Methods of measuring CSF Pressure: A Review

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Abstract:*Cerebrospinal fluid pressure is considered as one of the key diagnostic parameters to identify different pathological conditions related to the central nervous system. Different clinical methods have been used to measure the intracranial pressure (ICP) inside the craniospinal compartment of the brain. But most of those invasive methods pose a significant risk for the patients. Hence, CSF pressure is measured during Lumbar Puncture procedure as an indication to the ICP. The main aim of this review is to study and analyse the different methods of measuring CSF pressure specially during Lumbar Puncture procedure. But there is a limited literature regarding modern advanced methods of measuring CSF pressure during LP. Hence, this review emphasizes on the existing methods and peer review literature that focus on different methods of measuring CSF pressure.*

Keywords:*Lumbar Puncture, CSF Pressure, Intracranial Pressure*

1. Introduction

In human body, it is important to keep different parameters under normal range to maintain the homeostasis. Cerebrospinal fluid, also known as CSF, is one such important parameter that plays a major role in the nervous system including the brain. Thus, different neurological conditions can occur due to any abnormality in CSF pressure, composition, and the CSF flow.

Cerebrospinal fluid is a crystal-clear fluid that surrounds and baths the brain and spinal cord protecting the central nervous system. Mainly, cerebrospinal fluid gives mechanical and immunological protection for the nervous system (CSF leak Association, 2017). It also acts as a buffer in central nervous system (CNS) while giving a hydromechanical protection for the neuraxis (Sakka, Coll and Chazal, 2011). CSF further aids in regulating the electrolyte balance and eliminating the produced catabolites. Hence, CSF is important in regulating the neuronal functioning by maintaining and developing the homeostasis of the interstitial fluid (Sakka, Coll and Chazal, 2011).

According to existing literature, the mean density of cerebrospinal fluid is 1.00059+/- SD 0.00020gml-1 and hence it is considered as slightly thicker than the water (Lui, Polis and Cicutti, 1998). For healthy conditions, the CSF appears as a colorless fluid that is similar to the water. But due to various abnormalities in the body, CSF can appear in turbid or in a different color. Thus, CSF has become a main diagnostic key to identify different abnormalities and diseases within the body, specially related to central nervous system. CSF, extracted from the body, is hence tested in medical laboratories for diagnostic purposes.

Cerebrospinal fluid has a dynamic pressure which is caused due to the secretion of CSF, absorption, circulation and its resistance to flow. For a healthy individual, around 125-150ml CSF volume is present in the body at a time, where the 25ml of CSF volume is present in the brain ventricles and around 125ml CSF volume in subarachnoid spaces as an average (Sakka, Coll and Chazal, 2011), (CSF leak Association, 2017). Further, roughly around 400ml to 600ml Cerebrospinal fluid is secreted per day for a healthy adult (Telano and Baker, 2020). According to existing literature, approximately about 20ml of CSF is produced for each hour and the Cerebrospinal fluid secretion is majorly done by choroid plexuses in brain which contributes for around 60% - 70% secretion of the total CSF volume (Doherty and Forbes, 2014). Reabsorption of Cerebrospinal fluid is mainly done by Cranial and spinal arachnoid villi at a rate of about 0.35 ml/min (CSF leak Association, 2017). Depending on the pressure, the absorption of CSF by villous also adapts its filtration rate according to the cerebrospinal fluid pressure where the whole process is considered as a dynamic process. The dynamic circulation of CSF also affects cerebral homeostasis. It consists of a dynamic circulation which flows a pulsatile flow that is followed by systolic pulse wave. Despite that, respiratory waves, the posture and physical efforts of the individual jugular venous pressure also affects the dynamic flow of CSF (Sakka, Coll and Chazal, 2011). For normal conditions, Cerebrospinal fluid is renewed about 4-5 times per day for a young individual and this turnover rate can be changed when aging leading to various neurodegenerative diseases (Telano and Baker, 2020). Hence, Cerebrospinal fluid pressure is considered as one of the key indicators for several neurological conditions.

