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Foundations and Advancements in Hemodynamic Monitoring: Part I-Elements of Hemodynamics
Zeliha Aslı Demir, Emre Sertaç Bingül, Burhan Dost, Gamze Talih, Aslıhan Aykut, Muhammed Enes Aydın, Başak Akça, Ümit Karadeniz
Page **87**

Perioperative Anaesthetic Approaches to Paediatric Patients: A National Survey
Ayşe Çiğdem Tütüncü, Zehra Hatipoğlu, Halil Cebeci, Elif Çopuroğlu, Dilek Altun, Serpil Zehra Ustalar Özgen
Page **98**

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Contents

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Review Article

Perioperative Care

Turkish Journal of Anaesthesiology & Reanimation

Turk J Anaesthesiol Reanim 2025;53(3):87-97

Foundations and Advancements in Hemodynamic Monitoring: Part I-Elements of Hemodynamics

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Abstract

Standard monitoring guidelines by the American Society of Anesthesiologists and European Society of Anaesthesiology and Intensive Care have not been updated for over a decade, despite rapid advancements in monitoring technology and the growing complexity of surgical patients. Traditional parameters such as blood pressure and pulse oximetry often fail to detect critical intraoperative conditions, emphasizing the need for comprehensive hemodynamic assessment. This review, the first of a two-part series, explores the fundamental elements of hemodynamics, including cardiac output, stroke volume, blood pressure, and oxygen delivery, with a focus on their physiological basis, clinical significance, and perioperative applications. This article provides a detailed foundation for understanding hemodynamic monitoring, setting the stage for the second article, which addresses advanced monitoring tools and their applications in contemporary anaesthesia practice.

Keywords: Anaesthesia monitoring, hemodynamics, intensive care, patient outcomes, perioperative care

Main Points

- Fundamental hemodynamic parameters, including cardiac output, stroke volume, blood pressure, and oxygen delivery, are essential for maintaining adequate tissue perfusion and ensuring timely intervention in perioperative care.
- Cardiac output, as a product of heart rate and stroke volume, provides a key indicator of macrohemodynamic stability, while stroke volume is modulated by preload, afterload, and myocardial contractility.
- Blood pressure monitoring alone may not accurately reflect tissue perfusion; understanding its relationship with systemic vascular resistance and flow dynamics is critical for clinical decision-making.
- Oxygen delivery depends on cardiac output and arterial oxygen content, emphasizing the importance of markers such as $ScvO_2$, lactate, and the $Pv\text{-}aCO_2$ difference in detecting hypoperfusion and guiding resuscitation.
- Emerging and future technologies in hemodynamic monitoring aim to integrate global and microcirculatory parameters, improving diagnostic precision and outcomes in anaesthesia and critical care.

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Introduction

The elements of standard monitoring defined by the American Society of Anesthesiologists were last updated in 2011, and the European Society of Anaesthesiology and Intensive Care also published a similar guideline in 2012.[1] While efforts have been made in recent years to establish minimum monitoring criteria, the rapid advancement of technology, artificial intelligence, and monitoring algorithms some of which are now accessible via mobile phones has begun to make an impact.[2] With the increase in life expectancy, the likelihood of encountering patients with many comorbidities undergoing major surgeries has risen significantly. For such patients, standard intraoperative monitoring may not simultaneously detect critical conditions such as hemorrhage, anaphylaxis, vasodilation, hypoperfusion of vital organs, ischemia, neurodepression, respiratory and cardiac depression, blood gas imbalances, fluid and electrolyte disturbances, acute heart failure, and arrhythmias. Timely intervention is crucial for saving the lives of critically ill patients, and this is only achievable through the prompt detection of complications. Normal readings of blood pressure (BP) and pulse oximetry do not necessarily indicate stability in critically ill patients; hence, close monitoring of physiological parameters is vital. In contemporary anaesthesia practices, monitoring of both macrohemodynamic and microhemodynamic parameters is expected to become increasingly prevalent to ensure adequate tissue perfusion (Table 1).

In this first article, Part I, we describe and discuss the fundamental elements of hemodynamics, focusing on their clinical importance and applications in the perioperative settings. This includes a detailed exploration of macrohemodynamic and microhemodynamic parameters essential for ensuring adequate tissue perfusion and timely intervention. In the companion article, Part II, we delve into advanced hemodynamic monitoring parameters and tools, highlighting their roles in addressing the limitations of standard monitoring and optimizing patient outcomes. Together, these two articles aim to provide a comprehensive understanding of hemodynamic monitoring for contemporary anaesthesia practices.

Key Parameters and Physiological Concepts

Cardiac output

Cardiac output (CO) is defined as the volume of blood ejected by the heart per minute, and is the product of stroke volume (SV) and heart rate (HR), expressed as CO=SVxHR (liters/minute). The amount of blood ejected during a single cycle is called SV, which averages around 70 mL in a resting adult. Atrial systole contributes to this by providing 15-25% of left ventricular diastolic filling without increasing the mean left atrial pressure. This contribution varies depending on the PR interval, atrial inotropic state, atrial preload and afterload, autonomic status, and HR. At the end of the diastole, the volume of blood in the ventricle is referred to as the end-diastolic volume (EDV), which is typically around 120 mL. The ventricles do not empty completely with each beat; only 60-80% of the blood is ejected (ejection fraction). Under resting conditions, physiological CO equates to approximately 4,900 (70 beats per minute ×70 mL), mL/min. Since patients of different sizes have varying COs, the cardiac index (CI) is often preferred for meaningful comparisons. CI is calculated as CO divided by body surface area (CI=CO/body surface area) (liters/min/m^2).[3] Pressure-volume changes in the left ventricle during a cardiac cycle are depicted in Figure 1.

Table 1. Hemodynamic Parameters

	Macrohemodynamic parameters	Microhemodynamic parameters
Basic	- Electrocardiogram - Arterial blood pressure - Heart rate - Peripheral oxygen saturation - End-tidal carbon dioxide - Body temperature	- Skin color - Capillary refill time - Mottling score - Blood lactate level - Urine output
Advanced	- Central venous pressure - Stroke volume - Cardiac output - dP/dt - Parameters indicating fluid responsiveness - Arterial elastance and systemic vascular resistance - Oxygen extraction ratio - Pulmonary artery pressure and pulmonary capillary wedge pressure - Ventriculo-arterial coupling	- Mixed venous oxygen saturation and central venous oxygen saturation - Near-infrared spectroscopy - P(v-a) CO_2 gap - Pv-aCO_2/Ca-vO_2 - Sublingual capnometry - Oxygen saturation in the veins of specific organs

dP/dt, rate of pressure change (dP) over time (dt); P(v-a) CO_2 Gap, venous-arterial carbon dioxide difference; Pv-aCO_2/Ca-vO_2, ratio of central venous carbon dioxide difference to arterial-venous oxygen content difference

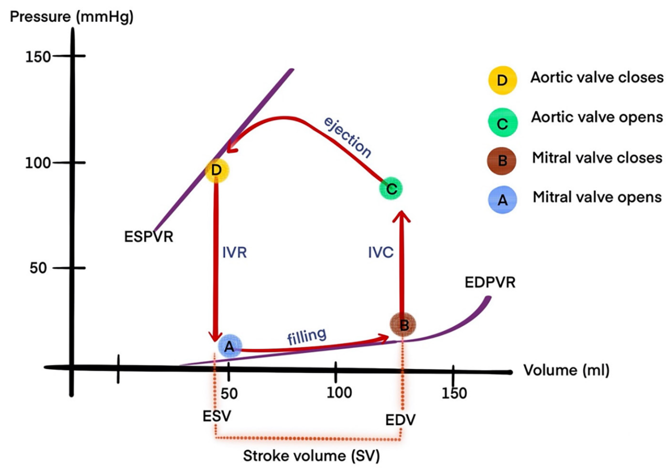

Figure 1. Left ventricle pressure volume loop.

IVR, isovolumic ventricular relaxation; ESPVR, end-systolic pressure-volume relationship; IVC, isovolumic contraction time; ESV, end-systolic volume; EDV, end-diastolic volume.

The resting HR is approximately 70 beats per minute in a person with normal physiology, and therefore each cardiac cycle lasts about 0.85 seconds. The approximate duration of systole is 0.3 seconds while diastole lasts 0.55 seconds. An increase in HR shortens diastole, reducing the time available for ventricular filling, which consequently leads to a decrease in SV. Perfusion of the ventricular muscles predominantly occurs during diastole. As a result of shortening diastole, the duration of coronary blood flow is shortened, perfusion is consequently impaired, and the workload increases. This is the time when the heart is working at maximum capacity, resulting in a high oxygen demand and an increased risk of myocardial ischemia.

Stroke volume

Preload

The more a muscle fiber is stretched before being stimulated to contract, the greater the force of contraction becomes. However, this characteristic is limited by the internal molecular structure of the muscle, such that further stretching beyond a critical (optimal) point reduces the force of contraction. This feature is known as the Frank-Starling mechanism.[4] During diastole, the blood returning to the heart stretches the ventricular muscle fibers. As the volume in the ventricle increases, the contraction becomes stronger. Thus, preload is directly related to EDV (or end-diastolic pressure as they change together), and if myocardial contractility and afterload are kept constant, increasing preload raises the EDV and consequently the SV. However, beyond a certain point, contractility begins to decline in overwhelmed muscle fibers.

In clinical practice, measuring EDV is challenging; therefore, estimations are made by measuring pressures. Central venous pressure (CVP) provides a reflection of right ventricular EDV, while pulmonary artery occlusion pressure reflects left ventricular EDV, although these values may not provide entirely accurate information.

Contractility

Contractility is the heart's ability to generate external work independently of preload and afterload. At the molecular level, an increase in inotropic state means stronger contractions due to increased calcium influx or myofilament calcium sensitivity, which results in higher peak pressure. Inotropy refers to the strength of the heart's contraction, chronotropy refers to the HR, dromotropy describes the conduction speed of electrical impulses within the heart, and lusitropy represents the heart's ability to relax. Positive lusitropic effects allow the heart to relax faster during diastole, enabling the ventricles to fill with more blood, thus enhancing CO. Negative lusitropic effects can lead to diastolic dysfunction.

Afterload

At the end of diastole, when ventricular muscle begins to contract, the goal is to overcome the "tension" in the ventricular wall and the "resistance" opposing the ejection of blood from the ventricle. In fact, the arterial system is not a simple conduit but a complex tree that represents several physical features such as compliance, resistance, and impedance. Given this complexity, theoretical calculation of afterload is utterly difficult. When ventricular wall tension is neglected, left ventricular afterload corresponds to the resistance posed by systemic circulation, termed systemic vascular resistance (SVR). Conversely, right ventricular afterload pertains to the resistance encountered in pulmonary circulation, known as pulmonary vascular resistance. Afterload is predominantly influenced by vascular tone, or the degree of vasoconstriction (or dilation) within the arteries and arterioles. Consequently, an increase in SVR results in reduced blood ejection for a given preload and contractility, leading to more blood remaining in the ventricle at the end of systole and a subsequent decrease in SV.[5] By recalling these fundamental concepts, one can gain practical experience through the application of our algorithm. The proposed algorithm is designed to provide clear guidance for hemodynamic monitoring, especially for novices (Figure 2).

Right ventricular function

All the principles and discussions mentioned so far are also applicable to the right ventricle. Essentially, the myocytes of the right and left ventricles are the same, with only a few minor differences. The most significant difference between the two ventricles is in the geometry of the cavity, according to Laplace's law, and the resulting pressure differences (the pressure in the right ventricle and pulmonary circulation is lower compared to the left). Because the right ventricle wall is thin, its shape changes quickly under varying conditions and is not adapted to contraction against high pressures. Therefore, in the presence of pulmonary hypertension, right heart failure appears more quickly and distinctly due to the excessive afterload.

Blood pressure

In daily practice, BP monitoring is essentially provided, yet CO is rarely assessed. It is important to understand the relationship between these two, because pressure is not equivalent to flow. Patients can have a "normal" BP with much lower flow, or normal flow with significantly different BP. BP results from the heart pumping blood into the

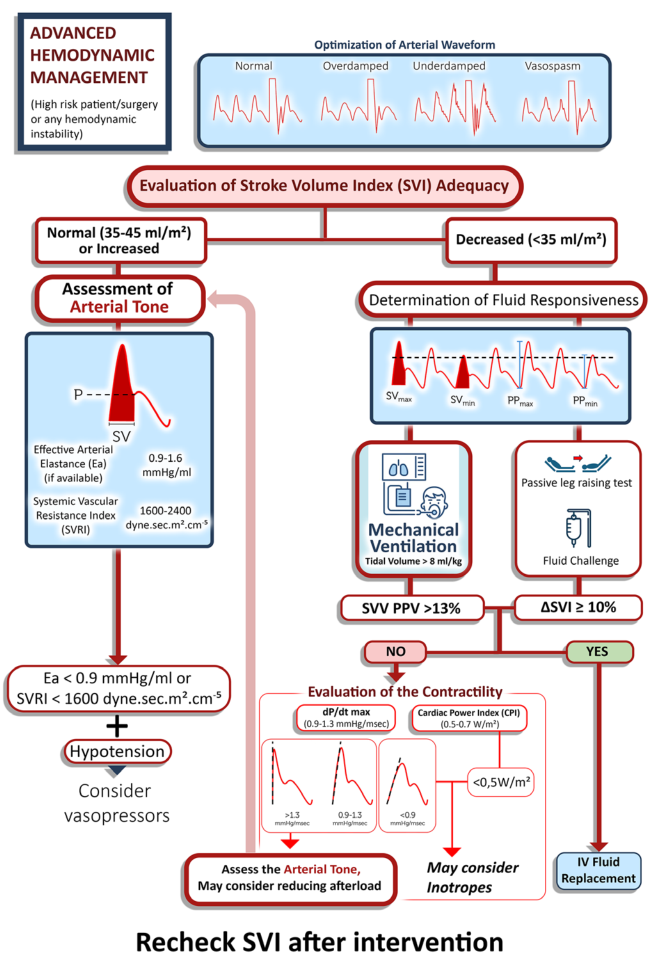

Figure 2. Algorithm for advanced hemodynamic management. This algorithm was designed as a simplified guide for the application of hemodynamic parameters. In clinical practice, patient-specific factors and varying clinical scenarios should be carefully considered when interpreting and utilizing an algorithm. Continuous reassessment and integration of additional physiological and diagnostic data are essential for optimizing hemodynamic management.

relatively small-capacity arterial system, which constitutes a significant resistance and contains only about 15% of the circulating volume. Resistance can be expressed in terms of pressure drop per unit of flow (according to Ohm's law, V=IR); circulatory resistance is defined as BP/CO, so BP=CO×SVR.

