

Review Article:

Success Rates and Complications of Ventriculoperitoneal and Ventriculoatrial Shunting: A Systematic Review



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ABSTRACT

Background and Aim: The insertion of Ventriculoperitoneal (VP) or Ventriculoatrial (VA) shunt is the first line of treatment in patients with hydrocephalus and normal-pressure hydrocephalus. The provision of a safety profile for shunting in the treatment of hydrocephalus patients is very important. This study aimed to determine the success rates and complications of VP and VA shunting in patients with hydrocephalus.

Methods and Materials/Patients: This systematic review investigated the complication rates of VP and VA shunting in managing patients with hydrocephalus. All the published studies were searched in three electronic databases of Web of Science, PubMed and Google Scholar from March 20 to April 10, 2020, using the keywords of "Ventriculoperitoneal" and "Ventriculoatrial" in combination with "Hydrocephalus".

Results: In total, nine articles met the eligibility criteria for being included in this review. Some studies showed a higher rate of shunt obstruction in patients undergoing VA shunting; however, other studies demonstrated no difference in terms of shunt obstruction. The rates of primary revision shunt were various within the ranges of 5.4%-48% and 9.1%-58% for VA and VP shunting, respectively. A higher rate of revision shunt was reported among the patients undergoing VP shunting, compared to that reported for VA shunting. The different mortality rates in various studies were estimated within the range of 0%-10% and at 13.9% for VA and VP shunting, respectively.

Conclusion: In general, no difference was reported between VA and VP shunting regarding the rates of complications and mortality. Due to the ease of placement and revision, VP shunting could be considered the first-line treatment of hydrocephalus. However, this approach has been preferred in newborns, and there have been insufficient data on adults in this regard.

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Highlights

- Some studies showed a higher rate of shunt obstruction in patients undergoing VA shunting.
- Other studies demonstrated no difference in terms of shunt obstruction.
- In general, no difference was reported between VA and VP shunting regarding the rates of complications and mortality.

Plain Language Summary

For management of hydrocephalus, we usually use Ventriculoperitoneal (VP) or Ventriculoatrial (VA) shunts that drain CSF (cerebrospinal fluid) in the abdominal cavity or heart, respectively. CSF shunting is the most popular operation in the field of pediatric neurosurgery. Shunt obstruction and shunt infection are the most important complications of the shunting process. The provision of a safety profile for shunting in the treatment of hydrocephalus patients is very important. This study aimed to determine the success rates and complications of VP and VA shunting in patients with hydrocephalus. Some studies reported a higher rate of shunt obstruction in patients undergoing VA shunting; however, other studies demonstrated no difference in terms of shunt obstruction. In general, no difference was reported between VA and VP shunting regarding the rates of complications and mortality. Due to the ease of placement and revision, VP shunting could be considered the first-line treatment for hydrocephalus. However, this approach has been preferred in newborns, and there have been insufficient data on adults in this regard.

1. Introduction

Commonly, a high rate of shunt failure that necessitates a shunt revision or replacement is reported in hydrocephalus patients. The insertion of Ventriculoperitoneal (VP) or Ventriculoatrial (VA) shunt is the first line of treatment in patients with hydrocephalus and Normal-Pressure Hydrocephalus (NPH) [1-4]. However, the administration of either of these treatments has complications and problems. Infection, shunt obstruction, and subdural hemorrhage are the main complications of using VA and VP shunts. Although severe morbidities in terms of cardiopulmonary and renal complications are reported due to the use of VA shunts, compared to that of VP shunts [5, 6], there is no significant difference between the VA and VP shunts in terms of complications among adult patients [7, 8].

Some reports demonstrated cardiopulmonary complications resulting from using VA shunting, which is rarely applied for patients with NPH. However, these severe complications are more frequently observed among adults for whom VA shunts have been placed during childhood. McGovern et al. showed no statistically significant difference in the perioperative and postoperative complications, including distal revision, proximal revision, and postoperative seizure, for VP and VA and shunting. However, symptomatic shunt infection and intracerebral hemorrhage and were only reported

in patients undergoing VP shunting [8]. Since technical challenges are associated with the insertion of VA shunts and complications, the use of VP shunts is more common, compared to that of VA shunts [9, 10]. Nevertheless, the patients with abdominal factors, such as cirrhosis-related ascites, complications of prior VP shunting, prior abdominal surgeries, as well as pseudocysts and peritoneal infections are not eligible for the placement of VP shunts [11-15]. Moreover, the infections due to the insertion of the catheter may lead to some severe complications, including cardiac damage, renal failure, and subacute endocarditis [5, 16, 17].

The effectiveness and complication rates of VA and VP methods have been reported in different studies; however, the comparison between the two techniques is difficult due to the different results [18]. The rates of complications may be different over time, even in the same investigated group. Regarding what was discussed, the assessment of the success rates and complications of VP and VA shunting is critical to guide the involved specialists regarding the use or nonuse. This study aimed to determine the complications of VP and VA shunting in patients with hydrocephalus. In this regard, the following questions were assessed by the present review:

Are there more complications with VA or VP shunting in patients with hydrocephalus?



Are there more shunt obstruction and revision in VP or VA shunting?

Are there any differences between the outcomes of VA and VP shunting in adults and newborns?

2. Methods and Materials/Patients

This systematic review investigated the complication rates of VP and VA shunting for managing patients with hydrocephalus. In this study, the eight stages of the Cochrane Handbook for Systematic Reviews of Interventions were used in the search process. These stages include investigating the exclusion and inclusion criteria, performing an extensive search for data collection, extracting the data, studying the extracted data evaluating the quality assessment, and removing ineligible articles [19].

Eligibility criteria

The inclusion and exclusion criteria were selected based on the Participants Intervention Comparison Outcome Study design. All the studies comparing VA with VP shunts in any age range were included in the present study. The primary inclusion criteria were publication in English, examination of human samples, clear explanation of VP and VA shunting with associated complications, and comparison of two VP and VA shunting approaches. Since the objective of the present study was to compare the consequences of VP and VA shunting in patients with hydrocephalus, the papers focusing only on one type of VP or VA shunts were excluded from the study. Moreover, animal and in vitro studies were removed from the current process. We also restricted short communications, meta-analyses, narrative articles, qualitative investigations, case reports or case series, reviews and editorial letters. Because of the observational nature of the present study, all case-control, retrospective and prospective studies on human subjects assessing the consequences of VP and VA shunting were entered in the present review.

Literature search

All the published studies were searched in three electronic databases of PubMed, Web of Science and Google Scholar, and from March 20 to April 10, 2020, using the keywords of "Ventriculoperitoneal" and "Ventriculoatrial" in combination with "Hydrocephalus".

Study design and data extraction

This systematic review has focused on the consequences of VP and VA shunting and determined which approach is more appropriate for the treatment of patients with hydrocephalus. In the first stage, three selected electronic databases of Web of Science, PubMed and Google Scholar, were searched up to April 10, 2020. The identified papers in each database were selected, and the duplicates and unrelated articles were removed. Subsequently, the abstracts and titles were reviewed, and the eligible articles were screened for relevancy. In total, two researchers worked together during the search process and separately reviewed the abstracts and titles of all the articles. In the next step, the full-text versions of the selected studies consistent with the objectives of the present study were obtained for final evaluation. In this step, the articles with insufficient data were removed from the study. The researchers were continuously in contact with each other to select papers, as well as extract and exchange data. Finally, the data were recorded in a researcher made checklist. PRISMA flowchart represents the stages in the selection of the articles (Figure 1).

