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Original article

Induced membrane technique for clavicle reconstruction in paediatric patients: Report of four cases

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ABSTRACT

Background: Clavicular reconstruction in paediatric patients is a rarely performed procedure that often raises complex technical challenges and produces unreliable outcomes. The induced membrane technique is an innovative two-stage procedure involving cement spacer placement into the defect to induce the development of a membrane, followed by the implantation of a cortical-cancellous bone graft. The primary objective of this study was to assess the medium- and long-term clinical and radiographic outcomes of clavicular reconstruction using the induced membrane technique in children and to highlight the advantages and drawbacks of this technique. The secondary objectives were to evaluate the fixation and the outcomes according to age and to the underlying diagnosis.
Hypothesis: Clavicular reconstruction using the induced membrane technique produces good outcomes in paediatric patients.
Patients and methods: The induced membrane technique was used for clavicular reconstruction in 4 children with a mean age of 9.7 years (range, 7.4–12.3 years). The diagnosis was congenital pseudarthrosis of the clavicle in 3 patients and aneurysmal bone cyst in 1 patient. Shoulder pain and mobility were assessed at last follow-up. Radiological bone healing was evaluated using the total radiographic union score (RUS, range, 0–10). Complications and number of procedures per patient were recorded.
Results: Mean follow-up was 3.9 years (range, 1–8.4 years). None of the patients had pain or motion range limitation. After 6 months, the clavicle was healed with a RUS of 10 in all patients. The mean number of surgical procedures per patient was 3.75 (range, 3–5). Two patients required revision surgery for distal pin migration and another for a subcutaneous abscess under the pin.
Discussion: When used for clavicular reconstruction, the induced membrane technique is effective and associated with a low complication rate. The induced membrane technique therefore deserves to be viewed as an alternative to other methods.
Level of evidence: IV, retrospective observational study.

1. Introduction

Clavicular reconstruction for any reason raises challenges in terms of obtaining bone healing and restoring normal bone length [1–7]. The many techniques described to date (e.g., cortical-cancellous autograft and fibula transfer) have produced widely variable outcomes. None of these techniques seems fully reliable [1–7]. The induced membrane technique is an innovative procedure that involves two stages. In the first stage, a polymethyl methacrylate spacer is placed in the bone defect to induce the formation of a surrounding membrane. The second stage is performed 6 weeks later and consists in implanting a cortical-cancellous bone graft. The induced membrane technique was initially developed for the treatment of large diaphyseal defects, first in adults and subsequently in paediatric patients [8–11] requiring reconstruction after tumour resection or due to septic or congenital pseudarthrosis. Reports of excellent healing rates, notably in children, indicate that the induced membrane technique is a valid treatment option [9]. We therefore decided to assess the induced membrane technique for clavicular reconstruction in children.

The primary objective of this study was to assess the medium- and long-term clinical and radiographic outcomes of clavicular reconstruction using the induced membrane technique in children and to highlight the advantages and drawbacks of this technique. The secondary objectives were to evaluate the fixation and the outcomes according to age and to the underlying diagnosis. The

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working hypothesis was that clavicular reconstruction using the induced membrane technique produces good outcomes in paediatric patients.

2. Material and methods

2.1. Patients

We retrospectively reviewed the clinical and radiological data available for patients who underwent clavicular reconstruction using the induced membrane technique at our centre between March 2010 and January 2018. Of 4 identified patients, 3 had congenital pseudarthrosis of the clavicle (CPC) and 1 had an aneurysmal bone cyst (ABC). The medical chart review was approved by the French Data Protection Authority (Commission nationale de l'informatique et des libertés, CNIL). Informed consent was obtained from all patients and their parents.

2.2. Operative technique

The same two-stage operative technique was used by a senior surgeon in all 4 patients. The first stage consisted in resection of the pseudarthrosis or cyst via a longitudinal incision along the axis of the clavicle. The length of the resected lesion ranged from 2.9 to 6 cm. An intramedullary pin was inserted using a to-and-fro movement under fluoroscopy control. Polymethyl methacrylate (Cerafixgenta, Ceraver Osteal, Roissy, France) was then used to fashion a spacer. To this end, a syringe was cut in two and placed between the two bone ends, taking care to surround each of the bone ends along a few millimetres. The syringe was easily removed after polymerization of the cement.

The two bone ends were kept as far apart as possible by the spacer. Immobilisation until the second stage of the procedure was with a Dujarrier bandage maintaining the elbow by the side and the forearm against the chest. A clinical and radiographic assessment was performed after 3 weeks, and the second stage was performed after 6 weeks (Fig. 1).

