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Craniosynostosis: State of the Art 2019

Reducing blood loss in pediatric craniosynostosis surgery by use of tranexamic acid

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ABSTRACT

Introduction. – Craniosysnostosis surgical corrections are routine procedures in the pediatric neurosurgical field. However, these procedures result in significant blood loss. Tranexamic acid (TXA) is an antifibrinolytic drug, which has demonstrated a significant reduction in perioperative blood loss in many pediatric surgical procedures such as cardiac surgery and scoliosis surgery. We conducted a systematic review to evaluate protocols of TXA use in pediatric craniosynostosis procedures and its effect on intraoperative blood loss and transfusions.

Material and methods. – A comprehensive literature review of the National Library of Medicine (PubMed) database was performed to identify relevant studies. We included any clinical study reporting on blood loss or blood transfusion for pediatric craniosynostosis surgery with intraoperative use of tranexamic acid, with the following limits: publication date from inception to May 2019; reports in English.

Results. – Thirteen studies were eligible for our review. Of the 13 studies, 4 were prospective, randomised, double-blind controlled trials, 9 were retrospective studies, tailored as a "before–after" studies, comparing blood loss and transfusion without/with TXA. TXA significantly decreases the number and volume of packed red blood cell transfusions and the rate of transfusion in children undergoing craniosynostosis surgery. Significantly fewer fresh frozen plasma transfusions were required in the TXA groups in 2 randomised studies. Length of stay in hospital was significantly lower with the use of TXA in three studies. Advantages of TXA administration also include an excellent patient tolerance of side effects, ease of administration and low cost.

Conclusion. – TXA significantly reduces blood loss and the need for transfusions in children undergoing craniosynostosis surgery. TXA administration should be a routine part of strategy to reduce blood loss and limit transfusions in these procedures.

1. Introduction

Craniosysnostosis surgical corrections are routine procedures in the pediatric neurosurgical field. However, these procedures result in significant blood loss, especially in patients younger than 18 months, weighing < 10 kg, in patients with craniofacial syndromes and those with multiple suture involvement [1,2]. Intraoperative total blood volume lost can be greater than 100% of the estimated preoperative volume [3] and should be considered as the major complication of these procedures, especially in syndromic craniosynostoses. Efforts to reduce perioperative blood loss have focused on endoscopic surgery, preparation with erythropoietin, autologous predonation, use of cell salvage, acute normovolemic hemodilution, and more recently intraoperative use of antifibrinolytics [4,5]. Unlike other alternatives, antifibrinolytics are able to prevent further bleeding by stabilizing microclots formed at a surgical wound [6].

Tranexamic acid (TXA) is an antifibrinolytic drug, which has demonstrated a significant reduction in perioperative blood loss in many pediatric surgical procedures such as cardiac surgery and scoliosis surgery [7,8]. Interest in using TXA in craniosynostosis surgery has appeared since publication of randomised-controlled studies in 2011 [9–11]. Despite accumulation of evidence regarding its effectiveness, TXA was not unanimously employed in pediatric neurosurgery teams: Goobie et al. [12] reported a total of 1638 cases of cranial vault reconstruction from 2010 to 2015 in 31 institutions but antifibrinolytic administration occurred in only 59.5%.

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Similarly, the Synostosis Research Group reported that TXA was routinely used in 3 sites but never in 2 others [13].

By conducting this systematic review, we aimed to evaluate protocols of TXA use in pediatric craniosynostosis procedures and its effect on intraoperative blood loss and transfusions.

2. Materials and methods

A comprehensive literature review of the National Library of Medicine (PubMed) database was performed to identify relevant studies. We used the following keywords: "craniosynostosis" and "tranexamic acid". We included any clinical study reporting on blood loss or blood transfusion for pediatric craniosynostosis surgery with intraoperative use of tranexamic acid, with the following limits: publication date from inception to May 2019; reports in English. The references from the reports included were also manually searched to find further references and reported studies not identified using our initial search strategy. We did not included studies with other antifibrinolytics such as aprotinin, and aminocaproic acid. Ethics committee approval was not required for our research protocol.

3. Results

3.1. Selection of reports and study design

Thirteen studies were eligible for our review. Of the 13 studies, 4 were prospective, randomised, double-blind controlled trials [9,10,14,15], 9 were retrospective studies, tailored as a "before–after" studies, comparing blood loss and transfusion without/with TXA [16–24]. Study characteristics are presented in Tables 1 and 2. A total of 729 patients were included: 160 in the randomised studies and 569 in the observational studies.