Risk of bias and quality assessment

The risk of bias for each paper was evaluated based on Cochrane's risk of bias tool. According to the tool, all selected articles were assessed in eight domains: selection of sample size, selective reporting, missing data, bias due to confounders, a departure from intended intervention, measurement outcome, measurement of intervention, and other sources [20]. The options were chosen based on the observational nature of the selected studies.

3. Results

Out of 1532 identified papers in the first step of the search process, 1304 articles were unrelated to the study's objectives and removed from the study. During the preliminary assessment of 228 remained studies, 37 duplicates were excluded from the review. Furthermore, the articles (n=55) evaluating only VP or VA complications in hydrocephalus patients were removed from the study because only the comparative studies were included assessing the complication rate of VP shunting, compared to that reported for VA shunting. In addition, the papers published in other languages, except for English (n=7), in vitro articles (n=0), animal studies (n=0), technical notes (n=11), editorial letters/short communications (n=5), books (n=2), reviews and narrative articles (n=12), case series (n=19) case reports

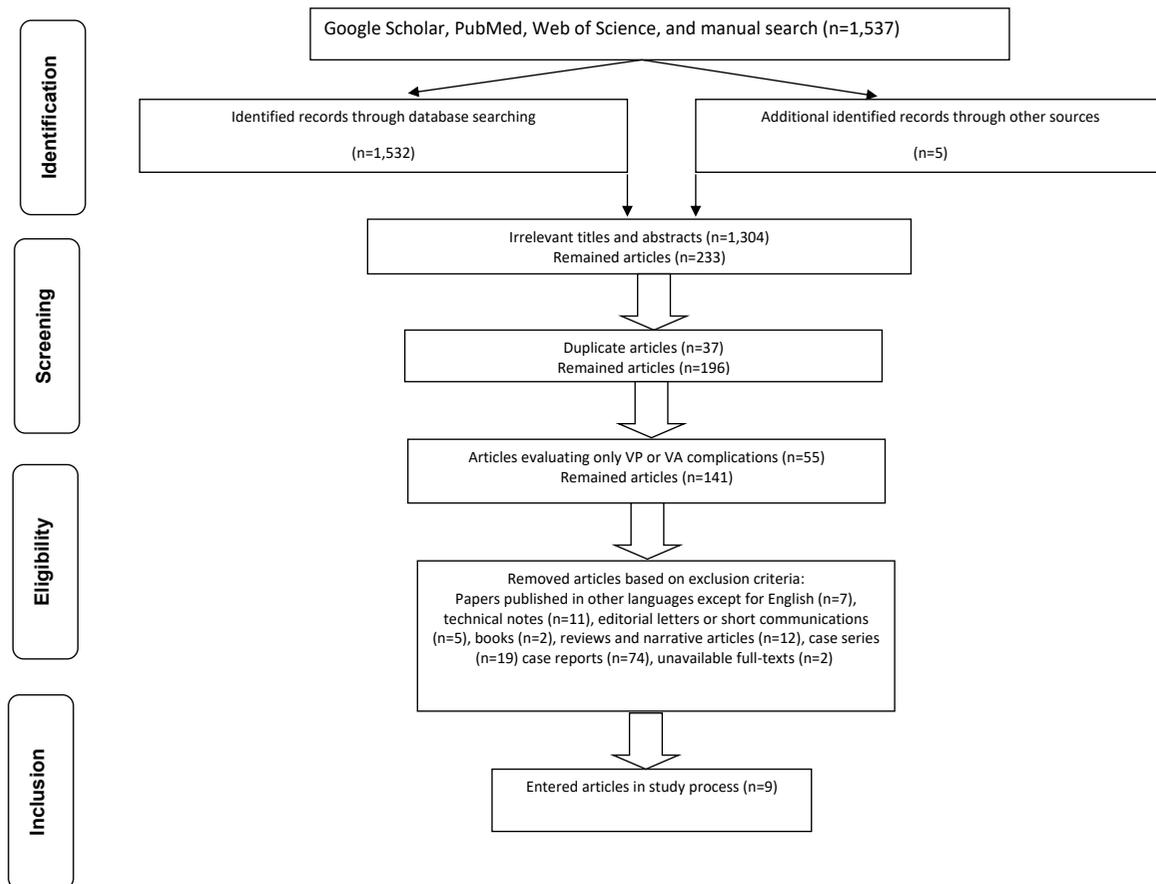


Figure 1. PRISMA flow chart representing the process of paper selection in the review



(n=74), and unavailable full-texts (n=2) were excluded from the study. Finally, 9 papers remained. PRISMA flowchart represents the process of paper selection in the review (Figure 1).

Given that restricting patients from treatment is immoral, there was no randomized clinical trial. All the papers were comparative retrospective studies. The included studies were performed in seven different regions, most frequent of which (33%) were carried out in the USA. In addition, two studies (22%) were conducted in Italy. Other studies were performed in Finland (n=1), Sweden (n=1), Canada (n=1), and Colombia (n=1). No study has been carried out in Asia and Africa. The included articles were performed on 2652 patients with NPH, among whom 876 and 1741 subjects were treated using VA and VP shunting, respectively. The mean age of the patients entered in the above mentioned studies was very different. Some studies focused on newborns with hydrocephalus; however, other studies were performed on adults with NPH. Accordingly, the subjects were within the age range of 1 day to 91 years. Totally, four (44.4%) studies were performed on adults, and four

(44.4%) studies on newborns. Furthermore, a study was conducted on both adult and newborn populations. Other studies were included if only hydrocephalus was reported in the description of patients.

In addition, the male/female ratio was not specific in the majority of the studies. Only four studies assessed the male/female ratio in which there was no remarkable difference between males and females. The reason for shunt placement was reported in only five studies. Tumors as the indicators of shunt placement were observed in 29% and 32% of the patients in studies performed by Lam et al. [21] and Puca et al., respectively [22]. Peritonitis, abdominal pseudocyst, and abdominal adhesions lead to shunt placement in 52%, 12%, and 7% of patients, respectively. Moreover, necrotizing enterocolitis and acute bowel obstruction result in shunt placement in 6% and 2% of the subjects, respectively [23]. Aqueductal stenosis was the reason for shunt placement in 42%, and only 3% of the patients in the studies carried out by Fernell et al. [24] and Lam et al., respectively [21].

