Painless childbirth? Epidural and spinal techniques in obstetric anesthesia

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Chapter 1

Introduction

1. INTRODUCTION TO OBSTETRIC ANESTHESIA

Were it not for Queen Victoria and her singular authority to challenge and silence medical, religious and political opposition in the UK in the 1850's, the initial development of obstetric anesthesia would have missed a crucial momentum. In an era where women's voices were seldom heard, her sardonic "Then let the bishops have the babies Mr. Gladstone" could not be ignored.(1)

Fig. 1. Queen Victoria with her daughter Victoria, the princess Royal.

(By Henry Collen: public domain, via Wikimedia Commons)

The evolution of obstetric anesthesia is closely aligned with the emergence and development of modern-day anesthesia in general, but obstetric anesthesia involves much more than a mere adaptation of standard anesthetic practices. The profound (patho)physiological transformations of pregnancy, the complex needs of women and their unborn children, the unpredictable challenges that may arise, and the need for crucial immediate anesthetic services demand a thorough understanding of fetal-maternal physiology, pathology and obstetric procedures.

Pregnancy and childbirth are fundamentally natural but complex physiological processes which unfortunately have historically been accompanied by significant feto-maternal morbidity and mortality. The advances in modern healthcare, including obstetric anesthesia, have dramatically reduced these risks. For many women, labour and delivery unfold as nature intended, but the delicate interplay between the physiology of labour, maternal coping capacity, and available support may not always suffice. When medical intervention becomes necessary, whether for pain relief, an urgent cesarean delivery, or surgery to address obstetric complications. anesthesia plays a crucial role.

This specialized field requires a combination of technical expertise, knowledge of administration tools and medications, understanding of maternal-fetal medicine, and strong interpersonal skills. Together with timely maternal education on pain relief options and potential anesthetic strategies during unexpected emergencies this also promotes clear communication and respects maternal autonomy, ultimately improving shared decision-making and well-being during childbirth and beyond.

Evolution of obstetric anesthesia

The evolution of obstetric anesthesia is closely aligned with the emergence and development of modern-day anesthesia in general. Within months after the first public use of ether for a surgical intervention in 1846, ether and soon thereafter chloroform were utilized to relieve the suffering of labour during childbirth and facilitate complicated deliveries in various European countries, including the Netherlands (1).

The use of inhalational analgesia during labour gradually spread, especially in the Anglo-Saxon countries. Elsewhere, a more cautious approach to the use of anesthesia and analgesia in obstetrics persisted, but as the anesthetic toolbox steadily expanded with new drugs and administration tools, the advantages of anesthesia in painful, complicated, or obstructed labours could no longer be dismissed.

New inhalational agents, intravenous anaesthetic drugs, and tools to ventilate patients while under anesthesia were introduced, which increased the use and gradually also the safety of general anesthesia. All these techniques soon found their way to obstetrics, for anesthesia during surgical procedures or to provide analgesia during labour. Together with the introduction of strict antisepsis measures, they led to new surgical delivery techniques and improved outcomes for cases previously requiring destructive procedures like craniotomy (where the fetus was extracted in pieces to save the mother's life).

These advances had initially paradoxical effects on maternal outcomes. Caesarean delivery previously considered a hazardous with pre-antisepsis mortality rates as high as 70-100%, indeed became safer.(2) Unfortunately, increased provision of labour analgesia, while reducing the pain associated with labour and delivery, also facilitated medicalisation of childbirth with

unexpected negative consequences. Inexperienced administration of inhalational analgesia, lack of understanding of the working mechanisms, presence of undesirable side-effects, and absence of adequate monitoring all contributed to elevated hazards.(3) In the USA, its widespread adoption also led to an increased incidence of forceps deliveries, as women under heavy sedation were unable to push effectively. This resulted in an higher incidence of maternal complications and deaths compared to countries that maintained a more natural approach to labour and delivery.(4)

