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Brachial plexus block with ultrasound guidance for upper-limb trauma surgery in children: a retrospective cohort study of 565 cases

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Abstract

Background: Upper-limb trauma is a common indication for surgery in children, and general anaesthesia remains the method of choice for these procedures, even though suitable techniques of brachial plexus block are available and fast provision of regional anaesthesia offers a number of distinct advantages.

Methods: A retrospective analysis was performed of the data of a large cohort of children undergoing ultrasound-guided brachial plexus blocks during a 4-yr period at a major trauma centre with a catchment area of 3.5 million. A total of 565 cases were sourced from two independently operating patient documentation systems. Patient data were stratified into age groups with block success as the primary outcome parameter. The influence of age on the incidence of block failure was assessed with logistic regression.

Results: The block failure rate was 5.1%, starting at 1.2% in the youngest (0–3 yr), then continuously increasing up to 12.5% in the oldest (15–18 yr) but also smallest group. Age emerged as an independent predictor of block failure with an odds ratio of 1.115 and a 95% confidence interval of 1.014–1.226 (P=0.025). No complications were observed.

Conclusions: In a cohort of children receiving real-world care, with regional blocks performed by a range of anaesthetists with different skill levels, a success rate of 94.9% for upper-limb blocks in children under various levels of sedation was observed. Upper-limb blocks can be performed with high probability of success and an excellent margin of safety; this particularly applies to small children.

Clinical trial registration: NCT03842423.

Keywords: anaesthesia; brachial plexus block; orthopaedic procedures; paediatric; regional anaesthesia; trauma; upper extremity

Editor's key points

- Surgery for upper-limb trauma is common in children.
- Although brachial plexus block techniques are suitable for use in children, they are seldom performed in this group.
- The authors work in a hospital with extensive experience of the use of brachial plexus blocks, with or without sedation.
- In a retrospective analysis of 565 cases, they show an overall 95% success rate, with even better success rates in children 0–3 yr old.

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Upper-limb trauma is a common indication for surgery in children and adolescents. Most of these injuries are caused by falls, followed by cutting accidents. The affected children are usually in severe pain and accompanied by agitated and nervous family members when admitted to the hospital. In this situation, fast management is a fundamental interest of all parties involved, including the medical staff.

Whilst brachial plexus block is a perfectly viable and effective technique to deal with this situation, general anaesthesia remains the method of choice because few institutions will perform upper-limb regional anaesthesia on a routine basis in children.[1–3] According to the Pediatric Regional Anesthesia Network, only 3% of all regional anaesthetic techniques are based on upper-limb blocks in children.[4] In the largest series available on this subject thus far, Fisher and colleagues[5] and Pande and colleagues[6] have reported on 250 axillary and 200 supraclavicular blocks, all of them performed with guidance techniques other than ultrasound. This clinical reality is contrasted by the fact that, over the past 25 yr, various techniques of ultrasound-guided brachial plexus block have been developed that allow local anaesthetic to be precisely administered around the relevant nerve structures, thus resulting in high success rates and better pharmacodynamics.[7–11]

In addition, fast provision of anaesthesia offers the inherent benefit of effectively shortening the period of pain, thus also minimising the risk of pain becoming chronic.[12–14] For all these reasons, it would seem only logical that these techniques should be implemented in paediatric upper-limb surgery, thus allowing for fast management of these cases associated with optimal pain relief and no need for general anaesthesia.

We therefore designed an investigation over a 4 yr period in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement for cohort studies. Our primary objective was to assess the success rates of brachial plexus blocks for upper-limb surgery in various age groups of children and adolescents. The secondary aim was to identify potential predictors of block failure.

Methods

Study design and patients

Our investigation had a retrospective design based on the STROBE statement,[15] and was authorised by the ethics committee of Medical University of Vienna (ref. 2090/2018) and registered as trial number NCT03842423. The study was performed at the Department of Orthopaedic and Trauma Surgery of Vienna General Hospital (Medical University of Vienna) as the main trauma centre for Vienna and Eastern Austria, with a catchment area of a 3.5 million population. Included were all children and adolescent patients who had been admitted to treat upper-limb trauma between March 2014 and October 2018.