According to the equation, in a patient with very low CO, the body can maintain BP up to a point by increasing SVR. All organs need a pressure difference between arteries and veins to ensure sufficient flow through the large capillary beds. The arterial pressure waveform consists of multiple forward and backward propagating waves. A distortion can be observed as the waveform continuously changes during the movement of blood along the arterial tree. Due to changes in arterial characteristics or vessel architecture, the phenomenon of reflection occurs in many areas of the arterial tree. As the pressure waveform moves through large elastic arteries and smaller conductive arteries, pulse pressure is amplified due to the decreasing compliance of the conductive vessels and wave reflection.

Pulse pressure amplification is actually a distortion rather than an amplification, since it does not require additional energy input into the arterial system. Therefore, the peripheral pulse pressure tends to overestimate central pulse pressure. The pulse pressure waveform decreases as it reaches smaller arteries, arterioles, and capillaries. This peripheral reduction is called damping, and is primarily determined by changes in vascular resistance and the compliance of these smaller vessels. Systolic arterial pressure (SAP) is the maximum pressure that occurs in the arterial system during ventricular systole. It is determined by factors such as left ventricular contractility, SV, and arterial elastance. Diastolic arterial pressure (DAP) is the minimum pressure measured in the aorta during the diastolic phase, which starts with the closing of the aortic valve. Although the effect of the left ventricle on the arterial system, ends with the closure of the aortic valve, blood flow and perfusion continue at a different level. In terms of coronary perfusion, this pressure perfuses both coronary arteries and the rest of the arterial system when the aortic valve closes. This pressure is influenced by factors like arterial elastance and other afterload determinants, which also determine the SV passing into the aorta during systole. Mean arterial pressure (MAP) is the average pressure in the arterial system during the systolic and diastolic phases, and it reflects the pressure required to provide tissue perfusion. It can be calculated using this pragmatic formula: MAP=DAP+1/3 (SAP-DAP). However, this formula assumes that, physiologically, each cardiac cycle consists of one unit of systolic duration and two units of diastolic duration. Of note, SV, CO, SVR, arterial elastance, and total blood volume can influence MAP. In cases of HR changes, arrhythmias, heart failure, or aortic valve pathologies, the formula-based calculation of MAP may not reflect the true value and is valid only within normal physiological limits. In these cases, arterial wave analysis and calculating the area under the curve for MAP would be more accurate approaches.

Pulse pressure is the difference between systolic and diastolic pressure (approximately 40 mmHg) and is used as an indicator of arterial stiffness. Pulse pressure is related to the elasticity of the arterial walls and the SV of the heart. A narrowed pulse pressure (below 25 mmHg) may indicate conditions like aortic stenosis, severe hypovolemia, heart failure, or tamponade. On the other hand, in of conditions such as arteriosclerosis, septic shock, aortic insufficiency, pregnancy, or hyperthyroidism, an expanded pulse pressure range above 100 mmHg may be observed.[6]

The venous system, which holds approximately 70% of the total blood volume, exhibits a compliance 30 times greater than that of the arterial system, allowing it to accommodate large volumes of blood with minimal increases in pressure, thus acting as a reservoir for regulating circulatory dynamics. This makes it quite difficult to establish a behavioral model for the venous system.[7] However, it is well known that evaluating circulatory and systemic filling pressures, particularly CVP, provides valuable information for the anaesthesiologist's fluid management and hemodynamic manipulations. The venous system maintains a certain amount of blood volume to prevent the collapse of the vascular bed. The volume that keeps the vessel open is known as the unstressed volume. When the amount of blood in the venous system exceeds a certain level, it creates an elastic tension in the vessel wall, facilitating blood flow towards the right atrium. This volume is known as the stressed volume. The venous return to the right atrium is determined by the difference between the systemic filling pressure created by the stressed volume, which facilitates blood movement toward the right atrium, and the right atrial pressure that must be overcome. The higher the filling pressure and the lower the right atrial pressure (not falling below zero), the better the venous return becomes. Conversely, when the filling pressure is low (due to low stressed volume, hypovolemia, or vasodilation) and the right atrial pressure is high (due to heart failure), venous return is impaired. The mean systemic filling pressure (Pmsf), unlike circulatory filling pressures, is the pressure at which the arterial and venous system pressures are equalized in any part of the system other than the heart and pulmonary circulation. This pressure can be measured using the Pmsf hold or the Pmsf analog technique.[8]

Blood flow

The volume passing through a given cross-sectional area per unit time is called flow, and a pressure gradient is required to overcome a certain amount of resistance for the flow to occur (Flow=ΔP/R). Flow characteristics are classified as "laminar", "turbulent", and "transitional" flows, determined by the Reynolds number. The Reynolds number is a unitless term reflecting a critical limit at which flow shifts from laminar to turbulent flow, and is influenced by the density, velocity, viscosity of the fluid, and the diameter of the vessels. When the Reynolds number is below 2,000, laminar flow is observed; between 2,000 and 4,000, transitional flow occurs; and above 4,000, turbulent flow is present.

Viscosity is the resistance created by the liquid against flow, and its unit is centipoise (cP). The viscosity of blood ranges from 2.3 to 5.6 cP. The viscosity of blood is said to be higher *in vitro* than *in vivo*, which is attributed to the greater axial linear flow tendency in vascular structures.[9] In human physiology, systemic arterial blood flow cannot be described purely as "laminar" or "turbulent". Considering the pumping function of the heart and the total vascular network, concepts such as arterial compliance, arterial resistance, and aortic impedance come into play. To address this concept comprehensively, the "arterial Windkessel" model was developed over the years. The term "Windkessel" is German for "air chamber" and refers to hydraulic accumulators used by fire brigades to extinguish fires. In short, large arteries, due to the elastic fibers in their tunica media, behave like reservoirs, distending during systole and continuing to supply blood flow to the periphery during diastole. This describes arterial compliance. Peripheral small arteries and arterioles that create arterial resistance are another factor influencing flow. When aortic impedance due to disturbed aortic pressure in diastole, and total arterial inertance (flow inertia) in low-frequency cycles, is added to these two concepts, a four-element Windkessel model is formed.[10] After blood is pumped into the aorta under high pressure, it passes first through the large and medium arteries, then to smaller feeding arteries, the terminal arterioles, and the pre-capillary resistance arterioles, completing the arterial transition. Then, it enters the true capillaries, which have no contractile properties, followed by post-capillary resistance venules and collecting veins. Finally, the circulation is completed through the venous capacitant veins and large veins, which have a high capacity for volume. Large and medium-sized arteries and their subsequent arterioles are vascular structures that conform to the Windkessel model. Vascular smooth muscle cells are present in the outer layer of arteries, arterioles, and large veins. Depending on the "tone" (tension) of these cells, blood flow is "regulated" (autoregulatory). In venules and collecting veins, the regulatory capacity is quite small, but they have been found to influence flow to some extent.[10]

At the organ level, the right heart, lungs, and left heart are serially connected organs that form a mechanism through which deoxygenated blood is oxygenated. In contrast, the brain, coronary vessels, gastrointestinal system, kidneys, skeletal muscles, and skin are "parallely connected" and do not receive deoxygenated blood from other organs. These organs are subject to autoregulation.[11]

Oxygen delivery (DO_2)

Oxygen is transported in the blood in two ways. Approximately 98% of total oxygen is bound to hemoglobin, while 2% is dissolved directly in the plasma. An oxygen molecule binds to the iron atom of the heme group, enabling each hemoglobin molecule to carry four O_2 molecules. The sequentially increasing binding ability of oxygen to each subunit results in a unique sigmoidal oxyhemoglobin dissociation curve. Various defects in the synthesis or structure of red blood cells, hemoglobin, or the globin polypeptide chain can impair the blood's oxygen-carrying capacity, leading to hypoxia. Factors contributing to the rightward shift of the oxygen-hemoglobin dissociation curve, supporting the unloading of oxygen at tissues, include an increase in body temperature, hydrogen ions, and 2,3-diphosphoglycerate. DO_2 to tissues is the oxygen supplied to tissues per minute, and it is dependent on CO and the oxygen content (CaO_2) of arterial blood defined by formula as follows: $DO_2 = CO x CaO_2$. Venous blood entering the lungs has a partial pressure of oxygen (PvO_2) of about 40 mmHg, and arterial blood exiting the lungs has a PaO_2 of approximately 100 mmHg. Many organs have compensatory mechanisms for hypoxia. One such mechanism is the production of erythropoietin by peritubular fibroblasts in the renal cortex during chronic hypoxia. However, during the acute phase, the primary compensation mechanism is an increased extraction rate. The amount of oxygen delivered in the blood includes the partial pressure of dissolved oxygen, hemoglobin oxygen saturation, and the oxygen carrying capacity of hemoglobin. Henry's law refers to the effect of ambient pressure on dissolved oxygen, stating that the amount of dissolved oxygen in plasma equals the PaO_2 multiplied by the oxygen solubility constant in blood (0.003 mL mmHg O_2 dL). Hyperbaric oxygen therapy increases this solubility constant (0.3 mL mmHg O_2 dL under 3 atm pressure) making the amount of dissolved oxygen "significant" when compared to a very "neglectable" previous constant. The oxygen-carrying capacity of hemoglobin has been empirically determined as 1.34 mL O_2 g Hb. Referred to as the Hufner constant, this capacity can be altered by physicochemical properties of the environment. The basic knowledge of "hemoglobine tends to bind more oxygen in oxygen-rich ambient" or "hemoglobine tends to release more oxygen in hydrogen-rich ambient" (defined by Bohr's effect) are the major determinants, and therefore, oxygen carried by hemoglobine in the arterial system is expected to be around 1.39 mL O_2 g Hb, whereas it is around 1.31 mL O_2 g Hb in the venous system. The degree of saturation of this capacity is indicated as SaO_2. Therefore, the total oxygen content of arterial blood is given by the formula: $CaO_2 = (1.39 x Hb x SaO_2) + (0.0031 x PaO_2)$, with a normal value of approximately 20 mL O_2 dL. The mixed venous oxygen content (CvO_2) is given by the formula $CvO_2 = (1.31 \times Hb \times SvO_2 + (0.0031 \times PvO_2)$, with a normal value of approximately 15 mL O_2 dL.[12]

DO_2 is the rate at which oxygen is transported from the lungs to the microcirculation, calculated as DO_2 (mL min^{-1})=COxCaO_2, with normal DO_2 being approximately 1000 mL/min. If the CI is used, normal DO_2 is approximately 500 mL min^{-1} m^2.

Oxygen consumption (VO_2) is the rate at which oxygen is removed from the blood for use by tissues. Direct measurement of VO_2 is performed through respirometry. In a resting person, normal VO_2 is approximately 250 mL O_2 min. VO_2 can be calculated by rearranging the fick equation: VO_2 (mL O_2 min)=COx(CaO_2-CvO_2).

