Hindbrain-related syringomyelia and raised intra-abdominal pressure: implications for safety of laparoscopic and robotic surgery

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BACKGROUND: *The causative role played by intra-abdominal pressure (IAP) in the syringogenesis of the Chiari 1 malformation syringomyelia has been still not adequately studied. The aim of this study is to validate the transmedullary theory about the hindbrain-related syrinx, also discussing the implications for safety of these patients related to the use of high-pressure CO_2 pneumoperitoneum during laparoscopic and robotic surgery.*
METHODS: *Fourteen patients with a hindbrain-related syrinx were candidate for a posterior fossa decompression. Preoperative and follow-up protocol involved conventional T1/T2 and cardiac-gated Cine phase-contrast MRI sequences. Peak systolic and diastolic velocities were acquired at four Regions Of Interests (ROI), namely syrinx, ventral and dorsal cervical subarachnoid space, and foramen magnum region. Data were reported as mean ± SD. Patients were followed for three years. One-way ANOVA with Bonferroni post hoc test of multiple comparisons were performed, where p-value was <0.001.*
RESULTS: *A systolic-diastolic pulsatile pattern of CSF was found in all cases inside the syrinx. Syrinx and premedullary cistern velocities decreased within the first month after surgery (<0.001). All symptoms apart from atrophy and spasticity improved. These data lead to validate the Oldfield and Heiss transmedullary theory about syringogenesis, within which an increased IAP play a key role.*
CONCLUSION: *Raised IAP plays a paramount role in the formation and maintenance of the hindbrain-related syrinx. High-pressure CO_2 surgical pneumoperitoneum is strongly discouraged in these patients because at risk of rapid neurological worsening. A low-pressure insufflation technique has a rationale in those patients having smaller or incidental syrinxes.*

KEY WORDS: Hindbrain-Related Syringomyelia, Intra-Abdominal Pressure, Laparoscopic Robotic Surgery

Background

The term "syringomyelia" was originally coined in 1827 by the French pathologist Charles-Prosper Ollivier d'Angers (Fig. 1). In his seminal publication "*Traité des maladies de la moelle épinière*" he reported for the first time some observations on the spinal cord regarding a pathologic primary cavitation extended over many segments[1,2]. Syringomyelia is associated with Chiari I malformation up to 70% of cases, this last involving a tight posterior cranial fossa and a caudal descent of the cerebellar tonsils below the level of foramen magnum[3,4].
Chiari I-syringomyelia complex is responsible of a heterogenous and variable symptomatology characterized by headache, dysesthetic pain, dissociated sensory loss, weakness, atrophy, spasticity, ataxia and lower cranial nerves dysfunction. The natural history of the hind-brain related syringomyelia is characterized by a stepwise and severe

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ABBREVIATIONS LIST

AP: anterior-posterior
C-SAS: cervical subarachnoid space
CO2: carbon dioxide
CSF: cerebrospinal fluid
IAP: intra-abdominal pressure
PFD: posterior fossa decompression
ROI: Regions of Interests

Fig. 1: French pathologist Charles-Prosper Ollivier d'Angers (Angers 1796 – Paris 1845).

myelopathy causing a progressive neurological deterioration mainly characterized by the occurrence of paralysis, sensory loss, and drug-resistant chronic pain [5,6].
However, the likelihood of symptomatic progression has been linked to the severity and duration of the clinical signs at presentation [4]. A huge number of theories have been reported to explain the syringogenesis in patients with Chiari I malformation, each of which having strengths and weaknesses [7-15]. Among these, the most accredited have hypothesized the existence, below the level of the foramen magnum, of a pressure gradient between the spinal subarachnoid space and spinal cord. This chronic centripetal cerebrospinal fluid (CSF) flow would penetrate the spinal tissue, ultimately causing the syrinx formation and its progression. In this pathophysiological scenario every cause of increased IAP, surgical pneumoperitoneum for first, would involve a worsening of the syrinx, with an easily predictable equal exacerbation or aggravation of the symptomatology. On the other hand, in the context of a still uncertain pathogenesis, the correlations between the raised IAP, secondary to the induced pneumoperitoneum during laparoscopic and robotic surgery, and the spinal subarachnoid space and hindbrain-related syringomyelia have aroused less interest in comparison with those with the intracranial and intrathoracic pressure[16-23].
The aim of this study prospective case-series is to test the hypothesis of a systolic-diastolic CSF pulsatile pattern inside the syrinx being exacerbated by the increasing of IAP, as those related to the surgical pneumoperitoneum. The implications for safety of laparoscopic and robotic surgery are also discussed.