The cerebrospinal fluid pressure in the body can be measured in two main ways.

1. *By inserting a needle into subarachnoid space in spine to measure the opening pressure during lumbar puncture procedure.*
2. *By inserting a needle into ventricle of the brain as a part of Intra Cranial Pressure (ICP) directly using a pressure sensor (Muhamed et al., 2014)*

In addition, different non-invasive procedures are being developed to measure the CSF pressure using different technologies which are still in research levels. In clinical practice, the CSF pressure is measured widely by obtaining the opening pressure when conducting a lumbar puncture procedure via a CVP manometer.

2. Methodology

Literature review plays a vital role in academic field that enables to conduct a deeper study and analysis in different research areas. To conduct the review, the specific research topic and the research scope was first identified and analysed. Using online and offline data bases including Google scholar, ResearchGate, ScienceDirect etc, Peer reviewed articles, research papers, journal articles were selected to study the research area in depth about methods of measuring CSF pressure highlighting the pressure measurements during Lumbar Puncture procedure. Mainly, Lumbar Puncture, CSF Pressure measurement, Intracranial Pressure etc were identified as the key words that were used to collect the related paper articles. Out of 55 paper results obtained, abstracts were read, and the number of citations were considered to collect the most suitable and related papers for the review, avoiding any duplicates. The selected papers were studied in depth to conduct a better analysis of the study, focusing the CSF pressure measurement methods related to Lumbar Puncture procedure.

3. Literature Review

Different comparisons have been done to evaluate the effectiveness of the main two methods of measuring the CSF pressure. Specially, studies have done to estimate the accuracy of measuring the intracranial pressure via LP procedure. In one of the studies, a brain tissue sensor that was located in the right ventricle anterior roof and a lumbar space transducer were used to conduct the comparison between the two methods (Lenfeldt et al., 2007).

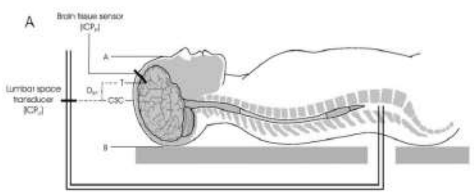

Figure 1. Set up of measuring ICP using Brain tissue sensor and lumbar space transducer

Source: (Lenfeldt et al., 2007)

As per the results, the total mean and the standard derivation of the difference between the two pressures, measured in brain tissue and lumbar space was 10 +/- 29 mmH_2O. Further, the results have shown that the corresponding individual mean were similar, and the standard derivation was similar as well. (Lenfeldt et al., 2007)

A. Intra cranial pressure measurement using invasive methods

Intra Cranial Pressure also known as ICP is mainly measured using different invasive methods that are accurate but can pose a high risk for the patients. Some of the methods are Intra Cranial Pressure measured using implantable ICP sensors, ventricular catheters etc (Evensen and Eide, 2020). Among them, intraventricular or intraparenchymal catheters are widely used as a golden clinical standard of measuring ICP (Xu et al., 2016). In addition to that, biocompatible and implantable telemetric ICP sensors have been introduced, that enables to obtain mean ICP of the patients using an external receiver (Evensen and Eide, 2020).

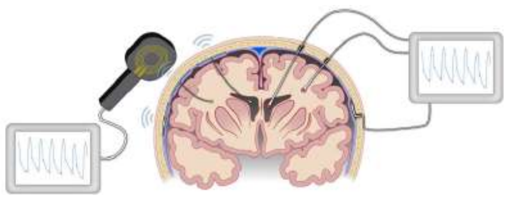

Figure 2. Different methods of ICP monitoring

Source: (Evensen and Eide, 2020)

The existing dedicated implantable ICP sensors include Fibre optic Camino ICP sensors, Strain gauge Codman micro sensors, Pneumatic sensors etc (Evensen and Eide, 2020). Fibre optic Camino ICP sensors serves as an advanced and novel platform that enables multimodality neuromonitoring where in Strain gauge Codman micro sensors, diffuse piezoelectric string gauges are included in transducer to measure ICP. In contrast, in Pneumatic sensors, the distal end of the probe contains a balloon to measure the pressure of the surrounding tissue in brain (Harary, Dolmans and Gormley, 2018).

