valve react different from juvenile hydrocephalus and treatment with differential-pressure valves. Furthermore, in many cases brain tissue damage may be severe. In agreement with the majority of authors [2, 3, 6, 8, 9, 19, 22] but contrary to others [1, 5, 7, 12] no correlation was found between grade of regression of ventricles and overall clinical outcome (Fig. 3).

The outcome of our series also stresses the necessity to improve the preoperative diagnostic tools and the importance of the possibility to adjust the valve in order to avoid functional underdrainage. The clinical and radiological results of our small series of 16 patients with the adjustable proGAV provides evidence that this construction principle can help to minimize the danger of functional underdrainge. But the cohort of our pro-GAVs is too small and the follow-up is too short to compare our results with series comprising other adjustable devices.

Conclusions

The outcome of our series proves the capability of the DSV to minimize overdrainage – related problems also in patients suffering from idiopathic NPH. The discrepancies regarding the definition of underdrainage are the main reason for the differences regarding the incidence of this mechanical complication reported in the shunt-literature. The results also point out that the choice of the ideal opening-pressure of the valve to achieve the optimal clinical result after shunting remains difficult and a matter of controversy up to the present time. This study of the new adjustable pro-GAV provides evidence which minimizes the problem of functional underdrainage in shunts. However, a larger series and a longer follow-up is necessary before we can decide whether the enigma of underdrainage can be solved by this device and lead us toward a new era of shunting.

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