Methods

The present study was approved by the internal Institutional Review Board and was scheduled to start in January 2015 and to finish in December 2019. Patients of age ranging between 18 and 70 years-old and candidate for a posterior fossa decompression (PFD) because of a Chari I malformation with associated syringomyelia were enrolled.
Previous moderate to severe brain injuries or neurosurgical procedures, CSF pathologies, chronic obstructive pneumopathy, obstructive sleep apnea syndrome, or thoraco-abdominal masses were exclusion criteria.
Preoperatively, all the patients underwent to an exhaustive neurological assessment, aimed to reveal symptoms and signs related to the syrinx and Chiari I malformation, and a T1-T2-weighted spin-echo images of the brain and spine. MRI study also involved a retrospective cardiac-gated cine phase-contrast sequence (Magnetom 1.5T MRI Scanner, Siemens Healthineers, Erlangen, Germany) in all patients. Acquisition datasets were as follow: repetition time 50 msec, echo time 10 msec, flip angle 15°, two signals acquisition, 256 x 192 matrix, thickness 3 mm, velocity encoding 5 cm/sec, increased to 10 cm/sec in case of aliasing. Cardiac triggering technique with finger photoplethysmography was used. Based on the heart rate, the radio-frequency pulses ranged between 12 and 24. This last varied from 50 to 100 bpm. CSF flow data were acquired in mid-sagittal and axial planes. Cardiac cycle was fractioned in 14 phases and, within selected regions of interest (ROI), the highest (peak) velocity was calculated for each voxel both in systole and diastole at each of these phases. Images were viewed in a video loop mode analysing the effects of the hart beat on the CSF motion. Syrinx cavity, cervical ventral and dorsal subarachnoid space, and foramen magnum were selected as ROIs. Sagittal length and maximum anterior-posterior (AP) diameter of the syrinx were measured on sagittal and axial T2-weighted MRI, respectively. Maximum AP diameter of the ventral and dorsal cervical subarachnoid space (C-SAS) was calculated on T2 MRI at the level of the C4-C5 intervertebral disk. At the level of foramen magnum, premedullary cistern and cisterna magna AP diameters were measured in correspondence of the McRae line. A DICOM imaging

workstation (Osirix DICOM Viewer@, Pixmeo, Bernex, Switzerland) was used for linear measurements.
Systolic and diastolic velocities were calculated for each ROI during the acquisition of cine MRI, and reported as mean ±SD.
All the patients underwent to a PFD encompassing a wide suboccipital craniectomy, microneurolysis of the arachnoid bends at the level of foramen of Magendie, and duraplasty with a xenogeneic bovine pericardium dural substitute (Tutopatch, SIAD Healthcare S.p.a., Assago, Milano, Italy). The scheduled clinico-radiological follow-up involved a neurological assessment and the same MRI protocol performed preoperatively at 72 hours from surgery, first-, second-, third- and sixth-month, and first-, second- and third-year.
Statistical analysis was executed with a commercially available software (SPSS Statistics for Windows, version x.0, SPSS Inc., Chicago, Ill., USA). One-way ANOVA was initially performed for each parameter. Significant results were further investigated with Bonferroni post hoc test of multiple comparisons, and the p-value was set as < 0.01.

TABLE I - *Overall Data about the ROIs Measurements*

ROI and PARAMETER	Pre-op.	Post-op.	1rst-mo	2nd-mo	3rd-mo	6th-mo	1rst-Y	2nd-Y	3rd-Y
SYRINX									
Length (cm)									
AVERAGE	14,01	13,06	10,11	8,32	9,41	9,19	8,12	8,21	5,27
SD	6,22	7,39	6,29	4,94	4,98	3,13	2,86	2,61	1,83
AP diameter (mm)									
AVERAGE	12,85	11,60	7,98	6,82	6,80	6,53	5,92	5,18	4,76
SD	2,05	2,70	1,75	1,79	2,90	1,41	2,05	1,74	1,87
Sys Vel. (cm/sec.)									
AVERAGE	1,23	0,67	0,30	0,32	0,23	0,18	ND	ND	ND
SD	0,34	0,28	0,18	0,09	0,12	0,04	ND	ND	ND
Dias Vel. (cm/sec.)									
AVERAGE	0,72	0,58	0,45	0,36	0,32	ND	ND	ND	ND
SD	0,35	0,15	0,10	0,09	0,11	ND	ND	ND	ND
VENTRAL C-SAS									
AP diameter (mm)									
AVERAGE	1,23	2,78	2,94	3,02	3,62	4,24	4,23	4,52	4,48
SD	0,72	0,74	1,04	0,87	0,63	0,43	0,42	0,67	0,46
Sys Vel. (cm/sec.)									
AVERAGE	5,63	5,47	5,28	4,48	3,38	3,73	2,68	2,16	1,94
SD	1,20	1,45	2,32	1,50	1,81	2,09	1,27	0,57	0,78
Dias Vel. (cm/sec.)									
AVERAGE	3,48	3,45	3,35	3,26	2,24	1,98	1,67	1,65	1,28
SD	1,18	1,34	1,46	1,47	1,08	0,84	0,83	0,93	0,78
DORSAL C-SAS									
AP diameter (mm)									
AVERAGE	1,36	1,52	1,62	1,96	2,72	4,38	4,67	4,56	4,27
SD	0,60	0,77	0,97	0,82	1,21	1,41	0,65	0,51	0,67
Sys Vel. (cm/sec.)									
AVERAGE	4,84	4,68	3,27	3,16	2,98	2,32	2,24	2,18	2,16
SD	0,77	1,76	1,90	1,06	1,50	1,35	0,50	1,16	0,91
Dias Vel. (cm/sec.)									
AVERAGE	2,98	2,87	2,25	2,23	2,14	1,98	1,76	1,37	1,28
SD	1,22	1,34	1,20	1,15	0,88	1,05	0,73	0,85	0,64
FORAMEN MAGNUM REGION									
Premedullary Cistern AP Diameter (mm)									
AVERAGE	2,35	3,07	3,21	3,30	3,57	4,14	4,28	4,35	4,35
SD	0,81	0,72	0,78	0,81	0,53	0,48	0,49	0,50	0,50
Cisterna Magna AP Diameter (mm)									
AVERAGE	2,36	4,42	5,64	6,07	7,21	10,57	11,29	11,50	11,93
SD	0,44	0,68	0,82	0,66	0,87	1,38	1,72	1,36	2,03
Sys Vel. (cm/sec.)									
AVERAGE	5,39	4,62	3,21	1,22	1,08	0,75	0,70	0,68	0,62
SD	0,78	1,43	0,92	0,18	0,30	0,32	0,30	0,29	0,28
Dias Vel. (cm/sec.)									
AVERAGE	2,71	2,46	1,16	0,87	0,83	0,82	0,81	0,81	0,66
SD	1,52	1,00	0,20	0,15	0,17	0,19	0,22	0,23	0,23

