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Ventricular drainage catheters versus intracranial parenchymal catheters for intracranial pressure monitoring-based management of traumatic brain injury: a systematic review and meta-analysis

Victor Volovici[1,2], Jilske A. Huijben[2], Ari Ercole[3], Nino Stocchetti[4,5], Clemens M. F. Dirven[1], Mathieu van der Jagt[6], Ewout W. Steyerberg[7], Hester F. Lingsma[2], David K. Menon[4], Andrew I. R. Maas[8], Iain K. Haitsma[1]

[1]= Department of Neurosurgery, Erasmus MC Rotterdam, The Netherlands

[2]= Center for Medical Decision Making, Department of Public Health, Erasmus MC, Rotterdam, The Netherlands

[3]= Division of Anesthesia, University of Cambridge, Addenbrooke's Hospital, Cambridge, UK

[4]=Department of Pathophysiology and Transplants, University of Milan, Milan, Italy

[5]= Fondazione IRCCS Ca' Granda - Ospedale Maggiore Policlinico, Department of Anesthesia and Critical Care, Neuroscience Intensive Care Unit, Milan, Italy

[6]= Department of Intensive Care Adults, Erasmus MC, Rotterdam, The Netherlands

[7]= Department of Medical Statistics and Bioinformatics, Leiden University Medical Center, Leiden, The Netherlands.

[8]= Department of Neurosurgery, Antwerp University Hospital and University of Antwerp, Edegem, Belgium

Corresponding author

Victor Volovici, MD
Erasmus MC University Medical Center, Erasmus MC Stroke Center
Department of Neurosurgery and Medical Decision Making
Doctor Molenwaterplein 40
3015 GD, Rotterdam, The Netherlands
tel: 0031-10-7039324
fax: 0031-10-7040704

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Co-authors:

Ms. Jilske A. Huijben, MD
Erasmus MC University Medical Center
Department of Public Health, Center for Medical Decision Making
Doctor Molenwaterplein 40
3015 GD, Rotterdam, The Netherlands
tel: 0031-10-7039324
fax: 0031-10-7040704
email: j.a.huijben@erasmusmc.nl

Dr. Ari Ercole, MD, PhD
Division of Anesthesia, University of Cambridge, Addenbrooke's Hospital, Cambridge, UK
Box 93, Addenbrooke's Hospital, Hills Road, Cambridge CB2 0QQ
Tel: +44 (0)1223 217889
Fax: +44 (0)1223 217887
E-mail: ae105@cam.ac.uk

Prof. Nino Stocchetti, MD, PhD
Fondazione IRCCS Ca' Granda - Ospedale Maggiore Policlinico, Department of Anesthesia and Critical Care, Neuroscience Intensive Care Unit, Milan, Italy
Via Francesco Sforza 28, 20122 Milano
Tel: +39 0255034422
Fax: n/a
E-mail: nino.stocchetti@policlinico.mi.it

Prof. Clemens M. F. Dirven, MD, PhD
Erasmus MC University Medical Center
Department of Neurosurgery
Doctor Molenwaterplein 40
3015 GD, Rotterdam, The Netherlands

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tel: 0031-10-7035993

fax: 0031-10-7040704

email: c.dirven@erasmusmc.nl

Dr. Mathieu van der Jagt, MD, PhD

Erasmus MC University Medical Center

Department of Intensive Care Adults

Doctor Molenwaterplein 40

3015 GD, Rotterdam, The Netherlands

tel: 0031-10-7035993

fax: 0031-10-7040704

email: m.vanderjagt@erasmusmc.nl

Prof. Ewout W. Steyerberg, PhD

Department of Medical Statistics and Bioinformatics, Leiden University Medical Center,

P.O. Box 9600

2300RC Leiden, The Netherlands

Tel: +31 71 5269712

Fax: N/A

E-mail: e.steyerberg@erasmusmc.nl

Dr. Hester F. Lingsma, PhD

Erasmus MC University Medical Center

Department of Public Health, Center for Medical Decision Making

Doctor Molenwaterplein 40

3015 GD, Rotterdam, The Netherlands

tel: 0031-10-7039324

fax: 0031-10-7040704

email: h.lingsma@erasmusmc.nl

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Prof. David K. Menon, MD, PhD

Division of Anesthesia, University of Cambridge, Addenbrooke's Hospital, Cambridge, UK

Box 93, Addenbrooke's Hospital, Hills Road, Cambridge CB2 0QQ

Tel: +44 (0)1223 217889

Fax: +44 (0)1223 217887

E-mail: dkm13@cam.ac.uk

Prof. Andrew I. R. Maas

Department of Neurosurgery, Antwerp University Hospital and University of Antwerp,

Wilrijkstraat 10

2650 Edegem, Belgium

Tel: +32 (0)3 821 30 00

Fax: n/a

E-mail: Andrew.Maas@uza.be

Dr. Iain K. Haitsma, MD

Erasmus MC University Medical Center

Department of Neurosurgery

Doctor Molenwaterplein 40

3015 GD, Rotterdam, The Netherlands

tel: 0031-10-7039324

fax: 0031-10-7040704

email: i.haitsma@erasmusmc.nl

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Abstract:

Intracranial pressure (ICP) monitoring is one of the mainstays in the treatment of severe traumatic brain injury (TBI), but different approaches to monitoring exist. The aim of this systematic review and meta-analysis is to compare the effectiveness and complication rate of ventricular drainage (VD) versus intracranial parenchymal (IP) catheters to monitor and treat raised ICP in patients with TBI.