Data collection and verification

All data were retrieved from two databases: AKH-PDMS (Philips Healthcare, Vienna, Austria) and AKIM (AKH Information Management, Vienna, Austria). Both are separate patient documentation and information systems that operate prospectively and independently of each other. For each included child, a predefined data set was extracted that included baseline characteristics (e.g. age, gender, and weight), facts about regional anaesthesia (e.g. type of block and volume of local anaesthetic), and surgery-related data (e.g. type or duration of procedure). To avoid selection bias, completeness and overlap were cross-checked between the databases. Where values were missing, alternative data sources (e.g. hospital records) were explored before inclusion was considered. Values were replaced by appropriate subgroup medians if $\leq$5% were missing. Cases with >5% of values missing were excluded from further analysis.

Stratification and outcome parameters

Children were stratified by age (0–3, 4–6, 7–10, 11–14, and 15–18 yr) and analysed for age, weight, gender, injury, type and duration of surgery, success rate, anaesthesia-related measures (type of block and solution/volume of local anaesthetic), and sedation regimen. The success rate of brachial plexus block and independent predictors of block failure served as primary and secondary outcome parameters, respectively.

Preoperative management

In 2002, we began to develop a standard of care for managing children with upper-limb injuries, which had reached maturity by 2014. Accordingly, all children were transferred to the preoperative ward right after their upper-limb injury had been diagnosed, and then the parents' informed consent was obtained for the anaesthetic procedure, including premedication, sedation, and the brachial plexus block. Compliance with fasting guidelines (6 h for solid food, 4 h for formula milk, and 1–2 h for clear fluids) may be assumed in all cases not requiring immediate surgery (fast swelling of upper limb and excruciating pain).[16] EMLA cream (Eutectic Mixture of Local Anaesthetics; AstraZeneca, Wedel, Germany) was topically applied to the prospective vascular access and premedication with oral midazolam (0.5 mg kg^{-1}; maximum 15 mg) administered either with or without oral S(+)-ketamine (1 mg kg^{-1}) depending on the clinical situation. Twenty minutes later, standard cardiorespiratory monitoring (ECG, noninvasive blood pressure, and Spo_2) was initiated and the vascular access established (contralateral arm). Whenever needed, propofol 1–2 mg kg^{-1} was administered preoperatively for mild sedation and continued intraoperatively at 5 mg kg^{-1} h^{-1}.

Brachial plexus block

A portable ultrasound unit (M-Turbo®; Sonosite, Bothell, WA, USA) was first used for a baseline examination with a linear transducer (25 mm; 13-6 MHz; Sonosite). Sterile preparation of the puncture site—and of the ultrasound transducer using a sterile sonography cover (Safersonic Conti; Safersonic, Ybbs, Austria)—was followed by creating a skin wheal with mepivacaine 1%, 0.5 ml (Mepinaest® purum 1%; Gebro Pharma, Fieberbrunn, Austria). All blocks were performed using a 21G facet-tip needle with an injection line (Temena, Felsberg, Germany) via an approach dictated by the type of intervention (interscalene[17–19] or supra- or infraclavicular for upper-arm or elbow procedures,[8,9,20,21] and axillary for procedures below the elbow[22,23]) with ropivacaine 0.75% (Naropin® 7.5 mg ml^{-1}; AstraZeneca, Wedel, Germany), bupivacaine 0.5% (Bucain® 5 mg ml^{-1}; Actavis, Hafnarfjördur, Iceland), or mepivacaine 1.5% (Mepinaest purum 1% and 2% in a 1:1 mixing ratio; Gebro

Table 1 Relevant patient data per age category. Data are presented as *n* (%) or median (inter-quartile range).

Age strata	0–3 yr (*n*=84)	4–6 yr (*n*=163)	7–10 yr (*n*=138)	11–14 yr (*n*=132)	15–18 yr (*n*=48)	P-value
Male	52 (61.9)	86 (52.8)	92 (66.7)	101 (76.5)	41 (85.4)	<0.001*
Female	32 (38.1)	77 (47.2)	46 (33.3)	31 (23.5)	7 (14.6)	
Age (yr)	3 (2–3)	5 (4–6)	8 (7–9)	12 (11–13)	16 (15–17)	<0.001†
Weight (kg)	15 (12–17)	20 (18–22)	30 (26–35)	45 (38–55)	67 (57–72)	<0.001†
Surgery (min)	30 (20–45)	25 (15–50)	30 (20–50)	35 (20–55)	47 (20–70)	0.67†
Ropivacaine‡ (mg kg^{-1})	3.3 (2.8–3.8)	3.2 (2.6–3.8)	2.57 (2.0–3.1)	2.3 (1.8–2.8)	2.1 (1.7–2.4)	<0.001†

* χ^2 test.
† Kruskal–Wallis test.
‡ Ropivacaine was used for 96% of all blocks (see Results).