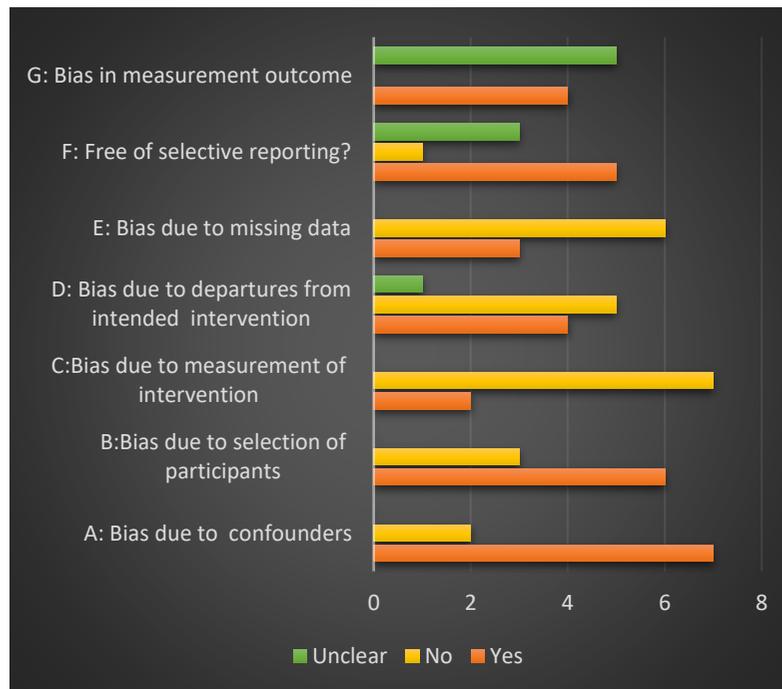


Figure 2. Quality assessment of the included articles in the review process



The total rates of complications for VA and VP shunting were within the ranges of 36%-43% and 42%-47% among adults, respectively. This rate was not reported in the studies performed on newborns with hydrocephalus. The rates of a subdural hematoma were various within the ranges of 4%-12.7% and 5%- 6.6% for VA and VP shunting, respectively. The rate of a subdural hematoma was not compared in four studies conducted on newborns. Among the studies comparing a subdural hematoma in hydrocephalus patients undergoing VA and VP shunting, some studies reported a significant difference in the rates of a subdural hematoma between VA and VP shunting; however, several studies showed no differences between the two techniques. The obtained results of the studies on intraventricular hemorrhage due to VP and VA shunting were incompatible. The findings of the two studies assessing the adults with hydrocephalus showed no significant difference between VA and VP shunting in terms of hygroma.

No study has reported cardiopulmonary complications. Some studies demonstrated a higher rate of shunt obstruction in patients undergoing VA shunting. Nevertheless, other studies indicated no difference between the two techniques in shunt obstruction. The rates of primary shunt revision were various within the ranges of 5.4%-48% and 9.1%-58% for VA and VP shunting, respectively. A higher rate of shunt revision was reported for the patients undergoing VP, compared to VA shunt-

ing. The different mortality rates in various studies were estimated within the range of 0%-10% and at 13.9% for VA and VP shunting, respectively. Quality assessment of the included article is shown in Table 1.

Determination of the risk of bias

Generally, to assess the quality of the included studies, nine articles were reviewed in this study based on the eight domains of the Cochrane guidelines. The low and high risks of bias were marked as "Yes" and "No", respectively. "Unclear" was considered for unknown or unclear risk of bias (Figure 2). Table 2 tabulates the extracted data from each study in details.

4. Discussion

For the first time, Nulsen and Spitz suggested VP shunting and Holter valve-regulated shunt system for patients with hydrocephalus [28]. In addition, VP shunts were used by Scott et al. in 1955 [29]. This systematic review investigated all the papers assessing the complications associated with VA and VP shunting for the treatment of children and adults with hydrocephalus. In this with exclusively VA shunts [24]. Similarly, based on another study conducted by Olsen et al. on pediatric patients, the complications of VP shunts were less severe, and the mortality rate was much lower, compared to those reported for the VA method [25].



Table 1. Quality assessment of the included articles in the review process

Authors	Bias Due to Confounders	Bias Due to Selection of Participants	Bias Due to Measurement of Intervention	Bias Due to Departures from Intended Intervention	Bias Due to Missing Data	Free of Selective Reporting	Bias in Measurement Outcome
Hung et al. [27]	Yes	Yes	No	No	No	No	Yes
McGovern et al. [8]	Yes	Yes	No	No	No	No	Yes
Ignelzi et al. [7]	Yes	Yes	No	No	No	No	Yes
Lam et al. [21]	Yes	Yes	No	No	Yes	No	Yes
Olsen et al. [25]	Yes	Yes	No	No	No	No	Yes
Pasqualin et al. [26]	No	No	Yes	Yes	Yes	Yes	Unclear
Fernell et al. [24]	Yes	Yes	Yes	No	Yes	No	Unclear
Puca et al. [22]	Yes	No	Yes	Yes	Yes	Yes	Unclear
Rymarczuk et al. [23]	No	No	Yes	No	No	Yes	No



The rates of mortality due to shunting are reported within the ranges of 0%-6% [33-37] and 0%-9% [18, 32, 35, 38] for VP and VA shunt surgeries, respectively. Formation of thrombosis on the distal catheter and thrombosis of jugular or vena cava after using VA shunts have been reported in some studies [7, 21], leading to consider the potential for future complications in cardiopulmonary system in patients treated with VA shunting. However, Rymarczuk et al. has recently shown no significant differences between the complications and mortalities of VP and VA shunts [23], which is in line with the obtained results of a study by Ignelzi et al. [7].

A study by McGovern et al. determined the safety of VA shunts, compared to that of VP shunts in adult patients with NPH [8], who were treated by a single surgeon at Columbia University Medical Center of USA from January 2002 to December 2011. Both idiopathic and secondary NPH patients were entered in the aforementioned study. The obtained results showed no significant difference between VA and VP shunting in terms of bleeding, infection, distal catheter malfunction, and proximal catheter malfunction. However, the frequency of the aforementioned variables was lower in VA shunting but not statistically significant. The incidence of a subdural hematoma was slightly higher in VA shunting than that reported for VP shunting but not statistically significant. No mortality and cardiopulmonary complications were reported due to VA or VP shunting [8].

Based on the results of a study by Hung et al., a subdural hematoma after shunt insertion was the most common intracranial complication (12.7%) in patients undergoing both VP and VA shunting, the rate of which is lower than those reported for previous studies (range: 20.8%-23%) [39, 40]. In addition, the rate of a subdural hematoma was higher among patients undergoing VA shunting, compared to that reported for VP shunting. In general, no difference was observed in the rates of complications between VA and VP shunting, as confirmed by the finding of other similar studies [18, 25, 30-32].

More severe morbidities, including pulmonary hypertension, cor pulmonale, renal and cardiopulmonary complications, are more frequently reported among patients undergoing VA shunting than those reported for VP shunting [5, 6, 41]. The infections due to the use of a catheter may lead to renal failure, progression to end stage renal disease, immune complex mediated nephritis, cardiac damage and subacute endocarditis, in both VA and VP shunting [5, 16, 17, 42, 43]. Renal problems, such as nephritis and renal failure, may be secondary to the infection and activation of the immune system [16, 27, 42, 43]. Although the long-term prognosis of renal dysfunctions is concerning, its frequency is reported as very low; accordingly, eligible patients should not be precluded from receiving VA shunts.