Pubmed, EMBASE, Web of Science, Google Scholar and the Cochrane Database were searched for articles comparing ICP monitoring-based management with VDs and monitoring with IP monitors until March 2018. Study selection, data extraction and quality assessment were performed independently by two authors. Outcomes assessed were mortality, functional outcome, need for decompressive craniectomy, length of stay, overall complications, such as infections, and hemorrhage. Pooled effect estimates were calculated with random effects models and expressed as relative risk (RR) for dichotomous outcomes and mean difference (MD) for ordinal outcomes, with corresponding 95% confidence intervals (CI).

Six studies were included: 1 randomized controlled trial and 5 observational cohort studies. Three studies reported mortality, functional outcome and the need for a surgical decompression, three only reported complications. Quality of the studies was rated as poor, with critical or serious risk of bias. The pooled analysis did not show a statistically significant difference in mortality (RR=0.90, 95% CI=0.60 to 1.36, p=0.41) or functional outcome (MD=0.23, 95% CI=0.67 to 1.13, p=0.61). The complication rate of VDs was higher (RR=2.56, 95% CI=1.17 to 5.61, p= 0.02) and consisted mainly of infectious complications, i.e. meningitis.

VDs caused more complications, particularly more infections but there was no difference in terms of mortality or functional outcome between the two monitoring modalities. However, the studies had a high risk of bias. A need exists for high quality comparisons of VDs versus IP monitor-based management strategies on patient outcomes.

Keywords: ICP monitoring; Ventricular Catheters; Intraparenchymal monitors; Monitoring Devices; Patient Outcomes; Severe TBI

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Introduction

Intracranial pressure (ICP) monitoring is one of the mainstays of current severe traumatic brain injury (TBI) treatment at the ICU and guidelines recommend using ICP monitoring in order to reduce mortality.[1]

There is a wide range of intracranial pressure sensors. Two types are most commonly used: Ventricular drainage (VD) and intraparenchymal catheters. The IP monitor catheters require a small opening in the skull and their small diameters cause little damage to the brain parenchyma. They have a low risk of infection and other complications, such as intracerebral hemorrhage.[2] The insertion of a ventricular catheter, usually into the frontal horn of the right lateral ventricle, requires a relatively larger opening and is thought to cause more damage to brain tissue than the insertion of a smaller parenchymal sensor.[3] VDs fulfill two objectives: besides monitoring, they permit drainage of CSF, thereby acting as an ICP-lowering intervention. However, this is accomplished at the expense of an increased risk of infections and complications.[2]

Not much is known about the superiority of one method over the other in terms of patient outcomes. In the second Brain Trauma Foundation Guidelines edition of 2000, in which this topic was addressed, no clear recommendation was made and in subsequent editions the topic was no longer addressed due to lack of evidence.[4] However, recently, a randomized controlled trial (RCT) was conducted, the first of its kind, that suggested the superiority of VDs over IP monitors on patient outcomes. Next to this single RCT, several observational studies have been published.

The aim of this study was to review the available evidence on the effectiveness and complication rate of VD versus IP-monitor-guided treatment of raised ICP in patients with TBI.

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Materials and methods

A protocol has been published on Prospero.[5]

Search strategy

Searches were not restricted by date, language or publication status. In collaboration with an information specialist from the Erasmus MC library we developed a search strategy (Appendix 1). We performed the search in MEDLINE, EMBASE, ISI Web of Science, Pubmed and Google Scholar, from the first publicly accessible date of a particular database until March 1st, 2018. Ongoing studies were searched on clinicaltrials.gov. Grey literature was screened using Google Scholar and ISI Web of Science. Reference lists of all relevant trials were hand searched and experts in the field that had previously published on this matter were contacted for unpublished literature on this topic.

Ethical approval and consent

This study did not require ethical approval.

Inclusion criteria and study selection

Given the expected scarcity of available literature on the topic, we included – next to RCTs - prospective and retrospective observational studies that described a direct comparison between patients with VDs and patients with IP monitoring and that reported either mortality, functional outcomes or complications. Inclusion criteria were: (1) mainly adult population, (2) severe or moderate TBI on admission defined as a Glasgow coma score (GCS) <=12 and (3) closed head injury

Exclusion criteria were (1) penetrating or blast TBI, (2) studies with a predominantly paediatric population, (3) studies without VD and IP comparisons and (4) studies on external lumbar drainage

For studies with mixed populations, including mixed ages (i.e. adults and children) and mixed injury types (i.e. TBI and stroke) we included studies in which the results for our population of interest were presented separately, or in which at least 85% of the participants represented our population of interest.

