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Chronic Subdural Hematoma —Evolution of Etiology and Surgical Treatment—

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Abstract

In this paper, I review the historical changes in the etiological concepts and surgical treatments for chronic subdural hematoma (CSDH) across the world and in Japan. I also examine future problems associated with its surgical procedures and medical costs. CSDH was first reported by Wepfer in 1657 as "delayed apoplexy." In 1857, Virchow described the famous concept of so-called "pachymeningitis hemorrhagica interna." He considered that the etiology of CSDH involved inflammation. In 1914, Trotter described the origin of CSDH as traumatic. Currently, CSDH is considered to arise with a first leak of blood from dural border cells after mild trauma. Inflammatory cells are then drawn to the border cell layer. At this point, new membranes form from activated inflammation; then, the hematoma enlarges, promoted by angiogenic factors and new capillaries. In 1883, Hulke reported successful trepanning of a patient with CSDH. Burr holes and craniotomy for removal of the hematoma were subsequently reported, and new methods were developed over the course of several decades around the world. In Japan, after the first report by Nakada in 1938, many Japanese pioneering figures of neurological surgery have studied CSDH. After Mandai reported the middle meningeal artery embolization in 2000, this method is now considered useful as an initial or second treatment for CSDH. However, the age of patients is increasing, so more minimally invasive surgeries and useful pharmacotherapies are needed. We must also consider the costs for treating CSDH, because of the increasing numbers of surgical cases.

Keywords: chronic subdural hematoma, etiology, surgical treatment, outcome, history

Introduction

Chronic subdural hematoma (CSDH) is a common disease that is increasingly treated surgically both around the world and in Japan due to the superaging of society.[1-4] From ancient times, such as the time of the Inca civilization in South America, treatments have been provided for CSDH, but the disease still has not been overcome. For over 350 years, great figures of medical history have struggled in finding the best treatment for this disorder and have argued about its etiology. The etiological concepts and surgical treatment applied to this disease have evolved over time, even though therapeutic methods have not been perfected and the recurrence rate is regrettably not 0%.

Recently, the number of articles about CSDH have increased exponentially.[5] Thus, in this paper, I review the historical changes in the etiological concepts and surgical treatments for CSDH around the world and in Japan and examine future problems associated with surgical procedures and medical costs for CSDH.

Changes in the Etiology of CSDH

Although trephination was developed as early as the Neolithic era, no conclusive evidence has been found to confirm whether this trephination was used as a therapeutic maneuver.[6,7] An Egyptian female mummy showing signs of trephination examined by dissection in 1975 was found to have had a subdural hematoma.[8] Presumably humankind has been afflicted by CSDH since the ancient times. Johann Jacob Wepfer, a pathologist in Northern Switzerland, first reported two cases of CSDH in 1657.[7,9-11] The

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Table 1 Historical changes in the etiological concept of CSDH

Year	Author	Etiological concept of chronic subdural hematoma	Expressions in papers
1657	Wepfer JJ[12]	Apoplex etiology "delayed apoplexy"	Serum accumulation between the dura and pia mater
1761	Morgagni GB[13]	Delayed bleeding between the meninges	Bleeding between the dura mater and arachnoid membrane
1857	Virchow R[14]	Chronic inflammation	Pachymeningitis hemorrhagica interna
1868	Kremiansky J[15]	Inflammation + alcoholism	Alcoholism is an important etiological factor
1914	Trotter W[18]	Traumatic origin	An injury "so trivial as to escape attention" caused tearing of a vein
1932	Gardner WJ[20]	Osmotic gradient theory	Raised osmotic gradient causes transport of CSF into the subdural sac after encapsulation of the original hematoma

CSDH: chronic subdural hematoma, CSF: cerebrospinal fluid

1675 edition of his textbook reported on cases in detail.[12] He described accumulation of serum between the dura and the pia mater in two cases and considered the cause to be "delayed apoplexy".[12] Eighty-six years after Wepfer's paper, Morgagni reported a case of bleeding between the dura mater and arachnoid membrane in CSDH.[10,13] CSDH was thought to involve a stroke-like etiology in those days.[9]