Pulsatile ICP monitoring is also one of the novel approaches that is practiced in very limited facilities. This method enables to study and analyse the ICP pressure changes that occurs during each cardiac cycle. Hence, the resultant output can be obtained as a wave or pulse ICP pressure graph.

In most of the scenarios, a hole is made in skull to insert the sensor or transducer into brain parenchyma. Depending on the requirement and availability, the duration of the pressure monitoring and the most suitable method is selected along with the sensor type. These invasive methods are highly complex, expensive, and mostly done in intensive care units under aseptic conditions and some of the methods are limited to highly advanced health care Centres. Also, they pose a greater risk for infections to the patients compared to other methods.

B. CSF pressure measurement during Lumbar puncture

Lumbar Puncture, also known as LP procedure, is considered as one of the widely spread methods of measuring the CSF pressure. It was initially explained by Dr. Heinrich Irenäus Quincke in 1890s (Bø and Lundqvist, 2020). Compared to other methods of measuring Intra Cranial Pressure, it is considered as a simple, less invasive method performed using minimal equipment that can be used to measure the ICP (Muhamed et al., 2014).

During the Lumbar puncture procedure, cerebrospinal fluid volume is extracted to perform laboratory tests to diagnose different neurological disease conditions aiding doctors to determine further treatment and therapeutic procedures. Mainly these laboratory tests are performed related to cell counts, protein levels, glucose levels, cultures and microscopic examination. In addition to that, the opening pressure is measured during lumbar puncture as an indirect measurement depending on the requirement.

Usually, LP procedure is performed by a neurologist where the procedure is invasive and should be done under aseptic conditions to avoid any infections and negative impacts to the patients. To perform the Lumbar puncture procedure, the patient can be either positioned in lateral recumbent position or sitting position, also known as upright position. But mostly, this procedure is done in lateral recumbent position, with patient's neck bent in full flexion and knees bent in full flexion up to the chest to provide the maximum lumbar spine flexion (Sternbach, 1985). Further, during the procedure, the patient must keep still without any physical movement because the positioning and the physical activity can affect the final readings of the overall procedure leading to inaccurate diagnosis.

This normal range of CSF pressure can be changed due to different reasons including age, weight, gender, positioning different health conditions etc. For an example, the pressure values for normal conditions can be ranged up to 25cmH2O for overweight adults even in healthy conditions (Doherty and Forbes, 2014). Moreover, for children, the CSF pressure values are higher than the adults which lies between 3mmHg-7.7mmHg (A. Artru, n.d.). For a healthy individual, the opening pressure of lumbar puncture procedure in lateral recumbent position lies around 6-20cmH2O. If the patient is seated while obtaining the opening pressure readings, normal pressure values lie between 20-30cm H2O (Muhamed et al., 2014). According to the literature, if the opening pressure is higher than 25cmH20, it is considered as an elevated intracranial pressure (Mogambery, Moodley and Connolly, 2018).

Lumbar puncture procedure is performed on the patient's back where a 22 Gauge lumbar puncture needle is inserted to the body pierces skin to enter the subarachnoid space below the cauda equina (Greenlee, 2021). Then after removing the stylet of the needle, the device is attached to the needle.

Currently, Cerebrospinal fluid pressure is mainly measured via 2 medical devices.

1. C.V.P manometer
2. Compass Lumbar Puncture

1). C.V.P manometer: During LP procedures, CSF pressure is widely measured using C.V.P. manometer, also known as central venous pressure manometer. This device has been using to measure CSF pressure from many years ago, but yet, most of the doctors around the world, still use water column manometer for pressure LP measurements. The device is simple and mainly consists of a 3-way stop cock that connects to the needle and a uniform tube as the fluid column. The pressure range that can be measured using CVP manometer lies between (-3) cmH_2O to $30cmH_2O$. Once the manometer is attached to the needle, CSF enter to the manometer and the level of filling can be identified with the aid of red marker inside of the manometer floating on the CSF. The length of the fluid column in the manometer is measured as the opening pressure of the procedure.