3.2. Analysis of protocols

Protocols of TXA administration varied from one study to another. A loading dose was commonly used, with doses ranging from 10 mg/kg [14,15,18,20–22] to 100 mg/kg [16], usually infused over 15 minutes after induction of general anesthesia and before skin incision. A continuous infusion until skin closure was performed in all studies, with different protocols: 5 mg/kg/h [10,14,18,20–23] or 10 mg/kg/h [9,16,17,19,24].

In their study, Goobie et al. [10] reported that a 50 mg/kg bolus dose followed by an infusion of 5 mg/kg/h could maintain TXA plasma concentrations above the in vitro thresholds reported for inhibition of fibrinolysis (10 μg/mL) and plasminogen-induced platelet activation (16 μg/mL). But in a further study, the same author reported that a loading dose of 10 mg/kg over 15 min followed by a 5 mg/kg/h maintenance infusion was sufficient to produce a steady-state TXA plasma concentrations above the 16 μg/mL threshold [25].

No TXA was used postoperatively except in two recent studies [15,22]. Kurnik et al. [22] compared a continuous infusion during the 24 hours after the end of surgery to an infusion stopped 4 hours postoperatively. Blood loss volume showed no difference between the 2 groups; neither did length of stay in the pediatric intensive care unit. Fenger-Eriksen et al. [15] used a protocol with a bolus dose of 10 mL/kg before incision followed by 8 hours' continuous infusion of 3 mL/kg/h.

3.3. Key results of each study

3.3.1. Population and procedures

Studies compared efficacy of TXA for both syndromic and non-syndromic craniosynostoses. Unfortunately, these 2 groups were grouped together in most of the studies [10,14–16,19,20], and small numbers of complex craniosynostoses did not allow particular conclusions on syndromic craniosynostoses, supposed to be more hemorrhagic when compared to non-syndromic. Furthermore, we observed the same confusion for monosutural and multisutural craniosynostoses.

Martin et al. [17] compared only sagittal craniosynostosis operated using a similar technique whatever the age of the child in order to maximize the uniformity of the patients included. In this study, as expected, the use of TXA was significantly associated with a lower total volume of packed red blood cell (PRBC) transfused. No significant correlation between duration of surgery or length of hospitalisation was observed between the 2 groups with/without TXA. Martin et al. [23] collected a large cohort of patients less than 15 months of age operated on for single suture non-syndromic craniosynostosis by the same interdisciplinary surgical team (a craniofacial surgeon and a pediatric neurosurgeon). They used the same TXA protocols as Goobie et al. [10], and TXA use was associated with a significant reduction in estimated intraoperative blood loss, cell saver volume transfused, red cell transfusion volume and length of stay in hospital.

Engel et al. [18] studied the value of TXA during fronto-orbital advancement in isolated metopic craniosynostosis only, with the same resulting benefit in reduction of blood loss and transfusion with TXA. Interestingly, the mean duration of the postoperative hospital stay was significantly lower in the TXA group.

Only one report studied the effect of TXA in craniosynostosis treated with minimally invasive techniques versus open procedures [16]. In this study, the sole parameter influenced by the use of TXA was the median weight-adjusted estimated blood loss in the mini-invasive procedure group. The other parameters such as weight-adjusted calculated blood loss, PRBC transfusion did not attain any statistical difference; moreover there was no difference whatever the parameters studied in the open procedure group. These results suggest an important bias in the estimation of data.

3.3.2. Blood loss and blood transfusion

Various parameters were studied in these reports including age, gender, weight, primary or redo surgery, ASA status, urine output, pre- and postoperative hematocrit/hemoglobin/platelet count/fibrinogen concentration, fluid therapy, but the most remarkable were PRBC transfusion volume and estimated/calculated blood loss. Because visual estimation of blood loss is known to be inaccurate in these procedures, blood loss volume was either estimated (EBVlost = Estimated red cell volume lost × hematocrit preop/100) and adjusted per kilogram of patient body weight, or calculated (CBL = RCM preop + RCM transfused − RCM postop)/average hematocrit; (RCM indicates red cell mass = 0.7 × volume transfused) [12,21,23,26].