The second stage started with the harvesting of an autologous cortical-cancellous bone from one of the posterior iliac crests. The approach to the clavicle was re-opened. A longitudinal incision was performed in the induced membrane. The spacer was fragmented and removed and the autologous cortical-cancellous graft was placed in the defect. In the patient with the ABC, autologous demineralized bone chips were added. The induced membrane was then carefully sutured.

The pin was removed after bone healing was confirmed radiologically. Intra-operative prophylactic antibiotics were given during both stages of the procedure.

3. Method

The demographic features of the patients were analysed. The reason for clavicular reconstruction was recorded (CPC or ABC). At last follow-up, the following were recorded: visual analogue scale (VAS) for pain intensity, condition of the scar, shoulder mobility, number of surgical procedures, and complications. The patients evaluated the cosmetic outcome as poor, average, or good [12].

Before surgery, the radiographs of the clavicle were examined to determine the distance between the bone ends in the patients with congenital pseudarthrosis and the size of the lesion in the patient with an ABC. Radiographs were then obtained immediately after surgery; 3 weeks, 6 weeks, 3 months, and 6 months later; and at last follow-up (Figs. 2 to 5). They were used to evaluate time to bone healing and to look for evidence of a fracture and/or of hardware migration.

Bone healing was assessed using the standardised 10-point total radiographic union score [13]. Of the 10 points, 4 are assigned to reflect bone formation and 3 to assess bone healing at each of the two bone ends. We defined healing as a total RUS of 8 to 10.

4. Results

We included 4 patients, all of whom were female. Among them, 3 had CPC of the middle third of the right clavicle and 1 had an ABC. All 3 patients with CPC reported pain with shoulder movements, despite normal range of motion, and concern about poor cosmesis. The ABC was located in the distal third of the left clavicle and confirmed by histological examination of a biopsy specimen.

Mean age at surgery was 9.7 years (range, 7.4–12.3 years). Mean follow-up was 3.9 years (range, 1–8.4 years). Table 1 reports the main outcomes.

At last follow-up, all 4 patients were free of pain and had normal motion ranges that were identical to those on the other side. None of the scars were painful although 1 was hypertrophic at last follow-up. Cosmesis was deemed good by the 3 patients with CPC and average by the patient with an ABC. None of the patients reported

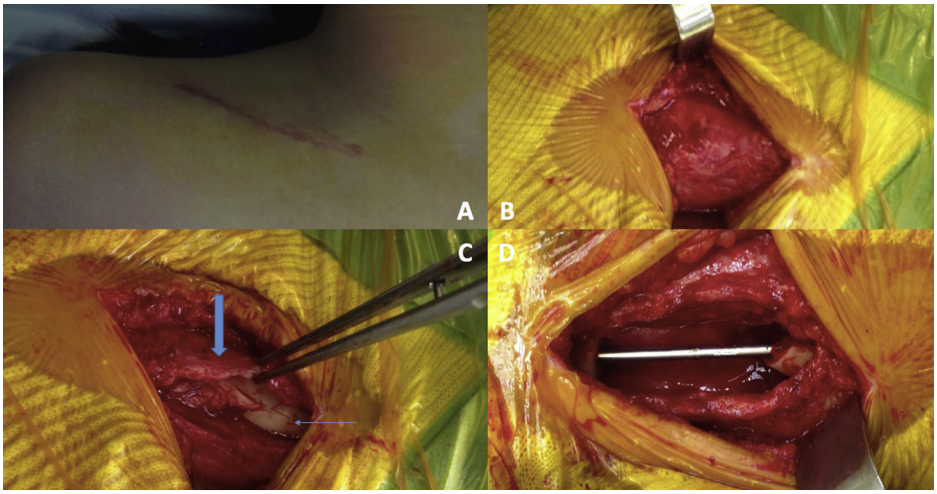

Fig. 1. Patient #3, intra-operative photographs taken during the second stage of the induced membrane procedure. A. Scar before the second stage of the procedure. B. Induced membrane before incision. C. Horizontal incision in the induced membrane (wide arrow) and bone cement (narrow arrow). D. Removal of the bone cement and visualisation of the pin inserted during the first stage of the induced membrane procedure.

