Relationships of Intracranial Pressure, Cerebrospinal Fluid Space and Head Circumference in Young Children

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A Dissertation Submitted to The Graduate School of
Ajou University in Partial Fulfillment of the Requirements
for the Degree of Master of Medicine

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February, 2013

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December, 14th, 2012

– ABSTRACT –

Relationships of Intracranial Pressure, Cerebrospinal Fluid Space and Head Circumference in Young Children

The purpose of this study was to retrospectively evaluate and analyze the relationships between intracranial pressure (ICP), cerebrospinal fluid space (CSF) and head circumference (HC).

The medical records at single institution from 2007 through 2011 inclusive were reviewed to identify 780 patients under 6-year-old who underwent a lumbar puncture for measuring the ICP. Exclusion criteria were as follows; 1) unrecorded HC or ICP on chart; 2) diagnosed craniosynostosis or intracranial tumor; and 3) performed shunt or cranial vault operation. The enrolled patients were divided into three age-groups (group 1: up to 12 months; group 2: over 12 to 36 months; group 3: over 36 to 72 months).

Eighty eight of total 780 patients were enrolled. The study group was composed of 62 boys and 26 girls, with a mean age of 20.6 ± 17.9 months. First aged group (group 1, n=38) was composed of 23 boys and 15 girls, with a mean age of 6.6 ± 2.7 months. In this group, a mean HC was 43.7 ± 4.8cm (56.6 ± 38.4 percentile) and a mean ICP was 24.1 ± 5.8cmH_2O. An average Evans ratio was 0.27 ± 0.06. The significant subdural hygroma (SDHG) was detected in 25 patients and the average thickness of it was 3.4 ± 2.7mm. There was a significant positive correlation between the ICP and the HC (r=.474, p=.003). Second aged group (group 2, n=31) was composed of 23 boys and 8 girls, with a mean age of 19.5 ± 6.7 months. In this group, a mean HC was 48.9 ± 3.4cm (68.6 ± 35.6 percentile) and a mean ICP was 27.6 ± 7.7cmH_2O. An average Evans ratio was 0.29 ± 0.10. The SDHG was detected in 11 patients and the average thickness of it was 1.9 ± 2.5mm. There was a significant positive correlation between the ICP and the HC percentile (r=.408, p=.023). The ICP and the thickness of SDHG were also significantly correlated (r=.429, p=.016). Third aged group (group 3, n=19) was composed of 16 boys and 3 girls, with a mean age of 50.5 (± 9.9

months). A mean HC was 50.1 ± 3.2cm (54.1 ± 36.9 percentile) and a mean ICP was 25.9 ± 6.6cmH_2O. An average Evans ratio was 0.25 ± 0.05. The SDHG was detected in two cases. There was no significant correlation between any factors in this group.

With closure of cranial suture, the ICP related to the HC especially in infant with non- or less closed sutures, and the SDHG related to the ICP in toddler with partial closed cranial sutures. In these results, the HC may be reflected in the ICP at early period with rapidly growing HC, and thickness of the SDHG could be expected from the ICP at period with cranial suture closure to some degree.

Key words: head circumference, intracranial pressure, subdural hygroma, ventricle

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I. INTRODUCTION

In infant and toddler with rapid growing cranial vault, intracranial pressure (ICP) is generally predicted from head circumference (HC) and cavity of cerebrospinal fluid (CSF) in image studies as computed tomography (CT) or magnetic resonance imaging (MRI) (Korobkin, 1975; Welch, 1980; Børgesen and Gjerris, 1987; Levine, 2008). In previous reports, relationships of the ICP and ventricle size were variable (Børgesen and Gjerris, 1987). In children, hydrocephalus and increased ICP may present whining and vomiting as similar symptoms, however the relations of the ICP and the ventricle size were different in above two disease categories and the diseases had with different treatment modalities. Especially, closure time and degree of cranial suture was related to increase ICP in the period of children under 6-year-old with rapid growing cranial vault (Fok et al, 1992). However, to our knowledge, there was no reports for analysis of correlation with the ICP, HC and CSF space in each groups classified according to closure grade of cranial suture. Therefore, the purpose of this study was to retrospectively evaluate and analyze the relationships between ICP, CSF and HC.

II. MATERIALS AND METHODS

The medical records at single institution from 2007 through 2011 inclusive were reviewed to identify 780 patients aged under six who underwent a lumbar puncture for measuring the ICP. Exclusion criteria were as follows; 1) unrecorded HC or ICP on chart; 2) diagnosed craniosynostosis or intracranial tumor; and 3) performed shunt or cranial vault operation.

All procedures of the lumbar puncture for check the ICP were performed under general anesthesia and aseptic environment. Opening pressure in manometer was measured and recorded as the ICP. Head circumference was measured by placing a plastic tape over the eyebrows and over the most posterior protuberance of the occiput. And then, HC percentile was recorded according to Korean national growth chart (Korea Center for Disease Control and Prevention, 2007). Ventricular size was measured using Evans index on brain CT or MRI. The Evans index was calculated by dividing the maximal frontal horn width at that plane by the maximal inner diameter at the skull at the same plane (Evans, 1942; Toma et al, 2011). If subdural hygroma (SDHG) or hematoma was detected, the subdural thickness was measured from inner wall of the skull to brain cortex in thickest subdural area.