ROI: Region of Interest; AP: anterior-posterior; mo: month; Y: year; C-SAS: cervical subarachnoid space; SD: standard deviation: Sys: systolic velocity; Dias: diastolic velocity, ND: not detectable

Results

Fourteen patients were enrolled. Average age was 30.5 years, and male/female ratio 0.7.

Headache, dissociated sensory loss, lower cranial nerve dysfunction and weakness were the most frequent findings (Graph. 1), whereas C2-C5 metameres were the most frequent involved (Graph. 2). Within 6-months from PFD, headache dysesthetic pain, weakness and dissociated sensory loss significantly improved, whereas atrophy and spasticity resulted unaffected up to 3rd-year (Graph. 3). Overall data about measurements, and results of ANOVA and Bonferroni multiple comparisons tests for each ROI are reported in Tables I, II, respectively (Tables I, II). Syrinx parameters all decreased after surgery (< 0.001) (Graph 4). Bonferroni post-hoc test revealed that syrinx length and AP diameter decreased at first-year and first-month, respectively. Systolic and diastolic peak velocities were found lower already at the post-operative and second-month evaluation, respectively (Table II). The systolic and diastolic velocities measured at the level of the ventral C-SAS, are reported in graph 5 (Graph. 5). Graph 6 shows the trend of the systolic-diastolic velocities at the level of dorsal (C-SAS) (Graph. 6). At the level of the foramen magnum region, premedullary cistern and cisterna magna were significantly enlarged after surgery. Diastolic velocity dramatically decreased immediately after PFD (Graph. 7).

Illustrative Case

A 45 years-old female underwent to a laparoscopic cholecystectomy for a gallstone disease. High-pressure carbon dioxide (CO_2) surgical pneumoperitoneum was used for laparoscopic surgery. She also referred a not specific history of sporadic headache exacerbated by cough.

Two weeks after cholecystectomy he developed a severe ataxia, associated with dysphagia and dysesthetic pain, by the reason of which she underwent to a brain and spine MRI. A holocord syringomyelia with a Chiari I malformation were diagnosed (Fig. 2 A-C). Cine MRI clearly showed that during systole the descendent cerebellar tonsils acted as a piston on the trapped spinal CSF pathways. At the same time, the syrinx was filled by a jet CSF flow and dilated in a caudad direction (Fig. 2D). In contrast, during diastole, the signal inside the syrinx became hypointense, as result of the cephalad direction of the CSF flow, and the upper part of the syrinx itself re-expanded. The patient underwent to a PFD, after which an almost complete disappearance of symptoms occurred within one month. Cine MRI revealed a significant collapse of the syrinx and a dramatic reduction of the caudad flow during systole (Fig. 2E).

Discussion

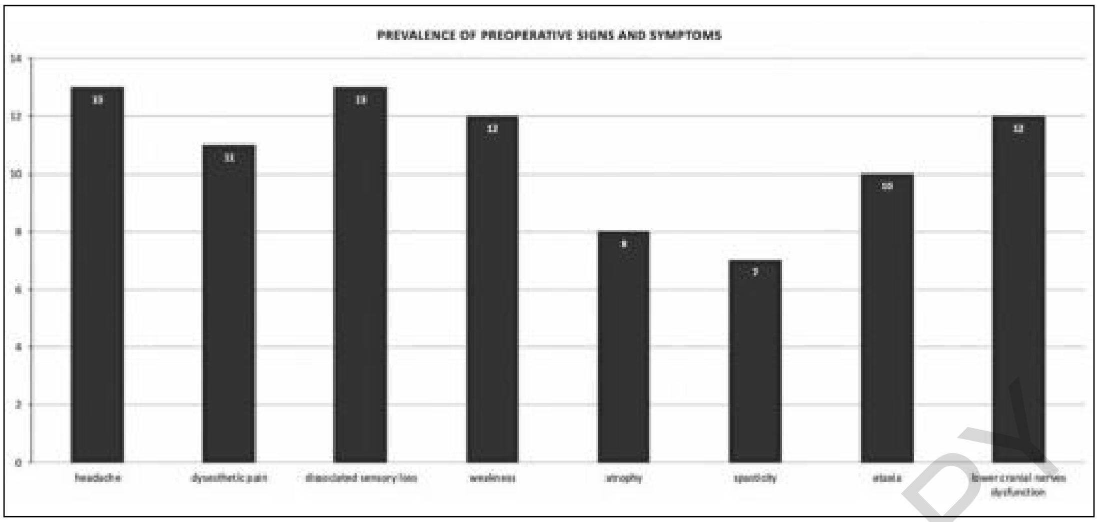
Pathophysiologic Effects of Surgical Pneumoperitoneum on the Spinal Subarachnoid Space

Laparoscopic and robotic techniques are becoming the standard of care for abdominal and pelvic surgery, by the reasons of well-proven benefits as reduced postoperative pain and hospital stays, but also better cosmetic results[24-26]. These techniques are united by the need to induce a pneumoperitoneum allowing a clearer visualization and a greater surgical freedom. CO_2 is used in