Figure 3. Linear regression between spinal manometer and IVGS when measuring opening CSF pressure

For accurate results, whole apparatus including puncture site, needle and the 3-way stop cock of the manometer should be in line while the water column manometer should be placed perpendicular to the needle.

The mechanism of the CVP manometer is simple and similar to a U-tube that is based on basic physics. Once the cerebrospinal fluid enters the manometer, due to the CSF pressure inside of the body, the fluid rises inside of the CVP manometer. After a certain period of time, the equilibrium point occurs where the pressure exerted by the fluid column in the manometer gets equal to the CSF pressure inside of the patient's body. At this point, the final reading is considered as the CSF pressure in water centimeters. where the pressure exerted by the fluid Colum is given by,

P=hpg **(1)**

P=cerebrospinal fluid pressure during LP

h= height of the CSF fluid column

p= density of the CSF

g= gravitational acceleration

Since the density of the cerebrospinal fluid is approximately similar to water, the final measurement of the manometer is read in water centimeters.

Despite that, in resource limited healthcare facilities, intravenous giving sets (IVGS) is also used as an alternative to the CVP manometer where the cost of IVG set is approximately 30 times lesser than the CVP manometer (Mogambery, Moodley and Connolly, 2018).

Figure 4. A. CSF opening pressure measure using IVGS,

B. CSF opening pressure measure using spinal manometer

Source: (Mogambery, Moodley and Connolly, 2018)

According to research done using 100 patients by applying both CVP manometer and the IVGS, the results have shown that when identifying the normal CSF readings and the elevated CSF pressure, the agreement between the CVP manometer and the intravenous giving set is 75% (Mogambery, Moodley and Connolly, 2018). The linear regression of the two devices when measuring the opening CSF pressure depicts a better correlation despite where the IVGS underestimates the CSF opening pressure. The research further emphasizes that the 25cmH2O of the CVP manometer is denoted by 19cmH20 in the IVGS. Thus, the CSF pressure measured by intravenous giving set should be considered as elevated ICP. Therefore, CVP pressure measurements using IVGS is discouraged in clinical practice. (Mogambery, Moodley and Connolly, 2018)

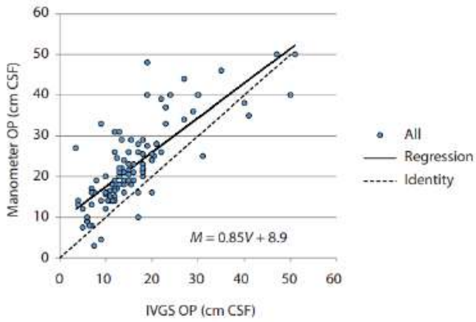

Figure 5. Linear regression between spinal manometer and IVGS when measuring opening CSF pressure

Source: (Mogambery, Moodley and Connolly, 2018)

2). Compass lumbar puncture: Compass lumbar puncture is considered as a novel medical device which is compact and single use medical tool that enables digital pressure measuring of CSF. It is known as one of the simplest methods to measure cerebrospinal fluid pressure during LP procedure. Yet, it is only used in limited healthcare facilities in the world.

The device mainly consists of 3 parts. (biomedical, n.d.)

1.Pressure transducer.

2.Integrated pre-programmed diagnostic computer.

3.Liquid crystal display (LCD).

The CSF pressure is measured via the sensor and then convert the pressure into an electrical signal displaying the resultant output value in the LCD display in water centimeters (cmH_2O). Compared to the water column manometer, compass lumbar puncture device is very fast and user friendly. But there is very limited literature regarding the specific components and mechanisms used in the device.

Figure 6. Compass Lumbar Puncture device

Source: (Biomedical, 2022)

According to a study done by the Department of Anesthesiology, Westchester Medical Center, New York, USA; 27 patients with Lumbar Puncture indications were used for the comparison of fluid manometer and compass lumbar puncture (Sekhri, Parikh and Weber, 2019). They have identified a significant time gap between the two devices to acquire the resultant readings where the compass lumbar puncture was very time-efficient compared to the CVP manometer.