For optimized classification of the enrolled patients, age-dependent grouping was performed with changing cut-off age point from 6 to 24 months. And then, the groups were analyzed by statistical methods for better statistical significance and correlation coefficient. Finally, the enrolled children were divided into three age-groups (group 1: up to 12 months; group 2: over 12 to 36 months; group 3: over 36 to 72 months).

The demographic characteristics of the three groups were compared using a contingency table or mean comparison. We conducted t-test and chi-square tests to show the statistical differences of continuous and non-continuous variable. Pearson or Spearman correlation analysis was conducted to show the relation between the CSF space (calculated Evans ratio and measured subdural thickness), HC and the ICP. All statistical analyses were performed using the SPSS version 18.0 software package (SPSS, Inc. Chicago, IL, USA). P-values were calculated using two-sided tests, and statistical significance was accepted at 0.05.

III. RESULTS

Eighty eight of total 780 patients were enrolled. The study group was composed of 62 boys and 26 girls, with a mean age of 20.6 ± 17.9 months. The demographics of three groups were shown in Table 1.

Table 1. Demographics in three groups

	Group 1 (n=38) age ≤ 12m	Group 2 (n=31) 12m < age ≤ 36m	Group 3 (n=19) age > 36m	*p*
Gender (boy, %)	23 (60.5)	23 (74.2)	16 (84.2)	.155
Age (month)**	6.6 ± 2.7	19.5 ± 6.7	50.5 ± 9.9	.000*
Body weight (kg)**	8.2 ± 1.9	11.2 ± 2.3	17.2 ± 3.6	.000*
HC (cm)**	43.7 ± 4.8	48.9 ± 3.4	50.1 ± 3.3	.000*
HC percentile**	56.6 ± 38.4	68.6 ± 35.6	54.1 ± 36.9	.298
ICP (cmH_2O)**	24.1 ± 5.8	27.6 ± 7.7	25.9 ± 6.6	.104
Evans ratio**	0.27 ± 0.06	0.29 ± 0.10	0.25 ± 0.05	.149
SDHG thickness (mm)**	3.4 ± 2.7	1.9 ± 2.5	0.2 ± 0.6	.000*

m: month; Sx: symptom; HC: head circumference; ICP: intracranial pressure; SDHG: subdural hygroma

*$p < .05$; **mean ± standard deviation

The most common referral cause was increased HC (29.5%). The others had symptoms as shown in Table 2.

Table 2. Causes of referral

	n (%)			
	Group 1 (n=38) age≤12m	Group 2 (n=31) 12m< age ≤36m	Group 3 (n=19) age>36m	Total
Increased HC	10 (26.3)	15 (48.4)	1 (5.3)	26 (29.5)
Delayed development	10 (26.3)	5 (16.1)	6 (31.6)	21 (23.9)
Rigidity	-	2 (6.5)	-	2 (2.3)
Nausea/vomiting	3 (7.9)	3 (9.7)	1 (5.3)	7 (8.0)
Seizure	1 (2.6)	2 (6.5)	5 (26.3)	8 (9.1)
Aberrant head shape	4 (10.5)	1 (3.2)	1 (5.3)	6 (6.8)
Visual disturbance (Abnormal VEP)	-	3 (9.7)	2 (10.5)	5 (5.7)
Headache	-	-	3 (15.8)	3 (3.4)
Apnea	1 (2.6)	-	-	1 (1.1)
Bulging fontanel	5 (13.2)	-	-	5 (5.7)
Image finding*	4 (10.5)	-	-	4 (4.5)
ventriculomegaly	2	-	-	
subdural hygroma	2	-	-	

m: month; HC: head circumference; VEP: Visual evoked potential

*In group 1, the ventriculomegaly and the subdural hygroma were detected on follow-up from postnatal period. An average Evans ratio was 0.34 and an average thickness of subdural hygroma was 5.6mm.

In each groups, the analysis of correlation coefficients (*r*) between CSF space (calculated Evans ratio and measured thickness of SDHG), HC and ICP was shown in Table 3.

Table 3. Analysis of correlation coefficients (*r*) between CSF space (calculated Evans ratio and measured thickness of SDHG), HC and ICP.

			HC percentile	Evans ratio	SDHG thickness
Group 1[a]	ICP	*r*	.359*	.033	.290
		p	.027	.844	.077
	HC percentile	*r*	1	.332*	.434**
		p		.042	.007
	Evans ratio	*r*	.332*	1	.281
		p	.042		.088
Group 2[a]	ICP	*r*	.408*	-.254	.429*
		p	.023	.169	.016
	HC percentile	*r*	1	-.304	.242
		p		.096	.190
	Evans ratio	*r*	-.304	1	-.031
		p	.096		.867
Group 3[b]	ICP	*r*	.204	.219	.020
		p	.403	.368	.936
	HC percentile	*r*	1	.048	.207
		p		.846	.395
	Evans ratio	*r*	.048	1	.445
		p	.846		.056