The origins of neuraxial techniques

The introduction of neuraxial techniques marked a revolutionary development in anesthesia. It was the surgeon August Bier who first injected cocaine in the lumbar intrathecal space in order to achieve anesthesia of the lower body. In 1898 he performed the first 6 successful cases of spinal anesthesia as the technique became known. Although 3 out of 6 cases also resulted in a severe positional headache which lasted several days, spinal anesthesia appeared a promising alternative to inhalational anesthesia.(3,5) Initially the technique gained popularity, and within 2 years Oskar Kreis used spinal anesthesia to relieve labour pain.(3) Although Bier soon abandoned the technique, due to concerns over complications, addiction potential and toxicity of cocaine, spinal anesthesia became widely used once a safer local anesthetic (LA), procaine, was developed in 1904, which effectively replaced cocaine.(6) But spinal anesthesia remained a dangerous technique with a high risk of cardiovascular and respiratory depression and compromise. When administered by inexperienced personnel without adequate monitoring, it resulted in mortality rates as high as 1 in 139 among pregnant women, as reported in Germany in 1934.(3) The beforementioned risks soon led to the search for alternative L.A. administration routes. Pudendal, paravertebral sacral and caudal epidural routes were all explored and developed in the years that followed. Eventually the lumbar epidural approach was used in labour, first described around 1938 by early pioneers like Pagés and Dogliotti.(6). Since then, epidural anesthesia has developed as an alternative to general anesthesia, which at that time carried inherent risks, such as failed airway management, aspiration and neonatal compromise due to transplacental transfer of anesthetics. The subsequent refinements in epidural analgesia -including reduced LA concentrations, addition of synergistic opioids- and improvements in spinal needle design have established neuraxial (epidural and spinal) procedures as the cornerstone of obstetric anesthesia.

2. PAIN IN OBSTETRICS

Pregnancy and childbirth are inevitably linked with a certain degree of discomfort and suffering, sometimes even resulting in a physical ordeal which can extend well beyond delivery. Mechanical factors such as stretching of supportive abdominal ligaments, postural changes due to the increasing weight of the gravid uterus, and increased laxity of the sacro-iliac joints resulting from hormonal changes, all contribute to musculoskeletal discomfort during pregnancy. Both vaginal and operative deliveries invariably cause acute tissue injury,

which not only further increases acute visceral pain during vaginal delivery, but may also lead to central sensitization, scar tissue and chronic postsurgical pain. Together with a changed pelvic architecture, which may never regain its original stability, it leaves a significant minority of women with unresolved and long-lasting discomfort.

Labour pain

Multiple areas of the central nervous system interact dynamically to generate individualized pain experiences during childbirth. Nociceptive input from the lower uterine segment, cervix and vagina travels through the thalamus to the somatosensory cortex. Individual pain perception varies due to suprathalamic modulation, which is influenced by neurohormonal processes, autonomic nervous system balance, previous experiences, sociocultural beliefs/ expectations, available support and maternal emotional state.(7,8).

During the first stage of labour, uterine contractions result in stretching of the lower uterine segment and cervical dilation, activating visceral afferent nerve fibers with thoracolumbar origins. This produces diffuse dull, visceral-like pain that characteristically waxes and wanes with the rhythm of contractions. Once the fetus descends further during the second stage, additional nociceptive input from pelvic floor tissue injury travels through sacral A-delta fibers, creating more localized, intense pain sensations.

The severity of labour pain varies significantly among women due to mechanical factors (cephalopelvic disproportion, fetal presentation, contraction intensity, obstetric interventions), pre-existing pain conditions, coping mechanisms, psychological state, provided analgesia and quality of care. Research has demonstrated its potential extreme intensity. Melzack quantified it as comparable to the unanesthesized amputation of a finger, while earlier experiments showed that women reproducing their labour pain with heat stimuli ended up with second-degree burns.(8)

Currently clinicians rely on subjective self-reported measurements like the Visual Analogue Scale (VAS) or the numerical rating scale (NRS). (8) While more objective assessment tools based on autonomic responses and neuroimaging are being developed, their application in obstetrics remains challenging due to the fluctuating nature of labour pain.