Pharma). Block *failure* was defined as children spontaneously moving or HR increasing by >25% from baseline after the skin incision *unless* an attempt to resolve the situation by a single shot of fentanyl 1 μg kg^{-1} eliminated the need for subsequent induction of general anaesthesia and mechanical ventilation.

Postoperative management

Postoperatively, all children were observed in the recovery room for 1–2 h. Those who had undergone surgical procedures for fractures were subsequently transferred to the ward. The others were allowed to leave the hospital provided that they achieved a 9-out-of-10 postoperative recovery and discharge score, and after their parents had received clear and detailed instructions on how to position the paralysed arm and manage adverse effects (e.g. postoperative nausea and vomiting and pain management).[24] On the first postoperative day, all children were examined for clinical signs of nerve damage (complete recovery from the block), inflammation or infection of the puncture area and surgical site, or other relevant complications (e.g. compartment syndrome).

Data evaluation and statistical analysis

SPSS Statistics (version 24.0.0.0; IBM, Armonk, NY, USA) was used throughout. All data were first screened for completeness, consistency, and outliers. Patient characteristics are presented as descriptive statistics in the form of medians with inter-quartile ranges (IQRs) or as absolute numbers and percentages. Continuous variables were compared between subgroups using non-parametric Mann–Whitney *U*-test or Kruskal–Wallis test, and proportions by χ^2 testing. The children were stratified into five age groups (0–3, 4–6, 7–10, 11–14, and 15–18 yr) to evaluate this parameter for success rates and as a potential predictor of block failure (see aforementioned definition) in a logistic regression model, the results being reported as odds ratios (ORs) with 95% confidence intervals (CIs). Our initial selection of factors considered for the analysis was based on the combination of either biological plausibility or statistical exploration. Factors associated with block failure were explored using Wilcoxon or Kruskal–Wallis test for continuous variables, and χ^2 test for categorical variables, as appropriate. In case of a P-value of <0.10 or biological plausibility in the bivariate analysis, the variables were considered for the multivariate logistic regression model. Subsequently, we used a stepwise forward orientated logistic regression model to assess the independence of any association between predictor and primary outcome. All factors were tested for interactions and co-linearity before inclusion in the multivariate model. All tests were performed two sided, and differences of $P<0.05$ were considered significant.

Results

Of 781 unilateral upper-limb injuries in paediatric and adolescent patients retrieved for the study period March 2014 to August 2018, a total of 216 cases were managed by general anaesthesia from the outset (*n*=151), by surgeons administering local anaesthesia (*n*=15), or were not adequately evaluable (*n*=50). The majority of 565 data sets (72%), covering 372 boys and 193 girls, were complete and involved provision of brachial plexus blocks as required. Table 1 summarises the relevant characteristics of these patients stratified into age groups.

Thirty-five different anaesthesiologists from our department were responsible for the performance of the brachial plexus blocks. Most of these blocks were performed during the evening and night (from 15:30 pm until 7:30 am). Table 2 gives an overview of block failures stratified by age. Based on the 565 patients included, the overall success rate of brachial plexus block was 94.9%. Hence, a switch to general anaesthesia as a result of block failure was documented for 5.1% of children, with the highest failure rate (12.5%) in the age group of 15–18 yr (P=0.01). Twelve children (2.1%) received a single dose of fentanyl 1 μg kg^{-1} without subsequent induction of general anaesthesia. Table 3 lists the failure rates based on the various anatomical approaches that had been taken for brachial plexus block.

Table 2 Block failures per age category. Data are presented as *n* (%).

Age strata	0–3 yr (*n*=84)	4–6 yr (*n*=163)	7–10 yr (*n*=138)	11–14 yr (*n*=132)	15–18 yr (*n*=48)	P-value
Block failures	1 (1.2)	4 (2.5)	7 (5.1)	11 (8.3)	6 (12.5)	<0.01*

* χ^2 test.

Table 3 Failure rates for each brachial plexus block technique. Data are presented as *n* (%).

	Interscalene (n=13)	Supraclavicular (n=412)	Infraclavicular (n=33)	Axillary (n=107)	P-value
Block failure	1 (7.7)	23 (5.6)	1 (3)	4 (3.7)	0.78*

* χ^2 test.