Table 2. Extracted data obtained from entered studies

Author Reference	Country	Sample Size	Age	Male/Female Ratio	Disease	Reason for Shunt Placement	Total Complications	Subdural Hematoma	Shunt Obstruction	Postoperative Infections	Intraventricular Hemorrhage	Hygroma	Cardiopulmonary Complications	Proximal Catheter Malfunction	Distal Catheter Malfunction	Primary Revision Shunt	Mortality	
Ignezi et al. (1975) [7]	USA	300	1 day to 90 years	--	H ³	Not reported	--	--	97 (32.3%)	VA: 11 (3.6%)	--	--	--	VA: 27 (31%)	VA: 47 (55%)	VA: 48% (55%)	VA: 0	
										VP: 7 (10.6%)				VP: 10 (15%)	VP: 49 (71%)	VP: 58% (81%)	VP: 0	
										Other: 9								
Olsen et al. (1983) [25]	Sweden	172	VA: 4.9 VP: 4.6 (months)	--	H	Not reported	--	--	29 (17%)	VA: 31 (30%)	--	--	VA: 23 (23%)	VA: 48 (47%)	VA: 40% (47%)	VA: 3 (2.9%)		
									VP: 16 (23%)	VP: 14 (18%)			VP: 46 (61%)	VP: 32% (32%)	VP: 0			
Mazz et al. (1980) [26]	Italy	180	21 months	90/75	H	Not reported	72 (43.6%)	VA: 3 (4%)	VA: 24 (33%)	VA: 5 (6.9%)	2 (1%)	--	--	VA: 23 (23%)	VA: 48 (47%)	VA: 33 (45.8%)	VA: 7.4% (4.1%)	
							VP: 6 (5%)	VP: 18 (16%)	VP: 14 (12.9%)		VP: 56 (51%)			VP: 13.9%				
Fennell et al. (1985) [24]	Finland	289	VA: 0.9±1.6 VP: 0.6±1.3 (months)	--	H	Perinatal complications: 28% Central nervous system anomalies: 25% Congenital or neonatal infection: 4% Miscellaneous: 2%	--	--	VA: 50 (42%)	VA: 9 (7%)	VA: 5 (6.9%)	--	--	VA: 78 (37%)	VA: 22 (11%)	VA: 22 (11%)	Higher in VP shunting (10%)	VA: 8 (10%)
									P<0.001	VP: 31 (18%)	VP: 11 (4%)			VP: 7 (5.3%)				
Puca et al. (1991) [22]	Italy	356	Adults	--	H	Tumor: 32% Idiopathic chronic hydrocephalus: 23% Hemorrhage: 14% Intracranial hypertension: 13%	--	--	VA: 5 (20%)	VA: 4 (16%)	VA: 4 (16%)	--	--	VA: 25 (27%)	VA: 25 (27%)	VA: 25 (27%)	VA: 25 (27%)	VA: 25 (27%)
									VP: 19 (27%)	VP: 17 (24%)	VP: 17 (24%)							

Author Reference (Year)	Country	Sample Size	Age	Male/Female Ratio	Disease	Reason for Shunt Placement	Total Complications	Subdural Hematoma	Shunt Obstruction	Postoperative Infections	Intraventricular Hemorrhage	Hygroma	Cardiopulmonary Complications	Proximal Catheter Malfunction	Distal Catheter Malfunction	Primary Revision Shunt	Mortality
Lam et al. (1997) [21]	Canada	128 VA: 49 VP: 73 Mixture: 6	Adults	--	H	NPH: 43% Tumors, including carcinomas meningiomas: 29% Intracerebral and subarachnoid hemorrhage: 13% Aqueeductal stenosis: 3% Post-trauma: 2% Meningitis/Ependymitis/Arachnoiditis: 2% Congenital: 2%	68 (40.5%)	VA: 10 (20%) VP: 5 (6%)	VA: 6 (12%) VP: 12 (16.9%)	3 (2.3%)	--	--	--	VA: 2 (4%) VP: 7 (9.8%)	VA: 4 (8%) VP: 5 (7%)	33 (25.7%)	VA: 2 (4%) VP: 7 (9.8%)
McGovern et al. (2014) [8]	USA	187 VA: 30 VP: 157	VA: 73.7 VP: 76 (years) P=0.19	VA: 14/16 VP: 86/71 P=0.34	NPH	Not reported	VA: 43.2% VP: 47.1%	VA: 8.1% VP: 6.6% P=0.74	VA: 1 (3%) VP: 5 (3.2%)	VA: 0 VP: 2%	VA: 0 VP: 1.5%	VA: 27% VP: 26.4%	VA: 0 VP: 0	VA: 2.7% VP: 2.5%	VA: 2.7% VP: 6.6%	VA: 5.4% VP: 9.1%	VA: 0 VP: 0
Hung et al. (2017) [27]	USA	496 VA: 150 VP: 346	VA: 74 VP: 73 (years) P<0.05	VA: 58/42 VP: 58/42 P=0.94	NPH	Not reported	VA: 54 (35%) VP: 147 (42.5%) P=0.18	VA: 19 (12.7%) VP: 19 (5.5%) P=0.006	VA: 10 (6.7%) VP: 53 (15.3%) P=0.008	VA: 3 (2%) VP: 10 (2.9%) P=0.52	VA: 5 (3.3%) VP: 3 (0.9%) P=0.06	VA: 9 (6%) VP: 16 (4.6%) P=0.52	VA: 0 VP: 0	--	--	VA: 16 (10.7%) VP: 100 (28.9%) P<0.001	VA: 0 VP: 0
Rymarczuk et al. (2020) [23]	Columbia	544 VA: 85 VP: 459	VA: 2.3 VP: 5.3 (years) P>0.05	VA: 41/44 VP: 236/223 P>0.05	H	Peritonitis: 52% Abdominal pseudocyst: 12% Abdominal adhesions: 7% Necrotizing enterocolitis: 6% Acute bowel obstruction: 2% Ascites: 2%	VA: 3% VP: 5.5% P>0.05	--	--	VA: 0.01% VP: 4% P<0.05	VA: 1% VP: 0.5 P=0.7	--	--	VA: 29% VP: 53% P<0.001	P=0.9	VA: 5.4% VP: 60% P<0.001	VA: 0 VP: 0

1 Ventriculoatrial; 2 Ventriculoperitoneal; 3 Hydrocephalus; 4 Normal-Pressure Hydrocephalus; 5 Lumbo-peritoneal

The exceedingly rare complications of the VP shunt placement include ascites, intra-abdominal cyst formation, perforation of a viscous, volvulus and perforation of the vagina or scrotum. The infection rate of VA placement was reported as high as 30% [31, 44]. Pulmonary emboli, pleural effusion, superior vena cava, inferior vena cava occlusions and septicemia are other possible complications observed in VA placement [45].

Are there more shunt obstruction and revision in VP or VA shunting?

Reoperations secondary to primary disease and valve malfunction, proximal and distal obstruction, poor placement of proximal end, cranial portion malfunction, and distal-end disconnection were the leading causes of revision in VA and VP shunting [21]. It was demonstrated that the revision during child growth is less frequently required in patients undergoing VP shunting than that reported for VA shunting. However, it seems that the rates of revision are different in various studies. In this regard, several studies are performed on the pediatric population [31]. Some studies comparing VA and VP shunting showed no difference in the rates of shunt obstruction and revision among patients with hydrocephalus [24-26]. Although Olsen et al. observed an equal revision rate for VA and VP shunting, the mortality rate of patients with VA shunts was higher than that reported for the cases with VP shunts [25]. In this regard, a recent study by Rymarczuk et al. confirmed the obtained results of a study by Olsen et al. [23].

In a study by Hung et al., ventricular obstructions or other morphological abnormalities were reported based on radiographic findings. The VA shunts were selected if the patients had previous abdominal procedures, other comorbidities, or better adjustment of anatomies to VA shunts (e.g. obesity); Otherwise, VP shunting was performed. They excluded all the patients with prior shunt treatments. However, it was shown that the rates of mechanical failures, such as obstruction, were higher among the patients undergoing VP regard, only nine studies were identified after searching the three databases. The collected studies were evaluated, and the obtained results are categorized into the following sections.