Pain during and after obstetric surgery

Neuraxial anesthesia for obstetric surgical procedures is achieved either through using an already present and functioning epidural catheter or through spinal anesthesia. Yet anesthesia is not always complete, as during cesarean delivery an uncomfortable pain or pressure may be present or develops which necessitates additional supplemental anesthesia. Incidences of intra-operative breakthrough pain between 1-20% have been reported, irrespective of the neuraxial administration route.(9)

Failure to extend intrapartum epidural analgesia to surgical anesthesia is associated with a previously suboptimal epidural analgesia, suboptimal dosing of LA for epidural anesthesia, degree of urgency of the cesarean delivery, duration of surgery and patient-related risk factors such as high BMI, co-morbidities, younger age and increased height of the patient.(9) After spinal anesthesia, breakthrough pain can occur with prolonged duration of the surgical procedure, inadequate assessment of proper block height before commencement of surgery, and absence of opioids in the intrathecal mixture together with patient related factors. Apart from serious physical and emotional trauma for the mother during operative delivery, breakthrough pain may contribute to persistent pain after childbirth, development of a posttraumatic stress disorder and postpartum depression.(8,10)

Severe postoperative pain is also not uncommon, as cesarean delivery has been determined to be one of the most painful surgical procedures.(11) Inadequate postoperative pain relief not only affects early maternal mobilisation, maternal-neonatal bonding and breastfeeding. It also contributes to development of chronic postsurgical pain: pain associated with the procedure which may last months after the procedure.(12) The severity of acute postpartum pain, both after cesarean and vaginal delivery, has been shown to be associated with persistent pain and postpartum depression at 8 weeks postpartum.(12,13) Both persisting pain and developing depression have negative consequences for maternal, neonatal and family health and wellbeing.

3. NEURAXIAL NEURAL BLOCKADE

Neural blockade results from the interaction of local anesthetics with various ion channels and receptors of neural cell membranes. Depending on location, dose, volume and concentration of the LA, and the specific characteristics of the nerve fibres, (myelination, diameter and conduction velocity), action potential generation is blocked, conductance along axons is disrupted and release of neurotransmitters and neuropeptides at presynaptic terminals is inhibited.(14)

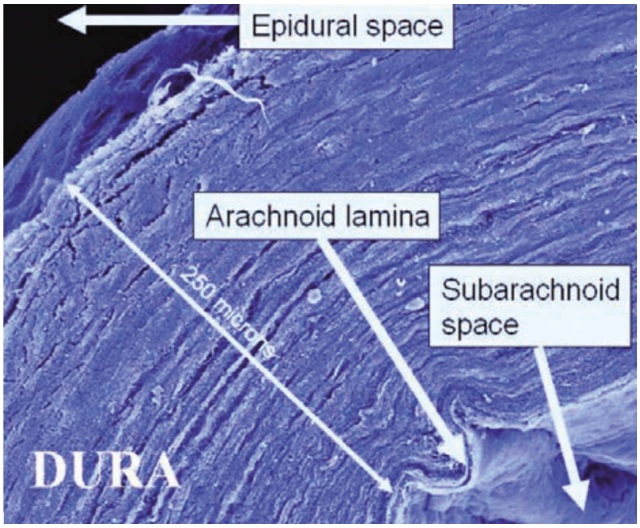
To achieve neural blockade in the neuraxial space, local anaesthetics are administered either in the intrathecal (subarachnoid) space or in the epidural space, targeting spinal cord tissue or spinal nerve roots and the dorsal root ganglia. Addition of opioids provides a synergistic effect through different receptor mechanisms, resulting in more profound anesthesia. For labour analgesia, where pain reduction rather than complete sensory loss is the aim, this combination facilitates reduction of LA concentration. This approach achieves targeted analgesia instead of profound anesthesia, which is desirable for labour as it preserves motor function and minimizes undesirable side effects such as motor block, sympathetic blockade (potentially causing hypotension), urinary retention and complete sensory loss that might interfere with pushing during the second stage.

Anatomy and physiology of the neuraxial space

The spinal cord, located within the bony vertebral column, contains a variety of ascending and descending pathways facilitating neural transmission between periphery and brain. Spinal nerves exiting through intervertebral foramina contain sensory fibers, motor fibers and depending on location, sympathetic (T1-L2) or parasympathetic (S2-S4) preganglionic fibers- all potential targets during neuraxial anesthesia.

