Clinical paper

Intraosseous needles in pediatric cadavers: Rate of malposition

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Abstract

Aim of the study: Intraosseous vascular access is a commonly conducted procedure especially in pediatric resuscitation. Very high success rates for intraosseous (IO) devices are reported. Aim of the study was to describe the rates of malposition of intraosseous needles (ION) in pediatric cadavers via post-mortem computed tomography (PMCT).

Methods: 212 consecutive pediatric cadavers underwent PMCT, of which 38 cadavers had visible ION and were included in the study. They were divided into two subgroups depending on their age (n = 22 infant cadavers (age <1 year) and n = 16 child cadavers (age ≥1 year)). Two independent readers evaluated the number and position of ION.

Results: In 22 infant cadavers 34 ION were found. Malposition of at least one ION was visible in 14 subjects (64%), among which 7 cadavers (32%) even had no correctly placed ION, thus being without established vascular access. Overall, 16 of the 34 used ION devices (47%) were in malposition. 23 ION were found in 16 child cadavers. In 8 subjects (50%) at least one ION was malpositioned, among which 3 cadavers (19%) had no correctly placed ION, resulting in a complete absence of vascular access. Overall, 9 of the 23 ION devices (39%) were malpositioned.

Conclusion: Our study showed relatively high malposition rates for ION devices in pediatric cadavers which was not to be assumed regarding the success rates of 80% and higher in previous literature. This should be clarified by further studies in living patients.

Keywords: Intraosseous needles, Vascular access, Pediatric cadavers

Introduction

Obtaining vascular access in critically ill patients is a vital component in emergency medicine. A delayed access can compromise patient outcome.[1] Peripheral intravenous (IV) cannulation in children is more difficult than in adults in general.[2−5] This especially applies during resuscitation e.g. in children with hemorrhagic shock. Therefore, intraosseous needles (ION) are common devices in situations where establishing a peripheral access is impossible or very time consuming.[6−9] There are multiple devices in use, which can be roughly divided in two groups: manual devices like the Cook Intraosseous Infusion

Needle (Cook Medical, Bloomington, USA) or Jamshidi Intraosseous Needle (Becton Dickinson, Franklin Lakes, USA) and mechanical devices like the EZ-IO device (Teleflex, Limerick, USA) with a motor-driven drilling system. In adults very high success rates are reported for intraosseous (IO) cannulation.[10−16] Concerning the literature, success rates in pediatric patients are also in general about 80% and higher (e.g. Bielski et al. 90% success rate for the EZ-IO device and 90% success rate for the Jamshidi needle),[2,7,17,18] but were often only evaluated in simulations with e.g. pediatric manikins or turkey bones.[2,7,17] In a retrospective study of Pifko et al. high IO access rates were described for children with a weight of $\geq$8 kg (100% with manual devices and 97% with the EZ-IO device).[19] However, significantly lower success rates for IO cannulation were reported in pediatric patients with a weight of $\leq$8 kg (55% for manual devices and 47% for the EZ-IO device).[19] For legal reasons, all pediatric cadavers designated for autopsy are examined in advance by post-mortem computer tomography (PMCT) in our institution. These PMCTs left the impression of much higher misplacement rates of ION in pediatric cadavers. This raises the question if the reported high success rates for obtaining vascular access via intraosseous needles in simulations are concordant with the success rates in clinical practice. To address this question, the positioning of IO devices in pediatric cadavers were evaluated by the use of PMCT.

Material and methods

Our study followed the declaration of Helsinki und was approved by the local board of ethics (reference-nr 151-08). Examinations of cadavers were performed in alignment with the regulations of the department of public prosecutors. All cadavers were acquired over a period of 5 years.

Investigated population eligible for inclusion

Population statistics for 2017 are given below as a guide
According to official statistics, 7,484,396 people lived in the catchment area of the Institute of Forensic Medicine on the cut-off date of December 31, 2017. Of these, 75,474 were infants and 1,176,518 were children between one year and under 18 years of age.[20]

Furthermore, according to official statistics, 196 infants and 194 persons aged between 1 year and 20 years died in the catchment area in 2017 (note: there are no official figures for the age range 1 year to 18 years).[20]

The Institute of Forensic Medicine performs a total of approximately 2200 autopsies per year. About 50 of these corpses are younger than 18 years, including about 50% infant cadavers.