In 1857, Virchow described the famous concept of so-called "pachymeningitis hemorrhagica interna."[14] He found recent bleeding within the old membrane in CSDH cases. He also advocated the notion that CSDH resulted from a generalized inflammatory disease. For a long time, this theory held sway. In 1868, Kremiansky reported 50 autopsy cases of "pachymeningitis hemorrhagica interna" and supported Virchow's theory.[10,15] He also proposed drinking alcohol as one cause of CSDH.[10,15] After Virchow's article, for almost 60 years, the etiology of CSDH was considered inflammatory disease.[7,9,10]

By the end of the nineteenth century and beginning of the twentieth century, several physicians had recognized that most patient with CSDH had a history of trauma.[9,10,16,17] In 1914, Trotter reported that CSDH had a traumatic origin.[18] He attributed the hemorrhage to bleeding of the bridging vein to the superior sagittal sinus.[18] However, many researchers stated objections to his opinion that the bridging vein around the superior sagittal sinus was the origin. After that report, in Western countries, CSDH became widely recognized. Horrax and Poppen reported that the frequency and recognition of CSDH increased in the 1930s.[19] In 1932, Gardner reported expansion of an original clot through osmotic attraction of cerebrospinal fluid by blood within the hematoma neomembranes.[20]

In 1946, Inglis reported the importance of the two layers in CSDH.[21] Before the formation of the two new layers, leakage of blood from "dural border cells" between the arachnoid and dura mater represents the initiating step of CSDH.[22,23] Many studies have investigated the etiology of CSDH. In general, CSDH assumes brain atrophy by aging and/or drinking as a baseline state, and the first bleeding is noted to occur in dural border cells following mild trauma (sometimes mild enough that it is ignored by the patient); then, inflammatory cells are drawn to the border cell layer. At this point, new membranes (first the outer membrane and then the inner membrane) form from activated inflammation with or without additional mild trauma. Angiogenic factors promote the formation of new capillaries within the outer membrane, and the hematoma gradually enlarges. Historical changes in the etiological concept are summarized in Table 1, and the contemporary understanding of the pathophysiological process underlying CSDH is shown in Fig. 1.[24-26]

The etiology of CSDH has not yet been completely solved, but it has been elucidated step by step through the insightful studies of pioneers.

Historical Changes in the Surgical Treatment of CSDH

In the classical era, Hippocrates performed trepanning as a surgical treatment on the parietal portion of the skull in a patient with spontaneous blindness. During this operation, liquid hematoma was discharged.[8,10] In 1883, Hulke reported trepanning as a successful surgical treatment of a patient with traumatic head injury.[10,27] His report described "evacuation of inflammatory fluid by incision through the dura mater."[10,27]

In 1914, Trotter reported two cases of patient with CSDH and an edematous disk in the ocular fundus in which he removed the hematoma by craniotomy. These patients reportedly returned to normal life.[18] In 1925, Putnam and Cushing reported 50 cases of CSDH treated by craniotomy.[28] They used the term "chronic subdural hematoma."[28] From this report, craniotomy became the first option for the treatment of CSDH for several years.[9,10]

Horrax and Poppen reported good results for CSDH treated by burr hole and irrigation with saline between 1935 and 1937.[19] McKissock *et al.* and Cameron *et al.* also reported good outcomes by burr hole and irrigation, so this surgery replaced craniotomy as the first-line treatment