The spinal cord is surrounded by cerebrospinal fluid (CSF) and three meningeal layers. The outermost dura mater consists of 70-80 permeable sheaths of randomly distributed collagen and fibrinogen fibres through which fluids can diffuse.(15,16)

Fig. 2. The spinal meningeal layers



Scanning electron microscopy image of the meninges showing the concentric rings formed by the dural laminae. (Magnification ×300.)(17)

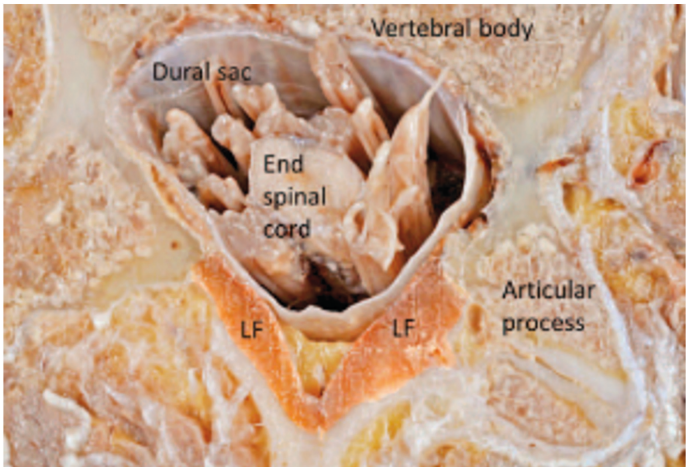
The middle meningeal layer, the arachnoid mater, forms the primary barrier preventing intrathecal CSF from leaking to the surrounding epidural space.(18–21) It is closely aligned with the inner dural surface. (17,22,23) The innermost pia mater adheres directly to the spinal cord.(20)

The subarachnoid space contains cerebrospinal fluid (CSF), which provides hydromechanical protection and maintains CNS homeostasis through a complex dynamic exchange of fluids and substances between CSF, interstitial fluid, nervous tissue and blood.(22,23)

Additional protection of the spinal cord is provided by the epidural compartment, which is far more complexly organized than previously thought and contains compartmentalized fat pads, vessels and fibrous septa.(24,25) The outer limit of the epidural space, the peridural membrane (PDM), encapsulates all components within the spinal canal including nerves, arteries, lymphatics and the epidural venous plexus.(26,27)

During neuraxial procedures, the ligamentum flavum – a supportive ligament connecting vertebral laminae posteriorly- must be passed. In epidural procedures, when one intends to stay outside the dural sac, it facilitates identification of the epidural compartment. When inserting an epidural needle with a saline or air-filled syringe attached upon which constant pressure is applied, the resistance the ligamentum flavum provides suddenly diminishes upon needle entry in the epidural compartment (loss of resistance technique). As the flavum is a paired structure with variable midline fusion, identification of the epidural space is not always straightforward, potentially leading to accidental dural puncture (Fig.3).(28)

Fig. 3 Transverse section of the human lumbar spine at L1 vertebral level.(28)



Abbreviation: LF, ligamentum flavum.

Neuraxial techniques

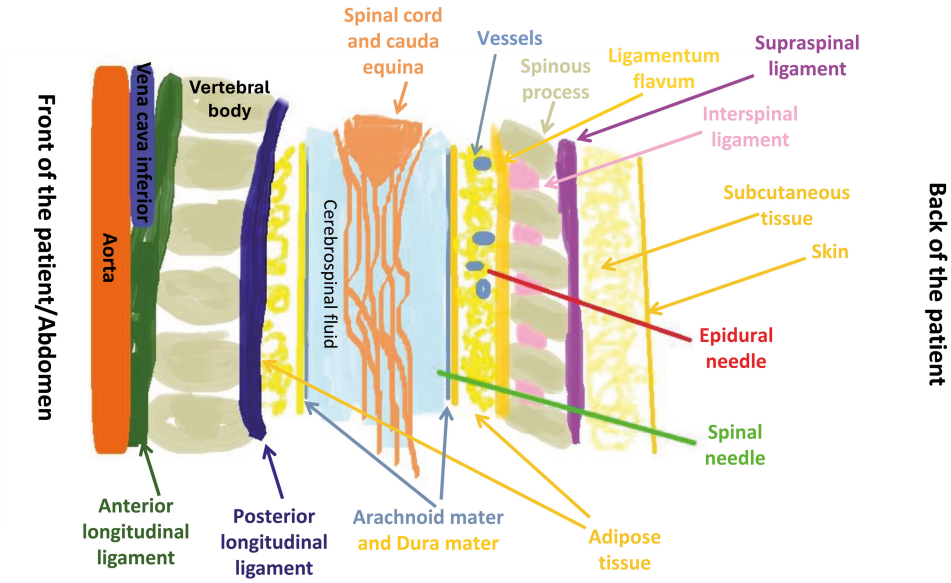
In obstetrics, neuraxial administration of LA, which blocks sensory nerve transmission, is preferred over inhalational or intravenous techniques to provide analgesia and anesthesia. Spinal or epidural drug administration less likely result in plasma concentrations sufficiently high to impact the fetus in utero. Advances in initiation techniques, delivery modes, drug combinations, and monitoring protocols have optimized efficacy and safety while minimizing interference with maternal and fetal wellbeing.