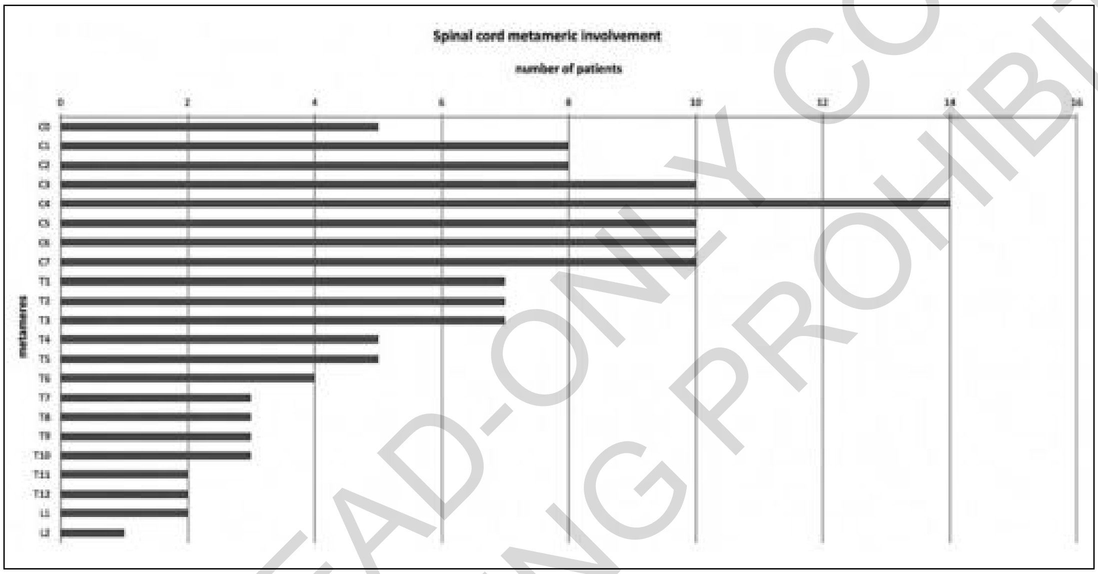
Table II - *Summary of ANOVA and Bonferroni multiple comparisons tests of the Parameters Calculated at each ROI*

ROI	Parameter	ANOVA Overall Follow-Up	P Value Bonferroni Multiple Comparisons Pre-op vs. Post-op	Pre-op vs. 1rst mo	Pre-op vs. 2nd mo	Pre-op vs. 3rd mo	Pre-op vs. 6th mo	Pre-op vs. 1rts Y
Syrinx	Length	< 0.001	0.717	0.265	0.012	0.040	0.015	< 0.001
	AP diameter	< 0.001	0.179	< 0.001	nc	nc	nc	nc
	Systolic Velocity	< 0.001	< 0.001	nc	nc	nc	nc	nc
	Diastolic Velocity	< 0.001	0.187	0.009	< 0.001	nc	nc	nc
Ventral C-SAS	AP diameter	< 0.001	< 0.001	nc	nc	nc	nc	nc
	Systolic Velocity	< 0.001	0,754	0,801	0,035	< 0.001	nc	nc
	Diastolic Velocity	< 0.001	0,948	0,790	0,653	0,007	< 0.001	nc
Dorsal C-SAS	AP diameter	< 0.001	0,830	0,123	0,104	0,046	0,027	< 0.001
	Systolic Velocity	< 0.001	0,757	0,008	< 0.001	nc	nc	nc
	Diastolic Velocity	< 0.001	0,830	0,123	0,104	0,046	0,027	< 0.001
Foramen Magnum Region	Premedullary Cistern AP diameter	< 0.001	0,019	0,008	0,008	< 0.001	< 0.001	0,019
	Cisterna Magna AP diameter	< 0.001	< 0.001	nc	nc	nc	< 0.001	< 0.001
	Systolic Velocity	< 0.001	0,090	< 0.001	nc	nc	< 0.001	0,090
	Diastolic Velocity	< 0.001	< 0.001	nc	nc	nc	< 0.001	< 0.001

ROI: region of interest; C-SAS: cervical subarachnoid space; AP: anterior-posterior; mo: month; Y: year; nc: not calculated



Graphic 1



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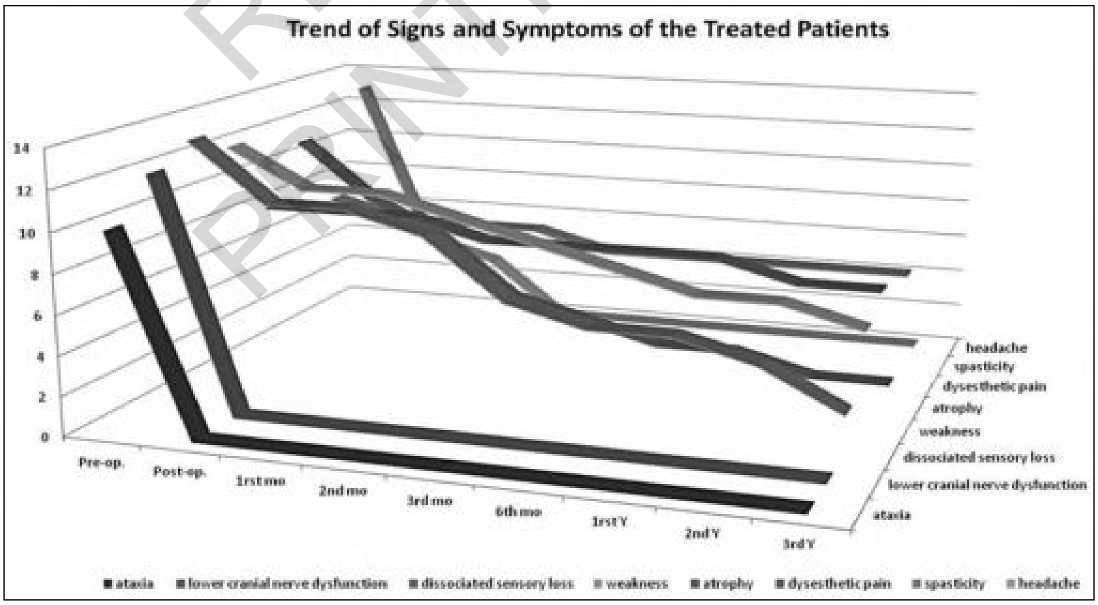

