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REVIEW ARTICLE

History of pediatric regional anesthesia

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Summary

The history of local and regional anesthesia began with the discovery of the local anesthetic properties of cocaine in 1884. Shortly afterwards nerve blocks were being attempted for surgical anesthesia. Bier introduced spinal anesthesia in 1898, two of his first six patients being children. Spinal anesthesia became more widely used with the advent of better local anesthetics, stovaine and procaine in 1904–1905. Caudals and epidurals came into use in children much later. In the early years these blocks were performed by surgeons but as other doctors began to give anaesthetics the specialty of anesthesia evolved and these practitioners gradually took over this role. Specific reports of their use in children have increased as pediatric anesthesia has developed. Spinals and other local techniques had periods of greater and lesser use and have not been universally employed. Initial loss of popularity seemed to relate to improvements in general anaesthesia. The advent of lignocaine (1943) and longer acting bupivacaine (1963) and increasing concern about postoperative analgesia in the 1970–1980s, contributed to the increased use of blocks.

The history of pediatric regional anesthesia followed its introduction in adults, which occurred after the discovery of the local anesthetic properties of cocaine in the eye by Koller in 1884. Then Corning, an American neurologist, tried injecting it into the epidural space (1885). On August 16, 1898, August Bier tried to induce spinal anesthesia with cocaine. All of his six patients, including two children – the first to have spinals – had postoperative vomiting and headache, and Bier felt that the technique had little advantage over general anesthesia. Before abandoning it, he and his assistant tried it on each other, but the next day, Bier (1) had vertigo and headache, and Hildebrandt had vomiting and headache for 4 days and some weakness for longer.

In 1900, Matas reviewed the world literature on local and regional anesthesia and concluded that Halstead and Hall were the first to use nerve blocks for surgical anesthesia in November 1884. Many nerve blocks preceded the use of spinal anesthesia. Unfortunately, he did not mention their specific use in children (2). Spinal anesthesia came into more general use following the introduction of Stovaine in 1904 by Fourneau and less toxic procaine in 1905 by Einhorn. Barker (3) refers to reports of 2000 cases by Tuffier in France and a 1000 from Bier's clinic in Germany in 1907, representing a huge increase in 3 years. The earliest papers from Continental Europe were by surgeons, such as Bier and Donitz (1904) and Deetz (1906), who used spinals in children (3,4). A.E.Barker, Professor of Surgery at University College Hospital, London, undertook a thorough study of 100 patients. He had some early failures, but his second 50 cases were all successful. There is a lengthy discussion on the influence of specific gravity of the solution and the use of gravity to control its spread, something that Etherington-Wilson (5) elaborated on in 1945, including in children. Barker concluded that there was a place for spinal anesthesia but also stressed the importance of sterility and that it was not for casual use by the inexperienced. He reported that those who had previously had chloroform overwhelmingly preferred spinal anesthesia (3).

In 1909–1910, H. Tyrell Gray, superintendent at the Hospital for Sick Children at Great Ormond Street, London, published three detailed papers each based on 100 more cases of spinal anesthesia in children (6,7). They occupied 14 ½ pages in the Lancet! He referred to papers from the Continent from 1904 to

1908 and Barker's one, from which he gleaned much guidance (3).

Safety depended on the ability of the surgeon to control the spread of the local anesthetic, Stovaine, by increasing its specific gravity with glucose or, in a later series, Dextrin, and by controlling the spread with posture. Stovaine lasted about 1–1 ¼ h. Barker also recommended raising the shoulders to prevent the paralyzing of the respiratory muscles.

Gray's patients were not anesthetized but were comforted by a nurse who knew them. Some were even allowed to have cake! Six retched and 21 vomited during the anesthetic. The incidence of vomiting postoperatively was very low, only 2%. In three patients, spinal anesthesia failed, and general anesthesia was instituted.

Gray concluded that the benefits to the patient were as follows: absolute anesthesia, no surgical shock, the analgesia was localized to the area of the block, and the postoperative vomiting was minimal. He also noted that younger children were less likely to vomit. The spinals usually took effect within 5 min and were quicker in infants. Gray observed that the temperature sense was more slowly abolished because a hot pack caused a response when no pain was being felt.