Are there more complications with VA or VP shunting in patients with hydrocephalus?

Multiple studies assessed the complications associated with VA and VP shunting. Several complications, including infection, shunt obstruction, and subdural hemor-

rhage, are observed due to using both approaches [27]. Based on a study carried out by Fernell et al., the relative risk of shunt obstruction was higher in VA shunts but only with a low level of statistical significance. Other complications were equal between VA and VP shunts. A higher rate of mortality was reported among children treatment, compared to those reported among the patients who were treated with VA shunts. Nevertheless, the rate of over drainage was higher among the subjects undergoing VA shunting but with no significance.

The higher rate of obstruction in VP groups explains the higher revision rate among these patients. Nonetheless, the findings of a study by Hung et al. and other studies are contradictory regarding VA shunts with a higher obstruction rate and need for revision [24, 46]. This difference may be due to a longer time of follow-up for the VP-shunted group than that reported for previous studies or higher sample size in a study by Hung et al. or other confounding variables. Therefore, VA shunts can be considered viable alternatives to VP shunts for the treatment of NPH patients. The obtained results of a study by Hung et al. are valuable since the two groups were matched in terms of demographic information, and there was no relationship between baseline characteristics and shunt complications. The need for revision and number of revisions did not correlate with age, gender, and baseline symptoms [27].

A study by Ignelzi et al. compared VP and VA shunt revisions. Based on the obtained results, most revisions were due to the obstruction of the distal end by adhesions [7]. At least one revision was performed for 58% and 48% of VP and VA shunting, respectively. They showed no difference between VP and VA placements regarding the primary and total rates of revision. Clotting in the shunt tubing and vascular occlusion of a significant venous channel due to the hazards of a foreign body in either the vascular system or peritoneal cavity were the most common causes of revisions. Although minor measurements under local anesthesia were mainly enough for VP distal revisions, general anesthesia was necessary for VA distal revisions. The interval between the initial placement and first non-elective revision was longer for the VA placement, compared to that reported for the VP placement (i.e., 14.1 and 4.8 months).

Moreover, the frequency of shunt placements requiring a revision within the first month was higher in VP placement (18% and 12%). However, during 2 years of follow-up, only 3% of VP shunts required a revision. This rate was calculated at 10% for VA shunts, indicating a slightly higher rate of revision for VP placement in the

first month after shunting; however, it is better to require a lower rate of primary revision in a longer period [7]. In the above study, 18 infections developed from primary placements. The rate of infection as a cause of primary revision was 1.6 times higher in VA shunts, compared to that reported for VP shunts. Although no mortality was observed, the morbidity rate in terms of requiring further revision was high [7].

Scarf et al. reported a strong tendency for the VP shunt placement to become obstructed at the distal end. They showed that VA shunting has a high incidence of rate of complications and permanent failures in comparison to those reported for the VP approach [47]. Moreover, the revision rates were estimated within the range of 46%-78% for VA shunts [48, 49]. Based on the studies performed by Robertson and Little, the rate of revision was reported within the range of 44%-47% for VP shunting [31, 44]. The obstruction of the distal end by adhesions in the above studies was in line with the findings of the study performed by Ignelzi et al.

The rate of VA shunt revisions was estimated at 10.7% in a study by Hung et al.; however, it has been reported within the range of 46%-78% in previous studies [7, 45, 48]. This discrepancy may be due to the different sample sizes of Hung et al., compared to those of previous studies, which were conducted on patients with multiple etiologies of hydrocephalus [27]. They focused on adult patients with NPH; nevertheless, most previous studies were performed on the pediatric population. On the other hand, the mean follow-up time for the first revision was very short in the study by Hung et al., which may not account for delayed complications and the need for revision. According to the literature, there has been no sufficient information on the time of the first revision, not allowing the comparison of the study results by Hung et al. with the findings of other studies. In general, VA shunts have a low rate of revision than VP shunts suggesting the use of VA shunting as a reasonable treatment option in patients with hydrocephalus. However, these findings cannot be generalized to all these patients.

Are there any differences between the outcomes of VA and VP shunting in adults and newborns?

There have been few studies assessing the complications of VA shunts in the adult population, and the majority of existing studies are conducted on the pediatric population. Considering the severe effect of hydrocephalus on the elderly population, the perception of the complication rate due to shunting is very important.

Due to the diverse etiologies and symptoms of hydrocephalus in adults, compared to those reported for newborns, it is proposed to examine the differences in the complication rates of the two methods (i.e., VA and VP shunting) in the adult population, compared to those reported for newborns.

The rate of shunting complications in adult hydrocephalus has been reported within the range of 36%-59% [5, 27, 46, 50]. Based on the literature, there is no difference between VA and VP shunting in the overall rates of complications among adult patients [1, 7, 8]. Totally, four studies compared VA and VP shunting in the adult population with NPH. The obtained results of the two studies showed no difference between VA and VP shunting in terms of distal and proximal catheter malfunctions. This factor was not assessed in other studies conducted on adult patients. Ignelzi et al. reported a significant difference between VA and VP shunting regarding distal and proximal catheter malfunctions. However, the aforementioned study was performed on both newborns and adults [7]. In this regard, different results were obtained in other studies carried out on newborns [24-26].

The rates of intraventricular hemorrhage and hygroma were not different in the adult population in terms of VA and VP shunting [1, 8]. These factors were not compared in the studies conducted on newborns. Based on two studies on adults, the infection rate was not different between VA and VP shunting. However, Puca et al. indicated a higher infection rate in VP shunting than that reported for VA shunting [22]. Ignelzi et al., in a study performed on both adults and children, reported a higher rate of infection in VA shunting than that of VP shunting; nonetheless, it was not statistically compared [7]. In this regard, two other studies conducted on newborns showed higher rates of infection in VP shunting than those reported for VA shunting [24, 26]. However, this finding was not corroborated by all studies carried out on newborns [25]. The infection of the endocardium due to VA or VP shunting can be fatal or lead to long-term damage to the valves (i.e., thromboembolism) and heart failure [41]. In patients undergoing VA shunting, the infection rate was reported within the range of 0%-6% in the adult population. The rate of infection due to VA shunting is higher among the pediatric population [8, 21, 45, 51].

In McGovern et al. study on the adult population, the assessment of VA and VP shunting showed no significant differences between the two techniques in terms of subdural hematomas and shunt obstructions [8]. However, the results of another study performed by Hung et al. demonstrated a higher rate of a subdural he-

matoma in VA shunting, compared to that reported for VP shunting. Moreover, they reported a higher rate of shunt obstruction in VP shunting than that of VA shunting. It was also shown that age is the only variable negatively correlating with shunt obstruction [27].

Various findings were observed in other studies performed on newborns [24-26]. Regarding primary revision shunting, a higher rate was reported in VA shunting than VP shunting in the adult population [1, 8, 22]. Nevertheless, no difference was observed in the studies conducted on newborns [24-26]. Moreover, cardiopulmonary complications due to VA shunting have been more frequently reported in children, not adults [56]. There were no cardiopulmonary complications in the studies performed on the adult population, which introduced VA shunting as a safe alternative to VP shunting [8, 27].