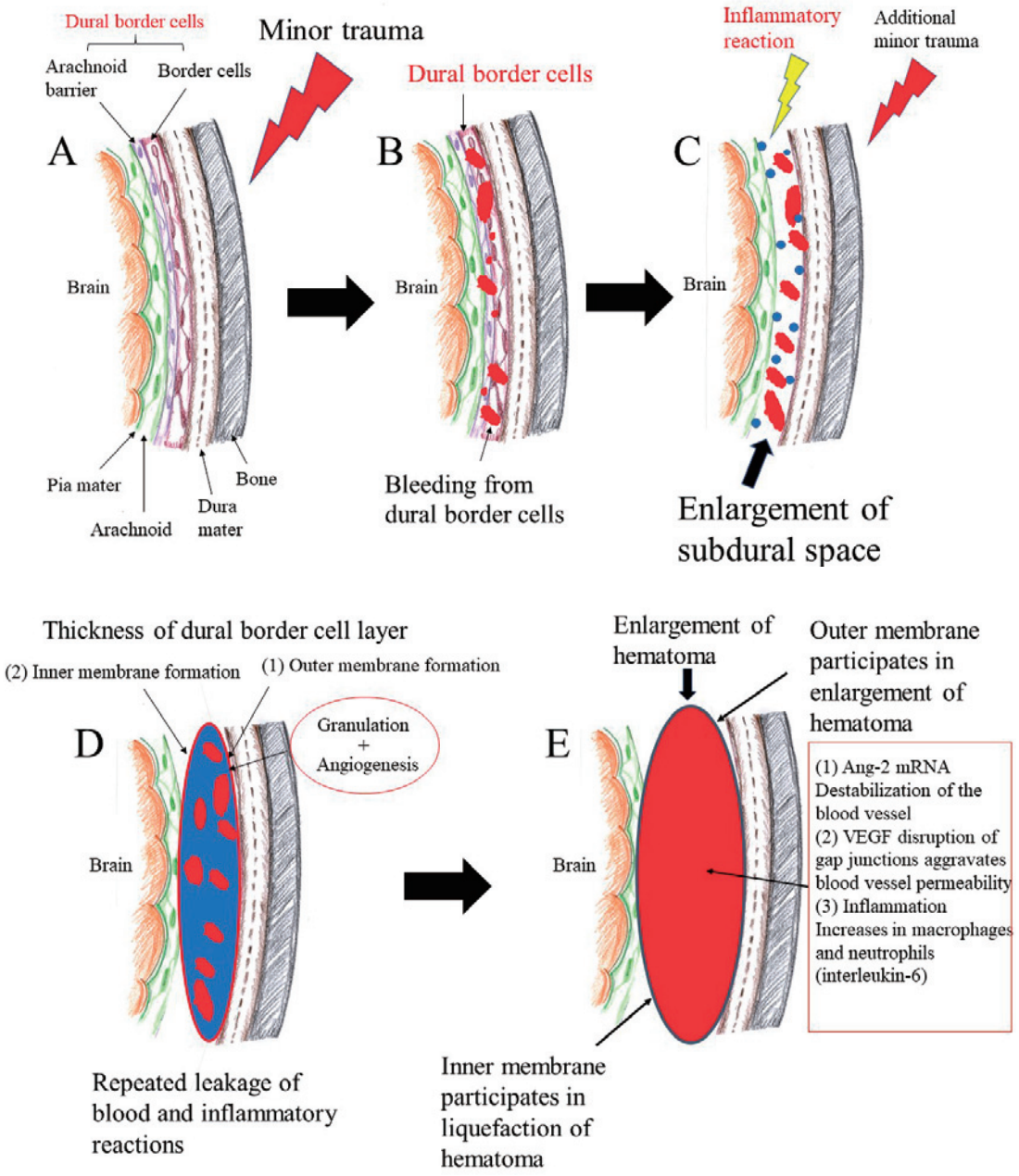

Fig. 1 Contemporary etiological concept of chronic subdural hematoma.
A: Anatomical schema of dural border cells. These cells exist between the arachnoid and dura mater.
B: After minor trauma, bleeding occurs from dural border cells.
C: After inflammatory reaction and additional minor trauma, the subdural space is noted to enlarge.
D: Blood leaks and inflammatory reactions are repeated; then, an outer membrane forms. Next, an inner membrane forms. Granulation and angiogenesis of the membrane gradually induce thickening of the dural border cell layer.
E: The outer membrane participates in the enlargement of the hematoma associated with various actions, and the inner membrane participates in liquefaction of the hematoma. These reactions lead to the enlargement of the hematoma and, ultimately, formation of the chronic subdural hematoma.