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Considering mixed injury types, one exception was made in the case of the secondary outcomes, i.e. infections, haemorrhage and catheter malfunctions. Since we did not expect any differences between mixed injury types (i.e. ischaemic stroke and severe TBI) in terms of complications when either device was used. We therefore chose to pool all studies that compared complications in patients with an VD and those with an IP monitor in mixed injury types, even if the population represented < 85% severe TBI.

The first phase involved screening the titles and abstracts (Appendix 3). Studies unrelated to the topics of VDs versus IP monitoring or TBI were excluded. In the second phase the remaining abstracts were screened for the inclusion and exclusion criteria.
In the final sifting phase, the full text of the remaining studies was reviewed. Conflicts were resolved by discussion until a final decision was reached.

Data extraction and risk of bias assessment

Each study was assessed by two investigators (VV, IH) and the data was extracted in a matrix consisting of trial details, such as: trial name and date, trial design, author contact information, inclusion and exclusion criteria, adherence to a published protocol, number of patients, duration of intervention, mean age of patients, mean GCS, percentage of severe TBI, male to female ratio, whether the groups were comparable or not and the effect size and confidence intervals for the primary and secondary outcomes individually (Appendix 2). Finally, potential sources of bias and sources of funding were noted.

Quality assessment was performed by two authors independently (VV and JH). For the RCTs we used the Cochrane Collaboration's Risk of Bias Assessment Tool[6] (assessing the risk of bias as high/low or unknown for each domain) tool and for observational trials the ROBINS-I Cochrane tool[7] (assessing the studies as low/moderate/serious or critical risk of bias for each domain and overall) (Appendix 4).

Outcomes

The primary outcomes were mortality and functional outcome at 6 months or final follow-up if earlier, defined by the Glasgow Outcome Scale/Extended (GOS/E).

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The secondary outcomes examined were: the need for decompressive craniectomy during ICU stay; the hospital and Intensive Care Unit (ICU) Lengths Of Stay (LOS); monitoring duration; device failure at any time point; all complications; infections, however defined in the paper; intracranial haemorrhage; and the number of episodes of refractory intracranial hypertension (RICH), defined as uncontrollable intracranial hypertension by conventional means requiring an increase in therapy intensity, either medical or surgical.

We anticipated that all outcome data will be dichotomous. As such, for each study, we have extracted the number of participants receiving each device and the number of events (i.e. n/N) or the GOS mean differences.

For the hospital and ICU LOS we calculated the mean difference between groups and the 95% CI.

Statistical analyses

The relative risk (RR) and corresponding 95% Confidence Interval (CI) were extracted for mortality, need for decompressive craniectomy, overall complications (specifically for device failure, infection and haemorrhage), when available and otherwise calculated.

The pooled RR and corresponding 95% CI was then determined using the Mantel-Haenszel approach, and its significance as the true effect estimate was assessed against the null hypothesis RR overall=1 using the z test. Statistical evidence for heterogeneity between studies was assessed using the Q-test and the I^2 index estimated the between-study variability. We used the random effects model for all analyses, as considerable heterogeneity may exist despite the absence of statistical evidence of this, especially in studies with small sample sizes.

For the outcomes reported as mean difference (MD) ± standard deviation (SD), we used the inverse variance method to obtain the pooled MD. In this case we also used the Q-test and I^2 index to estimate statistical heterogeneity between studies. The outcomes were ICU and hospital LOS, mean monitoring duration and mean GOS for each group.

Review Manager (RevMan, Cochrane Collaboration, version 5.3) was used for data synthesis.

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Results

Study characteristics

1208 studies underwent abstract screening. Among these, 37 were screened full text (Appendix 3). Six studies were included and characteristics of patients extracted (Appendix 2) with 3968 enrolled patients in total (minimum 122 patients[8], maximum 2562 patients[9]). One of these was an RCT, the rest were retrospective observational cohorts. Three studies included data on mortality, functional outcome, LOS and surgical decompression, the other three reported only complications.

Primary outcome

Three studies with 3013 patients reported mortality rates.[8-10] When the results were aggregated, mortality was not different between VD and IP monitors (RR=0.90, 95% CI=0.60 to 1.36, p=0.63). There was substantial heterogeneity (I^2= 76%, p value of the Q test=0.01) (*Figure 1a*).

In the analysis of studies reporting functional outcome at the end of follow-up, 2 papers involving 451 patients described functional outcome data using the mean GOS difference.[8, 10] When the results were aggregated, mean GOS was not different between the two interventions (Mean Difference (MD) =0.23, 95% CI=-0.67 to 1.13, p=0.61). Heterogeneity was high (Q test p=0.003, I^2=89%) (*Figure 1b*).

We contacted the authors of the Kasotakis et al study[10] in order to obtain the absolute numbers of the functional outcome, but the data on these outcomes were not available anymore.

Aiolfi et al[9] only described the absolute numbers for patients functionally independent at discharge. For the 2562 patients described, there was no difference regarding this number between the two groups patients at discharge (RR= 0.97, 95% CI= 0.83 to 1.13).