There is an interpatient variable response to neuraxial blockade which can be explained by an array of personal differences in anatomy of the spinal canal, nerve root organisation, CSF movement, epidural fat and vasculature, and co-morbidities which might affect ion channel composition and function. Together with the physiochemical properties and pharmacological actions of the used drug combination, these determine the resulting therapeutic effects and potential complications.

The resulting sensory, motor and sympathetic blockade depends on the injection site, the extent of the exposed nervous tissue surface and the dose and concentration of LA administered. Nerve fiber characteristics such as size, type and myelination also determine the response and extent of nerve blockade. Differences in block height and onset speed are observed between the various nerve fibre types, especially during spinal anesthesia.

Spinal and epidural techniques differ fundamentally in their anatomic target and resulting effects. Spinal anesthesia involves direct injection of local anesthetics into the CSF in the subarachnoid space, providing immediate access to the spinal cord and nerve roots. This results in a rapid onset of anesthesia (3-5 minutes), with a profound block achieved with smaller doses and a predictable duration (1.5-3 hours), depending on LA choice and additives. It is limited to levels below L2/L3 to avoid spinal cord injury, is generally easier to perform technically, has a lower failure rate, but is associated with a more profound and rapid-onset hypotension. As it is a single shot technique, its duration cannot be extended.

Fig. 4. Needle pathways in epidural and spinal techniques (posterior to anterior)



(Courtesy of Dr. Aleksandra Polen)

Epidural anesthesia results from LA injected into the epidural space, outside the dura mater. It requires a larger volume and results in a slower onset (15-20 minutes), as the spread is less predictable due to the more compartmentalized anatomy.(24,29)

The LA act on nerve tissue within the epidural compartment and eventually on intrathecal neural tissue, once diffusion through the meningeal membranes occurs. Contrary to common belief, the main barrier resisting diffusion is not the dural mater but the arachnoid mater. As drugs must pass the aqueous-lipid interface of the 6-8 layers of arachnoid membrane, an intermediate value of lipid solubility is preferable, as compounds with either low or high lipid solubility experience slower spinal diffusion.(16,30)

Table 1 Comparison of the epidural and spinal technique

Feature	Epidural technique	Spinal technique
Anatomical Space	Epidural compartment	Intrathecal space
Spinal level	Possible at all spinal levels, for obstetrics L2/L3 to L4/L5	Below L2/L3
Identification of location	Loss of resistance, hanging drop technique	Changed feeling, popping sensation
Needle Size	Larger (16-18G), facilitating catheter placement	Smaller (25-27G)
Catheter	Yes, can be left in place	No, single-shot technique
Duration	Can be extended with catheter for days	Limited (2-4 hours)
Onset Time	Slower (10-20 minutes)	Rapid (5-10 minutes)
Drug Volume	Larger volumes (10-20 mL)	Small volumes (1.5-3.5 mL)
Drug Concentration	Depending on purpose: anesthesia or analgesia	Depending on purpose, anesthesia or analgesia
Block Height Control	More controllable, gradual spread	Less controllable, rapid spread
Motor Block	Variable/can be minimized	Dense
Risk of PDPH	<1%, in case of accidental dural puncture (ADP)	Needle dependent, currently est. 1%
Hypotension	Less severe, gradual onset	More profound, rapid onset
Ideal Use Cases	Labour analgesia, postoperative pain, prolonged procedures	Cesarean delivery, in CSE also for labour analgesia
Technical Difficulty	More challenging	Relatively easier
Contraindications	Coagulopathy, infection at site, increased ICP	Same as epidural plus hypovolemia
Failure Rate	Higher (10-15%)	Lower (5%)
Post-procedural Care	May require more monitoring due to catheter	Less monitoring if uncomplicated