Study population

795 cadavers underwent PMCT between august 2012 and June 2017. Inclusion criteria were an age under 18 years (n = 212) and visible ION (n = 38; 18% of the cadavers under the age of 18). Cadavers with typical tibial bone defects indicating that IO cannulation may have been performed but without a visible needle were excluded (Fig. 1). The study population consisted of 38 pediatric cadavers, that were divided into infant (under the age of 1 year, n = 22) and child cadavers (older than 1 year, n = 16) (Table 1).

CT-Parameters (PMCT)

All cadavers were positioned supine, head first and were scanned in cranial caudal direction in a 64-row MDCT-System (Discovery CT 750 HD, GE Healthcare, Waukesha, IL). Standardized scan parameters for children and infants were used (infants: Scan field of view (SFOV) Ped body, helical scan mode, gantry rotation time 0.8 s, table feed 39.37 mm/s i.e. pitch 0,984:1, 120 kV 250 mA fixed; children: helical scan mode, gantry rotation time 0.8 s, table feed 39.37 mm/s i.e. pitch 0,984:1, 120 kV 650 mA fixed). SFOV was manually adapted to patient size to ensure optimal image quality. Reconstruction were done in soft- and bone kernel and in 0.625 mm slice thickness. This procedure ensured isotropic voxel size and therefore optimal image quality in multiplanar reformations (sagittal, coronal as well as oblique if needed).

Evaluation

Two independent readers (with 11 years and 6 years of radiological experience) evaluated the position of the ION blinded to the results of each other. Only clear malpositions were counted as unsuccessful attempt to establish IO access such as needles placed in total in soft tissue or needles which penetrated the cortical bone on both sides with a needle tip placed in soft tissue (Fig. 2). Needles with the tip within the bone, even ones where the tip is only slightly within the bone, and needles which may have been in correct position during resuscitation with secondary dislocation during transport were counted as successful attempt (Fig. 3). In case of doubt ION was reckoned as successful.
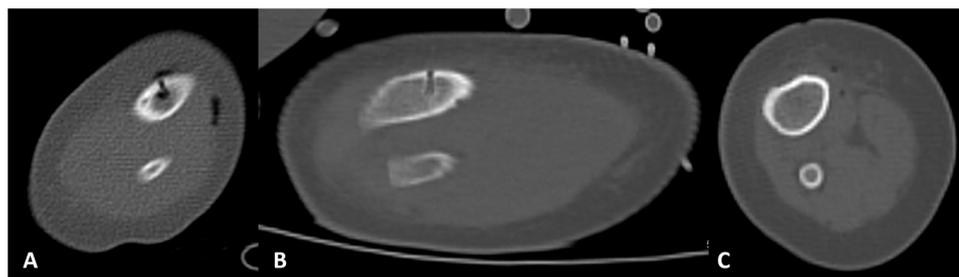

Fig. 1 – Examples for not included cadavers were typical defects indicate that intraosseous cannulation was performed. (A) Typical tibial bone defect with surrounding air bubbles in the soft tissue. (B) Typical tibial bone defect. (C) Little cutis defect and small air bubbles in a cadaver with sudden infant death syndrome and no history of limb trauma.

Table 1 – Basic data of cadavers and subgroups.

	n Cases	Mean age (SD*; range)	Sex female (%)
Age <18 years	38	3.67 (±5.82; 0,00−17.42)	17 (45)
Age <1 year	22	0.30 (±0.25; 0.00−0.91)	6 (27)
Age >1 year	16	8.30 (±6.62; 1.08−17.42)	11 (69)

In all cadavers, the depth from the skin surface to the proximal and distal borders of the intraosseous space at the medial surface of the proximal tibia was measured in a consensus decision.

The autopsy protocols were available in 37 cadavers (97%). They were reviewed regarding the cause of death, whether the children already required resuscitation before the vascular access attempt and whether the vascular access attempt was made out-of-hospital.