In 10 of the 13 studies, results were obviously the same: the use of TXA significantly reduces the volume of PRBC transfusion when compared to the placebo group [9,10,14,15] or to a group without TXA [17–19,21,23,24]. In 2 studies [16,20], the volume of PRBC transfused was similar between the TXA+/TXA− groups of patients undergoing open procedures. However, in Hansen et al.'s report [20], the TXA protocol used low-dose TXA infusion: standard loading dose of 10 mg/kg over 15 minutes followed by a 5 mg/kg/h infusion until skin closure. This result underlines the need for an optimal dose regimen for TXA to find the most effective haemostatic effect. Although blood loss is considered to be more difficult to evaluate, results showed similar conclusions in favour of the

Table 1
Characteristics of prospective, randomized, double-blind, placebo-controlled trials.

	Type of study	Included criteria	Patients	Purpose	Excluded criteria	Protocol	Main values studied	Transfusion protocols	Results
Dadure et al., 2011 [9]	Randomized, double-blind, placebo-controlled, single surgeon	Non-syndromic craniosynostosis Open surgery	39 patients (age range 3 m–15 m) 19 TXA+/20 TXA−	Reduced PRBC transfusions in children pretreated with erythropoietin	Bleeding diathesis, abnormal prothrombin time, partial thromboplastin time or platelets count; history of convulsive seizures, allergy to TXA	Loading dose of 15 mg/kg over 15 min followed by a 10 mg/kg/h infusion	Estimated blood loss, volume of PRBC transfused	PRBC transfusion if Hb 7.0 g/dL during surgery and in the first 72 h postop	Volume of PRBC transfusion reduced by 85% 2/19 patients transfused perop in TXA+ vs. 9/20 in TXA− ($P < 0.05$) No difference in blood loss. No adverse events
Goobie et al., 2011 [10]	Randomized, double-blind, placebo-controlled	Syndromic ($n = 9$) and non-syndromic ($n = 34$) craniosynostosis Open surgery	43 patients (age range 2 m–6 y) 23 TXA+/20 TXA−	Total blood loss, PRBC transfused	Hematologic abnormalities or coagulation, hepatic, renal or vascular disorder, ingestion of nonsteroid anti-inflammatory agents within 2 days, aspirin within 14 days before surgery	Loading dose of 50 mg/kg over 15 minutes followed by a 5 mg/kg/h infusion	Length of surgery, number of sutures, blood loss, PRBC transfused, length of stay in intensive care unit, in hospital	PRBC transfusion if Ht $\leq$ 0.25%	Perop blood loss significantly lower in TXA+ ($P = 0.008$), idem postop blood loss Volume of perop/postop PRBC transfusion significantly lower in TXA+ No difference for length of stay between TXA+/TXA− No thrombotic or neurologic adverse events
Kim et al., 2018 [14]	Randomized, double-blind, placebo-controlled	Syndromic and non-syndromic craniosynostosis Open surgery	48 patients (age range 7–30 m) 23 TXA+/25 TXA−	Total blood loss, transfusion requirement, hemostasis ROTEM™ analysis	PLT < $50 \times 10^3/\mu$L; INR > 1.5; history of epilepsy or brain surgery; treatment with a non-steroidal anti-inflammatory agent within the previous 2 days or aspirin within 14 days prior to surgery; allergy to TXA	Loading dose of 10 mg/kg for 15 minutes followed by a 5 mg/kg/h infusion	Estimated blood loss, PRBC-FFP-PLT transfused per/postop, hemostasis ROTEM™ analysis per/postop	PRBC transfusion: circulatory shock, low blood pressure + Ht < 30%, perop blood loss $\geq$ 15%, Ht < 24% with signs of anemia, PLT concentrate if PLT < $50 \times 10^3/\mu$L FFP if INR > 2	Perop blood loss significantly lower in TXA+ ($P = 0.003$) Volume of perop/postop PRBC and FFC transfusion significantly lower in TXA+ No significant differences in the results of the ROTEM™ analysis between the two groups No adverse events
Fenger-Eriksen et al., 2019 [15]	Randomized, double-blind, placebo-controlled	Syndromic and non-syndromic craniosynostosis Open surgery	30 patients (age range 4–110 m) 15 TXA+/15 TXA−	Total blood loss	Bleeding disorders, reduced renal function, history with unexplained seizures, and allergy to TXA	Loading dose of 10 mL/kg before incision, followed by 8 h continuous infusion of 3 mL/kg/h	Postop blood loss during the first 24 h. perop blood loss, transfusion requirements, volume fluid infusion, duration of surgery	PRBC transfusion if Hb < 5.0 mmol/L postop	Absolute postop bleeding reduction ($P < 0.001$) Volume of perop PRBC and FFP transfusion significantly lower in TXA+ Calculated blood loss significantly lower in TXA+ No adverse events

m: month; y: year; TXA: tranexamic acid; PRBC: packed red blood cell; FFP: fresh frozen plasma; PLT: platelet; RCM: red cell mass; EPO: erythropoietin; Hb: hemoglobin; Ht: hematocrit.