Secondary outcomes

Three studies including 3968 patients examined the risk of needing a surgical decompression in both groups.[8-10] There was no difference between the groups (RR= 0.79,

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95% CI= 0.56 to 1.10, p=0.16). Heterogeneity was large (Q-test p=0.005; I^2=81%) (*Figure 2a*) .

The mean LOS in the hospital[8-10] did not differ between groups with no heterogeneity (MD= 0.02, 95% CI= -0.42 to 0.46, p=0.93; Q-test p=0.80; I^2=0%). The mean ICU length of stay was shorter in the IP group (MD= 1.09, 95% CI= 0.41 to 1.78, p=0.002).[8-10] Heterogeneity was low (Q-test: p=0.25, I^2= 28%) (*Figure 2b and 2c*).

Two papers including 499 patients reported the mean monitoring duration for both groups.[8, 10] This did not differ when the results were pooled (MD= 1.78, 95% CI= -1.55 to 5.11, p=0.29). there was large statistical heterogeneity (Q-test: p <0.00001, I^2=96%) (*Figure 3e*).

Three studies including 607 patients reported device failures[8, 10, 11] and there was no difference between the two groups in this respect (RR=0.98, 95% CI= 0.35 to 2.69, p=0.96). There was a low level of statistical heterogeneity (Q-test p=0.13, I^2= 52%) (*Figure 3d*).

Six reports including 3968 patients reported overall complications.[2, 8-12] Five reports including 1406 patients reported infections of the device, hemorrhage and 'all complications'.[2, 8, 10-12] With regard to all complications, the VD group fared worse than the IP monitor group (RR=2.56, 95% CI=1.17 to 5.61, p= 0.02). Statistical heterogeneity was high (Q-test p< 0.00001, I^2=91%) (*Figure 3a*). Regarding infections[2, 8, 10-12] in particular, such as meningitis and ventriculitis, VD patients were more at risk (RR=7.09, 95% CI= 2.64 to 19.04, p=0.0001), without evidence of statistical heterogeneity (Q-test p=0.59, I^2= 0%) (*Figure 3b*). The VD group was also more at risk for hemorrhage (RR=2.64, 95% CI= 1.05 to 6.63, p=0.04),[2, 8, 10-12] without evidence of statistical heterogeneity (Q-test , p=0.94, I^2= 0%) (*Figure 3c*).

Episodes of RICH were only reported by one paper[8], and thus did not lend themselves to a pooled analysis. The RR was 0.41, with a 95% CI ranging from 0.24 to 0.70.

Risk of bias

The overall quality of the studies is poor (Appendix 4), with one underpowered RCT (N=122) with high risk of bias with regard to blinding of trial personnel and of the outcome

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assessors. Of the 5 observational studies, 2 were judged as serious risk of bias and the other 3 were deemed at critical risk of bias according to the methodological assessment.

The risk of bias for the RCT was low on most domains, except blinding of study personnel, which is inherently impossible given the nature of the intervention and the blinding of clinicians to the intervention in the clinical phase. The retrospective observational cohorts were judged as having overall serious[9] and critical risk of bias respectively.[2, 10, 11]

The criterion blinding could not be rated in the Cochrane tool since the monitoring device is identifiable when placed.

Discussion

This is the first systematic review that describes the potential effects of VDs versus IP monitor-guided management on patient outcomes. We found no difference in terms of mortality or functional outcome between the two groups. IP monitors are associated with a shorter ICU stay but not hospital stay and are associated with less complications, in particular less infections. The risk of malfunction is comparable among devices. However, strong inferences on effectiveness of VDs versus IP monitors cannot be made from this analyses given the high risk of bias of the included studies.

The effect of ICP monitoring is the subject of an ongoing debate in the scientific literature.[1, 13-15] General consensus remains that ICP monitoring is recommended in patients with severe TBI who have traumatic abnormalities on the CT scan.[16]

Considerable practice variation exists with respect to the choice of monitoring device. A recent questionnaire-based study carried out by our group in 66 centers in Europe[16] showed that both parenchymal and ventricular monitoring devices were available in more than half of centers (59%). One-third of the participants indicated that they used only parenchymal monitors, whereas one-tenth of the participants indicated that they used only ventricular catheters.[16]

This variation noticed in the study carried out by our group can be explained in light of the limited evidence base for clinical practice. When looking at studies that provide the best quality evidence with a least risk of bias, the only RCT on the topic suggests the superiority

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of monitoring and treatment using VDs[8] for both mortality and functional outcome, potentially also through a decrease in the number of patients requiring surgical decompression. Our meta-analysis shows no difference between the two groups which likely arises from the pooling of results with lower quality studies. Despite the importance of ICP monitoring and the clinical relevance of the comparison between VDs and IP monitors, we only found 6 papers dealing with this head-to-head comparison. This is perhaps due to the idea that a monitoring device in itself cannot improve outcomes, but guide treatment and because certain imaging characteristics (midline shift, mass lesions, narrow ventricles) might deter clinicians from inserting VD, making RCTs difficult to carry out and less generalizable.