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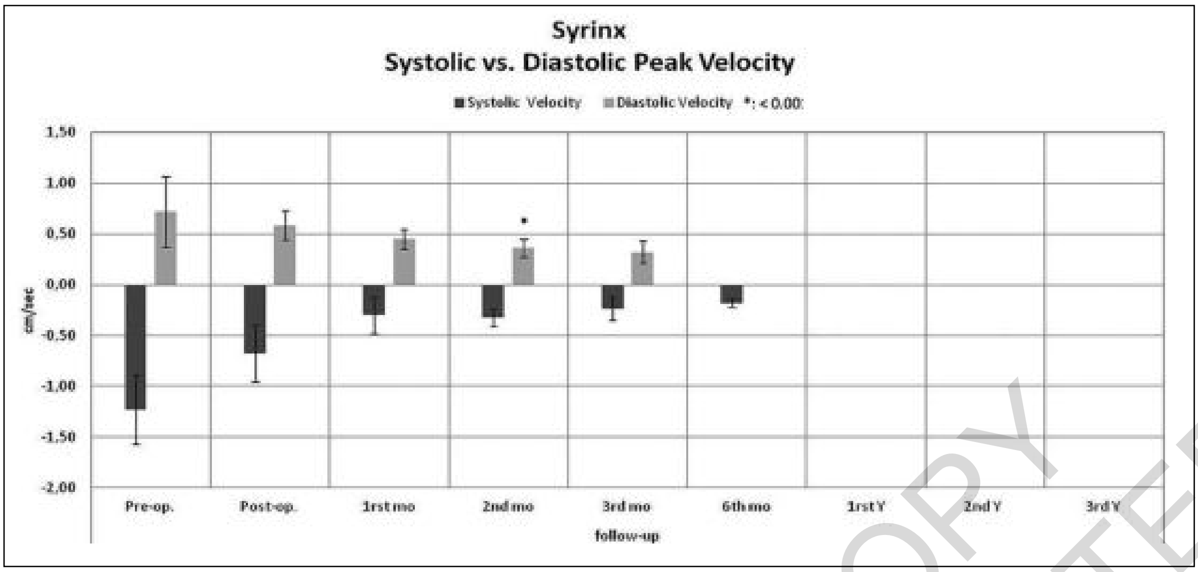

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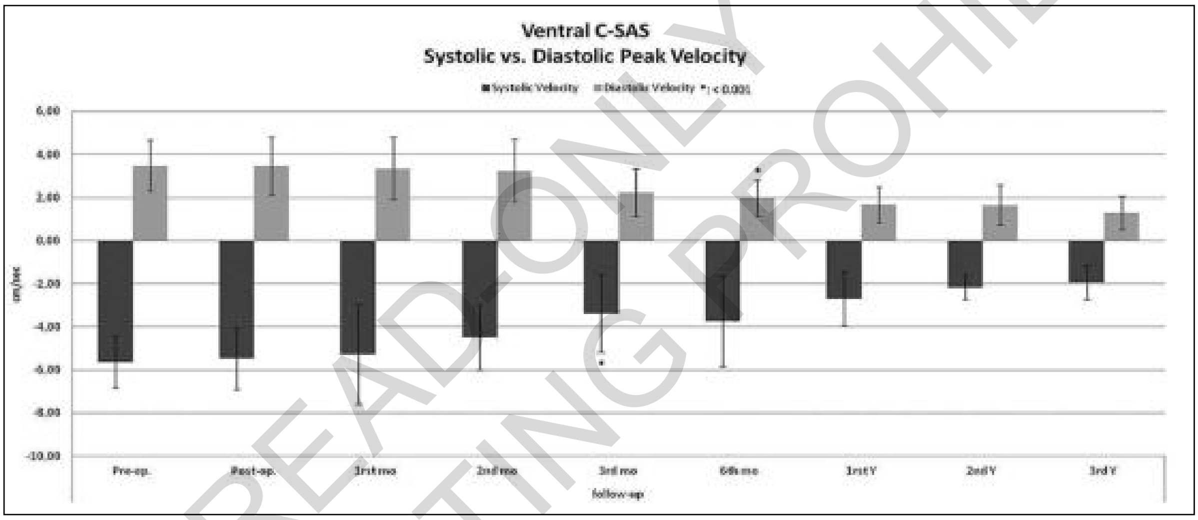