The advantages for the surgeon were as follows: good operating conditions, easy access to the abdomen, the bowel was constricted, surgery could be completed quicker, and he could administer it himself. Postoperatively, there was less pain, and feeding could be started sooner. These papers illustrate how much was known about spinal anesthesia in children, more than 100 years ago (6,7).

In this era, surgeons dominated the scene, supervising the administration of general anesthetics but putting the blocks in themselves. In 1920, a French surgeon, Gaston Labat, spent a year teaching regional anesthesia at the Mayo Clinic. During that year, he wrote his widely referred to book *Regional anaesthesia*: *Its techniques and clinical applications* (8). In 1924, Mayo appointed their first physician anesthetist, John Lundy, to head the section of Anaesthesia (9). Physician anesthetists increasingly took over anesthesia, but the surgical contribution continued for many years in some hospitals until anesthesia became an established specialty.

In 1920, Farr, in Minneapolis, reported 129 spinals in children, many of which were for pyloromyotomies, using 0.6–1.0% Novocaine. There were nine failures (10). In Romania, where there was much interest in nerve blocks, Marian (11) reported 653 spinals in children with only 15 failures.

Spinal anesthesia was used in children in Toronto by anesthetists in 1933 (12,13) and in Montreal in 1949 (14). Junkin commented on the lack of articles describing its use in children and, of those, he found them indefinite and unenlightening in their brevity. Junkin used morphine and Nembutal for premedication and inserted the needle at L4–5 because the spinal cord reaches lower in infants than adults – an important observation. It was used from 2 weeks of age upwards for a wide variety of cases including four thoracic operations. They observed that hypotension was less than that in adults and that vomiting did occur during anesthesia but was not distressing, and they had only two postoperative headaches of sufficient severity to warrant treatment.

Caudals now play a major role in pediatric anesthesia, but they were first reported for cystoscopies in children by Meredith Campbell (15) when she presented a paper to the American Society of Regional Anesthesia in 1933. Prior to this, children had morphine and, sometimes, phenobarbitone premedication and either Novocaine instilled into the urethra or general anesthesia (30%). As some parents refused the latter, caudal anesthesia was tried and proved to be a better option and so became more widely used. Eighty-three children, aged 4–14 year, having cystoscopy or transurethral surgery, were given caudals instead of general anesthesia, initially with 80% complete success, nine requiring conversion to a general anesthetic. In 1936, Sievers in Germany also reported the use of peridural block for cystoscopy (16).

In 1951, Berkowitz and Barnett reported on 350 spinals in children under 13 years – nine under 5 years. They used hyperbaric procaine, Nupercaine, or Pontocaine and checked with the cough test that they were not too high. The majority were for appendicectomy. They stressed the importance of evaluating the patient's personality and using premedication (17).

In the 1930s, 1940s, and 1950s, the specialty of anesthesia was developing with increasing numbers of doctors devoting themselves to it. Anesthesia societies were founded, and by 1955, the World Federation of Societies of Anaesthesiologists (WFSA) (18) came into existence with 26 members and 12 observer societies. Anesthetists had largely taken over the regional anesthesia practice, but in some less affluent places and where anesthetists were not available, spinal anesthesia remained a relatively simple, cheap alternative, still supervised by the surgeon. Specialist pediatric anesthesia was beginning, particularly in children's hospitals.

There seemed to be a lull in interest in regional anesthesia, probably as a result of the improvements in general anesthesia after the introduction of muscle relaxants (tubocurarine, 1941) and agents such as thiopentone (1934), cyclopropane (1933), and halothane (1956).

In more advanced countries, there were some centers where regional methods, mainly spinals, were still widely used, but this was not universal. So, we find that there were sporadic, isolated reports, such as those mentioned earlier, from around the world, of spinals, caudals, or epidurals being used in children. These continued but became increasingly frequent from the 1960s onwards.

Advances in pediatric surgery in the 1950s and 1960s were because of the improvements in pediatric anesthesia and the development of intensive care in the 1960s. It is against this background that pediatric regional anesthesia developed further in a sporadic fashion. Fortuna's review (19) highlights developments in many parts of the world. These reports were often by individuals or departments, not necessarily in major centers, and blocks were not universally employed. This is borne out by the fact that most of the textbooks available on pediatric anesthesia up to 1981 (20–24) apart from Leigh and Belton (25), Robert Smith, (26) and Brown and Fisk (27) do not have chapters or sections on regional anesthesia.