It is essential to distinguish acute craniotomy for the evacuation of life-threatening space-occupying lesions from decompressive craniectomy, a rescue therapy to resolve intracranial hypertension refractory to medical treatment because of the vastly different prognosis.

This was, however, only properly defined as such in the paper by Liu and colleagues.[8] In the other two papers that report this outcome[9, 10], it is unclear whether patients received a decompressive craniectomy or a craniotomy with decompression of the lesion. Kasotakis et al report “surgical decompression” and do not define it[10], whereas Aiolfi et al report in the text “The need for craniectomy” and “Craniotomy/Craniectomy performed within 24 hours” in the table.[9] When the results of Liu et al and Kasotakis et al were pooled, the difference was significant in that the VD group required surgical decompression more often. When the results of the Aiolfi study were added, the difference was no longer significant. Given the major differences in prognosis between a craniotomy with evacuation of a lesion and a craniectomy on patient outcomes, it is likely that confounding was introduced by adding the Aiolfi study to the pooled results, owing in part to the large number of patients included.[9]

The overall complication rate and in particular to the risk of infection and haemorrhage were higher for patients receiving a VD when compared to those receiving an IP monitor.

The infection risk for an VD in the literature ranges between as low as 0%[17] and as high as 22%[17], and this needs to be addressed when VDs are used by the implementation of a

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strict protocol of insertion, care and maintenance. In this review the calculated infection rate and overall complication rates were higher in the VD groups, ranging from 2%[8] to 9%[12]. The IP monitor group had consistently very low prevalence of infection, usually under 1%.[2, 10] It is known that a longer duration of monitoring usually leads to a higher infection rate.[12] Only two papers report the mean duration of monitoring and the pooled results show no statistically significant difference between the two groups,[8, 10] but future research on this topic needs to address this potential confounder.

Despite the difference being non-significant in all of the individual studies, the aggregated results show a significantly shorter duration of ICU admission in patients receiving IP monitors. At first glance, it might appear that the lower complication rate leads to a shorter ICU LOS. On average, patients spent one extra day in the ICU. Severe complications would prolong ICU stay for longer than a day and the hospital LOS does not differ significantly. This might, however, be a case of confounding by indication: the insertion of a ventricular probe requires a patent ventricle, and is best accomplished when the ventricular system is not displaced. In case of raised ICP the ventricles become slit and a considerable midline shift may develop, making the surgical insertion of the probe difficult or impossible. There is the risk, therefore, that VDs are used in less severe cases, where its insertion is feasible.

When looking at variables collected in the 6 included papers, we strikingly found no mention of the effect of CSF drainage on therapy intensity level, save for the need for performing a surgical decompression and the ICU LOS and number of episodes of RICH as indications of therapy intensity (the latter only available in the RCT). We feel that this is a necessary addition for future studies, as the beneficial effect of controlling ICP through CSF drainage might be counteracted by the risk of adverse events. It is more likely to assume that VD use decreases treatment intensity and is in this respect beneficial than to assume that it has, as a standalone entity, a direct effect on patient outcomes.

Moreover, except for the only RCT on the topic by Liu and colleagues[8], no other papers report whether CSF was drained intermittently or continuously. Within the aforementioned trial CSF was drained intermittently. So far only small studies suggest a

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potential benefit of continuous drainage above intermittent.[18] In addition, there was also no information available of crossover patients, i.e. patients that received an VD after receiving an IP monitor and whether there were differences in the readings. This also suggests another possible confounder: the values indicated by VDs during drainage might provide inaccurately low values, not detecting values above the threshold and leading to under-treatment.[19] Furthermore, no mention was made in any of the papers whether antibiotic impregnated catheters were used. These issues need to be dealt with when further research on this topic will be carried out.

In light of the complications, the use of VDs might seem counterintuitive. However, in the pediatric population continuous CSF drainage is a relatively common practice with evidence to support improvements in both ICP management and injury biomarkers.[20] In the adult population, however, only small studies show a potential benefit of continuous drainage[18]. This statement also figures as a recommendation in the guidelines.[1]

In light of many unanswered questions, a large comparative effectiveness study,[21] such as the ongoing CENTER-TBI and TRACK-TBI cohorts would be needed to address all of the questions regarding the effectiveness, complication rate, and to assess the cost-effectiveness of each device while keeping the risk of bias moderate or low and work around the confounding. The topic of intermittent or continuous drainage also needs to be addressed in a larger dedicated trial, and the focus should also be on the effect of CSF drainage on treatment intensity.

Despite the fact that the only RCT on this topic shows better results for patient outcomes, it did not create a paradigm shift in practice, nor does it figure in the current edition of the guidelines[1]. When all available data was pooled, the results of this RCT are challenged. Further high-quality comparisons are needed to address this issue.

Deviations from the protocol and limitations

We were unable to access absolute values of the GOS(E) in order to dichotomize. The only data available was the mean GOS for the two groups which is a limitation of this study. We would have favored an ordinal approach to data analysis.