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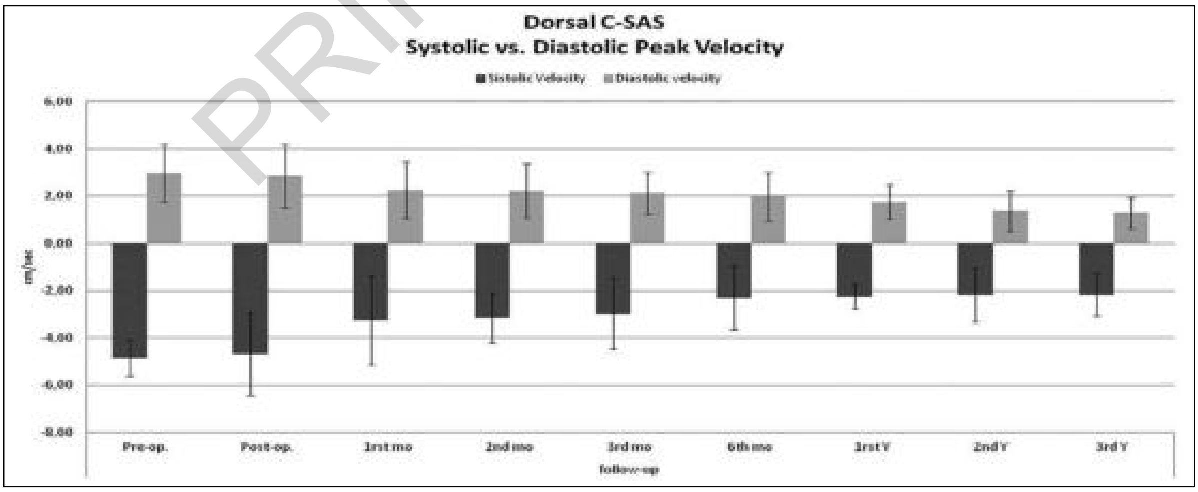

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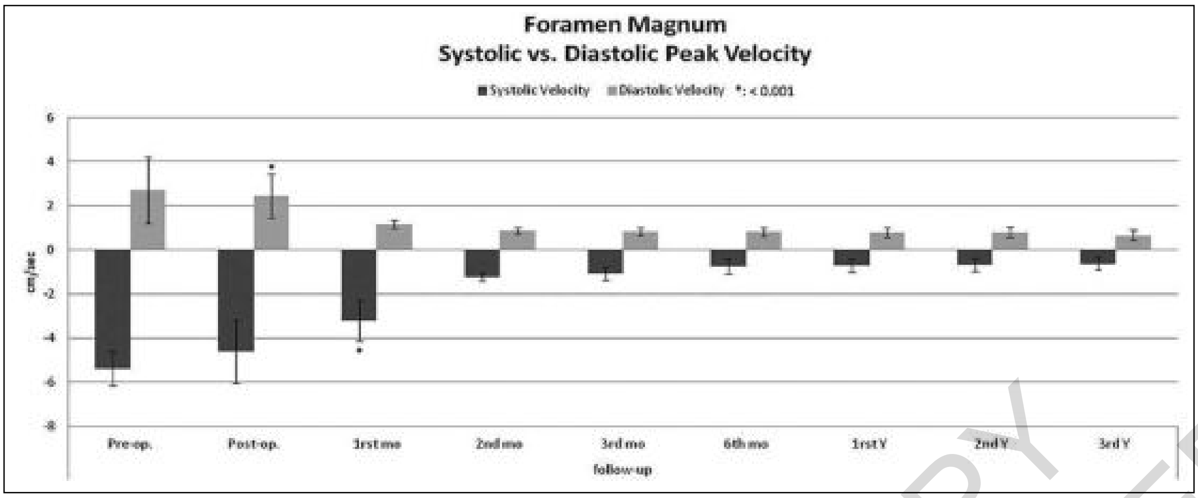