Results

Infant cadavers (< 1 year)

In 22 cadavers 34 IO devices were used (9 manual devices and 25 EZ-IO sytems). In 10 of these cadavers two ION and in one cadaver three ION were used. Malposition of at least one ION was seen in 14 cadavers (64%). 7 of these 14 cadavers, accordingly 32% off all subjects, had no correctly placed ION and were therefore without sufficiently established vascular access. Hence, in the 15 cadavers with at least one ION in correct position there were malpositioned ION in 7 cadavers (47%). In two cadavers with two needles both ION were malpositioned. Overall, 16 of the 34 used IO devices (47%) were in malposition. 8 of the malpositioned ION were inserted too deep (50%, 5 cases with penetration of the cortical bone on the proximal and distal side). The other 8 IO devices were inserted too shallow (50%) (Table 2).

Autopsy protocols were available for all 22 cadavers. In 20 of the 22 cases (91%) the infants were already in need of resuscitation before an attempt to gain vascular access was started. In 6 cases (27%) the attempt to establish vascular access was made either in an emergency department or in an intensive care unit. In the autopsy, there was in no case an indication that an ION failure led to death.

The mean measured depth from the skin surface to the borders of the intraosseous space at the medial surface of the proximal tibia was 11 mm (SD ± 3; min 7 mm; max 23 mm) for the proximal and 18 mm (SD ± 4 mm; min 12 mm; max 31 mm) for the distal border.

Child cadavers (≥1 year)

23 ION were found in 16 cadavers (2 manual devices and 21 EZ-IO devices). 5 of these cadavers had two inserted needles and in one case three needles were used. In 8 cadavers (50%) at least one ION was malpositioned. In 3 of these cadavers, accordingly in 19% off all subjects, no correctly positioned ION was visible, hence no vascular access was obtained. Therefore, in the 13 cadavers with at least one ION in correct position there were malpositioned ION in 5 cadavers (38%). Overall, 9 of the 23 IO devices (39%) were malpositioned. Of these 9 malpositioned ION, 2 were too deep (22%; 1 case with penetration of the cortical bone on the proximal and distal side) and 7 were too shallow (78%) inserted in the cadavers (Table 3).

In 15 cadavers (94%) autopsy protocols were available. 14 of these 15 children (93%) were already in need of resuscitation before the first attempt to gain vascular access was started. In all cases, this attempt was made in an out-of-hospital situation (e.g. at an accident site or at home). In none of the cases with autopsy protocol was any indication that an ION malfunction led to death.

The mean measured depth from the skin surface to the borders of the intraosseous space at the medial surface of the proximal tibia was 14 mm (SD ± 3; min 10 mm; max 23 mm) for the proximal and 31 mm (SD ±10 mm; min 18 mm; max 49 mm) for the distal border

Interreader agreement

The interreader agreement concerning the question if an ION was malpositioned was 100% (Cohens-Kappa 1.0).
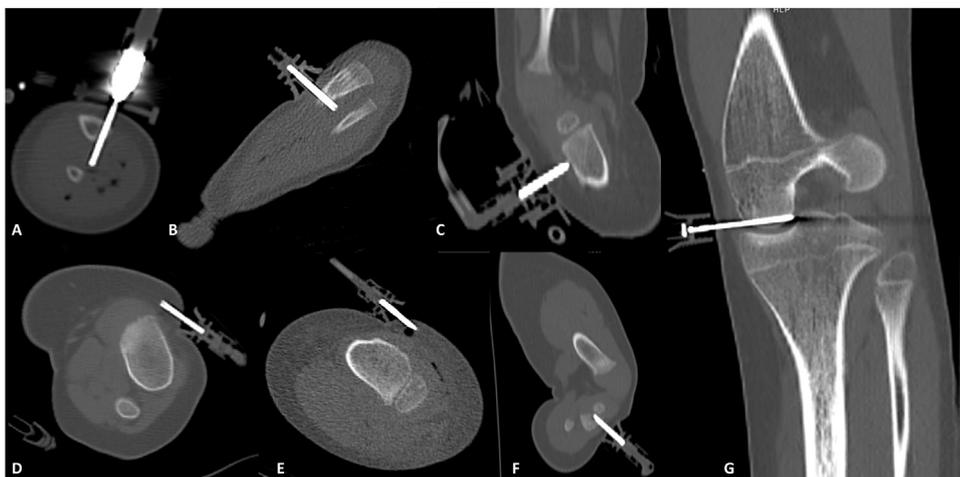