for CSDH.[29,30] Hematoma removal by craniotomy was performed for only limited cases, such as encapsulated hematoma or hematoma with multiple membranes.[30,31]

The twist drill technique, as a minimally invasive surgery, was developed by Cone at the Montreal Neurological Institute around 1940. However, the original technique was not published.[32] Rand *et al.* reported the safe use of the twist drill technique for 49 cases of CSDH.[32] Following that report, several neurosurgeons adopted the technique for CSDH.[33,34]

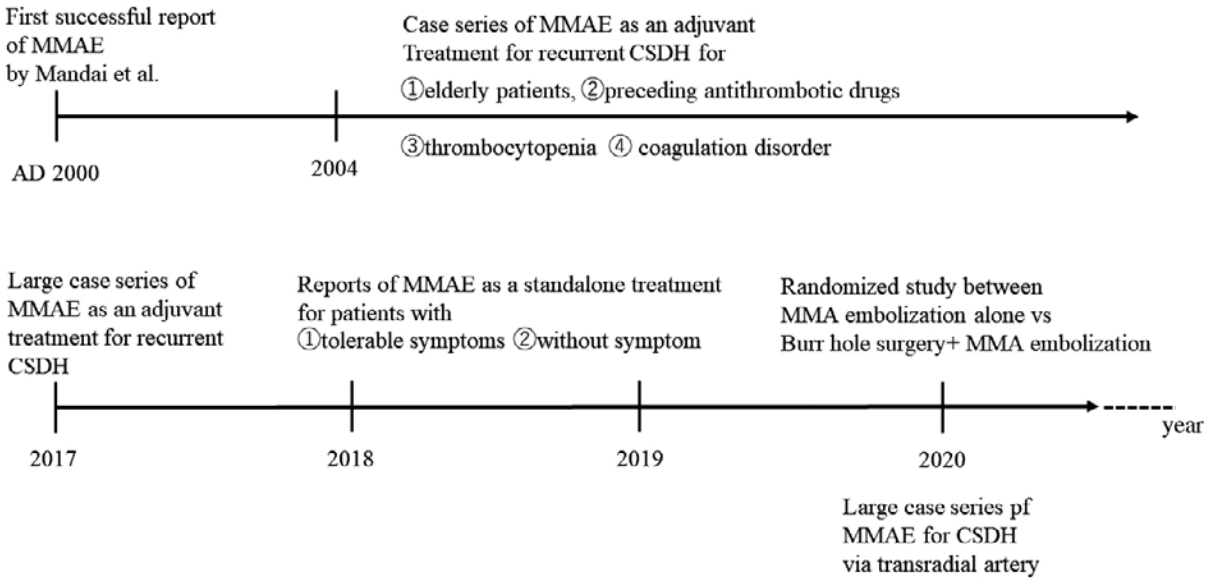

Fig. 2 Historical review of reports from around the world regarding middle meningeal artery embolization (MMAE) for chronic subdural hematoma (CSDH).

Recently, endoscopic hematoma evacuation was introduced for coagulated hematoma, multiple septal membranes in the hematoma, and recurrent CSDH.[35-37] The first endoscopic treatment for CSDH was described by Karakhan in 1988.[38] Since that paper, several studies have reported the safe management of CSDH by endoscopic surgery.[36,37,39] Amano *et al.* reported that the incidence of postoperative rebleeding and reoperation was significantly lower with endoscopic surgery than in controls treated without an endoscope.[36] On the other hand, Yan *et al.* reported that this method has failed to reduce the recurrence rate.[40] Thus, it is deemed crucial that surgeons must recognize the advantages and risks of each approach, such as cortical damage by the endoscope and the longer operation time.