By 1950, Harry Curwen in Durban, South Africa, was using caudals in neonates. He reported his experience with caudal anesthesia on about 90 neonates at a South African meeting. I met him in 1993, when he was an old man. He gave me a typed copy of this early paper (see Figure 1) (H. Curwen, personal communication).

Curwen recognized the potential advantages, especially for the occasional pediatric anesthetists or doctors working in the rural areas. He discussed his methods and highlighted the problem of not knowing what volume was needed to fill the epidural space. Empirically, he used 6–16 ml (1% procaine or amethocaine with 1 : 200 000 epinephrine) depending on the length and weight of the infant and the height of analgesia required. One of the points he made was to use a big-enough needle so that CSF or blood could flow back and be easily seen if dura or a vessel was punctured. He also noted that lack of myelination contributed to the intensity and rapidity of the block. Rushton, working in Hamilton General Hospital in Canada, published papers (1954, 1964) on his experience with epidurals in children (28,29). Others in Brazil took up caudals and epidurals (19,30,31). In 1967, Fortuna reported on 170 caudals in infants and children of whom 26 were <1 year of age. Lignocaine 0.5–2% in doses averaging $10\ mg{\cdot}kg^{-1}$ were used – 91.7% had good analgesia. Two children, who had doses of 15 and $20\ mg{\cdot}kg^{-1}$ lignocaine had convulsions, successfully managed with oxygen and one with Nembutal as well, without sequelae. It was a safe, reliable, and simple way to produce surgical anesthesia, especially in children in poor condition needing emergency surgery (32).

In Melbourne, Australia, caudals were introduced in children in 1968 by Ian McDonald and Evan Watts. The first 80 cases were reported by Lourey and McDonald (33). After that, caudals became commonly used for penile and some lower abdominal and leg surgery. Later, larger doses (1.0–1.2 ml of 0.25% bupivacaine) expanded their use to hernias, orchidopexies, etc. Dural puncture occurred in about 1 in 2000–3000 cases, usually because of a low dural sac. On one occasion, it was because of the incomplete sacral laminae. The blocks were performed under general anesthesia so that psychological trauma is avoided (27). This became a common practice in pediatric anesthesia despite criticism from adult anesthetists (34).

Local anesthesia provides more profound pain relief than opiate infusions. The factors that led to the great increase in interest in regional anesthesia and nerve blocks have been the introduction of epidural and caudal anesthesia for labor and delivery; and then the increasing recognition of the need to improve acute and postoperative pain control in children in the 1970s and 1980s (35). The long action of bupivacaine (1963), which provides several hours analgesia, was another stimulating factor. In addition, anatomical studies led to the refinement of some nerve block techniques.

Toxicity of local anesthetics is usually related to intravascular injection but occasionally is caused by excessive dosage. In 1976, Eyres (36), in Melbourne, was the first to study blood levels of local anesthetics in children after various doses and techniques. He showed that $3\ mg{\cdot}kg^{-1}$ bupivacaine given caudally reached the highest plasma levels in children under 1 year and that even this dose rarely reached plasma levels of $2\ \mu g{\cdot}ml^{-1}$ and averaged $1.39\ \mu g{\cdot}ml^{-1}$ (37). This dose is safe but higher than those usually recommended. He also showed in 99 patients that plasma levels of lignocaine averaged $5.5–6\ \mu g{\cdot}ml^{-1}$ after $4\ mg{\cdot}kg^{-1}$ was administered topically into the trachea. In four children, the level reached $10\ \mu g{\cdot}ml^{-1}$, which would be a convulsant level except that convulsions are prevented by general anesthesia (38). Estela Melman, in Mexico City, reported on 200 caudals in 1975 (39). Later, they used up to $4\ mg{\cdot}kg^{-1}$ without any signs of toxicity and claimed to have attained plasma levels to justify their dose.