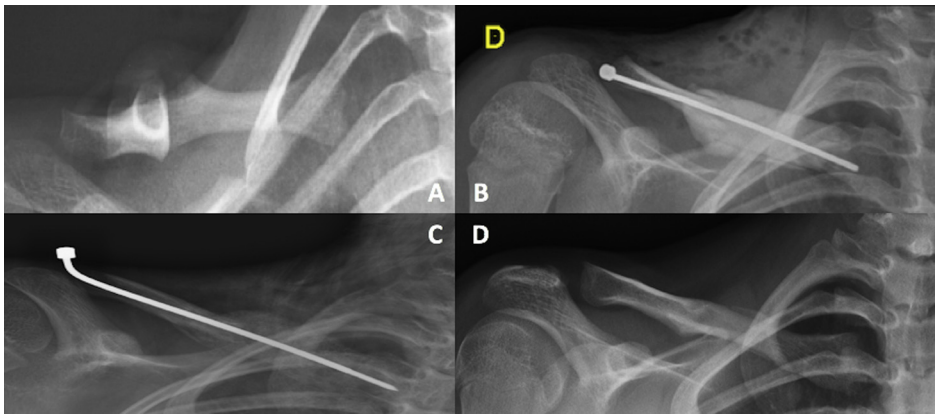

Fig. 2. Patient #1, clavicular reconstruction for congenital pseudarthrosis of the right clavicle. A. Pre-operative radiograph. B. Radiograph taken immediately after the first stage of the induced membrane procedure. C. Radiograph taken immediately after the second stage of the induced membrane procedure. D. Radiograph taken at last follow-up after 8.4 years, showing bone healing.

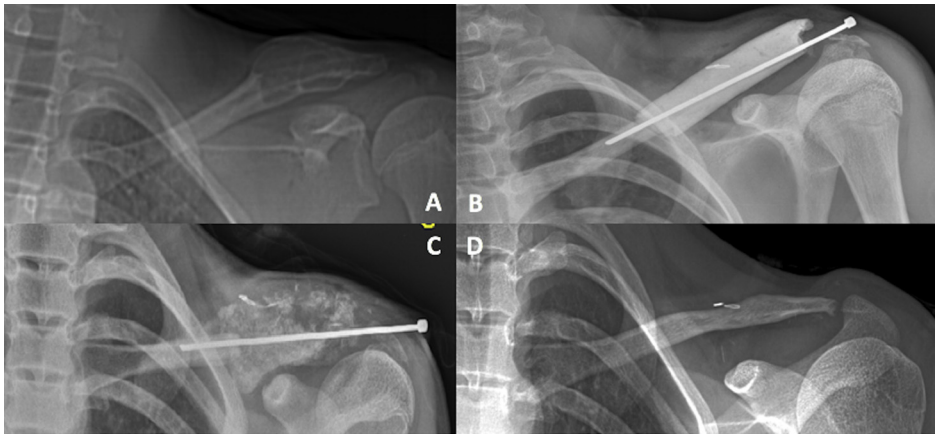

Fig. 3. Patient #2, clavicular reconstruction for an aneurysmal bone cyst in the lateral fourth of the left clavicle. A. Pre-operative radiograph. B. Radiograph taken immediately after the first stage of the induced membrane procedure. C. Radiograph taken immediately after the second stage of the induced membrane procedure. D. Radiograph taken at last follow-up after 5.1 years, showing bone healing.

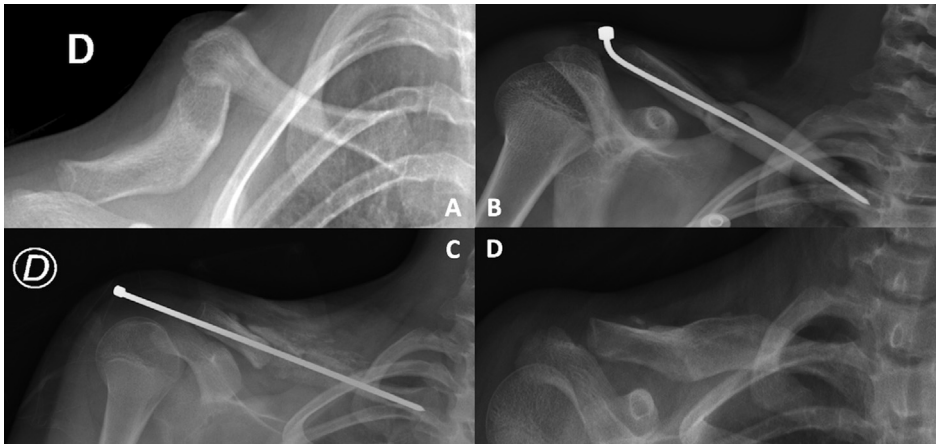

Fig. 4. Patient #3, clavicular reconstruction for congenital pseudarthrosis of the right clavicle. A. Pre-operative radiograph. B. Radiograph taken immediately after the first stage of the induced membrane procedure. C. Radiograph taken immediately after the second stage of the induced membrane procedure. D. Radiograph taken at last follow-up after 1.2 years.

pain or concern about the cosmetic appearance of the scars at the donor site. The mean number of surgical procedures per patient was 3.75 (range, 3–5).