Fig. 2 – Examples of malpositioned intraosseous needles. (A + B) Intraosseous needle penetrates tibial bone on both sides. (C) Intraosseous needle reaches the tibial bone but without cortical penetration. (D + E) Intraosseous needle is placed in the soft tissue. (F) Tip of the intraosseous needle is placed within the epiphyseal plate. (G) Intraosseous needle is malpositioned in the knee joint with the tip not within the bone.
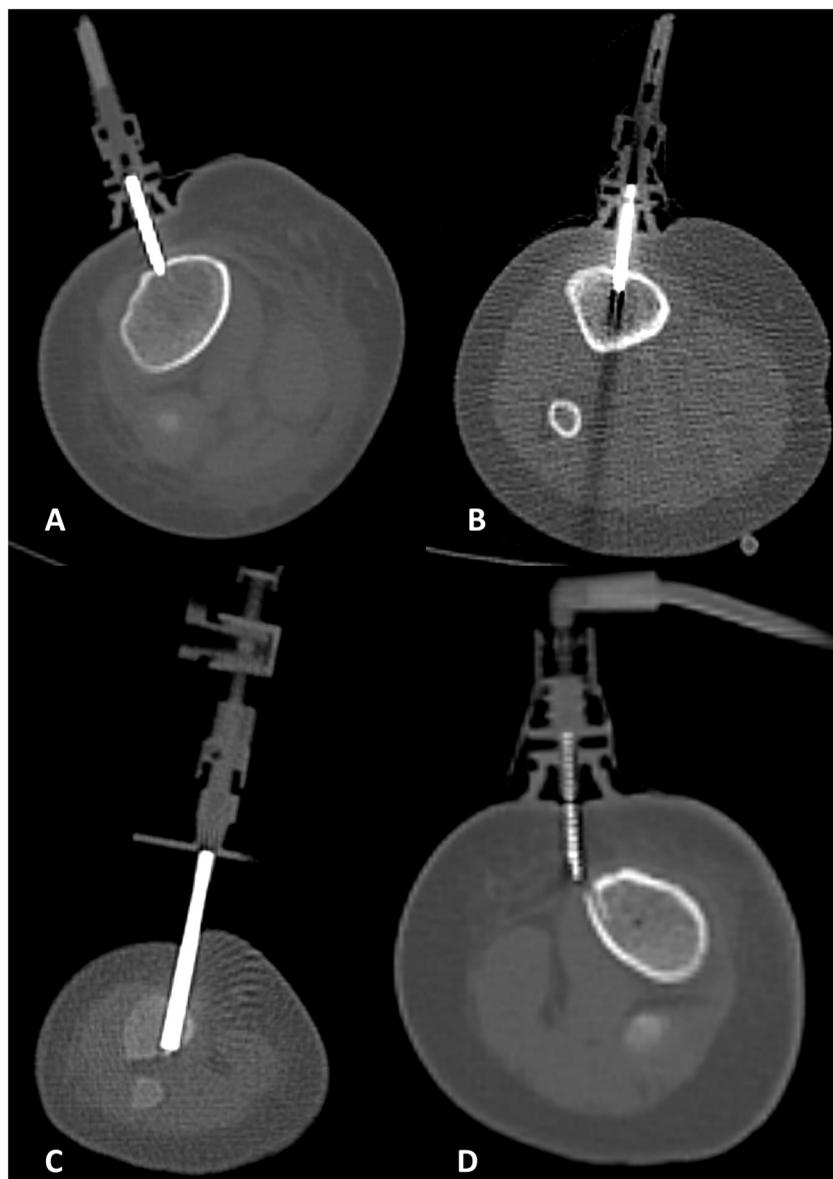
Fig. 3 – Examples of intraosseous needles which were barely counted as correctly positioned.
(A + B) Intraosseous needle tip barely within the bone marrow. (C) A part of the intraosseous needle penetrates the bone on both sides, but the tip is in part within the bone marrow. (D) Intraosseous needle is not within the bone, but the small bone defect indicates that cannulation was successful, and the needle might dislocated afterwards (e.g. during transport).

Table 2 – Infant cadavers (age <1 year).