Oxygen extraction ratio (ER) is the slope of the relationship between DO_2 and VO_2. The O_2 extraction ratio=VO_2/DO_2. To simplify, O_2 ER=1-SvO_2 can be used for practical calculation. The normal O_2 ER is between 20 to 30%. At rest, VO_2 remains constant over a wide range of DO_2 because changes in DO_2 are balanced by reciprocal changes in oxygen extraction. If DO_2 falls to a level that cannot be compensated by increasing oxygen extraction, VO_2 starts to decrease. The DO_2 threshold below which VO_2 decreases is called the "critical DO_2", at which point VO_2 becomes dependent on delivery. When metabolic demand increases (e.g., exercise, pregnancy, shivering, fever), VO_2 increases because more oxygen is needed to sustain aerobic cellular metabolism. If CO or arterial oxygen content decreases, DO_2 is expected to decrease. CO may decrease due to heart disease or hypovolemia, while CaO_2 may decrease due to anemia or hypoxia (Figure 3).[13]

Oxygen deficiency and hypoxia

In 1920, the classic types of hypoxia were first described as "stagnant hypoxia" (decreased CO or regional blood flow), "anoxic hypoxia" (arterial hypoxemia), and "anemic hypoxia" (decreased hemoglobin).[14] Later, "cytopathic hypoxia" (secondary to sepsis and inflammation) and "histotoxic hypoxia" (e.g., cyanide poisoning) were also identified.[15] Under these conditions, there is cellular failure to utilize oxygen, and increasing DO_2 has little effect on correcting hypoxia. Physiologically, only 20-30% of the oxygen delivered to tissues is used, (O_2 ER 0.2-0.3), and under these conditions, VO_2 is said to be "independent of delivery", meaning that VO_2 is maintained despite decreasing DO_2. However, in humans, at approximately 4 mL kg^{-1} min^{-1} of critical DO_2 (DO_2 critical), O_2 ER is at its maximum (O_2 ER 0.6-0.8), and below this level of DO_2, VO_2 becomes "delivery-dependent".[12,13] If DO_2 continues to fall below this critical value or VO_2 increases at a given critical DO_2 level, tissue hypoxia occurs. Anaerobic respiration and lactate production, resulting from the imbalance between adenosine triphosphate supply and demand, lead to type A hyperlactatemia. Type B hyperlactatemia, on the other hand, is seen in conditions such as SIRS or inflammation induced by cardiopulmonary bypass.[16] It is known that O_2ER increases during exercise, peaking at 0.8 during maximum exercise. This occurs because, although there is an increase in DO_2, it does not match the increase in VO_2 required by exercise. However, in critical illness, particularly in sepsis, VO_2 may continue to increase despite an increase in DO_2, and the DO_2 critical value may be higher than normal. This is referred to as "pathological DO_2 dependence", and O_2 ER may not increase in proportion to VO_2. Additionally, in conditions where tissue edema and a decrease in functional capillary density in the microcirculation occur, even though global DO_2 increases, sufficient oxygen may not reach the cells.[17]

Perfusion adequacy

At the microcirculatory level, ensuring adequate perfusion and tissue oxygenation and being able to maintain it are

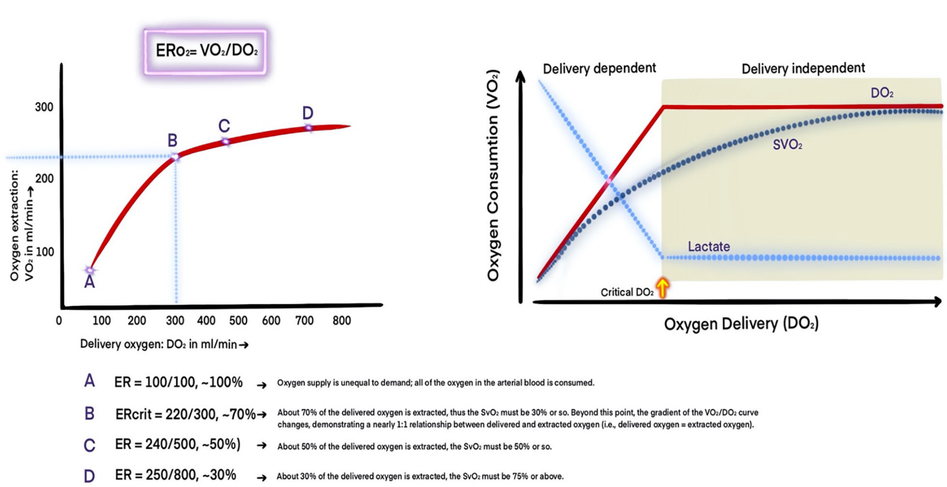

Figure 3. Relationship between oxygen delivery and consumption.

perhaps the primary goals of optimal hemodynamic patient management. The treatments are supposed to improve tissue perfusion, but simple and pragmatic tools reflecting organ-specific perfusion are lacking. Instead, global tissue perfusion is often monitored, and systemic findings are assessed by skin color, capillary refill time (CRT), urine output, arterial pH, mixed venous oxygen saturation, blood lactate, and markers of anaerobic metabolism, such as the venous-arterial carbon dioxide difference.[18] On the other hand, several methods have been developed for assessing regional organ perfusion, including the use of cerebral oximetry, gastric mucosal CO_2 tonometry, tissue oxygen electrodes, sublingual tonometry etc. Yet, these methods require further clinical evaluation.[19]

Capillary refill time

CRT is defined as the time needed for the skin to return to its normal color after 10 seconds of pressure applied to the nailbed. Normally, this time should be less than 3 seconds. Although the impact of CRT normalization on patient morbidity and mortality has not been clearly demonstrated, it is used as a quick and effective method for assessing perfusion, especially in pediatric and intensive care patients.[20]

Mottling score

The mottling appearance on the skin suggests microcirculatory insufficiency. Those patchy color changes are observed due to heterogeneous vasoconstriction in small vessels, often starting around the knees and elbows. The mottling score can easily be assessed at the bedside, and is scored in a spectrum between 0 (no mottling) to 5 (mottling extending to the inguinal folds).[21]

Lactate

When oxygen levels fall to critical levels, pyruvate is metabolized into lactate by lactate dehydrogenase. Therefore, lactate is considered a significant marker of anaerobic metabolism. In addition to hypoxic mechanisms, there are non-hypoxic pathways that also contribute to lactate production.[16] Factors such as systemic inflammatory response, cardiopulmonary bypass, poisoning, catecholamines, and excessive β-adrenergic stimulation in muscle cells can increase glycogenolysis and glycolysis and lead to increased lactate production due to the saturation of pyruvate dehydrogenase enzyme activity. On the other hand, liver and kidney failure, which are responsible for lactate clearance, as well as chronic alcoholism, can also lead to increased lactate levels. Hyperlactatemia is defined as a lactate level greater than 2 mmol L, and lactic acidosis occurs when lactate levels exceed 4 mmol L along with decreasing pH. Lactate is a "late" marker of hypoperfusion but serves three purposes: (1) it can diagnose severe sepsis (infection plus high lactate); (2) it can trigger early goal-directed therapy if ≥4 mmol L; and (3) high lactate levels can guide resuscitation efforts to reduce production and enhance clearance.[22,23] The literature clearly suggests that high lactate levels should raise concern and serial lactate monitoring should be performed to observe lactate clearance, which may be considered as a resuscitation goal for critically ill patients.[23]

Venous oxygen saturation (SvO_2, $ScvO_2$)

The oxygen saturation of hemoglobin in venous blood can be measured using a pulmonary artery catheter for mixed venous (SvO_2) or a jugular central venous catheter for $ScvO_2$. The normal value of SvO_2 is between 65-80%, and a cardiac pathology causing a left-to-right shunt must be excluded before SvO_2 measurements can be used. When oxygen extraction increases, venous oxygen saturation begins to decrease. Similarly, as oxygen extraction decreases (such as anaesthesia, increased FiO_2, hypothermia, etc.), $ScvO_2$ rises. It is a global parameter, and under physiological conditions, $ScvO_2$ is typically 2-7% lower than SvO_2. In pathological conditions, circulation centralizes to maintain brain perfusion, and SvO_2 becomes lower than $ScvO_2$. However, because of the similarity in trend graphicgraphics, the less invasiveness, and its ability to reflect the DO_2-consumption balance, $ScvO_2$ is frequently used instead of SvO_2.[24,25] Yet, the reliability of $ScvO_2$ for predicting SvO_2 in severe sepsis is still a matter of debate.[26] From another perspective, lactate can predict $ScvO_2$, but only at certain critical levels in a few shock patients, it is emphasized that lactate and $ScvO_2$ are not interchangeable markers of tissue oxygenation/perfusion.[27] These findings underscore the need for comprehensive patient monitoring through the use of multiple devices, employing all available modalities to ensure optimal care.

Near-infrared spectroscopic oximeter (NIRS)

NIRS devices are based on the modified Beer-Lambert law, which states that the intensity of transmitted light decreases exponentially as the concentration of a substance through which the light passes increases. Potential changes in perfusion and oxygenation in the frontal cortex are monitored, thus categorizing it as a regional parameter. Unlike pulse oximeters, it works even in non-pulsatile conditions. This allows continuous, non-invasive, real-time, and reliable oxygen saturation measurement even during cardiopulmonary bypass and arrest situations. Its ability to measure non-invasively is a significant advantage over jugular venous oxygen saturation measurements. Tissue oxygenation measured by NIRS is a combination of arterial, venous, and capillary blood. In frontal measurements, approximately 70-75% of the cerebral blood volume is venous.[28] The normal range for healthy individuals is accepted as 58-82%, with measurements between 0-15% providing significant information on cardiopulmonary resuscitation processes. A decrease of 20% unilaterally or bilaterally from an individual's baseline (before anaesthesia induction) or a 50% absolute decrease in $rScO_2$ is considered pathological.[29] In heart, and carotid surgery, unilateral decreases or increases can indicate issues like cannula malposition, shunt requirements, major stroke, or hyperperfusion. Although existing research suggests that a specific intervention or factor reduces postoperative cognitive dysfunction, more studies are needed.[30]

There are multiple potential measurement areas for peripheral tissue oxygenation with NIRS, and these are typically defined under the assumption that the underlying muscle body serves as a relatively homogeneous tissue compartment. The thenar eminence, which has a thin fat layer and is less prone to systemic edema than other skin areas, is commonly considered an ideal area for measurement.[31] Peripheral muscle tissue oxygen saturation (StO_2), which is also determined by NIRS, has been suggested as a more reliable indicator of traumatic shock than systemic hemodynamic or invasive oxygenation variables.[32] The main disadvantage of the thenar eminence is its cone-like structure, which causes problems with attaching the probe. Physiologically, the forearm, rather than just the thenar, is the dominant area for circulatory distress (reflex) vasoconstriction. Vascular response in this area may occur earlier and more intensely than in other body regions. This makes the forearm a suitable area for peripheral NIRS measurement, which has been validated in the literature, detecting circulatory distress in experimental hypovolemia more sensitively than the thenar eminence.[33] Other potential areas include the pectoral and deltoid muscles, the paravertebral region, the vastus lateralis muscle, kidneys, or intestines in neonates and infants, where NIRS monitoring can be performed. Yet, these promising indicators are not standard practice.

Pv-aCO_2 difference (ΔPCO_2 gap)

The Pv-aCO_2 gap is the difference between the partial CO_2 pressure in venous and arterial blood, whose normal value is 2-6 mmHg. The Pv-aCO_2 difference is proportional to CO_2 production and inversely proportional to CO, and it shows similar trends to SvO_2. It reflects the venous return in the capillary bed and the adequacy of microcirculation. Therefore, this particular indicator shows the adequacy of venous blood flow in order to eliminate CO_2 rather than hypoxia; the Pv-aCO_2 difference indirectly reflects CO. When Pv-aCO_2 is above 6 mmHg, CO is assumed to be inadequate.[34] However, hypoxia (except stagnant hypoxia) does not lead to an increase in the Pv-aCO_2 gap. This can help distinguish whether perfusion disorders are circulatory or respiratory in origin. CO_2 changes occur faster than changes in lactate levels, making PCO_2 a more sensitive marker for hemodynamic alterations. In many critical conditions, the Pv-aCO_2 gap has been argued to have significant predictive value for severe postoperative complications. Additionally, persistent high Pv-aCO_2 gaps may indicate increased mortality, but it is still unclear whether closing it improves prognosis.[35-37]

Pv-aCO_2/Ca-vO_2 ratio

This ratio is derived from the respiratory quotient (RQ) and indicates how many moles of O_2 are consumed for each mole of CO_2 produced. In aerobic metabolism, one O_2 molecule corresponds to one CO_2 molecule, and the RQ value is 1. In hypoperfusion, where anaerobic metabolism dominates, both VO_2 and VCO_2 decrease, but this decline is asymmetrical. VCO_2 decreases negligibly due to the contribution of anaerobic metabolism, while VO_2 increases significantly. Pv-aCO_2/Ca-vO_2>1.4 indicates anaerobic metabolism. At this level, a reaction is observed earlier than the change in lactate levels.[38] However, some studies emphasize that this ratio does not predict changes in postoperative cardiac surgery patients and may not reliably predict the onset of organ dysfunction.[39,40]

Sublingual capnometry

In hemodynamically unstable intensive care unit patients, sublingual PCO2 (PSLCO2) and the PSLCO2-PaCO2 gradient have been found to be better predictors of tissue hypoxia than traditional markers.[41,42] These suggestions have not yet gained widespread recognition in the current literature.

Future perspective in tissue oxygenation assessment

With more advanced devices, the goal is to measure several valuable parameters with a single measurement probe that can be applied at the bedside. The combination of spectrophotometry, laser Doppler-based perfusion measurement, and side-stream dark field imaging is expected to contribute to the diagnosis, improvement, and treatment of tissue hypoxia in the future.[43]

Conclusion

Comprehensive hemodynamic monitoring is essential for optimizing patient outcomes in anaesthesia practices. The fundamental parameters of CO, SV, BP, and DO_2 provide vital insights into the physiological state of patients and serve as the cornerstone for detecting hemodynamic instability. Understanding the interplay between these parameters, alongside advanced markers such as $ScvO_2$, lactate, and Pv-aCO_2 difference, enables timely and effective interventions, particularly in critically ill patients with complex comorbidities.