The results show that there is strong correlation between the opening pressures and the closing pressures, but the resultant readings of the compass lumbar puncture were always high compared to the water column manometer. (Sekhri, Parikh and Weber, 2019)

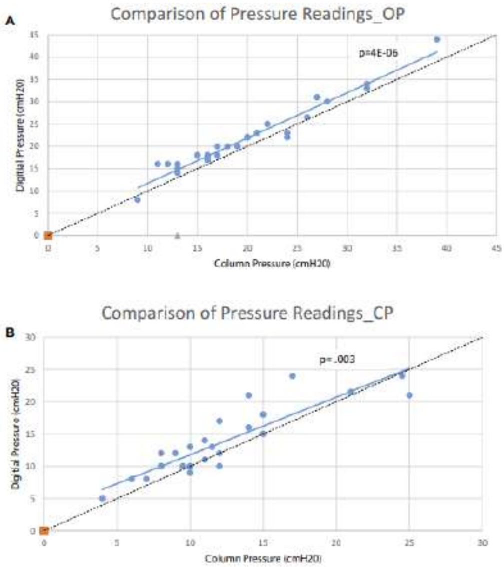

Figure 7. Linear regression of readings taken by compass Lumbar puncture device and CVP manometer,

A. Comparison between two devices for opening CSF pressure, B. comparison for closing CSF pressure

Source: (Sekhri, Parikh and Weber, 2019)

4. Discussion

ICP pressure has been one of the critical parameters to investigate pathological conditions related to nervous system and further used for therapeutic purposes as well. The invasive methods of measuring ICP in brain via ventricular catheters and implants are considered as complex methods which contains a higher accuracy, but those methods can pose a higher risk and different other complications to the patients. Hence, unless there a necessity, in all most all the clinical scenarios, the ICP is measured via CSF pressure during an LP. This practice is routinely performed using a water column manometer which is one of the simplest methods to investigate Intra cranial pressure. But this method is considered as a time consuming and a cumbersome procedure for physicians where the manual stability is requited during the procedure for accurate results.

According to the literature, the use of compass lumbar puncture in clinical scenario is limited even though it overcomes most of the difficulties of the existing method specially when measuring CSF of infants and kids. The device is highly time efficient compared to manometer and addressed the issues when measuring the closing pressure of the Lumbar puncture. Yet, the accuracy of the device is +/- 3cmH20 (Biomedical, 2022) and the whole device should be discarded per patient along with included pressure sensor and LCD display. Thus, it creates an unnecessary waste more than the CVP manometer.

Despite these methods, different structural and functional non-invasive methods of measuring ICP is still conducted under research levels. The research under structural modalities is mainly conducted using CT (Computed Tomography), MRI (Magnetic Resonance Imaging), OCT (optical coherence tomography), ocular ultrasound etc and the functional facilities are studied using TCD, (transcranial Doppler ultrasound, VEP (visual evoked potentials), near-infrared spectroscopy (NIRS) etc (Xu et al., 2016). Even though some methods including ocular ultrasound shows positive results in detecting elevated ICP, the overall reliability and the expected outcomes are still being studied.

5. Conclusion

The paper addresses different methods of measuring cerebrospinal fluid during Lumbar Puncture procedure. Even in a modern sophisticated world with advanced technologies applied in healthcare sector; water column manometer is widely being used in most of the countries for the CSF pressure measurement during LP which has been using even many years ago. However, Compass Lumbar puncture device addresses most of the difficulties and limitations of the existing fluid manometer but clinical differences may occur. Hence, the literature emphasizes that physicians should be careful when using the compass lumbar device for all the cases instead of the CVP manometer. In conclusion, it can be seen that the healthcare sector lacks an advanced, accurate, reusable user-friendly device to measure cerebrospinal fluid pressure overcoming the difficulties and limitations of the existing devices.

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