Graphic 7

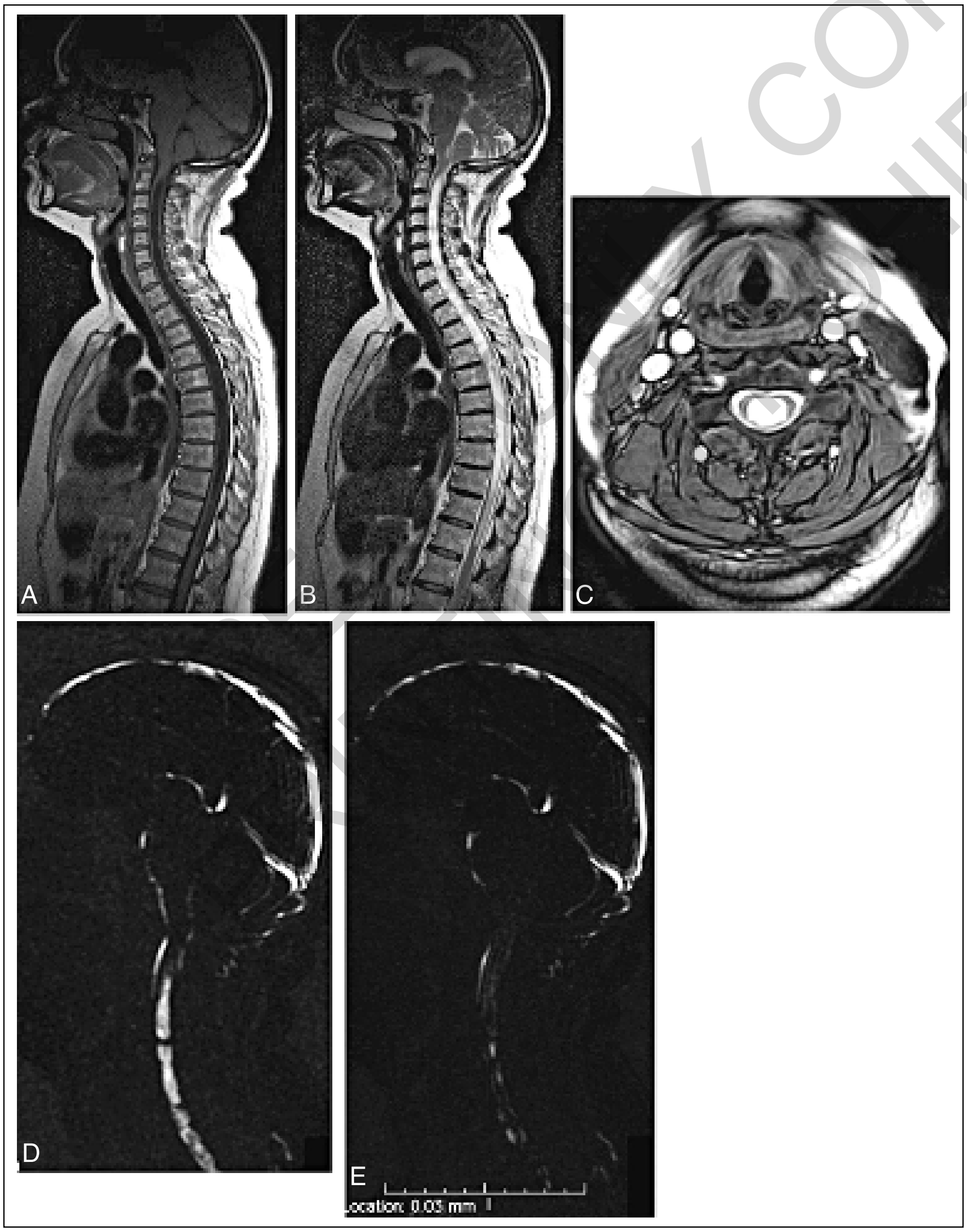

Fig. 2: Sagittal T1- (A) and T2-weighted MRI (B) of the brain and spine, and axial T2-weighted MRI (C) (C4-C5 intervertebral disk) showing a Chiari I malformation with a holocord syringomyelia. (D) preoperative Cine phase-contrast MRI during systole revealing the cerebellar tonsils moving downward, the dilation of the syrinx synchronous with the systole, and a CSF jet flow inside the syrinx. (E) Cine MRI performed one month after posterior fossa decompression documenting a significant systolic reduction of flow inside the syrinx.

the most of cases for this purpose, whose insufflation generally at a rate of 4-6 liter/min^{-1} to a pressure of 10-20 mmHg, causes an acute and significant increase of the IAP. Surgical pneumoperitoneum has been associated with a series of well-known physiological effects on cardiovascular, respiratory, renal, and gastrointestinal systems[21]. However, the only well-studied effects of the central nervous system are those about the intracranial and cerebral perfusion pressure, the former increased and the latter decreased, respectively [16-23,27]. Other studies have delineated the relationships between intra-abdominal and intra-ocular pressure, concluding that raised IAP causes an increase in intra-ocular one [27-29]. On the contrary, studies aimed to infer putative correlations between the surgical pneumoperitoneum during laparoscopic and robotic surgery and syringomyelia, especially that associated with Chiari I malformation, are lacking.

By means of the demonstration of the existence of a biphasic systolic-diastolic CSF pulsatile pattern inside the syrinx, it having a significant positive correlation with the severity of symptoms, our data support the hypothesis according to which, the syringogenesis would be due to the increasing of IAP transmitted to the spinal cord through the Virkow-Robin perivascular spaces [7,12,13].

Increasing in IAP pressure are also transmitted to the epidural spinal veins producing an ascending venous pressure wave from the spinal subarachnoid space through the foramen magnum. Because of the obstruction at the level of the cranio-cervical junction, the pressure wave ascends to the spinal axis, further expanding the syrinx [30,31]. This theory, initially postulated by Ball and Dayan in 1972 [7], and later revised by Oldfield and Heiss [12,13], is valid uniquely for hindbrain related-syringomyelia and is known as "transmedullary" theory. Raised IAP would add to the chronic effects of the heartbeat, with the systole and diastole leading to a self-maintaining mechanism of filling and progression of the syrinx.

In coherence with these concepts, we found CSF systolic velocity inside the syrinx decreased immediately after surgery. We also assume that the high-pressure pneumoperitoneum employed in the reported illustrative case may have play a key role in determine the worsening of the syrinx and neurological status of the patients.

Valsalva-Induced Worsening of Symptoms: Evidence of Link With Iap

Most of the symptoms and signs associated with hindbrain-related syringomyelia worse during Valsalva. Headache is the most common among these, being present in up to 70% of patients [32,33]. It is localized predominantly in the occipital region, accompanied by neck pain, and triggered by activities increasing IAP, as valsalva, coughing, sneezing, efforts and laughing [34]. The clinical spectrum comprises short-lasting, namely "cough headache", and long-lasting continuous headache. The short attacks last from few minutes up to three hours, and have been linked with the slipping of the tonsils causing an insult to pain-sensitive structures [35,36]. Similarly, long-lasting headache have been related to chronic herniation of cerebellar tonsils and are exacerbated by intracranial of IAP [37].