Despite the limitations of standard monitoring tools, integrating these fundamental principles into clinical practice enhances the ability to ensure adequate tissue perfusion and mitigate risks associated with perioperative complications. With advancements in technology and monitoring algorithms, future approaches are expected to bridge the gap between global hemodynamic assessments and microcirculatory insights, offering a more precise understanding of perfusion adequacy.

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Original Article

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Perioperative Anaesthetic Approaches to Paediatric Patients: A National Survey

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Abstract

Objective: This study aims to assess the practices of anaesthesiologists in Türkiye regarding paediatric anaesthesia. It focuses on preoperative, intraoperative, and postoperative care protocols.

Methods: Survey data were collected using a web-based electronic platform. The participants were asked to answer the questions based on the available equipment in their hospitals in daily practice. The questionnaire forms were sent to participants by the Turkish Society of Anesthesiology and Reanimation via e-mail

Results: Three hundred five anaesthesiologists responded to the survey. The specific practices and standards for paediatric anaesthesia in Türkiye along with how anaesthesiologists approach paediatric patients were concluded from the survey results.

Conclusion: There are still gaps in paediatric anaesthesia practice. We believe that further research and dedicated discussions on this topic will play a key role in addressing these drawbacks.

Keywords: Anaesthesia, national survey, paediatric, perioperative, postoperative, preoperative

Main Points

- This study highlights the choices of anaesthesiologists in Türkiye regarding the preoperative, perioperative and postoperative periods in paediatric patients.

Introduction

Newborns, infants, and children differ from adults in their anatomy, physiology, pharmacology, emotions and social interactions. Moreover, they differ from each other in terms of these features. These fundamental characteristics make paediatric anaesthesia for individuals under the age of 18 unique.

Even healthy children may require surgical or diagnostic interventions for their medical care at some point in their lives, the anaesthesia procedures required for these children hold an important place in daily practice. It is known that, on average, one out of every seven children receives general anaesthesia at least once before the age of 3.[1]

The development of new monitoring devices, updates in anaesthesia protocols, increased use of minimally invasive surgeries, and advances in postoperative care are guiding us as anaesthesiologists in our professional development. In this context, the characteristics of paediatric anaesthesia in Türkiye, the approach of anaesthesiologists to

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these patients, and the infrastructure of hospitals are not fully defined. This study aims to evaluate the approach of anaesthesiologists to paediatric anaesthesia in Türkiye, focusing on preoperative, intraoperative, and postoperative care.

Methods

The study was approved by the Çukurova University Faculty of Medicine Non-Interventional Clinical Research Ethics Committee (decision no.: 12/129, and date: January 6, 2023). The cross-sectional survey-based study was conducted between February and March 2023. Survey data were collected using a web-based electronic platform. First, the research team of seven anaesthesiologists discussed the content and created the structure. Then, a pilot study was conducted on twenty anaesthesia trainees. The research team reviewed the necessary corrections of the questionnaire, and the questionnaire was finalized. The participants were asked to answer the questions based on the equipment available in their hospitals in daily practice.

The questionnaire forms were sent to participants by the Turkish Society of Anesthesiology and Reanimation via e-mail. Simultaneously, the authors informed participants in nearby provinces again via WhatsApp.

Since the relevant article is a survey study, patient consent is not required.

Statistical Analysis

Statistical analysis was performed using the SPSS version 20.0 statistical software package (IBM SPSS Statistics for Windows, Version 20.0; IBM Corp., Armonk, New York, USA). Descriptive analysis, including frequency (%), mean ± standard deviation (and, if necessary, median, minimum and maximum), was used for statistical analysis.

Results

Three hundred and five anaesthesiologists responded to the survey. Demographic characteristics of participants have been presented in Table 1.

When the general characteristics are examined, 76% of the respondents indicated that the youngest age group was neonates. Additionally, 46.4% indicated that they administered anaesthesia to approximately 50 paediatric patients per month, and they administered anaesthesia to the 1-6 age group most frequently in their daily practice, with an average frequency of 30%. While American Society of Anesthesiologists (ASA) I-II group paediatric patients constituted more than 50% of the daily practice, ASA III-IV group patients accounted for less than 10% (Table 2). The majority of participants reported that daily anaesthesia practice consists of minor surgeries. 51.1% of surgical cases were from the Ear, Nose, and Throat (ENT) department (Table 3).

Table 1. Characteristics of Participants

	n (%)
Age (years)	43.9±8.3
Gender (Female/Male)	208/97 (68.2/31.8)
Position	
Specialist doctor	194 (63.8)
Assistant professor	30 (9.9)
Associate professor	48 (15.8)
Professor doctor	32 (10.5)
Graduated	
University hospital	243 (79.7)
Ministry of health education and research hospital	49 (16.1)
Ministry of health/university hospital	13 (4.3)
Affiliation	
University hospital	82 (26.9)
Ministry of health education and research hospital	61 (20.0)
Ministry of health/university hospital	39 (12.8)
Public hospital	67 (22.8)
Private hospital	56 (18.4)

Table 2. Age Distribution of Paediatric Patients in Anaesthesia Practice

	n (%)
Ratio of paediatric/adult patients in daily anaesthesia practice	
<10%	108 (35.4)
10-30%	120 (39.3)
31-50%	35 (11.5)
51-80%	12 (3.9)
81-100%	30 (9.8)
Paediatric age group most frequently anaesthetized in the daily practice	
0-1 month	38 (12.5)
1 month-1 year	80 (26.2)
1-6 years	249 (81.6)
6-10 years	122 (40.0)
>10 years	59 (19.3)
The smallest patient age range you have received in your anaesthesia practice	
<1 month	234 (76.7)
1-6 month	25 (8.2)
6 month-1 year	20 (6.6)
1-3 years	19 (6.2)
>3 years	7 (2.3)

Table 2. Continued	
What is the monthly count of paediatric patients receiving anaesthesia?	
<10	69 (22.7)
11-50	141 (46.4)
51-100	35 (11.5)
>100	59 (19.4)
Premature babies rate in daily anaesthesia practice	
<10%	279 (92.7)
10-25%	19 (16.3)
25-50%	2 (0.7)
>50%	1 (0.3)
Number of paediatric patients with ASA I-II in daily practice	
<10%	14 (4.6)
10-25%	27 (8.9)
25-50%	86 (28.2)
>50	178 (58.4)
Number of paediatric patients with ASA III-IV in daily practice	
<10%	101 (33.6)
10-25%	76 (25.2)
25-50%	88 (29.2)
>50	36 (12)

ASA, American Society of Anesthesiologists.

Preoperative Period

59.3% of the respondents reported no preoperative unit in their operating rooms. According to the survey results, the premedication usage rate in paediatric patients was 53.8%. The rate of acceptance for parents or guardians in the preoperative unit was 57.8% (Table 4).

Intraoperative Period

During minor surgeries, standard ASA monitoring methods, excluding temperature, were commonly employed. While invasive arterial blood pressure monitoring was most frequently used in addition to routine ASA monitoring in major surgeries, cardiac output (CO) monitoring was used the least frequently (Table 4).

The rate of intravenous agent use during anaesthesia induction was 65.6%, and for anaesthesia maintenance, sevoflurane, neuromuscular blockers, fentanyl, and remifentanil were the most commonly chosen options. The most commonly preferred fluids in the perioperative period were 0.9% NaCl as the crystalloid solution and hydroxyethyl starch (HES) 130/0.4 as the colloid solution. The internal jugular vein was the most frequently catheterized vein. During catheterization, the ultrasound (US) usage rate was similar to that of the landmark technique.

Table 3. Surgical Procedures

		n (%)
The most common surgical procedures in which anaesthesia is given in daily practice (Yes/No)	Ear nose throat	156/149 (51.1/48.9)
	Orthopedics and traumatology	145/160 (47.5/52.5)
	Paediatric surgery	131/174 (43.0/57.0)
	Urology	105/200 (34.4/65.6)
	Outpatient anaesthesia	87/218 (28.5/71.5)
	Neurosurgery	55/250 (18.0/82.0)
	Plastic and reconstructive surgery	46/259 (15.1/84.9)
	Cardiovascular surgery	37/268 (12.1/87.9)
	Ophthalmic surgery	38/267 (12.5/87.5)
	Other	69/236 (22.6/77.4)
Minor surgery rate in daily anaesthesia practice		
<10%		47 (15.4)
10-25%		66 (21.6)
25-50%		87 (28.5)
>50%		105 (34.4)
Major surgery rate in daily anaesthesia practice		
<10%		84 (27.7)
10-25%		66 (21.8)
25-50%		88 (29.0)
>50%		65 (21.5)

Table 4. Perioperative Applications

			n (%)
Preoperative period	Is there a paediatric preoperative unit? (Yes/No)		124/181 (40.7/59.3)
	Routine premedication (Yes/No)		164/141 (53.8/46.2)
	Acceptance of parents or guardians in the preoperative unit (Yes/No)		160/117 (57.8/42.2)
Anaesthesia	Monitoring methods used during minor surgery procedures (Yes/No)	ECG	298/7 (97.7/2.3)
		NIBP	246/58 (80.9/19.1)
		SpO_2	301/4 (98.7/1.3)
		$EtCO_2$	277/27 (91.1/8.9)
		Temperature	105/199(34.5/65.5)
	Monitoring methods used in addition to standard monitoring in major surgery procedures (Yes/No)	Depth of anaesthesia monitoring	90/187 (32.5/67.5)
		Neuromuscular monitoring	40/237 (14.4/85.6)
		Cardiac output monitoring	34/242 (12.3/87.7)
		Cerebral oximeter	77/200 (27.8/72.2)
		Invasive arterial blood pressure monitoring	230/47 (83.0/17.0)
		Other	80/197 (28.9/71.1)
	Induction	Intravenous agents	200 (65.6)
		Inhalation agents	65 (21.3)
		Intravenous+inhalation agents	39 (12.8)
		Inhalation+other	1 (0.3)
	Maintenance (Yes/No)	Sevoflurane	298/4 (98.7/1.3)
		Desflurane	82/220 (27.8/72.8)
		Neuromuscular blocker	220/82 (72.8/27.8)
		Fentanyl	218/83 (72.4/27.6)
		Remifentanil	228/74 (75.5/24.5)
		Dexmedetomidine	22/280 (7.3/92.7)
		Other opioids	44/258 (14.6/85.4)

Table 4. Continued

The most commonly used perioperative fluid choice	Crystalloid solutions	0.9% NaCl	166/137 (54.8/45.2)
		Ringer lactate	77/226 (25.4/74.6)
		Isolyte	127/176 (41.9/58.1)
		5% dextrose in 0.45% NaCl	143/160 (47.2/52.8)
		5% dextrose	18/285 (5.9/94.1)
		10% dextrose	0/303 (0.0/100.0)
		Other fluids	33/271 (10.9/89.1)
	Colloid solutions	Gelofusine	87/197 (30.6/69.4)
		Hydroxyethyl starch (130/0.4)	114/170 (40.1/59.9)
		Fresh frozen plasma	69/215 (24.3/75.7)
		Albumin	14/270 (4.9/95.1)

Table 4. Perioperative Applications

			n (%)
The most commonly used perioperative fluid choice	Crystalloid solutions	0.9% NaCl	166/137 (54.8/45.2)
		Ringer lactate	77/226 (25.4/74.6)
		Isolyte	127/176 (41.9/58.1)
		5% dextrose in 0.45% NaCl	143/160 (47.2/52.8)
		5% dextrose	18/285 (5.9/94.1)
		10% dextrose	0/303 (0.0/100.0)
		Other fluids	33/271 (10.9/89.1)
	Colloid solutions	Gelofusine	87/197 (30.6/69.4)
		Hydroxyethyl starch (130/0.4)	114/170 (40.1/59.9)
		Fresh frozen plasma	69/215 (24.3/75.7)
		Albumin	14/270 (4.9/95.1)
Perioperative catheterization	Most commonly used veins	Internal jugular venous	218/77 (73.9/26.1)
		Subclavian venous	75/220 (25.4/74.6)
		Brachiocephalic venous	17/278 (5.8/94.2)
		Femoral venous	78/217 (26.4/73.6)
		Peripheral veins	145/149 (49.3/50.7)
	Most commonly used method	Landmark	147 (50.7)
		Ultrasound-guided	143 (49.3)
Postoperative period	Is there a paediatric postoperative unit? (Yes/No)		166/139 (54.4/45.6)
	Acceptance of parents or guardians in the postoperative unit (Yes/No)		124/165 (42.8/56.9)
	Patient's waiting time in the postoperative unit		
	<30 min		180 (61.4)
	30-60 min		96 (32.8)
	>60 min		17 (5.8)
	Scoring systems in the postoperative unit		
	Aldrete score		202/96 (67.8/32.2)
	Ped-PADSS		64/234 (21.5/78.5)
	No		56/240 (18.9/81.1)
	Other		15/283 (5.0/95.0)
	Use of heater (Y/N)		263/34 (88.6/11.4)

ECG, electrocardiography; NIBP, non-invasive blood pressure; SpO_2, Peripheral oxygen saturation, $EtCO_2$, End-tidal carbon dioxide; Ped-PADSS, paediatric post-anaesthetic discharge scoring system.

Respiratory Management

The preferred modes of mechanical ventilation were as follows: pressure control ventilation (69.3%), volume control ventilation (68.9%), pressure support ventilation (16.9%), and spontaneous ventilation (7.9%). The most commonly applied values of mechanical ventilator parameters were as follows: 6-8 mL kg^{-1} for tidal volume (Vt), 5 cmH_2O for positive end-expiratory pressure (PEEP), and 40-49% for inspired oxygen concentration. The recruitment maneuver usage rate among respondents was 58.7%. The usage rate of the open system for anaesthesia was 17.8% (Table 5).