Table 4 illustrates how the injury sites, block techniques, and surgical procedures were distributed across the 565 patients. Fore- and upper-arm regions were predominantly affected, and three out of four brachial plexus blocks were conducted via the supraclavicular approach. Internal fixation of fractures was the predominant type of surgery, and the surgical procedures lasted for a median of 30 (IQR: 20–50) min. No postoperative complications (e.g. cases of infection or compartment syndrome) were observed.

Ropivacaine was used for 96%, mepivacaine for 3%, and bupivacaine for 1% of the blocks at mean volumes of 0.4 ml kg^{-1} (ropivacaine 7.5 mg ml^{-1} and mepivacaine 15 mg kg^{-1}) or 0.3 mg kg^{-1} (bupivacaine 5.0 mg ml^{-1}). For premedication, we used midazolam in 44% and midazolam plus S(+)-ketamine in 48% of cases. Intraoperative continuous infusion of propofol (0.1 mg kg^{-1} min^{-1}) was used in 78% of cases.

The final fully adjusted multivariate logistic regression model comprised the patient's age, the local anaesthetic dose per weight, and the type of injury (which was included for plausibility reasons) (Supplementary Table 1). Age emerged as an independent predictor of block failure with an OR of 1.194 and a 95% CI of 1.066–1.336 (P=0.002).

The dose of the local anaesthetic kg^{-1} body $weight^{-1}$ was included in the multivariate model to account for the usually higher weight in older children. Interestingly, this factor lost its predictive value in the fully adjusted model.

Discussion

This is the largest retrospective study yet to analyse ultrasound-guided brachial plexus anaesthesia in paediatric trauma surgery. No complications were observed, and the overall success rate was 94.9%. This 5.1% overall failure rate of brachial plexus block started out from 1.2% in the youngest group of up to 3 yr old and continuously increased with age up to 12.5% in the oldest group of 15–18 yr.

Our study has thus shown that, in experienced hands, upper-limb blocks can be performed with a high probability of success and an excellent margin of safety precisely in small children. Whilst the 12.5% failure rate in the oldest group may seem unacceptably high, this was a comparatively small group of 48, and the six failures do not represent an exceedingly high number in absolute terms. A small remainder of 12 cases (2.1%) were categorised as successful, although the block was not effective according to our strict definition because a single dose of fentanyl was required (see Methods). These children moved slightly during skin incision, possibly because of a series of stimuli breaking through in what has been referred to as 'Wedensky block'.[25]

Table 4 Distribution of injuries, brachial plexus approaches, and surgical procedures. Data are presented as %.

Types of injury	Brachial plexus approaches
Forearm: 59 Upper arm: 23 Hand: 17 Elbow: 1	Supraclavicular: 73 Axillary: 19 Infraclavicular: 6 Interscalene: 2
Surgical procedures	
Internal fixation: 77 Soft-tissue surgery: 15	Internal fixation removal: 5 Fracture reduction: 3

Brachial plexus blocks in children highlight a number of considerations for discussion, first and foremost being the issue of fast-track surgery in children. Upper-limb injuries are usually painful, and present-day surgery is capable of offering high levels of comfort to paediatric patients and their parents. However, given the fine line between improving comfort and compromising safety, fast-track surgery via brachial plexus block should remain the exclusive domain of adequately staffed and competent centres.

One major concern related to upper-limb fractures in children is tissue swelling with the risk of compartment syndrome.[11,26] Whether brachial plexus block may mask such syndromes is a subject of ongoing discussion, although evidence to the contrary is increasing.[27] What is more, providing surgical treatment of fractures without delay may be expected to prevent tissue swelling, so that rapid anaesthesia could actually be considered a pre-emptive treatment step that can avoid any sequelae of this kind. Nevertheless, we did not detect any postoperative compartment syndromes in this cohort study.