The difference between anesthesia and analgesia after neuraxial administration lies primarily in the concentration of LA used. Neuraxial (spinal or epidural) anesthesia requires high LA concentrations (such as bupivacaine 0.5% or lidocaine 2%) to achieve complete sensory and motor blockade for surgical procedures. This results in complete sensory and motor block with patient immobility, with more pronounced hemodynamic effects. In contrast, neuraxial analgesia can be achieved with lower concentrated LA solutions (such as bupivacaine 0.0635-0.125% or ropivacaine 0.1-0.2%), often combined with opioids to enhance pain relief while reducing LA requirements. This creates a partial sensory block which provides analgesia with minimal or no motor block, may allow for ambulation with low-concentrated solutions, causes less hemodynamic instability and permits active patient participation (table 2). It can be delivered epidurally via a catheter, facilitating continuous infusion or intermittent boluses, making it ideal for labour pain management.

Table 2 Comparison of Neuraxial Anesthesia and Analgesia

Feature	Neuraxial Anesthesia	Neuraxial Analgesia
Primary Purpose	Complete sensory and motor block for surgical procedures	Pain relief while maintaining some sensory and motor function
Drug Concentration	Higher concentration of local anesthetics	Lower concentration of local anesthetics, often with opioids
Degree of Block	Dense sensory block, complete motor block	Partial sensory block, minimal to no motor block
Patient Mobility	Immobile during effect	May allow ambulation when low concetrated LA solutions are used
Duration of Application	Usually for the duration of surgery	Can be maintained for hours to days (with catheter)
Hemodynamic Effects	More pronounced hypotension and bradycardia	Less hemodynamic instability
Common Applications	Cesarean delivery, lower abdominal/limb surgery	Labour pain, postoperative pain management
Consciousness	Patient remains awake (unless combined with sedation)	Patient remains awake and alert
Method of Administration	Bolus dose(s)	Continuous infusion, intermittent manual or programmed bolus administration
Common Agents	Bupivacaine 0.5%, lidocaine 2%, tetracaine	Bupivacaine 0.0625-0.125%, ropivacaine 0.1-0.2% to which fentanyl or sufentanil is added.
Monitoring Requirements	Continuous vital signs, block level assessment	Intermittent monitoring, regular pain assessment
Patient Participation	Limited during procedure	Active participation possible (e.g., pushing during labour)
Supplementation Needs	Rarely needs supplemental analgesia during procedure	May require additional analgesia in case of breakthrough pain

CONCLUSION

Neuraxial techniques have revolutionized obstetric anesthesia in various ways. They allow effective pain relief during labour when desired, without affecting maternal cognition and awareness, and provide safer anesthesia during caesarean delivery, while allowing women to experience and be present during the birth of their child. Despite continuous refinement of the techniques over decades, the delicate balancing act to provide optimal effectivity while minimizing side-effects and complications continues, as various persistent questions remain unanswered, some if which will be addressed in the studies included in this thesis, which explores these challenges and controversies from various perspectives, addressing several key questions:

As the persistent association between oxytocin augmentation and epidural labour analgesia has not completely been clarified yet, does electrohysterography provide a new tool to study the presence or absence of uterine responses to epidural analgesia initiation (Chapter 2)?

Can neuraxial administered drugs such as intrathecal morphine contribute to a reduced incidence of chronic postsurgical pain (CPSP) following caesarean delivery, and is there an association between CPSP and postpartum depression (chapter 3 and 4)?

Which technique and patient-related factors influence the incidence of hypotension after spinal anesthesia (chapter 5 and 6).

What are the current insights in postdural puncture headache, and what are European perspectives on management practice of PDPH after accidental dural puncture (ADP) during epidural labour analgesia initiation (chapters 7 and 8)? Which factors are associated with success or failure of an epidural blood patch as therapy in these patients, and will new insights in CSF physiology contribute to improved therapeutic options (chapters 9- 10)?

The evidence in these studies provides new insights in the nuances of neuraxial techniques and resulting desired or undesirable consequences. It identifies knowledge gaps and acknowledges that a renewed interest in underlying basic pathophysiologic mechanisms is needed if we want to move forward and further.

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