Postoperative Period

Sixty-one percent of participants stated that they kept their patients waiting for less than 30 minutes in the postoperative unit. Other answers related to the postoperative period are presented in Table 5.

Table 5. Respiratory Management		
		n (%)
Volume control ventilation modes	(Yes/No)	208/94 (68.9/31.1)
Pressure control ventilation modes	(Yes/No)	205/91 (69.3/30.7)
Pressure support ventilation	(Yes/No)	51/251 (16.9/83.1)
Spontaneous ventilation	(Yes/No)	24/278 (7.9/92.1)
Other	(Yes/No)	4/298 (1.3/98.7)
Tidal volume	<6 mL kg^{-1}	28 (9.3)
	6-8 mL kg^{-1}	178 (58.9)
	8-10 mL kg^{-1}	94 (31.1)
	>10 mL kg^{-1}	2 (0.7)
Use of recruitment maneuver	(Yes/No)	175/123 (58.7/41.3)
Use of PEEP	(Yes/No)	241/61 (79.8/20.2)
Table 5. Continued		
Value of PEEP	1-2	20 (8.2)
	3	70 (28.7)
	4	56 (23.0)
	5	89 (36.5)
	>5	9 (3.7)
Inspired oxygen concentration	21-29%	5 (1.7)
	30-39%	48 (15.9)
	40-49%	194 (64.2)
	50-99%	55 (18.2)
	100%	0 (0.0)
Use of open system	(Yes/No)	54/249 (17.8/82.2)
Reason for choosing manual ventilation		
Causes due to anaesthesia machine		82 (60.3)
Assistant training		24 (17.6)
Habit		9 (6.6)
Causes due to anaesthesia machine + assistant training		20 (14.7)
Assistant training + habit		1 (0.7)

PEEP, positive end-expiratory pressure.

Seventy point four percent of the respondents were using the regional analgesia technique less frequently. Among the various regional techniques used, the epidural method was the most common (63.2%). In the early postoperative period, the most commonly used intravenous analgesic options were fentanyl (83.8%) and morphine (83.1%). The CHEOPS and FLACC scores ranked first and second, respectively, in pain assessment (Table 6).

Table 6. Pain Management		
		n (%)
Pain management	**Regional analgesia administration rate**	
	<25%	209 (70.4)
	25-50 %	52 (17.5)
	50-75 %	20 (6.7)
	>75%	16 (5.4)
	The most preferred method of analgesia	
	Intravenous methods	181 (59.7)
	Regional methods	19 (6.3)
	Multimodal analgesia	103 (34.0)
	Intravenous analgesics preferred in the early postoperative period (in the first 2 hours)	
	Fentanyl	49/253 (16.2/83.8)
	Morphine	51/251 (16.9/83.1)
	Tramadol	143/159 (47.4/52.6)
	Paracetamol	285/17 (94.4/5.6)
	Ketamine	19/283 (6.3/93.7)
	Other	29/273 (9.6/90.4)
	The most commonly used regional analgesia methods	
	Caudal block	157/82 (65.7/34.3)
	Lumbar/thoracic epidural	88/151 (36.8/63.2)
	Truncal blocks (thorax plane and abdominal wall blocks)	114/125 (47.7/52.3)
	Upper extremity blocks	107/132 (44.8/55.2)
	Lower extremity blocks	59/180 (24.7/75.3)
	Pain scores	
	CHEOPS	27/249 (9.8/90.2)
	FLACC	66/210 (23.9/76.1)
	VAS	179/97 (64.9/35.1)
	Wong Baker Face Scale	125/151 (45.3/54.7)
	Medical staff assessing pain	
	Doctor	89/193 (31.6/68.4)
	Nurse	234/45 (83.9/16.1)
	Anesthesia student	2/280 (0.7/99.3)

CHEOPS, Children's Hospital of Eastern Ontario Pain Scale; FLACC, face, legs, activity, cry, consolability; VAS, visual analogue scale.

Discussion

In this study, we described the perioperative anaesthesia approaches used by anaesthesiologists in Türkiye for children of all age groups. To the best of our knowledge, this study is the first nationwide survey on paediatric anaesthesia. The results of the study show that paediatric patients in anaesthesia practice represent a minor proportion (<30%) of daily practice in our country, and most of these patients were >1 year old and underwent minor surgery.

In the article published in 2008, it was stated that according to data obtained from the World Health Organization, 30% of all anaesthesia procedures in daily practice occur in children under the age of 15.[2] This study revealed that paediatric anaesthesia accounts for a substantial portion, ranging from 10% to 30%, of daily anaesthesia practices in our country. The majority of this rate includes children aged 1 to 6 years with ASA I-II classification. Similarly, in the study by Bartels et al.,[3] where they examined 2,473,411 anaesthetics in patients aged <18 years, the majority of cases were children with ASA I-II classification. Consistent with the literature, our results showed that the ENT department had the highest frequency of surgeries.[4] The next most common surgical specialty was orthopedics and traumatology. The data from the research indicate that minor surgeries were primarily performed on children.

Anxiety is a distressing phenomenon for both the child and the parent and can potentially accelerate behavioral changes in children in the postoperative period. Therefore, the establishment of dedicated preoperative units provides an appropriate environment for waiting before surgery in the operating room and facilitates the implementation of measures aimed at reducing anxiety. These interventions may include the administration of premedication, enabling parental presence during the preoperative phase, and using visual aids such as videos.[5] However, based on the survey results, the prevalence of preoperative waiting areas is relatively low. In fact, expecting high rates of premedication or parental presence to alleviate anxiety, given the limited

Turk J Anaesthesiol Reanim 2025;53(3):98-106

number of preoperative units, would be misplaced, and our results support this.

The data highlight the extensive use of standard monitoring techniques in paediatric patients. These techniques, employed concurrently with modern surgical procedures, are evolving, serving as complementary tools alongside standard monitoring practices in paediatric patients. This integration aims to enhance perioperative safety and overall patient care. When examining all monitoring techniques, such as depth of anaesthesia, neuromuscular, CO, cerebral oximetry, and invasive blood pressure (IBP) monitoring, it becomes apparent that IBP is the most frequently used. Notably, it is thought that IBP is especially prioritized because it allows close monitoring of hemodynamic balance and blood gas evaluations.

Inhalation agents have always been the first choice in anaesthesia practices for children, especially in cases where vascular access cannot be established and the child is afraid of these procedures. However, inhalation agents may cause more respiratory problems than intravenous agents. In the course of time, the use of intravenous agents during anaesthesia induction has begun to increase. Currently, both inhalation and intravenous agents can be used.[6] According to our study, participants stated that they mostly used intravenous agents.

The most commonly used perioperative fluid choices were isotonic fluids such as 0.9% normal saline, Ringer's lactate, and isolyte. However, the use of 5% dextrose fluids in maintenance fluids was remarkable. However, current understanding discourages the routine use of dextrose fluids due to their potential association with neuronal damage. Informative seminars may be organized on this subject. In cases where crystalloids are used but the intravascular space is still not sufficiently filled, the fluids needed to maintain intravascular volume are colloids, which can be synthetic or natural. According to the survey result, the usage of HES and gelofusine was high.[7]

A central venous catheter (CVC) in paediatrics may be required both intraoperatively and postoperatively for monitoring, shock, dehydration, difficult peripheral venous cannulation, parenteral nutrition, vasopressor therapy, and procedures involving significant blood or fluid loss.[8,9] There are various infusion sites including the internal jugular vein (IJV), subclavian vein, femoral vein, brachiocephalic vein, and peripheral veins. In our study, participants stated that they preferred IJV first and peripheral catheterization second. We believe that these options are preferred because of lower complication rates and a more accessible location. Two techniques can be used for CVC placement: the landmark technique and the real-time US-guided technique. Nowadays, US-guided CVC placement is widely used because it shortens the procedure time, increases the success rate, and decreases the risk of inadvertent arterial punctures.[9,10] Both techniques are used at the same rate in our study.

In paediatric anaesthesia practice, pressure controlled ventilation modes are more often preferred to volume controlled ventilation (VCV) modes. Previously, it has been suggested that VCV modes are avoided due to the potential for high airway pressures, and lack of confidence in the accuracy of Vt delivery.[11] Today, it is recommended to use alternative modes to these.[12] In essence, the primary objective is to minimize potential lung injury and ensure lung-protective ventilation with the selected mode. In this study, both ventilation modes were used, with pressure support ventilation being mentioned as the second mode. Other parameters were Vt and PEEP. The participants' responses were generally in line with the literature. The literature recommends 6-8 mL of Vt per kg of ideal body weight for lung protective ventilation. PEEP is an essential parameter to prevent alveolar collapse, but there is no consensus on the optimal level of PEEP in children. The recommended PEEP level is within the physiological range, which is 3-5 cmH_2O.[13,14] A healthy child is typically expected to have an oxygen saturation level greater than 95% when breathing room air. Similarly, there is no consensus regarding the optimal fraction of inspired oxygen (FiO_2) value. Once the airway is secured, the minimum FiO_2 should be maintained according to the SpO_2 value.[13] However, we should note that the use of low FiO_2 values (<40%) was infrequent among participants, according to the survey findings. The survey also considers anaesthesia systems, revealing a lower ratio of efficiency associated with the use of open systems. Old anaesthesia machines for children did not have a functional ventilator, and ventilation was provided manually. However, manual ventilation may cause volutrauma, barotrauma, and atelectasis.[15] Today, modern anaesthesia machines, equipped with ventilators, are widely used. According to the survey, manual ventilation is frequently favored in anaesthesia training and during anaesthesia machine malfunctions.

Pain management is a crucial therapeutic approach that is equally applicable to paediatric patients. The initial step in pain management involves assessing pain based on the child's age. In our study, the most frequently utilized pain assessment tools were the Children's Hospital of Eastern Ontario Pain Scale (for ages 1-7 years), the Face, Legs, Activity, Cry and Consolability (for ages 2 months-7 years), the Wong Baker Faces Scale (for ages 3-7 years), and the Visual Analogue Scale (for school-age children). In fact, this finding appears to be consistent with the age range typically anaesthetized in routine clinical practice.[16,17] Currently, a multimodal approach is being employed to mitigate the adverse effects associated with opioid agents. The multimodal approach involves the use of non-opioid medications, such as paracetamol and non-steroidal drugs, as well as non-pharmacologic treatments, such as hypnosis, massage, and heat compresses. Additionally, it includes regional techniques, such as peripheral blocks and central neuraxial blocks.[16] However, this study observed that intravenous methods, especially opioid agents, are still preferred as the initial choice for managing certain types and severities of pain. Among regional techniques, peripheral nerve blocks are at the forefront, in parallel with the advancement of technology.

Paediatric patients are transferred to the post-anaesthesia care unit (PACU) to ensure they fully awaken, similar to adult patients. Although it is recommended to stay in the PACU at least 30 minutes, several factors can influence this duration.[18,19] However, the results of this study indicate that the waiting time in the PACU is generally less than 30 minutes. The lack of PACU facilities may contribute to this situation. The presence of parents with their children in the PACU may have a positive impact on the children's postoperative behavior.[20,21] Evaluating the breathing, circulation, and consciousness of children planned to be discharged from PACU will play an effective role in reducing possible complications. Respondents reported using Aldrete scoring more frequently in this study.[19]

Study Limitations

Considering the limitations of the study, since it is a survey study, the accuracy of the data will be limited to the statements of the survey participants. A larger number of survey participants would certainly increase both data diversity and accuracy.

Conclusion

In conclusion, acknowledge that we still have shortcomings in paediatric anaesthesia practice. We believe that the studies to be conducted and the meetings to be held on this subject will help reduce these imperfections.

Ethics

Ethics Committee Approval: The study was approved by the Çukurova University Faculty of Medicine Non-Interventional Clinical Research Ethics Committee (decision no.: 12/129, and date: January 6, 2023).

Informed Consent: Since the relevant article is a survey study, patient consent is not required.

Footnotes

Author Contributions: Surgical and Medical Practices - A.Ç.T., Z.H., H.C., E.Ç., D.A., S.U.Ö.; Concept - A.Ç.T., Z.H., H.C., E.Ç., D.A., S.U.Ö.; Design - A.Ç.T., Z.H., H.C., E.Ç., D.A., S.U.Ö.; Data Collection and/or/ Processing - H.C., S.U.Ö.; Analysis and/or/ Interpretation - Z.H., S.U.Ö.; Literature Review - A.Ç.T., Z.H., S.U.Ö.; Writing - A.Ç.T., Z.H.

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Original Article

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Assessing Caudal Epidural Anatomy in Children: A Comparison of Palpation and Ultrasound for Sacral Cornua Identification

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Abstract

Objective: The aim of this study is to compare the identification of the sacral cornua using palpation and ultrasound, and to evaluate the sacrococcygeal area via ultrasound across different age groups of children.