Complications occurred in 3 patients (#2, #3, and #4). Revision surgery was required in 2 patients 2 weeks after the second stage due to distal pin exteriorisation. In another patient, a subcutaneous abscess developed at the pin exit site 1 month after the second stage. Patient #2 experienced 2 fractures, one at the site of the bone graft 4 months after the second stage and the other at the junction between the graft and distal third of the clavicle 7 months after the second stage; both fractures were managed by immobilisation with the elbow by the side and healed within 1 month. Finally, another

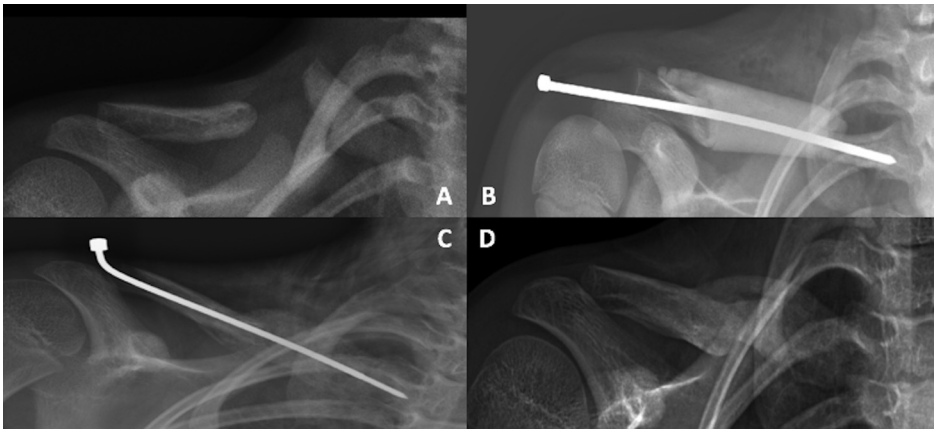

Fig. 5. Patient #4, clavicular reconstruction for congenital pseudarthrosis of the right clavicle. A. Pre-operative radiograph. B. Radiograph taken immediately after the first stage of the induced membrane procedure. C. Radiograph taken immediately after the second stage of the induced membrane procedure. D. Radiograph taken at last follow-up after 1 year.

Table 1
Main features of the study patients (demographic data; type, side, and location of the clavicular lesion; initial distance between the bone ends; length of the bone defect; follow-up duration; number and type of complications; and final outcome).

Patient #	Sex	Age at surgery (months)	Side	Location	Type of lesion	Distance between bone ends before resection (mm)	N of procedures	Size of resected zone (mm)	Follow-up (years)	Complications	Final outcome
1	F	7.4	R	Middle third	CPC	6	3	35	8.4	0	BH
ABC	F	12.3	L	Lateral third	ABC	NA	5	60	5.1	K-wire re-cut 2 fractures Excision of a spicula	BH
3	F	9.5	R	Middle third	CPC	7	4	29	1.2	K-wire re-cut	BH
4	F	9.5	R	Middle third	CPC	25	3	33	1	Subcutaneous abscess	BH

F: female; R: right; L: left; CPC: congenital pseudarthrosis of the clavicle; ABC: aneurysmal bone cyst; NA: not applicable; BH, bone healing.

surgical procedure was performed in this same patient 2.5 years after the second stage to remove a bothersome bony spicule. The ABC did not recur.

The total RUS 3 months after the second stage was between 8 and 10 in 3 patients and was 7 in the remaining patient. All 4 patients had a total RUS of 10.6 months after surgery.

5. Discussion

Our results confirm that the induced membrane technique ensures satisfactory and durable reconstruction of the clavicle, providing good clinical and radiological outcomes in paediatric patients. To date, no consensus exists about the best clavicular reconstruction methods in children. Only two cases of two-stage reconstruction using the induced membrane technique have been reported, including one of the patients included in our study [14,15].