	All IO devices		EZ-IO		Manual devices	
	n Cases	%	n Cases	%	n Cases	%
Cadavers	22		16[b]		7[b]	
ION[a]	34		25		9	
Number of cadavers with at least one malpositioned ION	14	64	11	69	4	44
Number of malpositioned ION	16	47	12	48	4	44
Number of malpositioned ION perforating the bone on both sides	5	31	4	33	1	25
Cadavers without a correctly placed ION	7	32	5	31	1	11
Cadavers with two ION	10	45	8[b]	50	3[b]	33
Cadavers with three ION	1	5	1	6	0	0

[a] Intraosseous needle.
[b] One cadaver with one EZ-IO and one manual device.

Table 3 – Child cadavers (age ≥1 year).

	All IO devices		EZ-IO		Manual devices	
	n Cases	%	n Cases	%	n Cases	%
Cadavers	16		14		2	
ION[a]	23		22		2	
Number of subjects with at least one malpositioned ION	8	50	7	50	1	50
Number of malpositioned ION	9	39	8	38	1	50
Number of malpositioned ION perforating the proximal and distal cortical bone	1	11	1	13	0	0
Cadavers without a correctly placed ION	3	19	2	14	1	50
Cadavers with two ION	5	31	5	31	0	0
Cadavers with three ION	1	6	1	6	0	0

[a] Intraosseous needle.

Discussion

Fast obtaining of vascular access is vital for treatment of critically ill children, e.g. in cases with cardiopulmonary resuscitation. IV access is in general more difficult to establish in young children, especially in situation with cardiac arrest or hypovolemic shock.[2–5,21] ION are an alternative approach which outperformed IV access in several studies concerning success rates and average time for placement.[2,22–24]

In our study higher rates of malpositioned ION were observed than was to be assumed with regard to previously published literature, where success rates of 80% and higher are common.[2,7,17,18] E.g. Bielski et al. described a success rate of 90% both with EZ-IO device as well as with the Jamshidi needle while Myers et al. observed success rates of 80.6% in the manual device group and in 83.9% in the mechanical device group.[2,18] In infant cadavers we had even higher rates of not correctly positioned ION than could be assumed in regard to the approximately comparable part of the study of Pifko et al. with children <8 kg which had already much lower success rates than described in several articles.[2,7,17] In child cadavers the percentage of cadavers without malpositioned ION was with 50% higher and thus better than in the infant group but nonetheless much lower than assumed regarding the common literature. Furthermore in 10 of the evaluated 38 cadavers (26%) no vascular access was obtained at all, this includes two cadavers with more than one needle. This indicates that obtaining vascular access with ION in children might be more difficult than commonly assumed independently from age and used device.

There are reports of puncture sites for IO devices other than the tibial bone.[21,25] In our study only two times a different puncture site was used. In both cases a cannulation of the femoral bone was tried, but both cannulations failed. This is in concordance with other reports that favor the tibial bone.[21]

In both subgroups, predominantly malpositions in the soft tissue were seen. The malpositioned ION of child cadavers were inserted much more often too flat, while too shallow and too deep needle intrusion in infant cadavers were balanced. It is presumed that this observed difference is due to the average larger leg circumference of the older cadavers. Accordingly, malpositions in which the cortical bone on the proximal and distal side was perforated were more frequent in the infant cadavers, although the overall number of cases was small. Nevertheless, this point should be considered especially in infants, since a felt tight fit of the needle is no proof for an anatomically correct position.

The measured depths from the skin surface to the borders of the intraosseous space at the medial surface of the proximal tibia can only be regarded as a rough approximation. The high pressure exerted when inserting the ION can lead to displacement of the soft tissue above the punctured bone, which has a significant effect on the required penetration depth. However, our measurements show that at least in individual cases it is possible to penetrate the cortical bone of infants on both sides even with the short 15 mm ION. Accordingly, it seems to make sense to first prick to the proximal surface of the bone to estimate the necessary penetration depth before attempting to penetrate the bone.

The study design might contribute to the observed high malposition rates

The literature describes success rates in living children and adults, even though it is not known which percentage of the study patients with ION survived. In our study only cadavers were included, and we cannot totally exclude, that the failure of the ION access caused death which would lead to unnormal high malposition rates. However, considering that the autopsy protocols showed no such indication and that only 26% of the cadavers were without a correctly placed ION, this should not be enough to explain the differences to the literature. And even if we exclude the cadavers without any correctly placed ION the rates of malpositioned ION are still higher than assumed in regard to most of the literature and approximately comparable to the <8 kg group of Piko et al. (infant group 47%; child group 39%).