Methods: This study included 348 children aged 1 to 84 months, who were divided into three age groups: 1-24 months, 25-48 months, and 49-84 months. Sacral cornua were assessed using both palpation and ultrasound imaging. Palpation findings were categorized as "good", "difficult", or "non-palpable". Ultrasound imaging of the sacral cornua was classified as "clear", "unclear", or "invisible". Measurements taken included the inter-cornual distance, the anteroposterior diameter of the sacral canal, the distance from the skin to the sacral canal, and the distance from the dural sac to the cornua level.

Results: Palpation of the sacral cornua was rated as "good" in 75.9% of patients, "difficult" in 22.4%, and "non-palpable" in 1.7%. All patients with "good" cornua palpation were also classified as "clear" on ultrasound imaging. Among the cases with "difficult" palpation, 76% showed a "clear" ultrasound image, while 24% were "unclear". Only one patient had "invisible" cornua on ultrasound. The mean distance from the dural sac to the cornua level was 3.72±1.64 cm, and this distance increased significantly with age ($P < 0.01$).

Conclusion: Ultrasound is a valuable tool for identifying the sacral cornua, especially when palpation is difficult, and offers reliable, detailed information on sacral anatomy.

Keywords: Analgesia, anatomy, caudal anaesthesia, paediatrics, regional anaesthesia, sacrococcygeal region, ultrasound

Main Points

- The study highlights that ultrasound is significantly more reliable than palpation in identifying sacral cornua. It offers clearer visualization, with nearly all showing identifiable cornua, compared to variable success rates with palpation.
- Younger children (1-24 months) tend to have less developed sacral structures, making both palpation and ultrasound more challenging compared to older age groups (25-48 months and 49-84 month groups).
- These findings have practical implications for anaesthetists performing caudal blocks. Ultrasound enables clinicians to accurately assess critical anatomical landmarks-such as the sacral cornua, sacrococcygeal membrane thickness, and the position of the dural sac-which change with age.

Introduction

Caudal block is a frequently preferred intervention, mostly for subumbilical surgery, because it is an easily applicable method, guided by distinct anatomical structures. Technically, this involves palpation of both sacral cornua to identify the sacral hiatus, with the patient in the prone or lateral decubitus position.[1]

However, palpation may be challenging due to high body weight, young age, or anatomical variations. A caudal block can fail if the local anaesthetic is administered to the wrong sites, specifically penetrating the superficial

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soft tissue or entering the intravascular, intraosseous, or intrathecal areas. Such incidences, although rare, can have serious complications such as systemic toxicity or total spinal anaesthesia.[2-4]

Ultrasonography has emerged as a non-invasive imaging modality that enables real-time visualization and assessment of anatomical structures. This advancement has led to a notable increase in the utilization of ultrasound-assisted caudal blocks, aiming to enhance the safety and success of intervention.[5] However, previous research indicates significant anatomical distinctions between paediatric and adult patients.[6] These variances arise from the ongoing growth and development period in children, resulting in variations among different age groups.

In this study, our primary aim was to compare the methods of palpation and ultrasound imaging in the detection of the cornua, used to find the needle insertion site during caudal block. Secondly, the sacrococcygeal area was examined using ultrasound in both transverse and longitudinal sections in children aged 1 to 84 months, covering the age range most commonly targeted for caudal block procedures. This examination aimed to investigate anatomical variations across different age groups.

Methods

Before patient enrolment, this prospective observational study was approved by the Clinical Research Ethics Committee of İstanbul University-Cerrahpaşa, Cerrahpaşa Faculty of Medicine (approval no.: 6470, date: 08.01.2019) and documented as no. 72109855-604.01.01- 103424, registered at clinicaltrials.gov (NCT03825172). Between January 2019 and January 2020, 348 children aged 1-84 months with American Society of Anesthesiologists I-II, who met the criteria for not having musculoskeletal, spinal anomalies, sacral dimples, history of prematurity, or a known syndromic illness were enrolled in the study after the written informed consent of the parents. Three age groups were formed as Groups 1, 2, and 3 to include, respectively, the 1-24 month, the 25-48 month, and the 49-84-month-old patients (Figure 1).

After induction of general anaesthesia, patients were placed in the lateral decubitus position with hips and knees in 90-degree flexion. The caudal area was then assessed through visual inspection and palpation. The cornua were classified as "good" when both cornua were easily palpable, as "difficult" if one or both were palpated with difficulty or one could not be palpated at all, and as "non-palpable" if both could not be palpated. Palpation was performed by two experienced anaesthetists, and classification was determined by joint consensus. Subsequently, the patients were examined using ultrasound to evaluate the sacral structures critical for the caudal block process.

All ultrasound investigations were carried out by the same anaesthetist in the presence of an observing anaesthetist with experience in the caudal applications of ultrasound. The ultrasound (Esaote Europe BV, Maastricht, The Netherlands) was used at a frequency of 12-18 MHz with the linear probe to visualize the caudal area. Firstly, a transverse section was obtained by positioning the probe on the spine over both cornua to capture the characteristic "toad face" image. The location was marked with a pen, and the following structures were identified (Figure 2).

Cornua: The transverse section was utilized to identify the highest points of both cornua, enabling the measurement of the distance between them.

If both shadows were clearly visible, the cornua were classified as "clear". Weak unilateral or bilateral shadows, believed to correspond to the cornua, were classified as "unclear". If no bone shadows were present, the image was categorized as "invisible".

Sacrococcygeal membrane (SCM): SCM appears as a thin, shiny strip in the transverse section, covering the sacral hiatus of the posterior sacral canal. We opted to measure the distance from the skin to the epidural space instead of directly assessing the thickness of the SCM due to challenges in distinguishing it from the subcutaneous tissue in transverse sections.

Posterior sacral bone: In transverse imaging, it exhibits a distinct bright white appearance. It serves as the anterior wall of the sacral canal within this specific area.

The antero-posterior diameter of the sacral canal is the distance between the SCM and the posterior sacral bone measured on the transverse section.

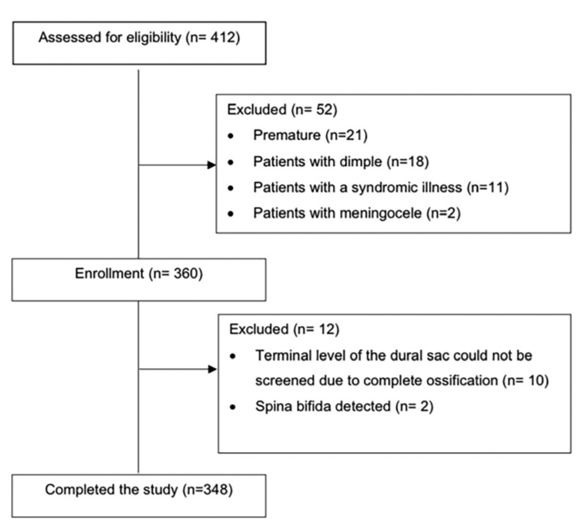

Figure 1. Flow diagram of the study.

Once the transverse section assessment was completed, the linear probe was rotated 90 degrees to obtain a longitudinal section. Subsequently, the dural sac, sacral epidural area, sacral vertebral bodies, intervertebral spaces and cornua level were clearly defined. The distance between the cornua level and the end point of the dural sac was measured (Figure 3).

Statistical Analysis

The data were analyzed using the Statistical Package for the Social Sciences (SPSS) version 15.0 software (SPSS, Inc., Chicago, IL, USA). The descriptive statistics for the categorical variables were expressed in numbers and percentages, and the numerical variables were expressed in terms of the mean, standard deviation, the minimum and the maximum, the median, interquartile range, and the 95% confidence interval. As the numerical variables did not meet the assumptions for normal distribution, comparisons of more than two groups were carried out with the Kruskal-Wallis test. The subgroup analyses using a nonparametric test were made using the Mann-Whitney U test with the Bonferroni correction. The ratios in the groups were compared with the chi-square test. Since the relationships between the numerical variables did not meet the parametric test conditions, correlations were determined by calculating the Spearman correlation coefficients. A *P* value of <0.05 is accepted to indicate statistical significance. Based on Aggarwal et al.'s[7] cadaveric study, which showed a bilateral cornua prevalence of 61.2%, the minimum sample size was determined to be 341 individuals, with 95% power and a 5% significance level.

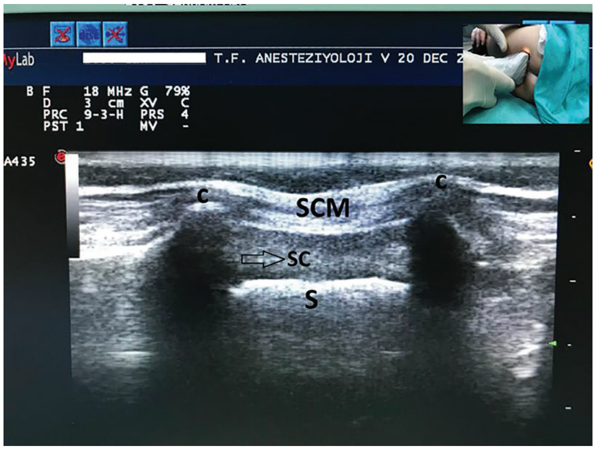

Figure 2. Transverse section of caudal ultrasonography at cornua level.

C, cornua; SC, sacral canal; S, posterior wall of the sacrum; SCM, sacrococcygeal membrane.

Results

This study was designed as a prospective observational with a planned duration of one year, based on our hospital's patient records and estimated sample size. An extension was not necessary, as we were able to recruit a sufficient number of eligible patients within the one-year period. As seen in the flow chart, 412 children were assessed for eligibility. After applying the exclusion criteria, 360 children were enrolled for sacrococcygeal ultrasonography. In 10 children, the termination level of the dural sac could not be evaluated due to ossification, and in 2 children spina bifida was detected by ultrasonography. As a result, 348 children were included in this study (Figure 1).

The demographic and clinical data on the 348 children included in the study are shown in Table 1.

Table 2 summarizes changes in the palpability and ultrasound visibility of the sacral cornua across different age groups. Overall, palpation of the sacral cornua was rated as "good" in 75.9% of patients, "difficult" in 22.4%, and "non-palpable" in 1.7%.

The percentage of patients with "good" palpation was 65.4% in Group 1, 81.5% in Group 2, and 83.7% in Group 3. Group 1 had a significantly lower rate of "good" palpation compared to Groups 2 and 3 (*P* < 0.01), while there was no significant difference between Groups 2 and 3 (*P*=0.33). A statistically significant difference was observed overall across the three groups (*P* < 0.01). Only six patients had non-palpable cornua.

Ultrasound examination revealed that the cornua image was "clear" in 93.7% of all patients. Specifically, clear imaging was observed in 89% of Group 1, 96.3% of Group 2, and 97% of Group 3.

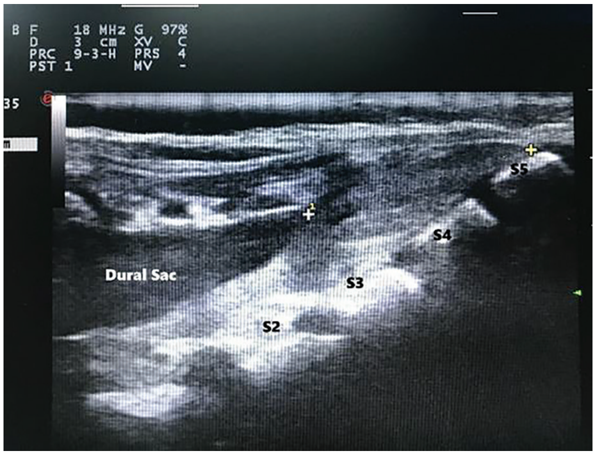

Figure 3. Longitudinal section of sacrococcygeal ultrasound. +...+ shows the distance between the terminal point of the dural sac and the cornua level.

The rate of clear ultrasound imaging was significantly lower in Group 1 compared to Group 3 (*P*=0.04), with no significant differences between other subgroups. Only one patient had an invisible cornua image.

All patients with "good" palpation (n=264) had "clear" cornua imaging on ultrasound. Among patients with "difficult" palpation (n=78), 75.6% showed "good" imaging, while 24.4% had "unclear" imaging. For those in whom the cornua were "non-palpable" (6 patients), 50% had "clear" ultrasound imaging (Figure 4).

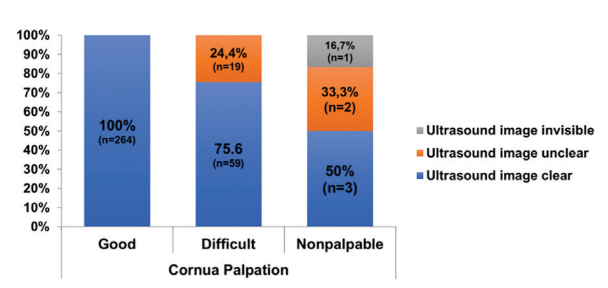

Figure 4. Ultrasound visibility of patients whose cornua palpation was classified as "Good", "Difficult", and "Non-palpable".