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We also did not measure the relative risk of receiving an VD when one had received an IP monitor first. We included some studies that did not respect our 85% severe TBI rule, but given that we felt that the risk of infections when these devices are used in other injury types or in mixed injury types are comparable, we avoided the introduction of confounding of our results. VDs used in stroke are usually inserted in cases of intraventricular haemorrhage and kept in until the blood clears, which might lead to a longer monitoring duration in the VD group and consequently more infections. The pooled data available did not suggest a longer monitoring duration with VDs, but only 2 of the 6 papers reported this outcome.

Subgroup analyses were impossible since the studies did not present the required data. Funnel plots could also not be compiled as there were insufficient studies in order to do so.

Conclusion

This systematic review suggests that in patients with severe or moderate TBI the use of VDs instead of IP monitors was not associated with less mortality or better functional outcome, but the patients did suffer more complications. Overall, these results need to be interpreted with caution given that the overall body of evidence is poor, consisting of mostly observational studies with serious and critical risk of bias. There remains a need for high quality head-to-head comparisons of VDs and IP monitors.

Acknowledgments

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Conflict of interest

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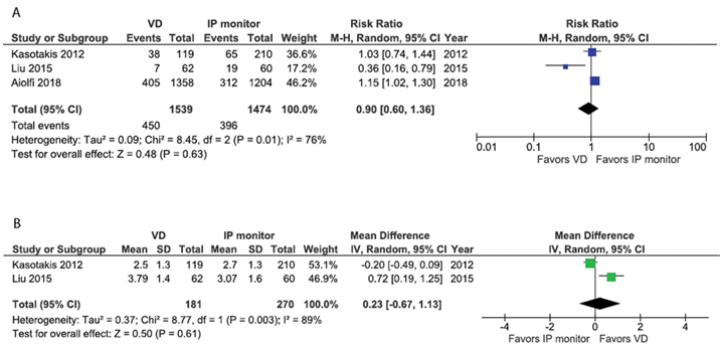

Figure 1: Forest plots of the primary outcomes.. A: Mortality.; B: GOS mean (M-H = Mantel–Haenszel test; IV = Inverse Variance; CI =Confidence Interval)

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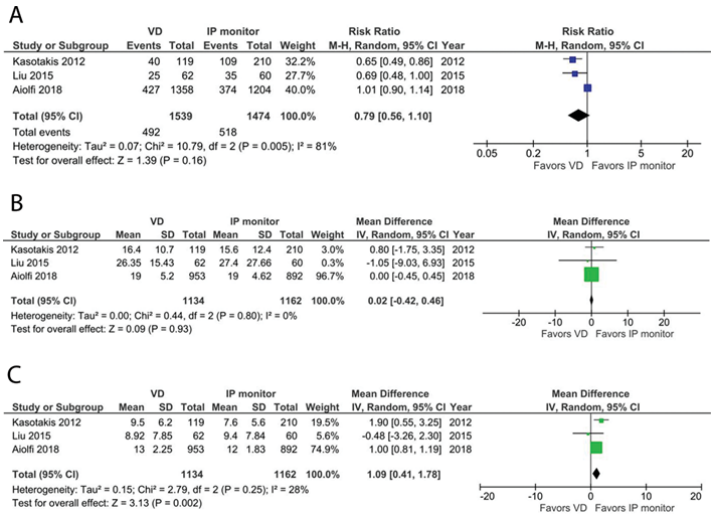

Figure 2: Forest plots of secondary outcomes. A: Need for surgical decompression; B: Hospital length of stay; C: ICU Length of Stay; (M-H = Mantel–Haenszel test; IV = Inverse Variance; CI =Confidence Interval)

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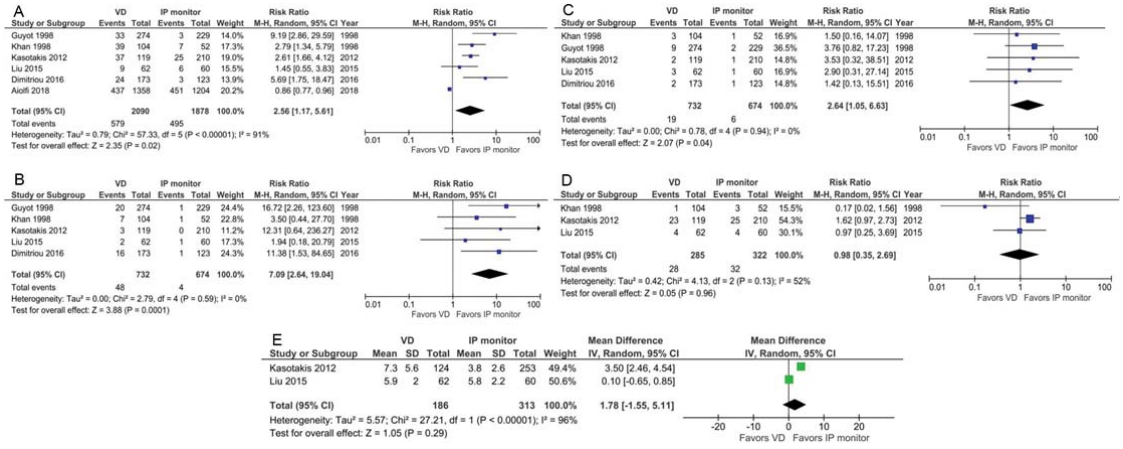