CSF: cerebrospinal fluid; ICP: intracranial pressure; HC: head circumference; SDHG: subdural hygroma

a: conducted by Pearson correlation analysis

b: conducted by Spearman correlation analysis

r= correlation coefficient

* $p < .05$

** $p < .01$

First aged group (group 1, n=38) was composed of 23 boys and 15 girls, with a mean age of 6.6 ± 2.7 months. In this group, a mean HC was 43.7 ± 4.8cm and a mean ICP was 24.1 ± 5.8cmH_2O. An average Evans ratio was 0.27 ± 0.06. The significant SDHG was detected in 25 (65.8%) patients and the average thickness of it was 3.4 ± 2.7mm. There was a significant positive correlation between the ICP and the HC percentile (r=.359, p=.027, Fig. 1A). Neither Evans ratio nor SDHG were shown significant correlation with the ICP (Fig. 2A and 3A). Their HC percentile was associated significantly with both Evans ratio and thickness of SDHG (Fig. 4A and 5A). There was no relationship between Evans ratio and the thickness of SDHG (Fig. 6A).

Second aged group (group 2, n=31) was composed of 23 boys and 8 girls, with a mean age of 19.5 ± 6.7 months. In this group, a mean HC was 48.9 ± 3.4cm and a mean ICP was 27.6 ± 7.7cmH_2O. An average Evans ratio was 0.29 ± 0.10. The SDHG was detected in 11 (35.5%) patients and the average thickness of it was 1.9 ± 2.5mm. There was a significant positive correlation between the ICP and the HC percentile (r=.408, p=.023, Fig. 1B). A relationship of the ICP and Evans ratio was unremarkable (Fig. 2B). In the other hand, the ICP and the thickness of SDHG were significantly correlated (r=.429, p=.016, Fig. 3B). Relationships of the HC, Evans ratio and the thickness of SDHG were unremarkable (Fig. 4B, 5B and 6B).

Third aged group (group 3, n=19) was composed of 16 boys and 3 girls, with a mean age of 50.5 ± 9.9 months. A mean HC was 50.1 ± 3.2cm and a mean ICP was 25.9 ± 6.6cmH_2O. An average Evans ratio was 0.25 ± 0.05. The SDHG was detected in two cases (10.5%). There were no significant correlation of the HC, Evans ratio and the thickness of SDHG for the ICP (Fig. 1C, 2C and 3C). Relationships of the HC, Evans ratio and the thickness of SDHG were also unremarkable (Fig. 4C, 5C and 6C).

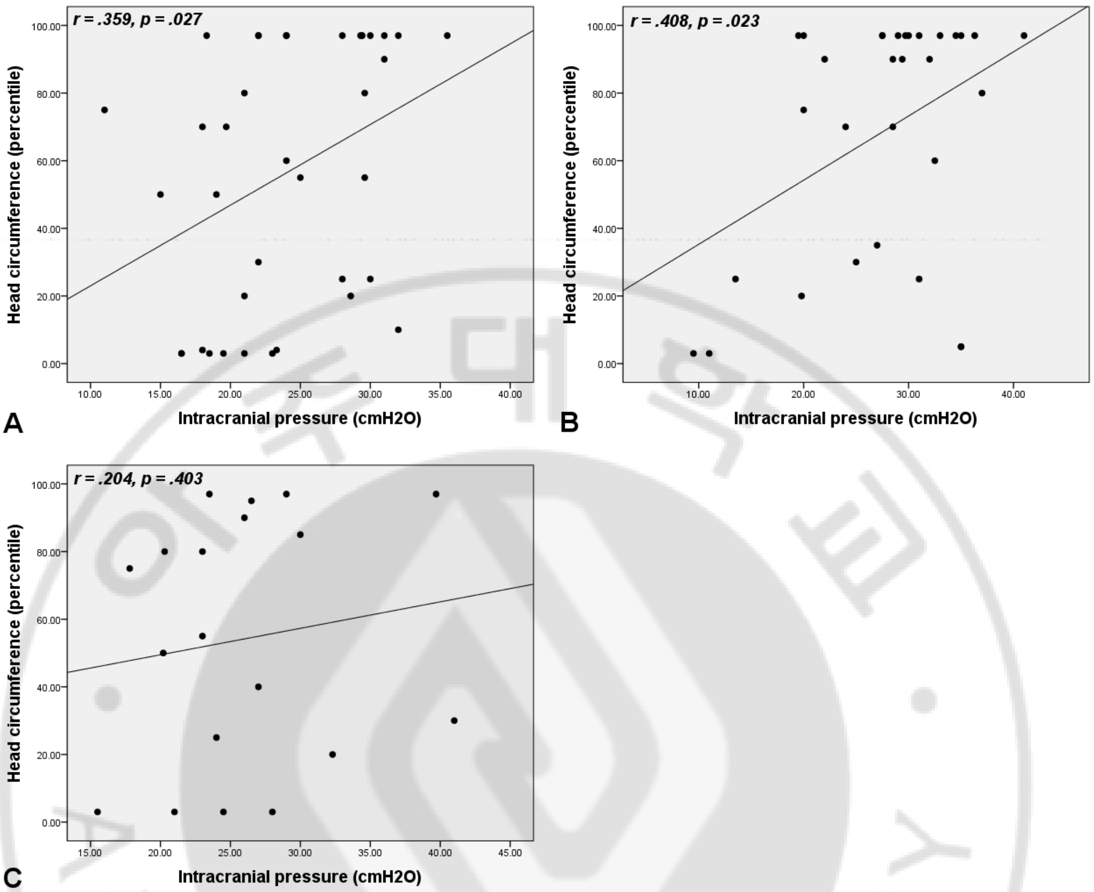

Fig. 1. Plot of head circumference (HC) correlated with intracranial pressure (ICP) in three groups. In group 1 (A), the HC was positively correlated with the ICP (*r*=.359, *p*=.027). Neither group 2 (B) nor 3 (C) were shown any significant correlation between the HC and the ICP.