In 2000, Mandai *et al.* first reported middle meningeal artery (MMA) embolization using polyvinyl alcohol particles for protection against recurrence.[41] Since that paper, many reports worldwide have described the usefulness of MMA embolization to eliminate blood supply to the membrane in CSDH.

This method was initially performed as adjuvant treatment before or after standard surgery for recurrent CSDH. Most reports involved small case series and were performed for high-risk patients who were elderly, had been receiving antithrombotic agents, or had thrombocytopenia or coagulation disorders. Recurrences were consistently uncommon, but indications for MMA embolization were found to differ among the reports.[42-46] In 2017, Kim reported 20 cases of MMA embolization for recurrent CSDH.[47] In 2018 and 2019, Ban *et al.* and Link *et al.* reported large case series of MMA embolization.[48,49] They first performed MMA embolization to prevent surgery in patients with paucisymptomatic CSDH as prophylaxis against recurrence after the initial surgery. Moreover, they showed that standalone MMA embolization was successfully achieved in almost all cases.[48,49] In 2020, Ng *et al.* described the first randomized study of CSDH allocating patients to receive surgery alone or surgery plus MMA embolization, revealing that surgery plus MMA embolization reduced the time needed for CSDH absorption.[50] Kan *et al.* have also presented a large, multicenter MMA embolization series in the United States, including 138 patients.[51] Most cases represented first-time CSDH intervention, and 90% of the patients in this series experienced favorable functional outcomes.[51] In 2020, Rajah *et al.* reported the utility and safety of transradial MMA embolization in a study including 46 patients with CSDH.[52] Most cases (80.4%) were performed as primary treatment for CSDH using Onyx. As per the findings, transradial MMA embolization was safe and effective for elderly patients with CSDH.[52] Figure 2 shows a summary of reports regarding MMA embolization for CSDH since 2000.

In summary, simple burr hole surgery remains to be the first choice for CSDH, but the twist drill technique and a new variation called the "Hollow screw system" are attracting significant attention as less invasive surgeries for elderly patients with CSDH.[53] The endoscope is used for recurrent or more complicated hematoma cases. Recently, MMA embolization has been considered a promising method of treatment for patients with initial and/or recurrent CSDH. In the future, randomized studies regarding the efficacy of MMA embolization for patients with new CSDH will be needed, and the indications for MMA embolization should be established. Table 2 summarizes reports from around the world regarding the surgical treatment of

Table 2 Records and reports from around the world regarding the surgical treatment of CSDH

Year	Authors	Surgical treatment
12,000 BC		Trepanation (therapeutic or magical ceremony)
460-377 BC	Hippocrates[10]	Parietal trepanation
1883	Hulke[27]	Successful surgical treatment of trepanning
1914	Trotter W[18]	Removal of hematoma by craniotomy
1925	Putnam and Cushing[28]	Fifty cases of CSDH treated by craniotomy
1937	Horrax and Poppen[19]	Good result of CSDH treatment by burr hole and irrigation with saline
1966	Rand BO[32]	Use of twist drill technique for 49 cases of CSDH
1988	Karakhan VB[38]	First endoscopic treatment for CSDH
2000	Mandai S[41]	Middle meningeal artery embolization for recurrent CSDH

CSDH: chronic subdural hematoma

CSDH.