Table 1. Patient Characteristics

	Total	1-24 m	25-48 m	49-84 m
Sample size, n, (%)	348	136 (39.1)	108 (31.0)	104 (29.9)
Age (months)	30	11	34.5	64
Median (IQR)	(14-51)	(5-16)	(29-39)	(53.25-74.75)
Sex, n (%)				
Male	251 (72.1)	99 (72.8)	82 (75.9)	70 (67.3)
Female	97 (27.9)	37 (27.2)	26 (24.1)	34(32.7)
Weight (kg)				
Mean (SD)	13.8 (5.9)	8.9 (2.9)	13.9 (2.7)	20.3 (4.8)
(Min.-Max.)	(3-40)	(3-18)	(10-21)	(11-40)
Height (cm)				
Mean (SD)	92.5 (19.2)	75.2 (14.1)	95.6 (9.6)	112.1 (9.4)
(Min.-Max.)	(48-140)	(48-105)	(70-130)	(85-140)
ASA classification, n, (%)				
I	273 (78.4)	114 (83.8)	86 (79.6)	73 (70.2)
II	75 (21.6)	22 (16.2)	22 (20.4)	31 (29.8)

SD, standard deviation; IQR, interquartile range; ASA, American Society of Anesthesiologists; m, months; Min.-Max., minimum-maximum

Table 2. Cornua Palpations, Ultrasonographic Evaluations of Cornua Positions and Changes with Respect to Age Groups

											Subgroup analysis		
Group (age-month)		**Total**		**1 (1-24 m)**		**2 (25-48 m)**		**3 (49-84 m)**			**1-24 vs. 25-48 m**	**1-24 vs. 49-84 m**	**25-48 vs. 49-84 m**
Cornua		**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	***P*[a]**	***P*[b]**	***P*[b]**	***P*[b]**
Palpation	Good	264	75.9	89	65.4	88	81.5	87	83.7	<0.01[c]	0.01[c]	<0.01[c]	0.33
	Difficult	78	22.4	43	31.6	20	18.5	15	14.4				
	Non-palpable	6	1.7	4	2.9	0	0.0	2	1.9				
Ultrasound image	Clear	326	93.7	121	89.0	104	96.3	101	97.1	0.04[c]	0.07	0.04[c]	1.00
	Unclear	21	6.0	14	10.3	4	3.7	3	2.9				
	Invisible	1	0.3	1	0.7	0	0.0	0	0.0				

[a]Kruskal-Wallis test used to compare all of three groups; bSubgroup analysis with Mann-Whitney U test (Bonferroni correction P < 0.017); cChi-square test used to compare proportion.
m, month

Table 3. Ultrasound Assisted Measurements on the Transverse and Longitudinal Sections

			Age				Subgroup Analysis		
		Total (n = 348)	1-24 m (n = 136)	25-48 m (n = 108)	49-84 m (n = 104)	P^a	1-24 vs. 25-48 m P^b	1-24 vs. 49-84 m P^b	25-48 vs. 49-84 m P^b
Inter-cornual distance (cm)	Mean (SD)	1.19 (0.11)	1.13 (0.19)	1.23 (0.20)	1.23 (0.20)	<0.001	<0.001	<0.001	0.42
	Median	1.21	1.14	1.22	1.28				
	IQR	1.06-1.33	0.98-1.26	1.08-1.36	1.12-1.37				
	95% CI	1.17-1.22	1.10-1.17	1.19-1.26	1.20-1.27				
Antero-posterior diameter of sacral canal (cm)	Mean (SD)	0.33 (0.06)	0.32 (0.05)	0.34 (0.06)	0.32 (0.05)	<0.01	<0.001	0.22	0.04
	Median	0.33	0.31	0.34	0.33				
	IQR	0.30-0.36	0.28-0.34	0.31-0.36	0.29-0.36				
	95% CI	0.32-0.33	0.31-0.33	0.33-0.35	0.31-0.33				
Distance from skin to sacral canal (cm)	Mean (SD)	0.46 (0.14)	0.41 (0.11)	0.46 (0.13)	0.53 (0.16)	<0.001	0.03	<0.001	<0.001
	Median	0.44	0.395	0.425	0.505				
	IQR	0.36-0.55	0.32-0.50	0.36-54	0.41-0.59				
	95% CI	0.45-0.48	0.39-0.43	0.43-0.48	0.49-0.56				
The distance between the dural sac terminal point and the cornua level (cm)	Mean (SD)	3.72 (1.64)	3.11 (1.53)	3.99 (1.97)	4.30 (0.95)	<0.001	<0.001	<0.001	<0.001
	Median	3.76	3.09	3.885	4.48				
	IQR	2.90-4.25	2.36-3.76	3.28-4.21	3.81-4.88				
	95% CI	3.54-3.90	2.85-3.37	3.61-4.37	4.10-4.49				

[a]Kruskal-Wallis test used to compare all three groups
[b]Subgroup analysis with Mann-Whitney U test (Bonferroni correction) $P < 0.017$
SD, standard deviation; IQR, interquartile range; SCM, sacrococcygeal membrane

Table 3 presents the ultrasonographic measurements of the caudal area in transverse and longitudinal sections, along with their variations across different age groups.

Discussion

In the caudal block procedure, the epidural area is easily accessed through the sacral hiatus. This opening is formed by the non-fusion of the 5th vertebral arches and in some cases, the 4th sacral vertebral arches. Although caudal block is implemented quickly, and easily, the highly variable anatomical structure of the sacrum affects its safe application.[8] In children, the distance between the dural sac termination point and the sacral hiatus is shorter than in adults, and the resultant proximity can cause accidental perforation of the dura.[9] Understanding the anatomy of caudal block is critical for prevention of complications. Therefore, the anaesthetists have to determine the correct position of the patient and make the appropriate markings if necessary.

In an ultrasound-assisted study comparing straight position and flexion, it was shown that the dural sac progressed cranially with flexion. Positioning the patients with hip and knee flexion during caudal block was found to help the caudal needle reach the desired distance.[10] Therefore, in this study, all children were placed in a standard position during the ultrasound imaging. The measurements were taken with hips and knees flexed at a 90-degree angle, a positioning commonly employed in caudal block procedures. Since urological surgery is more frequent with male children for reasons of circumcision or orchiopexy, the number of male patients exceeded the female patients in this study. However, Adewale et al.[9] showed that magnetic resonance imaging of the sacral anatomy did not show significant differences between male and female children.

In children, ossification of the sacral bone is completed around 8 years old.[8] Therefore, ultrasound can provide more detailed information in children compared to adults. After ossification is complete, it may not be possible to screen the lower level of the dural sac by ultrasound, hence, the upper age limit was set as 84 months. Ten patients near this upper age limit were excluded because the end of the dural sac was not visible on ultrasound. Additionally, palpation was done by 2 experienced anaesthetists to avoid any bias, and there was no conflict during the classification.

Although palpating the cornua to determine the sacral hiatus is a commonly employed method by clinicians, it is crucial to acknowledge that not all anatomical markers used to identify it are uniform across all patients. Sekiguchi et al.[11] reported only being able to palpate 19 of the cornua in

92 adult cadavers, while Aggarwal et al.[7] achieved bilateral palpation in only 30 out of 49 adult cadavers. In another cadaveric study by Aggarwal et al.,[12] bilateral palpation was identified in 23 out of 39 fetuses (58.97%) that were at a gestational age of 7-9 months.

This underscores how ultrasound can be a viable alternative by considering the specific site of the sacral hiatus.

In our study, palpation of the sacral cornua was rated as "good" in 75.9% of patients, and when investigated by ultrasonography, it was found to be "clear" in 93.7% of these cases. Among patients whose cornua were rated as "difficult" to palpate, ultrasound revealed "clear" visualization in 75.6%, while 24.4% were "unclear". Of the six patients with non-palpable cornua, three had "clear" visualization, two were "unclear", and one was 'invisible' on ultrasonography (Figure 4). The effectiveness of ultrasound in imaging the caudal cornua was demonstrated by the fact that only one patient out of 348 had "invisible" cornua, leading to the assumption that this patient may not have developed cornua. Therefore, it can be concluded that in patients with developed cornua, ultrasound is unlikely to miss these structures. In summary, ultrasound proves to be a highly sensitive method for identifying the sacral cornua compared to palpation.

Additionally, there is greater difficulty in detecting the cornua by palpation and ultrasound in the 1-24-month age group (Table 2). Given that the bone structure of infants is not fully developed and anatomical markers may still be cartilaginous, some patients experience challenges due to the underdeveloped state of these structures and the presence of presacral fat tissue that may obstruct palpation. Analysis of ultrasound images by age group revealed that the percentage of "unclear" cornua was 10.3% in Group 1, decreasing to 3.7% in Group 2 and 2.9% in Group 3 (Table 2). This higher incidence of "unclear" images in infants likely reflects the incomplete development of the cornua in this age group. However, the percentage of "good" images remains high in Group 1, and given our experience with successful visualization in younger patients, ultrasound can be a valuable technique to guide anaesthesiologists during caudal block procedures.

In our study, the mean inter-cornual distance in the entire patient group was 1.19±0.11 cm, which was statistically less in Group 1, in comparison to the two older groups (Table 3). The shortness of this distance would make entry into the sacral canal difficult[13], implying that manipulation of the needle is more difficult in younger age groups, including newborns.

The sacral canal should have the appropriate diameter for manipulating the needle with ease. Measurement of the antero-posterior diameter of the sacral canal during ultrasound imaging on the transverse section, gives important information to the physicians. Chen et al.[14] measured the antero-posterior diameter of the sacral canal at the apex of the sacral hiatus and determined a mean value of 0.53±0.2 cm in 47 adult patients, who were injected caudally to treat sciatica pain during caudal ultrasonography on the longitudinal section. Despite previous findings indicating that the widest diameter of the sacral canal is at the upper section of SCM,[9,12] it is not always possible, as shown in this study, to obtain the image of the sacral hiatus apex on the longitudinal section in paediatric patients. Therefore, we have preferred to measure the antero-posterior diameter of the sacral canal from a specific image, obtained at the cornua level on the transverse section, simulates the "Toad" face (Figure 2). Therefore, our findings indicate a small sacral canal diameter. In our study, the mean value of antero-posterior diameter was 0.33±0.06 cm for all age groups. Interestingly, this distance was found to be wider in the second group compared to the other groups, which can be considered as an anatomical variability finding (Table 3). It is challenging to enter such a narrow canal with a needle. As a result, the frequent bone and subcutaneous tissue penetration may be a sign of narrower canals, which can be investigated with ultrasound.

The distance from the skin to the sacral canal is an important marker for directing the needle to the right point and ensuring a safe block. Very thin subcutaneous tissue can make it difficult to detect when the needle passes through the SCM, which would also complicate retracting the needle back to the subcutaneous tissue for adjustment to another angle. However, it is not always possible to differentiate the subcutaneous tissue from the SCM with ultrasound. Therefore, we opted to take these two structures together when making measurements (Figure 2). In our measurements, a notable and statistically significant increase in this distance was observed among older children (Table 3). This finding suggests a positive correlation between the child's age and the combined subcutaneous and SCM thicknesses, indicating that as the child's age advances, these thicknesses tend to increase.

One of the most feared complications of caudal block is penetration of the dural sac. Although rare, it can result in the life-threatening advent of total spinal anaesthesia.[2] Such complications are avoidable since ultrasound enables detection of the position of the dural sac and the proximity to the injection site in children (Figure 3). In our study, the estimated mean distance between the termination points of the dural sac and the cornua level, which is considered acceptable for the site of injection, was 3.72±1.64 cm in children aged 1-84 months (Table 3). This measurement varied with age, such that the mean distance was 3.11 cm, 3.99 cm, and 4.30 cm, respectively, in Groups 1, 2, and 3. The differences were statistically significant ($P < 0.01$). These results indicate the necessity of care to prevent dural puncture in the infant group.

Conclusion

This study demonstrates that ultrasound is a highly effective tool for identifying the sacral cornua in paediatric patients, especially when palpation is challenging. Compared to palpation, ultrasound provides superior clarity of the sacral anatomy, with nearly all patients showing clear visualization. Subsequently, inter-cornual distance, cornua level, combined subcutaneous tissue and SCM thickness, and distance between the dural sac level undergo modifications as individuals age.

Ethics

Ethics Committee Approval: This prospective observational study was approved by the Clinical Research Ethics Committee of İstanbul University-Cerrahpaşa, Cerrahpaşa Faculty of Medicine (approval no.: 6470, date: 08.01.2019) and documented as no. 72109855-604.01.01-103424.

Informed Consent: Consent obtained directly from parents.

Footnotes

Author Contributions: Surgical and Medical Practices - C.K., P.K., Concept -C.K., P.K., G.K., Design - C.K., A.C.T., G.K., Data Collection and/or/Processing - C.K., P.K., A.C.T., Literature Review - C.K, P.K., A.C.T., G.K., Writing - C.K., P.K., A.C.T., G.K.

Declaration of Interests: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Optimizing Paediatric Hypospadias Surgical Repair: Pudendal Nerve Block Versus Caudal Block for Superior Analgesia

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Abstract

Objective: Postoperative pain control after hypospadias surgery can be challenging, and the effectiveness of caudal block (CB) for analgesia is limited. This study evaluated the analgesic efficacy of pudendal nerve block (PNB) using both ultrasound and a peripheral nerve stimulator (PNS), compared to a CB performed using landmark guidance, in paediatric patients undergoing hypospadias surgical repair.

Methods: A total of 40 patients scheduled for hypospadias surgery were included in this prospective, randomized, double-blind controlled trial, who received either a PNB or a CB. Patients in the pudendal group received an ultrasound- and PNS-guided, PNB with a combination of bupivacaine (0.25%) at a dose of 0.5 mL kg^{-1} and clonidine at a dose of 1 µg kg^{-1}, whereas those in the caudal group received a landmark-guided CB with bupivacaine (0.25%) at a dose of 1 mL kg^{-1} along with clonidine at a dose of 1 µg kg^{-1}. The objective pain scale (OPS) was used to assess pain intensity in each group within 24 hours post-surgery. Perioperative hemodynamic changes and analgesic requirements were also recorded.