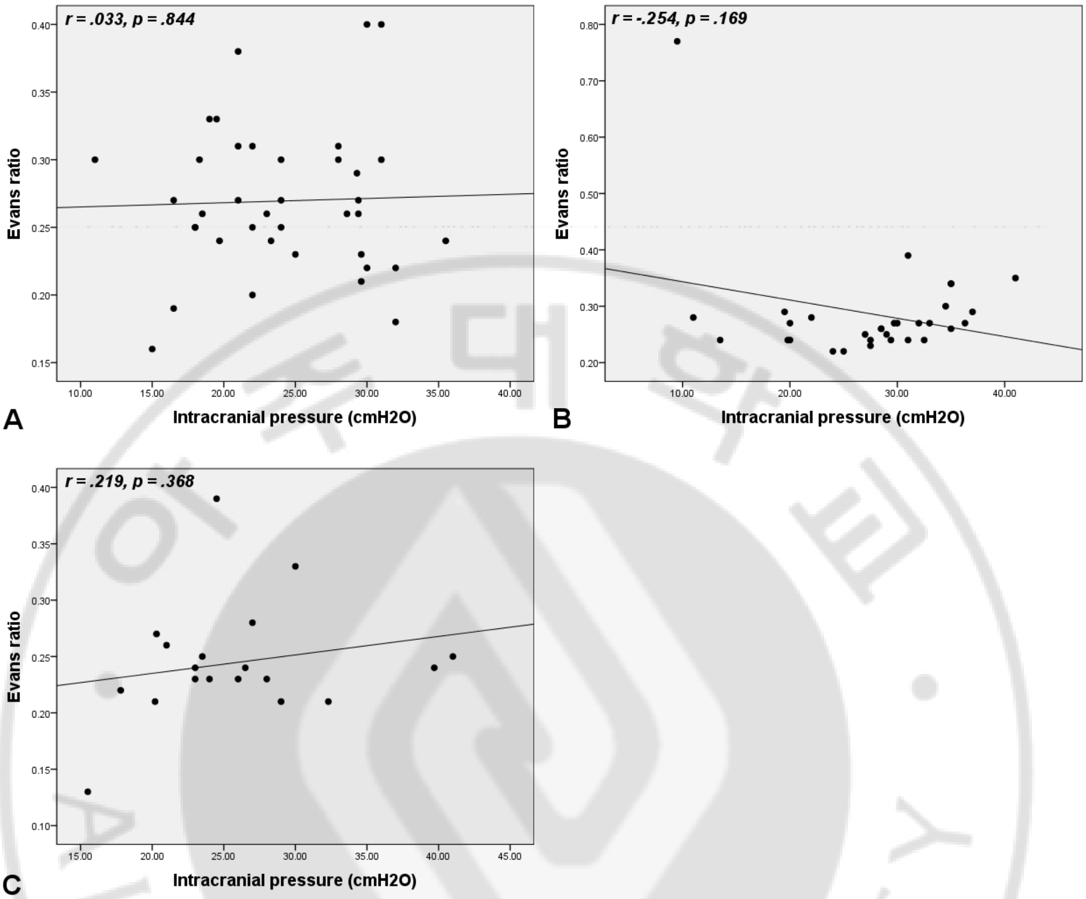

Fig. 2. Plot of Evans ratio correlated with the intracranial pressure (ICP) in three groups. None of them (Group 1: A; Group 2: B and Group 3: C) showed significant correlation between Evans ratio and the ICP.