Historical Review of Treatments for CSDH in Japan

In Japan, a case report of CSDH were first published by Professor Nakada in 1938.[54] Professor Nakada from Niigata Medical University reported a case of 40-year-old man who presented with headache and confused state with a history of head trauma 4 months earlier. He then diagnosed this patient with CSDH and removed the hematoma and outer and inner membranes using a 6-cm-diameter craniotomy under general anesthesia. This patient was discharged from the hospital without neurological deficit.[54] Several case reports were published following this paper, although all of the papers are written in Japanese.[55-59] In 1943, Professor Araki from Kyoto University reported the five cases of CSDH (three of adults, two of infants).[55] In 1951, Morita from Yokosuka Kyosai Hospital and Shimizu from the University of Tokyo reported cases of CSDH treated by craniotomy.[56,57] Neither of those case reports used the word "chronic." The authors instead referred to "subdural hematoma," although the presenting illness and operative findings were typical of CSDH and the hematoma was removed via craniotomy.[56,57] Suzuki *et al.* from Tohoku University reported ten cases of CSDH, but two were subacute cases.[59] They mainly performed craniotomy, and the mortality rate was 20%.[59] Since then, according to our search of the literature, Professor Kitamura from Kyushu University reported more than ten cases of CSDH for the first time in 1959.[60] According to that paper, they performed placement of two burr holes and irrigation in 11 of the 17 cases and craniotomy and removal of the membranes in the remaining 6 cases.[60] In 1963, Professor Moriyasu reported 30 cases of CSDH, treated mainly by burr hole (one or two) and irrigation.[61] In contrast, Kondo reported 21 cases of CSDH, which were all treated using craniotomy.[62] Okada and Kawabuchi described surgical treatment for 123 cases of CSDH at Gunma University Hospital.[63] They operated on 69 patients between 1955 and 1967 using large craniotomy.[63] Since 1968, burr holes and irrigation had mainly been used, showing no significant difference in postoperative outcomes among the two methods.[63] Miyazaki *et al.* from Sapporo Medical University reported treatment of CSDH by placement of a 5-cm-diameter bone window and irrigation of the hematoma.[64] However, all these papers are also written in Japanese.

Professors Suzuki and Takaku from Tohoku University Hospital wrote the first report of CSDH in English in 1970.[65] They reported nonsurgical treatment comprising osmotherapy with 20% mannitol for 23 consecutive male patients with CSDH.[65] In 1972, Professor Hirakawa *et al.* from the University of Tokyo reported 309 cases of CSDH between 1948 and 1972.[66] They then performed large craniotomy and removal of the hematoma with capsule in 137 cases, burr hole surgery and irrigation in 133 cases, and small craniotomy and irrigation of the hematoma without removing the capsule in 33 cases. They concluded that burr hole surgery represented a superior method because the operative outcomes were better, and no differences in postoperative social activities were evident among the three groups.[66] Professor Waga from Kyoto University reported on 24 patients over 60 years old with CSDH between 1963 and 1972.[67] During that period, only four patients were over 70 years old, and women comprised only 12.5% (3/24). All patients were diagnosed by angiography, and in 20 of the 28 lesions, the hematoma was removed via burr hole surgery (two burr holes were used in 10 of 20 cases). The outcomes of surgical treatment were good; however, these patients did not include any on anticoagulant therapy or hemodialysis.[67] After these early reports from Japan, many pioneering figures in Japanese neurological surgery have examined CSDH.

From 1980 to 2000, surgical treatment for protection against recurrent CSDH improved. Aoki described a tapping and irrigation method that was performed through the skin in 1984.[68] This tapping was performed at the bedside and used a specially designed needle. Aoki described a