Table 2
Characteristics of retrospective studies.

	Type of study	Included criteria	Patients	Purpose	Excluded criteria	Protocol	Main values studied	Transfusion protocol	Results
Maugans et al., 2011 [16]	Retrospective, single surgeon	All craniosynostosis treated by mini-invasive procedure ($n = 20$) or open surgery ($n = 36$)	56 patients Mini-invasive: 10 TXA+/10 TXA– Open surgery: 16 TXA+/20 TXA–	Estimated blood loss, transfusion volume	Personal or family history of thromboembolic events or bleeding diatheses	Loading dose of 100 mg/kg over 20 minutes followed by a 10 mg/kg/h infusion	Estimated blood loss: calculated blood loss formula = red cell mass (RCM) preop + RCM transfused – RCM postop/average hematocrit	No transfusion protocol	Mini-invasive surgery: weight-adjusted blood loss significantly lower in TXA+ ($P = 0.02$); weight-adjusted transfusion volume nearly significantly lower in TXA+ ($P = 0.07$) Open surgery: no significant difference between TXA+/TXA– No adverse events
Martin et al., 2015 [17]	Retrospective, same neurosurgeon/craniofacial plastic surgeon, "before–after" study	Sagittal craniosynostosis, open surgery	28 patients 14 TXA+/14 TXA–	Total volume of each type of blood product transfused during surgery and postop	Previous cranial vault procedure, associated syndrome, synostosis of other cranial sutures	Loading dose of 30 mg/kg followed by a 10 mg/kg/h infusion	Mean adjusted volume transfused, length of surgery, hospital length of stay	No transfusion protocol	Volume of PRBC transfusion reduced by 50% ($P = 0.004$): 34% reduction perop ($P = 0.017$), 67% reduction postop ($P < 0.001$) Same significant results with fresh frozen plasma No adverse events
Engel et al., 2015 [18]	Retrospective, "before–after" study	Isolated metopic craniosynostosis (fronto-orbital advancement)	33 patients (median age 9.8 m) 17 TXA+/16 TXA–	Reduced intraoperative blood loss and PRBC transfusion	NA	Loading dose of 10 mg/kg over 15 minutes followed by a 5 mg/kg/h infusion	Length of surgery and hospital stay, calculated blood loss formula [10], volume of blood transfused	No transfusion protocol PRBC transfusion if Hb < 9 g/dL	Volume of PRBC transfusion significantly lower in TXA+ ($P < 0.0001$) Calculated blood loss significantly lower in TXA+ ($P < 0.0001$) Length of stay in hospital significantly lower in TXA+ ($P = 0.004$) No adverse events
Crantford et al., 2015 [19]	Retrospective, "before–after" study	All craniosynostosis, open surgery, bicoronal > unicoronal > metopic > sagittal > multiple > lambdoid	37 patients (age range 4–25 m) 17 TXA+/20 TXA–	Estimated blood loss, transfusion volume	History of hematologic, renal, hepatic or vascular abnormalities; allergy to TXA; ingestion of aspirin/nonsteroid anti-inflammatory agents within 14 days before surgery	Loading dose of 20 mg/kg over 15 minutes followed by a 10 mg/kg/h infusion	Length of surgery, estimated blood loss, volume of blood transfused	No transfusion protocol	Volume of PRBC transfusion significantly lower in TXA+ ($P < 0.0001$) Blood loss significantly lower in TXA+ ($P < 0.0001$) All patients transfused in TXA– versus 76% in TXA+ No adverse events

Table 2 (*Continued*)