Drocephalus patients

The provision of a safety profile for shunting in the treatment of hydrocephalus patients is very important. To the best of our knowledge, VA shunting is an effective treatment strategy for the management of hydrocephalus. However, it is accompanied by cardiopulmonary complications, which may increase the risk of thromboembolism [52]. Pulmonary hypertension and cor pulmonale may be developed due to subsequent chronic and recurrent pulmonary embolisms [41]. Although the rate of pulmonary hypertension resulting from VA shunting is less than 1% [53] due to the high morbidity and mortality of thromboembolism, this treatment is used as a backup option after not responding to other treatment approaches including the use of VP shunts. Based on a study performed by Ignelzi et al., although differences in the rates of primary and total revisions between the placements were not statistically significant, VA shunt failures were reported with a higher rate of morbidity than the VP placements. Fernell et al. concluded that despite the higher risk of infection in VP shunting, this approach is still a safer choice than VA shunting [24].

Because of the technical challenges associated with the insertion of VA shunts and associated complications, the use of VP shunts is more common in comparison to that of VA shunts in patients with hydrocephalus [3]. However, in subjects with abdominal factors, such as previous abdominal procedures, complications due to prior VP shunting, cirrhosis-related ascites, and peritoneal infections and pseudocysts, VA shunting is the preferred choice [11, 14, 15, 54, 55].

The VA shunting has some progressions in comparison to VP shunting. This approach allows an intraoperative confirmation of placement location and consistent low pressure [8]. Because of the global obesity epidemic, the advantages of VA shunting should be considered in the treatment of adult patients with NPH [57]. Moreover, the frequency of abdominal surgeries is higher among adult patients preventing them from undergoing VP shunting. The frequency of abdominal surgery among the population over 65 years was estimated at 43.8% [58], making VP shunting more difficult for them due to their intraabdominal pathology. Therefore, VA shunting may be introduced as a suit adult patients with NPH. McGovern et al. also described VA shunting as safe as VP shunting for NPH patients. However, there are still unanswered questions about the use of the VA method [8].

The papers published between 1975 and 2017 were included in this study to investigate whether the standards of care for the treatment of patients with hydrocephalus undergoing shunting have been changed over time. Based on the obtained results, about 3%-10% of patients undergoing VA shunting died in most studies conducted within 1975-97 [24-26]. Moreover, 5.3% of patients undergoing VA shunting died [24]. However, no mortality has been reported in the studies conducted in recent years. In addition, the rate of infection was higher in earlier studies [8, 23, 27], which can be due to increasing care standards in hydrocephalus patients undergoing shunting. In general, the first treatment of choice is VA shunting. The external jugular vein or facial vein is a more common choice for distal catheter insertion to the atrium. Before shunting, all patients should be investigated for the foci of infection and laboratory parameters, such as white blood cell count and C-reactive protein. Furthermore, two or more negative cerebrospinal fluid cultures of bacterial growth should be performed in cases with the previous implantation of the external ventricular drainage [59].

5. Conclusion

Although the primary and total revision rates of VP and VA placements are not different, the complications of VP shunting are less life-threatening with lower rates of morbidity and ease of correction. The use of VP shunts should be considered the first line of treatment of hydrocephalus. Nevertheless, this approach has been preferred in newborns, and there is not enough data on the adult population. The VA shunting can be regarded as an effective alternative to VP shunting, especially in patients with contraindications to abdominal catheter placement.

Study limitations

The obtained results of the selected studies may have caused attrition bias and selection bias due to the exclusion criteria, missing data, and patient loss to follow-up. One major disadvantage of VA shunting is the possible occurrence of cardiopulmonary complications. However, there was no possibility to include patients with cardiopulmonary complications in this study which was considered the main limitation of the current study. There was a tendency to compare VA and VP shunting in terms of anatomical peculiarities, the connection of different body cavities, risk of infection, and assessment of the causes of complications. However, since there was no common information in the entered studies, it is recommended to carry out further studies on investigating the issues mentioned above.

Ethical Considerations

Compliance with ethical guidelines

This research is a systematic review of available data, and no animal or human participant was indirectly or directly involved in this study.

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Authors' contributions

Conception and design: Ehsan Keykhosravi; Data collection, drafting the article, reviewing submitted version of manuscript: Hamid Rezaee; Data analysis and interpretation: Amin Tavallaii; Critically revising the article: Ehsan Keykhosravi; Approving the final version of the manuscript: Ehsan Keykhosravi.

Conflict of interest

The authors declared no conflict of interest.

References

- [1] Klinge P, Hellström P, Tans J, Wikkelsø C, European iNPH Multicentre Study Group. One-year outcome in the European 2012; 126(3):145-53. [DOI:10.1111/j.1600-0404.2012.01676.x] [PMID]
- [2] Klinge P, Marmarou A, Bergsneider M, Relkin N, McL Black P. Outcome of shunting in idiopathic normal-pressure hydrocephalus and the value of outcome assessment in shunted patients. *Neurosurgery*. 2005; 57(Suppl 3):S40-52. [DOI:10.1227/01.NEU.0000168187.01077.2F] [PMID]
- [3] Koivisto AM, Alafuzoff I, Savolainen S, Sutela A, Rummukainen J, Kurki M, et al. Poor cognitive outcome in shunt-responsive idiopathic normal pressure hydrocephalus. *Neurosurgery*. 2013; 72(1):1-8. [DOI:10.1227/NEU.0b013e31827414b3] [PMID]
- [4] Mori K. Management of idiopathic normal-pressure hydrocephalus: A multi-institutional study conducted in Japan. *Journal of Neurosurgery*. 2001; 95(6):970-3. [DOI:10.3171/jns.2001.95.6.0970] [PMID]
- [5] Vernet O, Rilliet B. Late complications of ventriculoatrial or ventriculoperitoneal shunts. *The Lancet*. 2001; 358(9293):1569-70. [DOI:10.1016/S0140-6736(01)06670-3] [PMID]
- [6] Kluge S, Jörg Baumann H, Regelsberger J, Kehler U, Gliemroth J, Koziej B, et al. Pulmonary hypertension after ventriculoatrial shunt implantation. *Journal of Neurosurgery*. 2010; 113(6):1279-83. [DOI:10.3171/2010.6.JNS091541] [PMID]
- [7] Ignelzi RJ, Kirsch WM. Follow-up analysis of ventriculoperitoneal and ventriculoatrial shunts for hydrocephalus. *Journal of Neurosurgery*. 1975; 42(6):679-82. [DOI:10.3171/jns.1975.42.6.0679] [PMID]
- [8] McGovern RA, Kelly KM, Chan AK, Morrissey NJ, McKhann GM. Should ventriculoatrial shunting be the procedure of choice for normal-pressure hydrocephalus? *Journal of Neurosurgery*. 2014; 120(6):1458-64. [DOI:10.3171/2014.1.JNS131808] [PMID]
- [9] Zehri AH, Ramey W, Georges JF, Mooney MA, Martirosyan NL, Preul MC, et al. Neurosurgical confocal endomicroscopy: A review of contrast agents, confocal systems, and future imaging modalities. *Surgical Neurology International*. 2014; 5:60. [DOI:10.4103/2152-7806.131638] [PMID] [PMCID]
- [10] Clark DJ, Chakraborty A, Roebuck DJ, Thompson DNP. Ultrasound guided placement of the distal catheter in paediatric ventriculoatrial shunts-an appraisal of efficacy and complications. *Child's Nervous System*. 2016; 32(7):1219-25. [DOI:10.1007/s00381-016-3120-4] [PMID] [PMCID]
- [11] Bryant MS, Bremer AM, Tepas JJ, Mollitt DL, Nquyen TQ, Talbert JL. Abdominal complications of ventriculoperitoneal shunts. Case reports and review of the literature. *The American Surgeon*. 1988; 54(1):50-5. [PMID]
- [12] Chung JJ, Yu JS, Kim JH, Nam SJ, Kim MJ. Intraabdominal complications secondary to ventriculoperitoneal shunts: CT findings and review of the literature. *American Journal of Roentgenology*. 2009; 193(5):1311-7. [DOI:10.2214/AJR.09.2463] [PMID]
- [13] Popa F, Grigorean VT, Onose G, Popescu M, Strambu V, Sandu AM. Laparoscopic treatment of abdominal complications following ventriculoperitoneal shunt. *Journal of Medicine and Life*. 2009; 2(4):426-36. [PMID] [PMCID]
- [14] Martin K, Baird R, Farmer JP, Emil S, Laberge JM, Shaw K, et al. The use of laparoscopy in ventriculoperitoneal shunt revisions. *Journal of Pediatric Surgery*. 2011; 46(11):2146-50. [DOI:10.1016/j.jpedsurg.2011.07.001] [PMID]