Another consideration is the choice of regional *vs* general anaesthesia.[1] Note that the former is superior to opioid-based methods and can provide optimal perioperative pain therapy, considering that pain intensity during the first 24 h appears to contribute greatly to chronicity of pain.[13,14] All techniques for upper-limb regional anaesthesia are suitable not only in adults but also in children, and any relevant anatomical structures, and the needle and the spread of local anaesthetic, can be clearly visualised by ultrasound.[11] Various clinical studies have highlighted the advantages of ultrasound guidance compared with previous guidance techniques for peripheral regional anaesthesia, such as the use of surface landmarks, eliciting paraesthesia, and nerve stimulation.[7,10]

Another issue is preoperative fasting, given that the current international guidelines (6 h for solid food and cow milk, 4 h for breast and formula milk, and 1–2 h for clear liquids[18]) are not always applicable when traumatised children are admitted to the hospital. Moreover, against the pathophysiological background of trauma and pain delaying bowel movement,[28–30] it cannot be taken for granted that postponing anaesthesia and surgery will avert pulmonary aspiration of gastric content. Therefore, paediatric trauma patients must never ever be considered to have an *empty* stomach, so that the interval between trauma and treatment can arguably be minimised without increasing the risk of aspiration. That said, the ideal timing for anaesthesia induction, and hence brachial plexus block, requires circumspect decisions on a case-by-case basis.

Clinicians should weigh the need for pain therapy against what the patients (or parents) report about their latest fluid and food intake. The clinical records used for the present study did not contain precise data on how much time had elapsed before the anaesthetic and surgical procedures. However, considering our well-established standard of care in the management of children with upper-limb injuries, it is fair to assume that sedation for the brachial plexus blocks was induced as required by said fasting guidelines whenever immediate management was not required (as by excruciating pain or rapid swelling with a risk of compartment syndrome). The robustness of this management is also supported by the fact that there is not a single documented case of pulmonary aspiration of gastric content.

Treating children with upper-limb trauma as soon as possible will offer the inherent benefit of effectively shortening the period of pain, thus also minimising the risk of pain becoming chronic as a result.[13,14] When interpreting the currently reported favourable results, it should be borne in mind that this single-centre study was performed in a centre with a long history of paediatric regional anaesthesia and with ideal provision of personnel. The minimum staffing requirement for the aforementioned method comprises an assistant nurse besides two anaesthesiologists, one in charge of performing the block and one taking care of the vascular access, any sedation, and airway surveillance.

Every study design has its advantages and disadvantages.[31–33] Our decision to investigate the efficacy of brachial plexus block in children retrospectively was well considered. Prospective studies of regional anaesthesia may carry a risk of unrealistically favourable outcomes, particularly when all blocks are performed by one dedicated and highly skilled specialist. Hence, we believe that real-life clinical practice is bound to be reflected more truthfully by retrospective analysis, as it involves a range of different anaesthetists, even though the resultant data may be qualitatively less accurate and carry the additional risk of depending heavily on one specific documentation system. We addressed this latter concern by sourcing our data from two hospital documentation systems that operate separately and independently of each other. As already mentioned, our institution has extensive experience, having managed children with upper-limb injuries via brachial plexus blocks since 2002.

Given this long-standing experience, we should also explain our non-inclusion of data from before March 2014. A preliminary search for upper-limb injuries on record in the CareVue Anaesthesia Documentation system (AKH-PDMS; Philips Healthcare) for the period of January 2002 to February 2014 returned 1268 paediatric cases. Whilst most of these were managed by brachial plexus block, the data quality was inadequate for an exact analysis of parameters, such as true incidence or success rates. Also, today's high-resolution ultrasonography is not comparable with the technology available in 2002. When new technology becomes available, colleagues using it require time to learn how to use it optimally. We believe that this learning curve was overcome by 2014, so that truthful data from a well-developed technique can now be presented.

In summary, fast-track treatment via ultrasound-guided brachial plexus block and sedation can be safe and effective in children with upper-limb injuries. This study covers the largest retrospective series to date of children managed by ultrasound-guided brachial plexus block. The resultant success rate of 94.9% is encouraging, not least bearing in mind that this cohort truly reflects the real-life clinical practice of blocks being performed on children under various levels of sedation by a range of anaesthetists with different hand skills. Prerequisites for implementing rapid treatment of upper-limb injuries in children include the provision of adequate staffing, theoretical knowledge, and manual dexterity. Its main advantages include fast and optimal elimination of pain along with avoidance of tissue swelling and its potential sequelae like long-term pain.

Authors' contributions

Study conception/design: MZ, PM, TH
Organising approval by the ethics committee and trial registration: TH
Analysing of medical records: AIW
Statistics calculations: PO
Interpreting results: MZ, PO, PM, TH
Drafting of manuscript: MZ, PO, PM, TH
All authors approved the final version of the article.

Declarations of interest

The authors declare that they have no conflicts of interest.

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Appendix A. Supplementary data

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