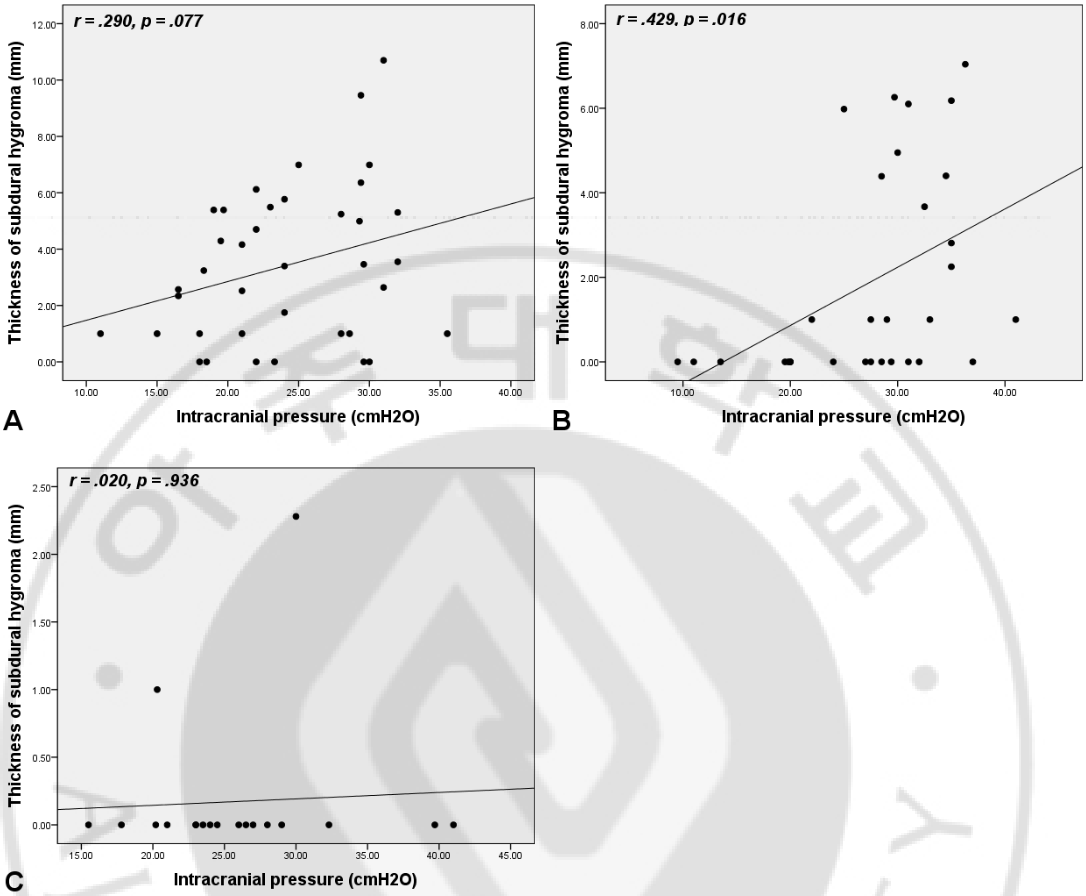

Fig. 3. Plot of thickness of subdural effusion or hygroma (SDHG) correlated with intracranial pressure (ICP) in three groups. In group 2 (B), the thickness of SDHG was significantly correlated with the ICP (*r*=.429, *p*=.016). Neither group 1 (A) nor group 3 (C) were shown any significant correlation between the ICP and the thickness of SDHG.

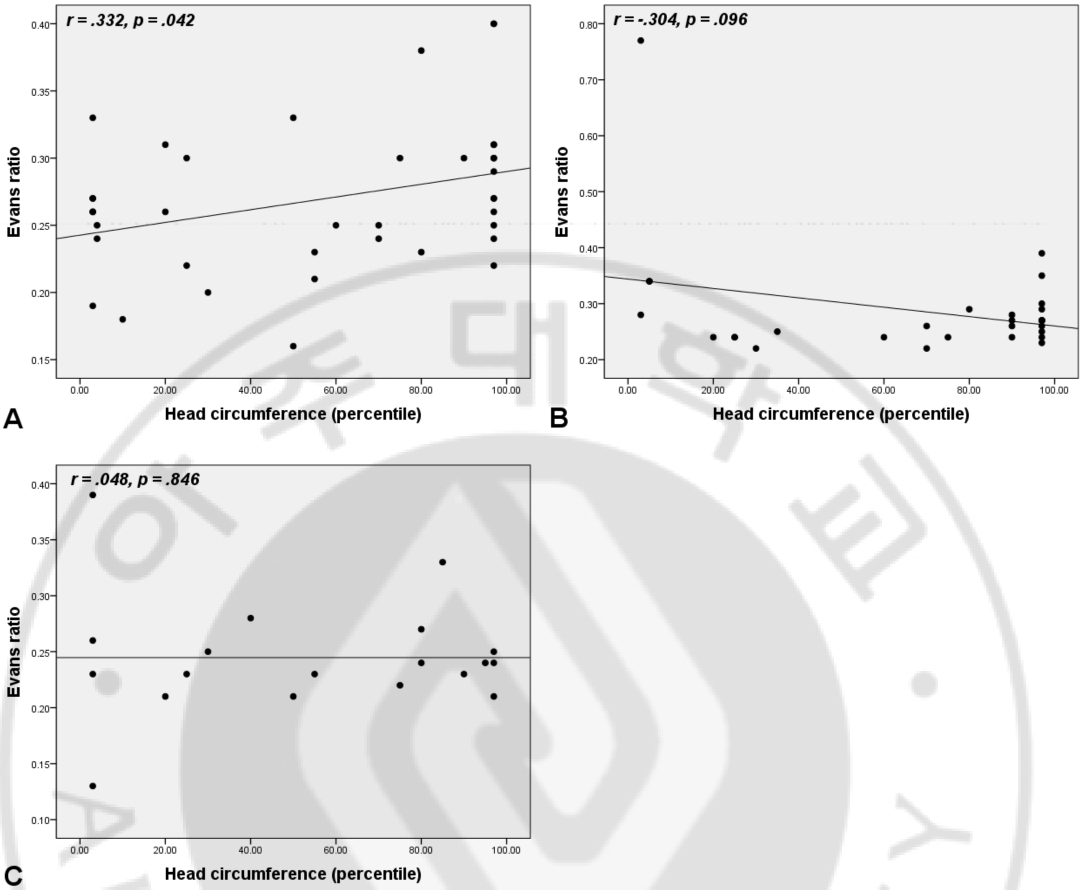

Fig. 4. Plot of Evans ratio correlated with head circumference (HC) in three groups. In group 1 (A), Evans ratio was significantly correlated with the HC (*r*=.332, *p*=.042). Neither group 2 (B) nor group 3 (C) were shown any significant correlation between the HC and Evans ratio.