- [15] Farach SM, Danielson PD, Chandler NM. Diagnostic laparoscopy for intraabdominal evaluation and ventriculoperitoneal shunt placement in children: A means to avoid ventriculoatrial shunting. *Journal of Laparoendoscopic & Advanced Surgical Techniques*. 2015; 25(2):151-4. [DOI:10.1089/lap.2014.0278] [PMID]
- [16] Haffner D, Schindera F, Aschoff A, Matthias S, Waldherr R, Schärer K. The clinical spectrum of shunt nephritis. *Nephrology, Dialysis, Transplantation*. 1997; 12(6):1143-8. [DOI:10.1093/ndt/12.6.1143] [PMID]
- [17] Samtleben W, Bauriedel G, Bosch T, Goetz C, Klare B, Gurland HJ. Renal complications of infected ventriculoatrial shunts. *Artificial Organs*. 1993; 17(8):695-701. [DOI:10.1111/j.1525-1594.1993.tb00617.x] [PMID]
- [18] Illingworth RD, Logue V, Symon L, Uemura K. The ventriculocaval shunt in the treatment of adult hydrocephalus: results and complications in 101 patients. *Journal of Neurosurgery*. 1971; 35(6):681-5. [DOI:10.3171/jns.1971.35.6.0681] [PMID]
- [19] Higgins JPT, Green S. *Cochrane handbook for systematic reviews of interventions*. Hoboken: Wiley; 2005. <https://books.google.com/books?id=RepLNQEACAAJ&dq>
- [20] Higgins JPT, Green S. *Cochrane handbook for systematic reviews of interventions*. Volume 4. Hoboken: John Wiley & Sons; 2011. <https://books.google.com/books?id=NKMg9sMM6GUC&dq>
- [21] Lam CH, Villemure JG. Comparison between ventriculoatrial and ventriculoperitoneal shunting in the adult population. *British Journal of Neurosurgery*. 1997; 11(1):43-8. [DOI:10.1080/02688699746681] [PMID]
- [22] Puca A, Anile C, Maira G, Rossi G. Cerebrospinal fluid shunting for hydrocephalus in the adult: Factors related to shunt revision. *Neurosurgery*. 1991; 29(6):822-6. [DOI:10.1227/00006123-199112000-00003] [PMID]
- [23] Rymarczuk GN, Keating RF, Coughlin DJ, Felbaum D, Mysero JS, Oluiqbo C, et al. A comparison of ventriculoperitoneal and ventriculoatrial shunts in a population of 544 consecutive pediatric patients. *Neurosurgery*. 2020; 87(1):80-5. [DOI:10.1093/neuros/nyz387] [PMID]
- [24] Fernell E, von Wendt L, Serlo W, Heikkinen E, Andersson H. Ventriculoatrial or ventriculoperitoneal shunts in the treatment of hydrocephalus in children? *Zeitschrift für Kinderchirurgie*. 1985; 40(Suppl 1):12-4. [DOI:10.1055/s-2008-1059758] [PMID]
- [25] Olsen L, Frykberg T. Complications in the treatment of hydrocephalus in children: A comparison of ventriculoatrial and ventriculoperitoneal shunts in a 20-year material. *Acta Paediatrica Scandinavica*. 1983; 72(3):385-90. [DOI:10.1111/j.1651-2227.1983.tb09733.x] [PMID]
- [26] Mazza C, Pasqualin A, Da Pian R. Results of treatment with ventriculoatrial and ventriculoperitoneal shunt in infantile nontumoral hydrocephalus. *Pediatric Neurosurgery*. 1980; 7(1):1-14. [DOI:10.1159/000119545] [PMID]
- [27] Hung AL, Vivas-Buitrago T, Adam A, Lu J, Robison J, Elder BD, et al. Ventriculoatrial versus ventriculoperitoneal shunt complications in idiopathic normal pressure hydrocephalus. *Clinical Neurology and Neurosurgery*. 2017; 157:1-6. [DOI:10.1016/j.clineuro.2017.03.014] [PMID]
- [28] Nulsen FE, Spitz EB. Treatment of hydrocephalus by direct shunt from ventricle to jugular vein. *Surgical Forum*. 1951; 399-403. [PMID]
- [29] Scott M, Wycis HT, Murtagh F, Reyes V. Observations on ventricular and lumbar subarachnoid peritoneal shunts in hydrocephalus in infants. *Journal of Neurosurgery*. 1955; 12(2):165-75. [DOI:10.3171/jns.1955.12.2.0165] [PMID]
- [30] Keucher TR, Mealey J. Long-term results after ventriculoatrial and ventriculoperitoneal shunting for infantile hydrocephalus. *Journal of Neurosurgery*. 1979; 50(2):179-86. [DOI:10.3171/jns.1979.50.2.0179] [PMID]
- [31] Little JR, Rhoton Jr AL, Mellinger JF. Comparison of ventriculoperitoneal and ventriculoatrial shunts for hydrocephalus in children. *Mayo Clinic Proceedings*. 1972; 47(6):396-401. [PMID]
- [32] Udvarhelyi GB, Wood JH, James Jr AE, Bartelt D. Results and complications in 55 shunted patients with normal pressure hydrocephalus. *Surgical Neurology*. 1975; 3(5):271-5. [PMID]
- [33] Boon AJ, Tans JT, Delwel EJ, Egeler-Peerdeman SM, Hanlo PW, Wurzer HA, et al. Dutch normal-pressure hydrocephalus study: Randomized comparison of low-and medium-pressure shunts. *Journal of Neurosurgery*. 1998; 88(3):490-5. [DOI:10.3171/jns.1998.88.3.0490] [PMID]
- [34] Greenberg J, Shenkin H, Adam R. Idiopathic normal pressure hydrocephalus--a report of 73 patients. *Journal of Neurology, Neurosurgery & Psychiatry*. 1977; 40(4):336-41. [DOI:10.1136/jnnp.40.4.336] [PMID] [PMCID]
- [35] Hebb AO, Cusimano MD. Idiopathic normal pressure hydrocephalus: A systematic review of diagnosis and outcome. *Neurosurgery*. 2001; 49(5):1166-86. [DOI:10.1227/00006123-200111000-00028] [PMID]
- [36] Larsson A, Wikkelso C, Bilting M, Stephensen H. Clinical parameters in 74 consecutive patients shunt operated for normal pressure hydrocephalus. *Acta Neurologica Scandinavica*. 1991; 84(6):475-82. [DOI:10.1111/j.1600-0404.1991.tb04998.x] [PMID]
- [37] Weiner HL, Constantini S, Cohen H, Wisoff JH. Current treatment of normal-pressure hydrocephalus: Comparison of flow-regulated and differential-pressure shunt valves. *Neurosurgery*. 1995; 37(5):877-84. [DOI:10.1097/00006123-199511000-00005] [PMID]
- [38] Metellus P, Hsu W, Kharkar S, Kapoor S, Scott W, Rigamonti D. Accuracy of percutaneous placement of a ventriculoatrial shunt under ultrasonography guidance: A retrospective study at a single institution. *Journal of Neurosurgery*. 2009; 110(5):867-70. [DOI:10.3171/2008.10.17674] [PMID]
- [39] Samuelson S, Long DM, Chou SN. Subdural hematoma as a complication of shunting procedures for normal pressure hydrocephalus. *Journal of Neurosurgery*. 1972; 37(5):548-51. [DOI:10.3171/jns.1972.37.5.0548] [PMID]
- [40] McCullough DC, Fox JL. Negative intracranial pressure hydrocephalus in adults with shunts and its relationship to the production of subdural hematoma. *Journal of Neurosurgery*. 1974; 40(3):372-5. [DOI:10.3171/jns.1974.40.3.0372] [PMID]
- [41] Piatt JH, Hoffman HJ. Cor pulmonale: A lethal complication of ventriculoatrial CSF diversion. *Child's Nervous System*. 1989; 5(1):29-31. [DOI:10.1007/BF00706743] [PMID]
- [42] Wakabayashi Y, Kobayashi Y, Shigematsu H. Shunt nephritis: histological dynamics following removal of the shunt. Case report and review of the literature. *Nephron*. 1985; 40(1):111-7. [DOI:10.1159/000183441] [PMID]