	Type of study	Included criteria	Patients	Purpose	Excluded criteria	Protocol	Main values studied	Transfusion protocol	Results
Hansen et al., 2017 [20]	Retrospective	All craniosynostosis, syndromic/non-syndromic	25 patients (age range 6 m–14 y) 16 TXA+/9 TXA−	Reduced perioperative blood loss and PRBC transfusion with low-dose infusion of TXA	NA	Loading dose of 10 mg/kg over 15 minutes followed by a 5 mg/kg/h infusion	Associated syndrome, estimated blood loss, length of surgery and in intensive care unit, postop drain output	No transfusion protocol. PRBC transfusion if Hb < 7 g/dL or Hb < 9 g/dL + hemodynamic instability	Similar volume of PRBC transfused in TXA−/TXA+ No difference in number of patients transfused ($P = 0.434$) Mean estimated red cell volume lower in TXA+ ($P < 0.017$) Postop drain output lower in TXA+ Other parameters non-significant No adverse events
Kurnik et al., 2017 [21]	Retrospective, 3 craniofacial surgeons + 2 neurosurgeons, “before–after” study	Open craniofacial procedures: anterior approach = fronto-orbital advancement	114 patients 35 TXA+/79 TXA−	Total blood transfused, (intra-operative/postop)	Mini-invasive endoscopic approach	Loading dose of 10 mg/kg followed by a 5 mg/kg/h infusion during 24 h	Perop/postop blood transfused, length of hospital stay and in intensive care unit	No transfusion protocol	Perop blood transfusion significantly lower in TXA+ ($P < 0.0001$). Postop transfusion lower in TXA+ ($P < 0.0001$) Weight-based blood loss lower in TXA+ ($P = 0.014$) Length of stay in hospital lower No adverse events
Kurnik et al., 2018 [22]	Retrospective, 1 craniofacial surgeon + 2 neurosurgeons, 2 different TXA protocols, “before–after” study	Open craniofacial procedures: anterior approach = fronto-orbital advancement	53 patients 30 TXA during 24 h 23 TXA during 4 h	Total blood transfused, (intra-operative/postop)	Syndromic craniosynostosis, multiple approaches, mini-invasive approach, second surgery	TXA1: loading dose of 10 mg/kg followed by a 5 mg/kg/h infusion during 24 h TXA2: same loading dose followed by same infusion during 4 h	Perop/postop blood transfused, length of hospital stay and in intensive care unit, cost of transfusion/TXA infusion	No transfusion protocol	No difference for total blood transfusion in the 2 groups No difference in length of stay in pediatric intensive care unit in the 2 groups Cost significantly lower in 4 h group No adverse events

Table 2 (*Continued*)

	Type of study	Included criteria	Patients	Purpose	Excluded criteria	Protocol	Main values studied	Transfusion protocol	Results
Martin et al., 2016 [23]	Retrospective, same neurosurgeon/craniofacial plastic surgeon "before–after" study	Patients less than 15 months of age, primary surgical repair of single suture Non-syndromic craniosynostosis	187 patients (median age 8 m) 69 TXA+/118 TXA−	Total blood loss and blood transfused (intraoperative/postoperative)	NA	Same protocol as Goobie et al. [10] Loading dose of 50 mg/kg over 15 minutes followed by a 5 mg/kg/h infusion	Per- and postoperative: blood lost, blood transfusion. Length of surgery and hospital stay	PRBC transfusion if low arterial pressure + Ht < 30%, or acute blood loss > 15% of estimated blood volume	Reduction in estimated intraoperative blood loss (P < 0.001) and PRBC transfusion volume (P < 0.001). Reduced length of stay and postoperative output from drains No adverse events
Escher et al., 2019 [24]	Retrospective, "before–after" study	Sagittal craniosynostosis, open surgery Non-syndromic craniosynostosis	36 patients, 22 patients EPO-Iron-TXA−/ 14 patients EPO + Iron + TXA+	Reduced PRBC transfusions in children pretreated with EPO and iron	NA	Loading dose of 40 mg/kg followed by a 10 mg/kg/h perop infusion and postoperative 10 mg/kg/dose every 8 h, 3 doses	Estimated blood loss, length of surgery, length of stay in intensive care unit and in hospital, fraction transfused	PRBC transfusion if Hb < 6 g/dL or Hb < 8 g/dL + hemodynamic instability	Volume of PRBC transfusion significantly lower in EPO + Iron + TXA+ group (P < 0.0001) and lower estimated blood lost (P = 0.038) in this group Shorter length of hospital stay (P = 0.038) in EPO + Iron + TXA+ group

m: month; y: year; TXA: tranexamic acid; PRBC: packed red blood cell; RCM: red cell mass; Hb: hemoglobin; Ht: hematocrit; EPO: erythropoietin; NA: not available.

benefit of TXA. When considered, the mean calculated blood loss [10,14,15,18] or the estimated blood loss [19–21,23,24] were significantly lower in the TXA+ group, except for Dadure et al. [9].