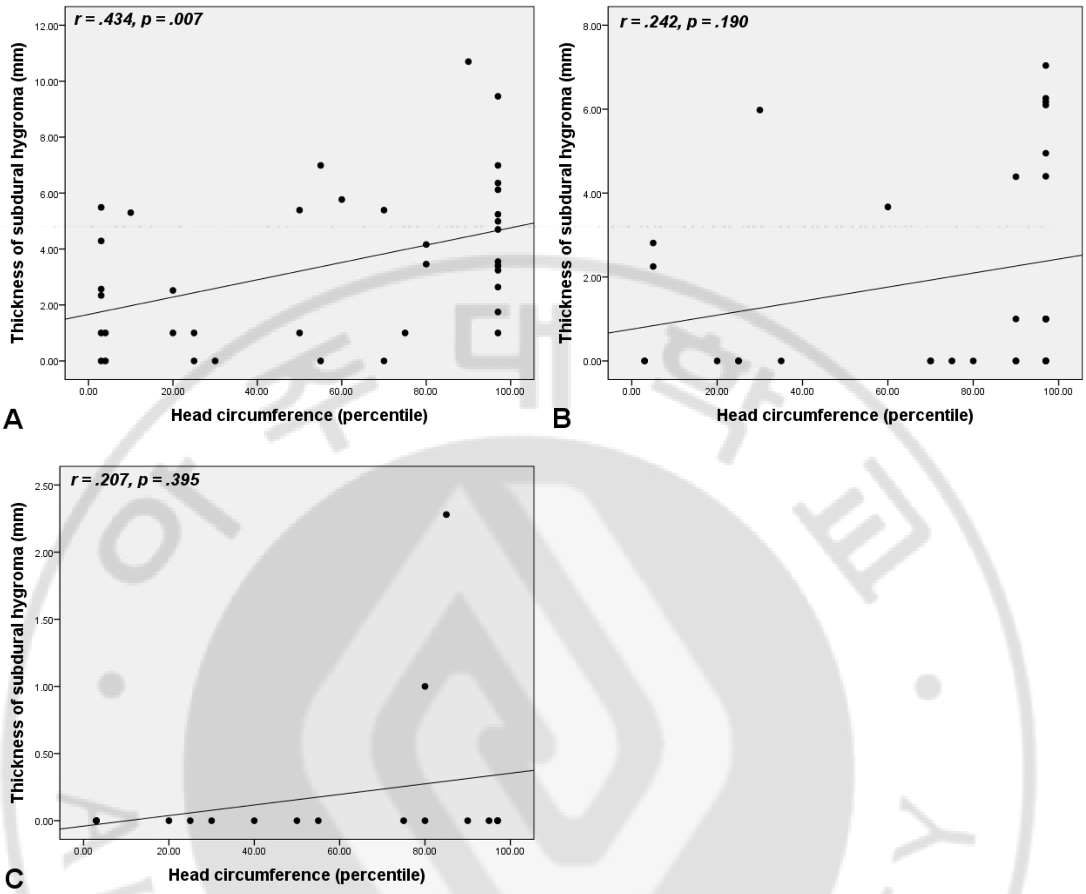

Fig. 5. Plot of thickness of subdural effusion or hygroma (SDHG) correlated with head circumference (HC) in three groups. In group 1 (A), the thickness of SDHG was significantly correlated with the HC (*r*=.434, *p*=.007). Neither group 2 (B) nor group 3 (C) were shown any significant correlation between the HC and the thickness of SDHG.