Figure 3: Forest plots of complications and monitoring duration. A: Overall complications; B: Infection; C: Haemorrhage; D: Device malfunction; E: Monitoring duration; (M-H = Mantel–Haenszel test; IV = Inverse Variance; CI =Confidence Interval)

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Appendix 1 – Search strategy

Source	**Number of studies**	**Number after duplicates removed**
Embase.com	785	774
Medline ovid	444	178
Web-of-science	232	68
Cochrane	22	2
Google scholar	200	136
Total	**1683**	**1158**

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Embase.com

('cerebrospinal fluid drainage'/exp OR 'ventriculostomy catheter'/exp OR ('cerebrospinal fluid'/exp AND monitoring/exp) OR 'fiberoptic catheter'/de OR (((cerebrospinal OR extern* OR extracran* OR csf OR ventricul* OR subdural*) NEAR/3 (drain* OR monitor* OR dynamic* OR shunt* OR catheter*)) OR evd OR evds):ab,ti) AND ('intracranial pressure monitoring'/exp OR 'intracranial pressure'/exp OR 'intracranial pressure monitoring device'/exp OR ((intracran* NEAR/3 pressure* NEAR/6 (monitor* OR record*)) OR (icp NEAR/3 (monitor* OR record*))):ab,ti) AND ('brain injury'/exp OR 'head injury'/de OR 'nervous system injury'/de OR (injur* OR traum* OR tbi OR (brain NEAR/3 damage*)):ab,ti) NOT ([animals]/lim NOT [humans]/lim)

Medline ovid

(("Cerebrospinal Fluid"/ AND (drainage/ OR "Monitoring, Physiologic"/)) OR (((cerebrospinal OR extern* OR extracran* OR csf OR ventricul* OR subdural*) ADJ3 (drain* OR monitor* OR dynamic* OR shunt* OR catheter*)) OR (ventricul* ADJ3 catheter*) OR evd OR evds).ab,ti.) AND ("intracranial pressure"/ OR ((intracran* ADJ3 (pressure* OR monitor*)) OR ((intraparenchym* OR parenchym*) ADJ3 monitor*) OR icp OR (fiberoptic ADJ3 catheter*)).ab,ti.) AND (exp"brain injuries"/ OR "Craniocerebral Trauma"/ OR "Trauma, Nervous System"/ OR (injur* OR traum* OR tbi OR (brain ADJ3 damage*)).ab,ti.)

Cochrane

((((cerebrospinal OR extern* OR extracran* OR csf OR ventricul* OR subdural*) NEAR/3 (drain* OR monitor* OR dynamic* OR shunt* OR catheter*)) OR (ventriculostom* NEAR/3 catheter) OR evd OR evds):ab,ti) AND (((intracran*NEAR/3 (pressure* OR monitor*)) OR ((intraparenchym* OR parenchym*) NEAR/3 monitor*) OR icp OR (fiberoptic NEAR/3 catheter*)):ab,ti) AND ((injur* OR traum* OR tbi OR (brain NEAR/3 damage*)):ab,ti)

Web-of-science

TS=(((((cerebrospinal OR extern* OR extracran* OR csf OR ventricul* OR subdural*) NEAR/2 (drain* OR monitor* OR dynamic* OR shunt* OR catheter*)) OR (ventriculostom*

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NEAR/2 catheter) OR evd OR evds)) AND (((intracran*NEAR/2 (pressure* OR monitor*)) OR ((intraparenchym* OR parenchym*) NEAR/2 monitor*) OR icp OR (fiberoptic NEAR/2 catheter*))) AND ((injur* OR traum* OR tbi OR (brain NEAR/2 damage*))))

Google scholar

"cerebrospinal|csf drainage|monitoring|dynamics"|"External Ventricular Drainage"|evd|evds "intracranialpressure|monitoring"|"intraparenchymal|parenchymal monitoring"|icp|"fiberoptic catheter"injury|trauma|tbi

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Appendix 2 - Characteristics of included studies

Study	Design	Number of patients	Number of patients in ICP monitor group	Number of patients in EVD group	Mean age	% of women	Mean of median GCS	Mean of median ISS
Khan, 1998[1]	Retrospective observational	156	52	104	50	N/A	N/A 104 GCS 3-8 27 GCS 9-12	N/A
Guyot, 1998[2]	Retrospective observational	503	229	274	N/A	N/A	N/A	N/A
Kasotakis, 2012[3]	Retrospective observational	377	253	124	46.5	N/A	6.7	30.2
Liu 2015[4]	Randomized controlled trial	122	60	62	43.37	17.2%	7.84	20.58
Dimitriou, 2016[5]	Retrospective observational	288	123	173	N/A	N/A	N/A	N/A
Aiolfi, 2018[6]	Retrospective	2562	1204	1358	49	25.2%	N/A	25

	observational							

1. Khan, S.H., Kureshi, I.U., Mulgrew, T., Ho, S.Y. and Onyiuke, H.C. (1998). Comparison of percutaneous ventriculostomies and intraparenchymal monitor: a retrospective evaluation of 156 patients. Acta Neurochir Suppl 71, 50-52.