This raised the question about the maximum safe dose and toxic dose of bupivacaine. Because the cardiovascular system is usually affected before convulsions occur, it is difficult to determine toxic levels in humans. Plasma levels of 5.1 and $7.5\ \mu g{\cdot}ml^{-1}$ have been measured during convulsions treated with oxygen

Figure 1 Contributors to pediatric regional anesthesia. 1. Harry Curwen (S.Africa) with his 1950 paper, 2. Armando Fortuna (Brazil), 3. Estela Melman (Mexico), 4. Claude St Maurice (France), 5. Ottheinz Schulte Steinberg (Germany), 6. Adrian Bosenberg (S. Africa), 7. Ted Armitage, (UK), 8. Rob Eyres (Australia), 9. Kester Brown (Australia.), 10. Paulo Busoni (Italy), Bernard Dalens (France), 11. Carlos Riquelme (Chile), 12. Douglas Arthur, 13. Roddie McNicol, 14. Luz Hidela Patiňa (Col, Ven), 15. Zhan Zeng Gang (China), 16. Khoo Siew Tuan (Singapore), 17. Elizabeth Giaufré. (France), 18. Cedric Hoskins (New Zealand).

and without cardiac decompensation (40,41). Most cases where toxicity occurred were associated with intravascular injection. There have been some reports where the patient was given an excessive dose. McGown reported 4 deaths and 7 cardiac arrests in a series of 500 cases of which at least 4 were because of overdosage. (lignocaine 27.8–41.1 $mg{\cdot}kg^{-1}$ or bupivacaine 5 $mg{\cdot}kg^{-1}$ in a 3-kg baby) (42). Arthur and McNicol (43) discussed toxicity and factors affecting it in detail in their review in 1986.

A French review of 24,005 regional blocks between 1982 and 1991 had five patients with serious neurological sequelae with three deaths (44). This paper dampened the enthusiasm of some anesthetists for regional anesthesia but stimulated much discussion.

Riquelme undertook a series of sequential experiments in anaesthetized puppies at 2, 6, 13, 26, and 52 weeks, where he infused bupivacaine until the blood pressure dropped to 25 mmHg or dysrhythmias (only 3/35 were ventricular) occurred. They were resuscitated successfully. The toxic dose was significantly lower in the 6-week-old pups (4 $mg{\cdot}kg^{-1}$ compared with 6–9 $mg{\cdot}kg^{-1}$ at other ages) and the plasma levels, when the infusion was terminated, were significantly lower in the 13-week-old pups and younger dogs, below 3 $\mu g{\cdot}ml^{-1}$ compared with 4.6–6 $\mu g{\cdot}ml^{-1}$ when they were older (45).

Dissections undertaken for anesthetists in Melbourne used windows of decreasing size as each tissue layer was traversed to reach the nerves. These enabled new or improved techniques to be developed, particularly for the lower limb, where the blocks have provided excellent analgesia following skin harvesting in burns. Three principles for nerve blocks evolved. Aponeuroses and fascia can usually be felt as a resistance, and a 'pop' can be felt when a short-beveled needle is passed through them. If a short-bevel needle is not available, a sharp needle can be moved back and forth until it 'grates' against the aponeurosis (C.M. Riquelme, personal communication). This is the *first principle* in finding the depth of a nerve. (e.g., two layers – fascia lata and iliaca – have to be penetrated just lateral to the femoral artery to block the femoral nerve) (46).

The *second principle* is to advance the needle with gentle pressure on the syringe plunger. It is difficult to inject into muscle, but easy when a space is reached where the nerve usually lies. (e.g., sciatic nerve, when approached through biceps femoris in the mid-thigh). The *third principle* is never to inject against resistance (47). If one knows the anatomy accurately, using these principles it is possible to have a high degree of success without the aid of nerve stimulators or ultrasound. Under general anesthesia, pain resulting from an inadequate block will cause tachycardia. Feeling loss of resistance on the plunger can also help to identify the final injection point for penile and intercostal blocks, making sure the needle is not in a blood vessel (48).

Schulte Steinberg, who had trained with Bromage in Montreal, working in the county hospital in Starnberg (Germany) used caudal anesthesia and undertook studies on the levels reached in children, with different volumes of local anesthetic with added X-ray contrast (48). Similar studies were carried out in Melbourne (27) and by Cedric Hoskins* in Auckland, New Zealand (personal communication). These complimented other studies, e.g., by Busoni and Andreuccetti (49), where the levels reached by various doses were assessed clinically. There was some variation (27).

Further development of epidural needles and catheters allowing continuous administration of local anesthesia and subsequently, other drugs, such as morphine and clonidine, led to the increasing use of this technique, even in babies. A major problem in using continuous epidural infusions postoperatively is providing adequate expert supervision. Nurses need to be trained to look after them and either the anesthetist or a pain management team has to be available should any problems arise. This can be time-consuming, inconvenient, and costly but, overall, has improved the standard of postoperative care where they have been instituted.