Table 3 A summary of reports from Japan regarding the surgical treatment of CSDH

Year	Authors	Reports of surgical treatment
1938	Nakada M[54]	A case report of CSDH treated by craniotomy*
1943	Araki C[55]	Five cases report of CSDH treated by craniotomy*
1951	Morita M[56]	Two cases of CSDH treated by craniotomy*
1951	Shimizu K[57]	A case report of CSDH treated by craniotomy*
1956	Suzuki J[59]	Ten cases of CSDH treated by craniotomy and burr hole surgery*
1959	Kitamura K[60]	Evaluation of 17 cases of CSDH treated by burr hole and craniotomy*
1962	Kondo S[62]	Evaluation of 21 cases of CSDH treated by craniotomy*
1963	Moriyasu M[61]	Evaluation of 30 cases of CSDH mainly treated by burr hole surgery*
1963	Miyazaki Y[64]	A 5-cm-diameter bone window and irrigation of hematoma*
1972	Hirakawa K[66]	Evaluation of 309 cases of CSDH treated by craniotomy and burr hole surgery
1972	Waga S[67]	Evaluation of 24 cases of CSDH in patients over 60 years old treated by burr hole surgery
1973	Okada K[63]	Evaluation of 123 cases of CSDH treated by craniotomy and burr hole surgery*
1984	Aoki N[68]	Tapping and irrigation method
1992	Aoki N[69]	Replacement of hematoma with oxygen via percutaneous subdural tapping
1995	Kitakami A[70]	Replacement of hematoma with carbon dioxide

CSDH: chronic subdural hematoma
* Paper is written in Japanese.

lower recurrence rate compared to burr hole or twist drill surgeries. Aoki has also reported replacement of the hematoma with oxygen via percutaneous subdural tapping.[69] Kitakami *et al.* reported carbon dioxide replacement of CSDH using single burr hole irrigation. They described the hematoma cavity and gas as having disappeared the next day.[70]

As mentioned above, Mandai *et al.* reported MMA embolization for protection against recurrence in 2000. I emphasize that this was the first successful report of MMA embolization for CSDH. Table 3 shows a summary of reports from Japan.

Irrigation has generally been performed using normal saline or Ringer's solution. On the other hand, artificial cerebrospinal fluid (ACF) has been used for irrigation in CSDH burr hole surgery. Several studies have shown that irrigation using ACF reduces the recurrence rate compared with irrigation using normal saline.[71,72] Toi *et al.* conducted a prospective multicenter, randomized study that investigated whether the recurrence rate of CSDH was decreased in an ACF group compared with a normal saline group and to verify the safety of ACF as an irrigation solution for CSDH surgery.[73] They concluded that no differences in recurrence rate or time to recurrence were noted between the ACF and normal saline groups. ACF was considered to offer sufficient safety as an irrigation fluid for CSDH.[73]

Problems with Surgical Treatment for CSDH

To date, several different approaches have been attempted to prevent recurrence of CSDH. Examples of these approaches include irrigation methods, placement of a drain into the hematoma cavity or subgaleal space, propping the patient's bed up after surgery, and medical treatment with or without surgery.[1,5,74-76] Nowadays, patients are getting older,[1] so less invasive surgeries and better pharmacotherapies will be needed in the future.

We must also consider the costs for the treatment of CSDH, because of the increasing number of surgical cases. Rauhala *et al.* reported the cost of CSDH in the Pirkanmaa Region of Finland.[77] According to their study, the mean total cost from first hospital admission until final follow-up visit per patient treated surgically was 5250 € (median, 3810 €), with means of 3820 € (median, 3370 €) per patient with no recurrence and 8850 € (median, 7110 €) per patient with recurrence. They concluded that reducing recurrences is crucial to lessen both complications and costs.[77] Moreover, while reducing the length of the hospital stay is crucial, elderly patients often experience difficulty returning home directly from the hospital.[2,78] If patients are transferred to a nursing home or rehabilitation hospital more frequently in the future, costs will thus increase further. We must therefore aim to shorten the duration of hospitalization and accelerate the process of returning patients home.

Conclusion

In this study, I reviewed the historical changes in the etiological concepts and surgical treatments for CSDH around the world and in Japan. Many pioneering figures have examined CSDH, even though therapeutic methods have not been perfected. The age of patients is increasing; thus, more minimally invasive surgeries and useful phar-

macotherapies are needed. We must also consider the costs for treating CSDH, because of the increasing numbers of surgical cases.

Conflicts of Interest Disclosure

Author has no conflicts of interest to declare regarding this study or its findings.

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