Moreover, we only know that most attempts to gain vascular access were made under out-of-hospital conditions, but we do not know the exact conditions. For example, obtaining vascular access in a patient at an accident site with its relatives around him might be more difficult than in an intensive care unit due to an increased stress level for the health professional. Also, we do not know the training level regarding IO devices of the health professionals which tried to establish an IO access. But then our study probably shows a cross section of the usage scenarios. In fact, this is probably an advantage because the study reflects the current state of the diverse multicenter-like situations in the catchment area of the institute for forensic medicine and not the success rates of a single-center emergency department or artificial training sites with uniform conditions e.g. concerning patient preparation.

The study has further limitations.

First, we can only describe the rates of anatomically malpositioned IO devices and not definitive success/failure rates, because we do not know the exact number of attempts which were made to gain access via ION in our study group. Thus, only a limited comparison with the success rates of literature is possible.

For several reasons, the observed results may not be uncritically transferred one-to-one to living infants and children. Even if to our knowledge there was no indication in the autopsies that ION in the wrong position were responsible for the death, this cannot be completely ruled out. Even autopsies cannot always determine the exact cause of death without any doubt. In addition, most children were already in need of resuscitation when the health professionals arrived. It cannot be ruled out that this may have a negative effect on ION success rates. Children in need of resuscitation represent an exceptional stress situation even for experienced staff, which could have a negative effect on puncture attempts. In addition, the situations in which they are found can be unusually stressful for medical professionals (e.g. violent crimes).

Even if a needle is placed anatomically correct, this does not rule out dysfunction. For example, the needle lumen may be blocked by tissue. Accordingly, the number of non-functioning ION may be higher than the number of anatomically incorrectly placed needles.

Cases of ION attempts and subsequent removing of the needle were not recorded due to the retrospective design.

In addition, it could not be assessed if it was possible to eventually gain IV access in the cadavers without any successfully placed IO device. But then no other kind of vascular access was visible in the PMCT of the cadavers.

Likewise, we do not know if the health care professionals trying to attempt IO access were aware of malpositioned ION due to a failure of common clinical confirmatory tests (e.g. bolus injection of 10 ml infusion solution without increased or decreasing resistance and without extravasation).

Last, the study population was not very high, although it is in a comparable range to other studies.[11,13,16,17,19,21,23] Therefore, especially the access rates of the relatively little subgroups of manual devices might not be reliable due to its small sample size. Furthermore, different manual devices were used but a reliable differentiation concerning the malposition rates between the different needles was not possible due to the small sample size.

Conclusion and outlook

ION are valuable and important tools in emergency medicine offering a fast way to gain vascular access in situations where this kind of access would be otherwise impossible or too time consuming to obtain. Our study showed considerably higher malposition rates of IO devices in infant cadavers as well as in child cadavers than assumed concerning the literature. Further prospective studies in living pediatric patients should be conducted to verify the success rates.

In addition, a feedback loop between the emergency medical services, the pediatricians and the coroners could be established to ensure that user of an ION got feedback concerning the ION position which would provide learning effects.

Besides, it could be helpful to intensify training with ION for health professionals and to turn attention to the verification of the right needle position via common clinical confirmatory tests.

Conflicts of interest

None.