Schulte Steinberg's other major contribution was to pass a caudal catheter up to the thoracic region in children, a technique initially considered risky by many pediatric anesthetists. Schulte Steinberg did a sabbatical in Durban, where there was already a culture of caudal anesthesia. He studied the caudal catheters in piglets and then cadavers and found it was possible to thread them up easily to the thorax in small children. Bosenberg then applied the method clinically in newborns with biliary atresia and subsequently found that by using continuous infusions via caudal catheter, the need for postoperative ventilation in babies with oesophageal atresia and other surgical conditions was reduced (50). This was important as there were not enough specialist nursing staffs to cope with patients on ventilators. Bosenberg has subsequently performed, or supervised, over 500 cases without any serious complication despite using the technique in some very sick babies (personal communication).

Paolo Busoni in Florence, Italy, furthered the technique. Busoni was working in a childrens hospital where they predominantly performed general surgery using caudal anesthesia only. While the caudal was inserted, a brief halothane induction was followed by IV diazepam for sedation. The remarkable feature of their technique was a very low incidence of postoperative vomiting. Their psychologist did a fascinating study on children's reactions to the procedure by having them draw their impressions the following day. One child drew himself lying on the operating table with the lower half of his body colored red. One wonders if he felt warm in the region covered by the block (personal communication).

Giaufré*, St. Maurice, Ecoffey (51) and other French colleagues also developed caudal and epidural anesthesia that became very popular in France. Bernard Dalens, in Clermont-Ferrand, reported on 750 caudal anesthetics (52) and subsequently wrote two important books on Paediatric Regional Anaesthesia (53,54). Epidural anesthesia was also in use at Filitov Children's Hospital in Moscow, where they even did thoracic epidurals in the 1970s. They must have been one of the first to use thoracic epidurals in children. They used lignocaine infusions because that was all that was available (S. Rajev, personal communication). Kay (1974) and Armitage(1979), separately, were the early proponents of caudals in children in UK (55,56). The widespread use of caudals seemed to develop later in USA. In 1987, Broadman reported 1154 caudals in children without deaths or neurological complications (57). Zahn Zeng Gang (58) reported on 10 000 epidurals performed at the Beijing Children's Hospital. Spinal anesthesia in infants, particularly ex-prems, has again become popular following the report in 1984 by Abajian (USA) of 78 prems (59). By 2000, the Vermont Spinal Registry had recorded over 1000 cases (19). It has proved safe and it is associated with less apnea in ex-prems than following general anesthesia. Subarachnoid injections or infusions of morphine have been used more recently to provide analgesia, including in cardiac surgery (60).

Other developments included the use of neural blockade for chronic pain management. For example, sympathetic blocks have been used successfully (57) in children with chronic regional pain syndrome (61).

The increasing use of local and regional anesthesia is evident from the large number of papers, review articles, book chapters, and books that have appeared in recent years, some specifically referring to their use in infants and children (27,53,54,62,63). Despite the greater interest in regional anesthesia and peripheral nerve blocks in children since 1980, its use is still not practiced everywhere mainly because the standard of general anesthesia, which is easy to administer, has improved and in many anesthetist's hands is more reliable, some would say is quicker, and because litigation for neurological damage can have serious consequences. In some hospitals, there are no suitable 'anesthetic or block rooms' to do the blocks. Other factors include inadequacies of training, lack of a good anatomical knowledge, and lack of understanding the benefits of regional anesthesia.

The introduction of ultrasound is changing the practice of regional anesthesia. It requires special training with the equipment and to understand the images. Many, who are already very proficient at producing reliable blocks, wonder whether this is really necessary in all cases, especially single-shot blocks, and are concerned with the way it is being introduced lest it becomes regarded as negligent if ultrasound is not used. Reliable blocks can be achieved quickly without ultrasound guidance if the anatomy, including the layers being penetrated, is well understood.

This paper has focused on the history of spinals, caudals, and epidurals in children. There is not enough room here to review the many peripheral nerve blocks, such as brachial plexus, intercostal, femoral, and sciatic, that are also useful in children (35,47).

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* Preceding name – included in photographs.