- [43] Burström G, Andresen M, Bartek Jr J, Fyttagoridis A. Subacute bacterial endocarditis and subsequent shunt nephritis from ventriculoatrial shunting 14 years after shunt implantation. *BMJ Case Reports*. 2014; 2014:bcr2014204655. [DOI:10.1136/bcr-2014-204655] [PMID] [PMCID]
- [44] Robertson JS, Maraga M, Jennett B. Ventriculoperitoneal shunting for hydrocephalus. *British Medical Journal*. 1973; 2(5861):289-92. [DOI:10.1136/bmj.2.5861.289] [PMID] [PMCID]
- [45] Forrest D, Cooper D. Complications of ventriculo-atrial shunts: A review of 455 cases. *Journal of Neurosurgery*. 1968; 29(5):506-12. [DOI:10.3171/jns.1968.29.5.0506]
- [46] Borgbjerg BM, Gjerris F, Albeck MJ, Hauerberg J, Børgesen SV. A comparison between ventriculo-peritoneal and ventriculo-atrial cerebrospinal fluid shunts in relation to rate of revision and durability. *Acta Neurochirurgica*. 1998; 140(5):459-65. [DOI:10.1007/s007010050125] [PMID]
- [47] Scarff JE. Treatment of hydrocephalus: An historical and critical review of methods and results. *Journal of Neurology, Neurosurgery, and Psychiatry*. 1963; 26(1):1-26. [DOI:10.1136/jnnp.26.1.1] [PMID] [PMCID]
- [48] Becker DP, Nulsen FE. Control of hydrocephalus by valve-regulated venous shunt: Avoidance of complications in prolonged shunt maintenance. *Journal of Neurosurgery*. 1968; 28(3):215-26. [DOI:10.3171/jns.1968.28.3.0215] [PMID]
- [49] Overton M, Snodgrass S. Ventriculo-venous shunts for infantile hydrocephalus: A review of five years' experience with this method. *Journal of Neurosurgery*. 1965; 23(5):517-21. [DOI:10.3171/jns.1965.23.5.0517] [PMID]
- [50] Hanak BW, Bonow RH, Harris CA, Browd SR. Cerebrospinal fluid shunting complications in children. *Pediatric Neurosurgery*. 2017; 52(6):381-400. [DOI:10.1159/000452840] [PMID] [PMCID]
- [51] Børgesen SE, Gjerris F. The predictive value of conductance to outflow of CSF in normal pressure hydrocephalus. *Brain: A Journal of Neurology*. 1982; 105(Pt 1):65-86. [DOI:10.1093/brain/105.1.65] [PMID]
- [52] Crome L, Erdohazi M. Main pathological findings in hydrocephalic children treated by ventriculo-atrial shunt. *Archives of Disease in Childhood*. 1966; 41(216):179-82. [DOI:10.1136/adc.41.216.179] [PMID] [PMCID]
- [53] Pascual JM, Prakash UB. Development of pulmonary hypertension after placement of a ventriculoatrial shunt. *Mayo Clinic Proceedings*. 1993; 68(12):1177-82. [DOI:10.1016/S0025-6196(12)60069-X] [PMID]
- [54] Fleischer AC, Lyshchik A, Andreotti RF, Hwang M, Jones HD, Fishman DA. Advances in sonographic detection of ovarian cancer: Depiction of tumor neovascularity with microbubbles. *American Journal of Roentgenology*. 2010; 194(2): 343-8. [DOI:10.2214/AJR.09.3446] [PMID]
- [55] Liu A, Sankey EW, Jusué-Torres I, Patel MA, Elder BD, Goodwin CR, et al. Clinical outcomes after ventriculoatrial shunting for idiopathic normal pressure hydrocephalus. *Clinical Neurology and Neurosurgery*. 2016; 143:34-8. [DOI:10.1016/j.clineuro.2016.02.013] [PMID]
- [56] Milton CA, Sanders P, Steele PM. Late cardiopulmonary complication of ventriculo-atrial shunt. *The Lancet*. 2001; 358(9293):1608. [DOI:10.1016/S0140-6736(01)06655-7] [PMID]
- [57] World Health Organization (WHO). Obesity: Preventing and managing the global epidemic: Report of a WHO consultation on obesity [Internet]. 1997 [Updated 3-5 June 1998]. Available from: <https://apps.who.int/iris/handle/10665/63854>
- [58] Nunoo-Mensah JW, Rosen M, Chan LS, Wasserberg N, Beart RW. Prevalence of intra-abdominal surgery: What is an individual's lifetime risk? *Southern Medical Journal*. 2009; 102(1):25-9. [DOI:10.1097/SMJ.0b013e318182575b] [PMID]
- [59] Al-Schameri AR, Hamed J, Baltasavias G, Winkler P, Machegger L, Richling B, et al. Ventriculoatrial shunts in adults, incidence of infection, and significant risk factors: A single-center experience. *World Neurosurgery*. 2016; 94:345-51. [DOI:10.1016/j.wneu.2016.07.002] [PMID]