The same positive results were observed for fresh frozen plasma transfusions in the 2 recent randomised studies: significantly fewer fresh frozen plasma transfusions were required in the TXA groups [14,15].

3.3.3. Length of stay in hospital

Length of stay in hospital was significantly lower with the use of TXA in three studies [18,23,24]. It was not different between groups TXA+/TXA− in 5 [10,14,17,19,21].

3.3.4. Adverse events

No adverse effects directly related to TXA were reported in the 13 studies of the review.

4. Discussion

Our review focused on TXA. This drug was substituted for aprotinin whose marketing in France was stopped because of serious adverse events [1,26]. Aminocaproic acid is another antifibrinolytic, 6–10 less potent than TXA and not distributed in France. In clinical practice they may have comparable efficacy [27,28].

Unfortunately, meta-analyses which studied efficacy of antifibrinolytics in pediatric craniofacial surgery did not compare drugs one with another [4,28,29]. Most of the literature analysing strategies used to reduce perioperative blood transfusion (preoperative autologous donation, preoperative erythropoietin, intraoperative cell salvage, acute normovolemic hemodilution, fibrin sealants or fibrin glue; and postoperative drain reinfusion) was non-randomised and non-comparative. Studies with TXA were comparatively well conducted: TXA is clinically effective in reducing allogeneic blood transfusion. Already published meta-analyses neglected other drugs such as aprotinin and aminocaproic acid [28].

TXA is a synthetic derivative of lysine that exerts an antifibrinolytic effect. It blocks lysine binding sites in a reversible manner on plasminogen molecules, which inhibits the interaction of plasminogen and plasmin with lysine residues on the surface of fibrin. This action leads to an inability of plasmin to degrade fibrin. The half-life of TXA is approximately 1.5 to 2 hours [25]: it therefore continues to stabilize the clot and prevent bleeding in the immediate postoperative period after the infusion is stopped. TXA is considered as a well-tolerated medication with rare side effects: orthostatic reactions, diarrhea and nausea are the most commonly reported. Some authors have demonstrated no increased risk of thrombogenicity associated with TXA even in cases of complicated pregnancy [30]. Goobie et al. [27] published a report from the pediatric craniofacial collaborative group on the safety of antifibrinolytic use in cranial vault reconstructive surgery: among the 591 patients who received TXA, only 2 cases (0.34%) of postoperative seizure were described and only one case of femoral deep vein thrombosis in a patient with an indwelling femoral venous catheter. No significant difference was detected in the incidence of postoperative seizures between patients who received TXA and those who did not. Recently, Chung and Karlberg [31] described a case of ulnar artery thrombosis following ulnar arterial line placement in a patient who received TXA for cranial vault reconstructive surgery.

Use of TXA may significantly reduce cost of these surgical procedures by reducing length of hospital stay [18,23,24]. Furthermore, Dadure et al. [9] reported a reduction in the median cost of perioperative treatment for blood loss in the TXA group greater than 200 US$.

Taking into account the results of this review, we can consider that TXA should be systematically proposed in pediatric craniosynostosis surgery in order to reduce blood loss and transfusion. A protocol with a loading dose of 10 mg/kg over 15 minutes after induction of general anesthesia followed by a 5–10 mg/kg/h infusion until skin closure could be safely used when considering the Goobie et al. [25,27] study. We have used this protocol in our institution since 2011 with significant results on reducing transfusion [unpublished data].

Finally, we would like to emphasize that the use of antifibrinolytics is part of the arsenal, which permits safer craniosynostosis surgical procedures but it is not the only element. We must also consider other methods: iron supplementation, erythropoietin as well as mini-invasive surgical techniques such as endoscopy when feasible, and surgical/anaesthesiological expert teams.

5. Conclusion

Tranexamic acid significantly reduces blood loss and the need for transfusions in children undergoing craniosynostosis surgery. Advantages of TXA administration also include an excellent patient tolerance of side effects, ease of administration and low cost. TXA administration should be a routine part of strategy to reduce blood loss and limit transfusions in these procedures.

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Disclosure of interest

The authors declare that they have no competing interest.

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