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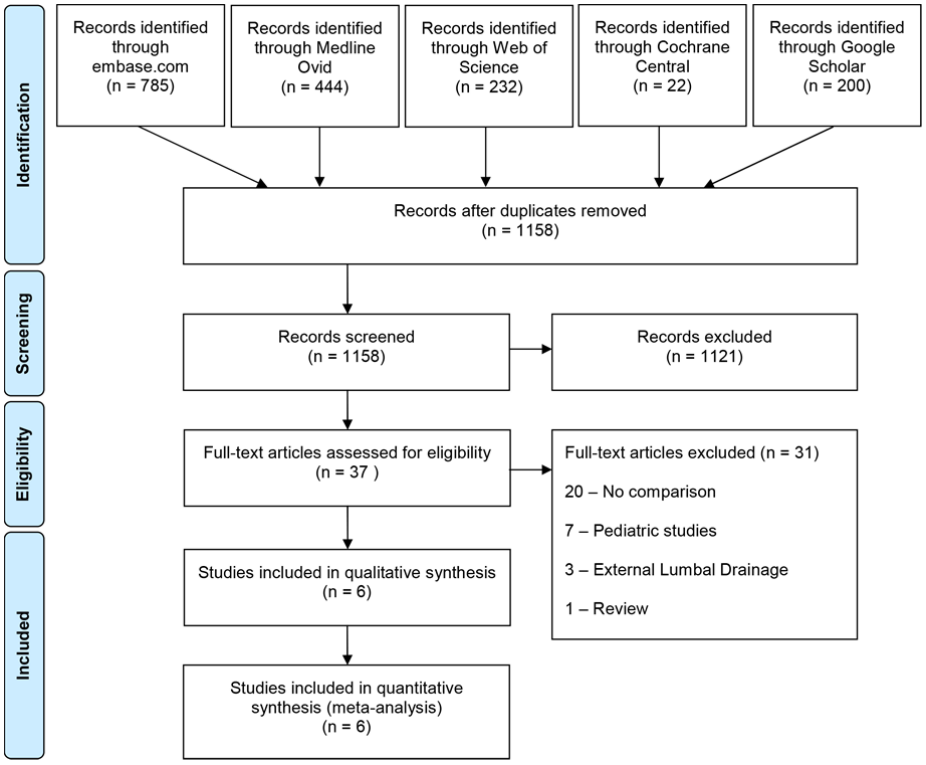
Appendix 3- PRISMA flowchart of included studies



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Appendix 4- Risk of Bias of included studies

Study/Domain	Risk of bias assessment
Liu, 2015	
Random sequence generation	LOW
Allocation concelament	LOW
Blinding	HIGH
Blinding of outcome	UNCLEAR
Incomplete data	LOW
Selective reporting	LOW
Other	LOW
Kasotakis, 2012	
Bias due to confounding	CRITICAL
Bias of selection of participants into the study	SERIOUS
Bias in classification of interventions	SERIOUS
Bias due to deviations from intended intervention	NI
Bias due to missing data	SERIOUS
Bias in measurement of outcomes	NI
Bias in selection of the reported result	NI
Overall	**CRITICAL**
Guyot, 1998	
Bias due to confounding	CRITICAL
Bias of selection of participants into the study	NI

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Bias in classification of interventions	SERIOUS
Bias due to deviations from intended intervention	NI
Bias due to missing data	NI
Bias in measurement of outcomes	SERIOUS
Bias in selection of the reported result	LOW
Overall	**CRITICAL**
Khan, 1998	
Bias due to confounding	CRITICAL
Bias of selection of participants into the study	CRITICAL
Bias in classification of interventions	SERIOUS
Bias due to deviations from intended intervention	NI
Bias due to missing data	NI
Bias in measurement of outcomes	SERIOUS
Bias in selection of the reported result	LOW
Overall	**CRITICAL**
Dimitriou, 2016	
Bias due to confounding	CRITICAL
Bias of selection of participants into the study	NI
Bias in classification of interventions	SERIOUS

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Bias due to deviations from intended intervention	NI
Bias due to missing data	NI
Bias in measurement of outcomes	NI
Bias in selection of the reported result	LOW
Overall	**CRITICAL**
Aiolfi, 2018	
Bias due to confounding	SERIOUS
Bias of selection of participants into the study	SERIOUS
Bias in classification of interventions	LOW
Bias due to deviations from intended intervention	NI
Bias due to missing data	NI
Bias in measurement of outcomes	NI
Bias in selection of the reported result	LOW
Overall	**SERIOUS**

NI= No information