The limitations of our study include the retrospective design, absence of a control group, and small sample size precluding statistical tests. In addition, our patients were still young at the last assessment, and data from a longer follow-up are needed.

We chose the induced membrane technique based on reports of good outcomes and low morbidity in children [11,16,17]. The mechanisms by which the induced membrane promotes angiogenesis, osteo-induction, and osteogenesis remain incompletely elucidated [8,10]. The main drawback of the induced membrane technique is the need for two surgical stages. The other drawbacks and complications are related to the clavicular reconstruction and to the internal fixation methods available for this anatomical region.

Most studies of other clavicular reconstruction methods were done in patients with CPC [1–5,18]. Several reconstruction techniques can be considered. However, most studies emphasise the importance of using a cortical-cancellous bone graft. Di Gennaro et al. [2] studied 27 patients with CPC, whose mean age was 8.1 years. Among them, 19 were managed by one-stage resection and bone grafting, including 15 who received autologous cortical-cancellous grafts. Of the 5 patients who did not achieve bone healing, 3 had been managed with allogeneic demineralised bone chips. In addition, of the 4 patients treated with a fibular allograft, 2 did not achieve bone healing and 1 experienced graft resorption. Cadhilac et al. [1] reported their experience with 17 children who had CPC and a mean age of 6 years 4 months at the time of plate fixation. Autologous iliac crest bone grafting was performed in 9 patients, whereas the remaining 8 patients received no bone graft material. Healing was achieved in all 9 grafted patients, compared to only 5 of the 8 non-grafted patients. These results support the need for bone grafting regardless of the fixation method used. Eliott and Richards [18] reported 2 cases of failed CPC reconstruction with use of a bovine cancellous xenograft, which underwent complete lysis. These authors advise against using this material.

Nevertheless, healing was achieved in all 8 patients with CPC treated by Grogan et al. [5] using excision of the pseudarthrosis followed by cerclage wiring, without grafting or internal plate or pin fixation. It is worth noting that 6 of the 8 patients were younger than 2.5 years of age at surgery. This young age may explain that grafting was not used. However, whether clavicular length was restored remains unclear. In 1 patient, revision surgery using a vascularised fibular graft after massive lysis of the previous graft was followed by full osteo-integration within 7 months [7]. However, the scarring

and perhaps also functional impairments at the donor site are drawbacks of this method. Although the post-operative course seems comparable, we would use a vascularised fibular graft only for revision surgery after failure of the induced membrane technique.

None of the currently available fixation methods seems ideal. Pins were used in our study, but re-cutting of exteriorised pins was required in 2 patients. In a comparison of pin vs. plate fixation, Chandran et al. found that non-union was more common after pinning (2/5 vs. 0/5 cases) [4]. However, opposite results were obtained by Persiani et al., who compared 8 patients managed using pinning to 9 managed with plate fixation [3]. Based on a literature review, Huntley recommended a cortical-cancellous graft without internal fixation in patients younger than 4 years and plate fixation rather than pinning in patients older than 4 years [6]. Our results and those reported previously suggest that plate fixation may be associated with a lower complication rate but carries a risk of hardware breakage and skin impingement, which may require further surgery to remove the material.

We found no differences in healing or complication rates according to age. However, our sample size was small. No consensus exists about the best age for clavicular reconstruction. The prevalent view, however, is that surgery should be performed before 5 years of age and perhaps as early as possible [3,5,19].

The nature of the clavicular lesion may influence the outcome. ABC is an uncommon lesion that rarely affects the clavicle. The most common clavicular site of involvement is the lateral third [19]. Kaiser et al. reported a high recurrence rate after curettage with or without grafting [20]. In an 8-year-old with an ABC of the lateral fourth of the clavicle, Bakkaly et al. obtained a good outcome after resection without reconstruction [21]. For our patient with an ABC, we chose the induced membrane technique as a method that provides a more anatomical reconstruction. Healing was achieved but fractures occurred subsequently. Rather than the nature of the lesion, its lateral location may explain the large number of complications.

6. Conclusion

Clavicular reconstruction using the induced membrane technique deserves to be considered as a therapeutic option that provides good healing rates with a limited number of complications but requires two surgical stages.

Disclosure of interest

The authors declare that they have no competing interest.

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Contributions of each author

B. Haddad and C. Klein wrote the manuscript.
R. Gouron and E. Haraux revised the manuscript.
S. Zribi and F. Deroussen collected the data.

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