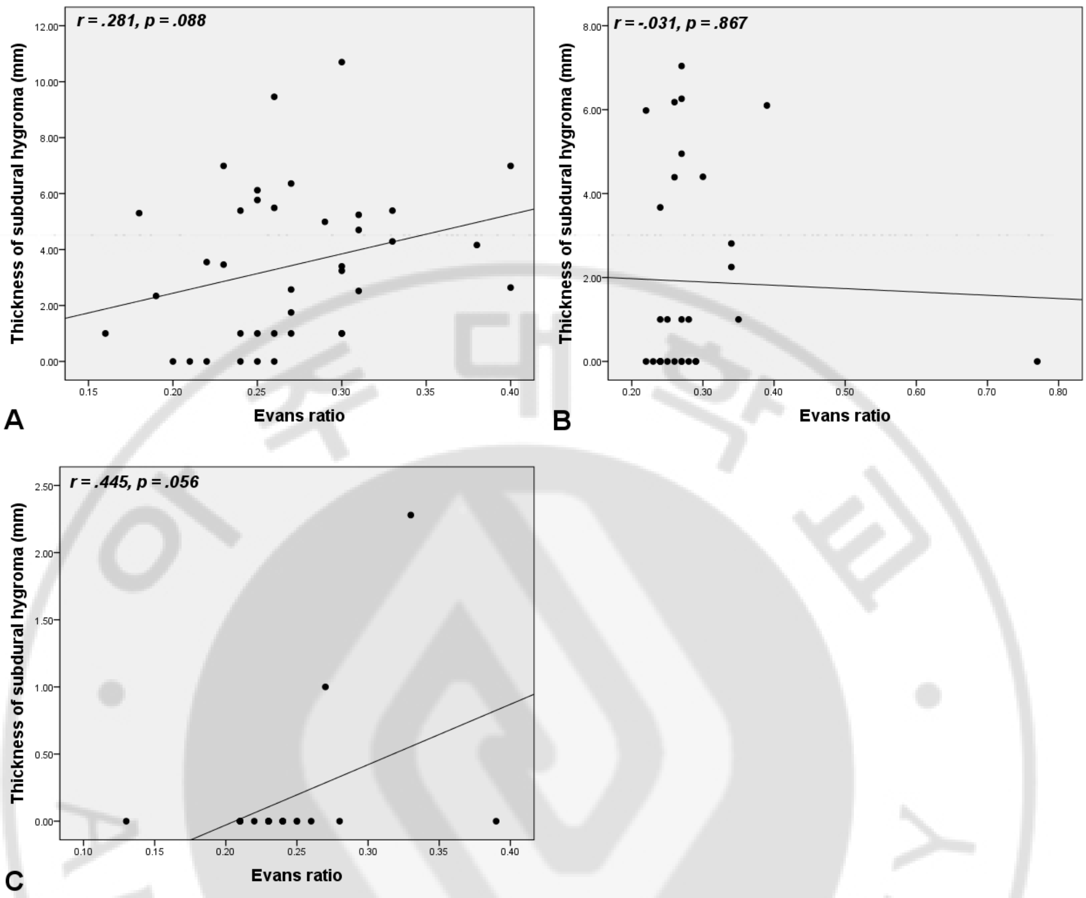

Fig. 6. Plot of thickness of subdural effusion or hygroma (SDHG) correlated with Evans ratio in three groups. None of them (Group 1: A; Group 2: B and Group 3: C) showed significant correlation between Evans ratio and the thickness of SDHG.

IV. DISCUSSION

This study demonstrated that the ICP and the HC or the thickness of SDHG had some positive correlations according to the aged period divided into three groups reflected degree of the cranial sutural closure. Physiologic closure of cranial sutures has a sequential process, and the earliest beginning of suture closure processing is within from one to five months for each suture (Sim et al, 2012). And then, their closure rates reach near 90% at the 12 months age except sagittal suture with about half percentage of closure (Sim et al, 2012). The physiologic fusion time of cranial sutures varies according to past literatures (Manzanares et al, 1988; Cohen, 1993; Fearon et al, 1996; Mathijssen et al, 1996; Vu et al, 2001). Nevertheless the relationship among ICP and head circumference in infants is not well defined, one might expect elevated intraventricular pressure to be transmitted to skull, and especially in infants with patent fontanelles and open sutures, and the elevated pressures could be relieved with expansion of the cranial vault (Korobkin, 1975; Zahl and Wester, 2008). This theory is supported by the results of our study that infant and toddler group under 36 months birth age with non- or incomplete fusion of the cranial suture showed that their HC percentile increased with increasing ICP. However, the others with moreover or near completely fusion of the cranial suture had no relationships between the ICP and the HC percentile. On basis of this study, we suggested that increasing ICP would play a role of hydrostatic pressure factor for expansion of cranial vault with open suture in rapid growing period, on the other hand, cranium with more or near complete sutural fusion would be difficult to expand by the ICP.

The skull is filled with three compartments composed of brain, CSF and blood. Expansion of one compartment is at the expense of another. Macrocephaly can be due to hydrocephalus as increased CSF space (Menounou, 2011). In early infancy the skull bones are not fused together to allow for brain expansion. This period in our study showed significant relationship between the HC and the CSF space (ventricle size and subdural effusion).

Several authors reported the relationship of the ICP and CSF space (i.e. ventricle size) and it was variable. Some literatures demonstrated that ventricular narrowing had no correlation with ICP elevation (Sadhu et al, 1979; Auer et al, 1980; Holliday et al, 1983; Mizutani et al, 1990), whereas opposite literatures reported that narrowing of the third ventricle and basal cistern was well correlated with ICP (Murphy et al, 1983; Teasdale et al, 1984). Tabaddor et al. (1982) proved that Evans ratio well reflected ventricular compression and was related to ICP and Børgesen et al. (1987) demonstrated that Evans ratio correlated with ICP. Our analysis did not support the previous results in overall groups of this study. These results show that the relationship of the ICP and ventricle size is not well defined. Especially, Levin (2008) demonstrated that it is the small pressure gradient and not the elevated intracranial pressure that is needed for the ventricular dilatation that characterizes hydrocephalus. Without it the ventricles do not enlarge, even if intracranial pressure is very high, as in dural sinus thrombosis or pseudotumor cerebri (Levine, 2000). Therefore we suggested that Evans ratio as ventricular size may not represent the ICP and it might need to reestablish the relationships of them.