REFERENCES

1. Andersen LW, Berg KM, Saindon BZ, et al. Time to epinephrine and survival after pediatric in-hospital cardiac arrest. JAMA 2015;314:802 −10.
2. Bielski K, Szarpak L, Smereka J, Ladny JR, Leung S, Ruetzler K. Comparison of four different intraosseous access devices during simulated pediatric resuscitation. A randomized crossover manikin trial. Eur J Pediatr 2017;176:865−71.
3. Black KJ, Pusic MV, Harmidy D, McGillivray D. Pediatric intravenous insertion in the emergency department: bevel up or bevel down? Pediatr Emerg Care 2005;21:707−11.
4. Larsen P, Eldridge D, Brinkley J, et al. Pediatric peripheral intravenous access: does nursing experience and competence really make a difference? J Infus Nurs 2010;33:226−35.
5. Reigart JR, Chamberlain KH, Eldridge D, et al. Peripheral intravenous access in pediatric inpatients. Clin Pediatr (Phila) 2012;51:468−72.
6. Schauer SG, Naylor JF, April MD, et al. The prehospital trauma registry experience with intraosseous access. J Spec Oper Med 2019;19:52−5.
7. Szarpak L, Ladny JR, Dabrowski M, et al. Comparison of 4 pediatric intraosseous access devices: a randomized simulation study. Pediatr Emerg Care 2018 [Epub ahead of print].
8. Blumberg SM, Gorn M, Crain EF. Intraosseous infusion: a review of methods and novel devices. Pediatr Emerg Care 2008;24:50−6 quiz 7−8.
9. Schauer SG, Ng PC, April MD, Hill GJ, Arana AA, Bebarta VS. Pediatric prehospital intraosseous access during combat operations in Iraq and Afghanistan. Pediatr Emerg Care 2019 [Epub ahead of print].
10. Kurowski A, Timler D, Evrin T, Szarpak L. Comparison of 3 different intraosseous access devices for adult during resuscitation. Randomized crossover manikin study. Am J Emerg Med 2014;32:1490−3.
11. Leidel BA, Kirchhoff C, Bogner V, Braunstein V, Biberthaler P, Kanz KG. Comparison of intraosseous versus central venous vascular access in adults under resuscitation in the emergency department with inaccessible peripheral veins. Resuscitation 2012;83:40−5.
12. Leidel BA, Kirchhoff C, Bogner V, et al. Is the intraosseous access route fast and efficacious compared to conventional central venous catheterization in adult patients under resuscitation in the emergency department? A prospective observational pilot study. Patient Saf Surg 2009;3:24.
13. Leidel BA, Kirchhoff C, Braunstein V, Bogner V, Biberthaler P, Kanz KG. Comparison of two intraosseous access devices in adult patients under resuscitation in the emergency department: a prospective, randomized study. Resuscitation 2010;81:994−9.
14. Szarpak L, Czyzewski L, Woloszczuk-Gebicka B, Krajewski P, Fudalej M, Truszewski Z. Comparison of NIO and EZ-IO intraosseous access devices in adult patients under resuscitation performed by paramedics: a randomized crossover manikin trial. Am J Emerg Med 2016;34:1166−7.
15. Curran A, Sen A. Best evidence topic report. Bone injection gun placement of intraosseous needles. Emerg Med J 2005;22:366.
16. Ngo AS, Oh JJ, Chen Y, Yong D, Ong ME. Intraosseous vascular access in adults using the EZ-IO in an emergency department. Int J Emerg Med 2009;2:155−60.
17. Feldman O, Nasrallah N, Bitterman Y, et al. Pediatric intraosseous access performed by emergency department nurses using semiautomatic devices: a randomized crossover simulation study. Pediatr Emerg Care 2018 [Epub ahead of print].
18. Myers LA, Russi CS, Arteaga GM. Semiautomatic intraosseous devices in pediatric prehospital care. Prehosp Emerg Care 2011;15:473−6.
19. Pifko EL, Price A, Busch C, et al. Observational review of paediatric intraosseous needle placement in the paediatric emergency department. J Paediatr Child Health 2018;54:546−50.
20. Statistik BLf. Statistikdaten Bayern [Available from: https://www.statistikdaten.bayern.de/genesis/online?Menu=Willkommen.
21. Szarpak L, Truszewski Z, Smereka J, et al. A randomized cadaver study comparing first-attempt success between tibial and humeral

intraosseous insertions using NIO device by paramedics: a preliminary investigation. Medicine (Baltimore) 2016;95:e3724.

22. Ross EM, Mapp J, Kharod C, Wampler DA, Velasquez C, Miramontes DA. Time to epinephrine in out-of-hospital cardiac arrest: a retrospective analysis of intraosseous versus intravenous access. Am J Disaster Med 2016;11:119−23.

23. Santos D, Carron PN, Yersin B, Pasquier M. EZ-IO((R)) intraosseous device implementation in a pre-hospital emergency service: a prospective study and review of the literature. Resuscitation 2013;84:440−5.

24. Suyama J, Knutsen CC, Northington WE, Hahn M, Hostler D. IO versus IV access while wearing personal protective equipment in a HazMat scenario. Prehosp Emerg Care 2007;11:467−72.

25. McCarthy G, Buss P. The calcaneum as a site for intraosseous infusion. J Accid Emerg Med 1998;15:421.