Implications for Safety of Laparoscopic and Robotic Surgery

The evolution of the surgical techniques imposes a constant evaluation of their safety profile, in general surgery [38,39], as in other disciplines [40-47]. Noteworthy, especially in neurosurgery, some basic concepts at the base of the management of Chiari I-syringomyelia complex are derived from the large experience coming from neurovascular [48-55] and brain tumor surgery [56-69]. The implications that the reported data have for safety of laparoscopic and robotic surgery in patients with syringomyelia secondary to Chari I malformation are numerous. The first aspect regards the advisability to use laparoscopic techniques in these patients. Even though further studies are necessary, the results of the present one led to believe that Chiari I-syringomyelia complex, with very large or symptomatic syrinx, may be a relative contraindication. A second issue concerns the pressure regimen utilized to induce the surgical pneumoperitoneum in those asymptomatic patients harbouring syrinxes limited in length, or also incidental. Literature reports some studies supporting the opportunity of a change of practice in abdominal and gynaecologic pelvic surgery about the adoption of low-pressure regimens [70-73]. In particular, the use of a low-pressure pneumoperitoneum has been reported to be associated with a better control of post-operative pain, and a shorter hospital stay. Angioli and colleagues also reported that CO_2 pressure does not affect the visualization of surgical field during robotic vs. laparoscopic surgery[73]. These data lead to strongly advice the employment of a low-pressure pneumoperitoneum or robotic techniques in those patients with Chari I-associated syrinx. A further aspect includes the type gas employed to induce the surgical pneumoperitoneum. Different gases have been used as alternative to CO_2, with the goal to avoid its well-known effects in promoting an increase in intracranial and intraocular pressure, as well as the risk of hypercapnia and acidosis. Helium, argon, nitrogen, nitrous oxide was among the most popular, together with the room air also. Although some of these studies reported advantages in the use of helium vs. CO_2, the latter having fewer negative effects on respiratory function and moderate effect on hemodynamic function [74-79], a recent Cochrane review aimed to establish the gas to be preferred for surgical pneumoperitoneum concluded that quality of current evidence is too low to draw definitive conclusion[80].

Limitations of the Study

The reported study has some limitations worthy to be listed. The number of patients is limited mainly because of the intrinsic incidence of the hindbrain-related syringomyelia.

Cine phase-contrast MRI is affected by a not negligible number of false positives and negatives, mainly coming from the choice of the velocity encoding, and aliasing also. The choice of a prospective vs. retrospective cardiac gating technique, each of which having pros and cons, is a further element making the difference. Randomized trials are necessary to furtherly validate these data and to draw definitive conclusions. Being the present a prospective case-series study, it didn't involve a control group.

Conclusion

The evidence of a biphasic systolic-diastolic CSF pulsatile pattern inside the syrinx related to the Chiari I malformation supports the Oldfield and Heiss "transmedullary" theory about the syringogenesis.

Chronic increases of IAP, along with the systolic-diastolic cardiac cycle, determine the maintenance and progression of the syrinx itself.

Acute increasing of IAP, as those related to the high-pressure CO_2 surgical pneumoperitoneum, can lead to an equally rapid worsening of the neurological status of these patients.

The safety and advisability of laparoscopic and robotic surgery has to be questioned in those patients harbouring large syrinxes associated with a Chiari I malformation.

In patients having smaller or incidental syrinxes, the implementation of a low-pressure pneumoperitoneum is advisable when possible.

To date, the quality of evidences is too low to support the routinely use of a gas different from CO_2 which, despite the known side-effects on different systems, is still preferred by most of the surgeons because of its significant advantages.

Clinical trials are necessary the definitively validate these data.

Riassunto

Il ruolo svolto dalla pressione intra-addominale (IAP) nella siringogenesi associata alla malformazione di Chiari 1 non è stato ancora adeguatamente studiato.

Lo scopo di questo studio è di convalidare la teoria transmedullaria, discutendo anche delle implicazioni per la sicurezza di questi pazienti legate all'uso di pneumoperitoneo CO_2 ad alta pressione durante la chirurgia laparoscopica e robotica.

Quattordici pazienti con una *hindbrain-related syrinx* sono stati candidati per una decompressione della fossa posteriore. Le velocità di picco sistolica e diastolica sono state acquisite in quattro regioni di interesse (ROI), vale a dire siringa, spazio subaracnoideo cervicale ventrale e dorsale e regione del forame magnum. I dati sono stati riportati come media ± SD. I pazienti sono stati seguiti per tre anni. Sono stati eseguiti test ANOVA a una via con Bonferroni test post hoc di confronti multipli, con un valore $p <0{,}001$.

Un pattern pulsatile sistolico-diastolico di CSF è stato trovato in tutti i casi all'interno della siringa. La velocità della siringa e della cisterna premedullare è diminuita entro il primo mese dopo l'intervento (<0,001). Tutti i sintomi a parte l'atrofia e la spasticità sono migliorati. Questi dati portano a convalidare la teoria transmedullare di Oldfield e Heiss sulla siringogenesi, all'interno della quale un aumento della PAI gioca un ruolo chiave.

L'aumento della PAI svolge un ruolo fondamentale nella formazione e nel mantenimento della siringa correlata alla malformazione di Chiari I. Lo pneumoperitoneo chirurgico CO_2 ad alta pressione è sconsigliato in questi pazienti perché a rischio di rapido peggioramento neurologico. Una tecnica di insufflazione a bassa pressione ha una logica in quei pazienti con siringhe più piccole o accidentali.

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