Subdural hematoma in infancy appears to produce an unusual picture on CT (Orrison et al, 1978). The reason for ventricular dilatation, wide cerebral sulci, and prominent cisterns in infants with subdural hematomas is not known (Orrison et al, 1978). Orrison et al. (1978) found that the occurrence of these CT findings in infants with symptoms of increased ICP to be indicative of subdural effusion. Therefore, subdural CSF space will be used to estimate the ICP. Kuurne et al. (1983) reported that the thickness of the subdural effusions was related to the change in the opening pressure of the shunt valve in all patients. For this reason, we suggested that the thickness of SDHG would be related to the ICP. Our study showed that the SDHG was significantly related to the ICP in toddlers with partially fused cranial suture and not infant with open suture. On the base of this result, we speculated that if almost cranial sutures opened with expansion capacity of the cranial vault, elevated ICP would be compensated by cranial expansion. However if some cranial sutures closed and had some resistance against cranial expansion, the SDHG would reflect the ICP. In addition, the balance between cortical subdural pressure and intraventricular pressure is extremely delicate according to the “Law of La Place” (Kuurne et al, 1983). Therefore, we suggested that the thickness of SDHG as surrogate of the intraventricular pressure could be measured for prediction of the ICP in toddlers with partial closure of the cranial sutures. However, in many cases of our first group, delayed development with brain atrophy and concurrent SDHG on CT finding was detected therefore the SDHG would be unclearly reflected the ICP.

Our study showed no relationships of ICP, HC, Evans ratio and thickness of SDHG in late group with more fusion of cranial sutures. We suggested that more matured and fused the cranium played a role of some resistance against expansion of the skull. However, a small number of the enrolled group was a limitation of this study. Especially, a relationship between the SDHG and the others was uncertain because few cases with SDHG were detected in this group.

Infancy, toddler and children with elevated the ICP have several symptoms. Of them, increasing HC is most frequent in infants in whom much of the cranial growth is occurring (Zahl and Wester, 2008). Our authors found that the increasing HC was a frequent symptom in infant and early children under 3-year-old with non- or partial sutural fusion. In addition, as mentioned earlier, this study proved definite positive correlation of the ICP and the HC in infant with rapid growing cranium and beginning of sutural fusion, and also, in toddler or early children with partial fused cranium.

V. CONCLUSION

With closure of cranial suture, the ICP related to the HC especially in infant and toddler with non- or less closed sutures, and the SDHG related to the ICP in toddler with partial closed cranial sutures. In these results, we suggest that the HC may be reflected in the ICP at early period with rapidly growing HC, and thickness of the SDHG could be expected from the ICP at period with cranial suture closure to some degree.

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- 국문요약 -

영유아의 뇌압, 뇌척수액 공간 및 두위의 상관관계

아주대학교 대학원 의학과

김 명 진

(지도교수: 윤 수 한)

본 연구의 목적은 두개 성장이 급속히 일어나는 환아에 있어 뇌압, 뇌척수액 공간, 두위의 상관관계에 대해 후향적으로 분석하는 것이다.

2007 년부터 2011 년까지 단일 의료기간에서 뇌압 측정을 위해 요추 천자를 시행 받은 6 세 이하의 환아 780 명을 대상으로 의무기록 및 영상 자료를 분석하였다. 그 중 1) 두위나 뇌압 측정치가 기록되지 않은 경우, 2)두개골 조기유합증 또는 뇌종양이 진단된 경우, 3) 뇌실 단락술이나 두개 수술을 시행 받은 경우는 대상에서 제외하였다. 모집된 집단은 세 집단으로 재분류 하였다. 출생 시부터 12 개월까지는 제 1 집단, 12 개월 초과부터 36 개월까지는 제 2 집단, 그리고 36 개월 이후는 제 3 집단으로 명명하였다.

총 780 명 중 88 명이 연구 대상으로 선정되었고, 남아가 62 명, 여아가 26 명으로 구성되었으며 평균 연령은 20.6 ± 17.9 개월이었다. 제 1 집단에서는 뇌압과 두위가 서로 유의한 상관관계가 있는 것으로 나타났다 (r=.359, p=.027). 제 2 집단에서 마찬가지로 뇌압과 두위가 유의한 상관관계를 보였고 (r=.408, p=.023) 뇌압과 뇌경막하수종의 두께 또한 유의한 양의 상관관계를 나타냈다 (r=.429, p=.016). 제 3 집단에서는 상관관계에 있는 요소가 없었다.

두개 봉합선이 열려 있는 영유아의 경우 뇌압은 두위 증가에 영향을 주었고, 두개 봉합선 부분적으로 닫혀가는 과정인 아동에 있어서는 뇌경막하수종이 뇌압 상승에 영향을 주었다. 이를 바탕으로 두개골 성장이 급속히 일어나는 기간에는 두위 증가 정도를 측정함으로써 뇌압을 예측할 수 있고, 어느 정도 두개 봉합이

이뤄진 후에는 뇌경막하수종의 정도를 통해 뇌압을 예측할 수 있을 것으로 사료된다.

핵심어: 뇌압, 뇌실, 뇌경막하수종, 두위