Results: The CB provided effective analgesia, lasting an average of 6 hours. OPS scores at 6, 12, 18, and 24 hours after surgery were significantly lower in the PNB group than in the CB group. The PNB group had a significantly longer time to the need for initial analgesia, while the CB group required a significantly greater dose of paracetamol after surgery ($P < 0.001$).

Conclusion: Findings from this study suggest that, at these doses, PNB is more effective than CB in providing longer-lasting pain relief, significantly lower pain scores, and a reduced need for postoperative analgesics.

Keywords: Caudal block, child pain, hypospadias, pudendal nerve block, regional

Main Points

- Postoperative pain is a notable concern in hypospadias surgery.
- Pudendal nerve block provided more effective and longer-lasting postoperative analgesia, resulting in significantly lower pain scores compared to caudal block in the first day post-surgery.

Introduction

Hypospadias, a prevalent congenital malformation of the penis, affects approximately 1 in 300 live infants. This condition results from developmental anomalies of the foreskin, penile urethra, and the ventral region of the penis during the embryonic stage.[1]

Early surgical intervention improves both functional and cosmetic outcomes, but it often leads to significant postoperative pain that is inadequately managed by systemic analgesics.[2]

Regional anaesthesia, particularly caudal block (CB) and penile block, plays a crucial role in pain control during paediatric genital surgeries. While CB is easy to administer and reduces the need for intraoperative analgesia, it can

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cause complications such as penile engorgement, impaired wound healing, and fistula formation.[3] Similarly, penile block may result in hematoma, swelling, or inconsistent pain relief.[4] Recently, pudendal nerve block (PNB) has been growing in popularity as a preferred alternative, providing effective intraoperative and prolonged post-surgical analgesia with reduced adverse effects.[5,6] Therefore, we carried out a double-blind, randomized controlled trial with a prospective study design to compare the analgesic efficacy and duration of analgesia of PNB with CB in paediatric patients undergoing hypospadias surgery. We hypothesized that PNB would offer superior outcomes compared with CB. This study primarily focused on comparing postoperative pain levels between the two groups using the objective pain scale. The secondary objectives included assessing hemodynamic changes during surgery and the analgesic requirements for both groups.

Inclusion Criteria

Paediatric patients between 1 and 7 years old, with ASA grade 1 or 2 undergoing elective hypospadias surgical repair.

Exclusion Criteria

Patients with a known allergy to local anaesthetics, coagulation disorders, bleeding tendencies, infections or rashes at the injection site, spinal deformities, or neurological impairments were excluded.

Methods

This research followed a double-blind, randomized controlled trial methodology with authorization from the Institutional Ethics Committee of King Edward Memorial Hospital Seth Gordhandas Sunderdas Medical College (approval no.: EC/OA-186/2022, date: 27.02.2023). This trial was officially registered with the Clinical Trials Registry-India (CTRI/2023/06/053651). In the pre-anaesthesia assessment clinic, forty paediatric patients, ranging in age from 1 to 7 years, scheduled for elective surgery for hypospadias, were recruited a day before surgery. Written informed consent was obtained from parents for their children's participation in the study. A comprehensive pre-anaesthetic evaluation, including a detailed medical history, physical examination, and necessary investigations like complete blood count, urine analysis, and microscopy was done. A computer-generated random number technique was used, and patients were allocated randomly to 2 groups, each consisting of 20 participants: Group CB and Group PNB. To maintain blinding, the allocation sequence was placed in sealed envelopes. The anaesthesiologist, who was not part of the study, opened the envelope and was aware of the group assignment. However, the physician collecting postoperative data and the patient were kept unaware of the group assignment, ensuring the study remained double-blinded.

After confirming adequate NPO status, all children were administered oral midazolam of 0.75 mg kg^{-1} mixed with a fruit-flavoured (watermelon) clear solution, 30 minutes before induction in the preoperative area. During this time, monitoring included vital signs, sedation level, and behavioural responses.

Patients were then transferred to the operating room, where they were connected to standard ASA monitors, such as a blood pressure cuff (non-invasive), ECG and pulse oximeter, and their baseline values were recorded. Induction was performed using a face mask with a 50:50 mixture of oxygen and nitrous oxide at 6 L min, along with incremental sevoflurane (2% to 8%), with the patient breathing spontaneously. Once a sufficient depth of anaesthesia was achieved, an intravenous (IV) line was secured, and an initial infusion of balanced electrolyte solution containing 1-2.5% dextrose was administered at a rate of 10 mL kg^{-1} h^{-1}, with subsequent adjustments based on the patient's needs. An i-gel® (Intersurgical, Berkshire, UK), a second-generation supraglottic airway device, was placed following the manufacturer's instructions. Anaesthesia was maintained with spontaneous ventilation using a 50:50 mixture of oxygen and N_2O, with end-tidal sevoflurane regulated to 1 MAC, corrected for the patient's age.

PNB group

Patients were placed in the lithotomy position, followed by cleaning and draping of the surgical site. Injection sites were identified at the 3 and 9 o'clock positions, approximately two to three centimetres from the centre of the anus. A transverse ultrasound scan, using a curvilinear transducer with a frequency range of 2-5 MHz, was performed to visualize the ischium along the lateral edge of the sciatic notch. With caudal movement of the probe, the ischium aligned with the ischial spine, exposing the pudendal artery and nerve, both positioned medially to the spine. A 22-24-gauge stimuplex A nerve stimulator needle (50-100 mm; B. Braun, Melsungen, Germany) was utilized to stimulate the nerve, allowing for the observe contractions. The needle was inserted just medial to the ischial tuberosity, at a right angle to the skin, and passed through the sacrotuberous ligament. The stimulation current was decreased to 0.5-0.6 mA by adjusting the needle position to maintain muscle contractions. After confirming no blood aspiration, 0.5 mL kg^{-1} of 0.25% bupivacaine, along with 1 μg kg^{-1} of clonidine was injected.[7,8]

CB group

Patients allocated to this group were positioned laterally, and with the aid of a landmark-based approach, after preparing and draping the area, a 22-gauge needle was directed into the sacral hiatus at a 45° angle. Following a negative blood aspiration, after reaching the sacral epidural space, 1 mL kg^{-1} of 0.25% bupivacaine combined with 1 μg kg^{-1} of clonidine was injected over 30-60 seconds.[9,10] Once the block was completed, the patients were repositioned supine, and surgery commenced 10 minutes later.

During surgery, an elevation in mean arterial pressure or heart rate exceeding 20% from the preincision baseline was considered indicative of inadequate analgesia. In such cases, an injection of fentanyl (1 to 2 μg kg^{-1}) was used to provide rescue analgesia, and these patients were labelled as block failures. The surgery duration and the time needed to complete the block were recorded. Vital signs, including heart rate, SpO_2 and mean arterial pressure, were continuously monitored. All patients remained hospitalized for 24 hours after surgery to determine the block's effectiveness.

The OPS, formulated by Broadman et al.[11], was utilized to assess the effectiveness of pain control. This scale evaluates five factors, namely positioning, movement, crying, mean arterial blood pressure, and agitation, each rated from 0 (none) to 2 (severe), as outlined in Table 1. A scoring scale between 0 and 10 is used, with 0 to 1 indicating adequate analgesia, 2 to 3 indicating mild pain, and scores above 3 indicating severe pain. A resident in the post-anaesthesia care unit (PACU) recorded OPS scores immediately upon the patient's arrival and at 30-minute intervals for the first 24 hours post-surgery. Those with an OPS score falling within the range of 2 to 3 received intravenous paracetamol (15 mg kg^{-1}) every 6 hours, whereas those with a score of 4 or above were given intravenous fentanyl (0.5 μg kg^{-1}).

The required sample size was derived with SPSS software using the appropriate formula: $n = (Z\alpha/2 + Z\beta)^2 \times 2 \times \sigma^2/d^2$, setting the alpha error at 5% and power at 80%. A study conducted by Naja et al.[12] showed that 70% of children in the caudal epidural block group needed analgesics 24 hours post-surgery, while only 20% of those in the PNB group did. The calculation determined that each group required 20 patients, making a total of 40 participants.

Statistical Analysis

The data were analysed using SPSS version 20.0, a statistical tool created by IBM. For comparing frequencies and percentages of qualitative variables, the chi-square or Mann-Whitney test was utilized, whereas the Student's t-test was applied for quantitative variables, with a *P* value of <0.05 indicating statistical significance.

Results

This trial included 40 patients, who were evenly assigned into two groups of 20, with Group A receiving PNB and Group B undergoing CB (Figure 1). As shown in Table 2,

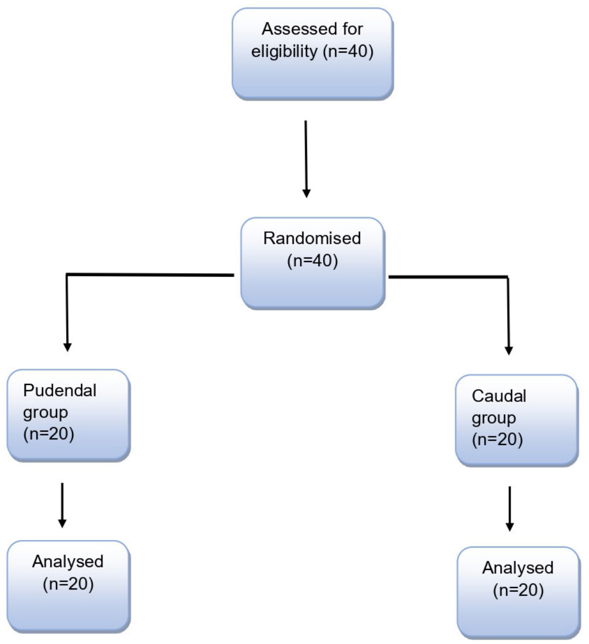

Figure 1. CONSORT flow diagram of the study process.

After assessing eligibility, 40 patients were recruited and randomly allocated into two groups, with 20 patients assigned to the pudendal group and 20 to the caudal group, followed by subsequent monitoring and analysis.

Table 1. Objective Pain and Discomfort Scale Used to Assess Pain Control (Naja et al.[12], 2013)

Parameter	Score 0	Score 1	Score 2
1) Blood pressure	Within ±10% of preoperative value	Exceeds preoperative value by >20%	Exceeds preoperative value by >30%
2) Crying	No crying	Crying but calms with comforting	Crying and does not respond to comforting
3) Movement	No movement	Restless	Vigorous thrashing
4) Agitation	Calm or asleep	Mildly agitated	Extremely agitated
5) Posture	Normal posture	Flexing legs & thighs	Holding hands to the neck
Pain score	Interpretation		
0 to 1	Adequate analgesia		
2 to 3	Mild pain		
≥4	Moderate to severe pain		

two groups had similar attributes concerning age, weight, and surgical duration; however, the time taken to perform the PNB was significantly longer ($P < 0.001$). The CB was effective, with a mean time span of 6 hours. During the first 6 hours postoperatively, there was no statistically significant variation in OPS scores between the CB and PNB groups. After 6 hours, a significantly greater OPS score was observed in the CB group when compared to PNB group at 12, 18, and 24 hours after surgery (Table 3) ($P < 0.05$). No notable variations in heart rate (HR) were detected between the groups during or after surgery, and MAP remained stable throughout (Table 4). Paracetamol intake was markedly higher in the CB group, with a *P* value of < 0.001.

Discussion

In our study, we evaluated the analgesic effectiveness of two techniques, the peripheral nerve block (PNB) and the CB, for children undergoing hypospadias surgery. CBs are the most commonly used method for this procedure. We hypothesised that the PNB would provide superior analgesic control compared with the central block. The primary objective was to evaluate postoperative pain severity in both groups using the OPS. Our secondary objectives included comparing perioperative haemodynamic changes and analgesic requirements in both groups. Our findings showed that the pudendal block provided longer-lasting analgesia in the postoperative period than the CB.

Arising from the second, third, and fourth ventral sacral rami, the pudendal nerve travels through the pudendal canal alongside the inferior rectal nerves before branching into the perineal nerve and the dorsal nerve of the penis.[13,14] Providing sensory and motor input, the pudendal nerve innervates the perineum and the penis, the primary site affected in hypospadias surgery. PNB offers comprehensive

Table 2. Data on Patient Demographics and Clinical Details

	Group A Pudendal nerve block (Mean ± SD)	Group B Caudal block (Mean ± SD)	Unpaired t-test value	*P* value
Age (in years)	4.38±1.91	3.45±1.68	1.627	0.112
Weight (kg)	14.49±3.35	12.63±2.66	1.951	0.058
Duration of surgery (minutes)	190.5±45.1	192.0±42.38	-0.108	0.915
Procedure duration to administer the block (min)	22.25±4.99	6.40±1.23	13.783	<0.001
Time elapsed until first analgesic requirement (hours)	20.30±3.51	12.15±3.00	7.897	<0.001
Subgroup analysis of children up to 2 years of age				
Time elapsed until first analgesic requirement (hours) in children aged ≤2 years	19.5±3.00	9.25±1.893	5.779	<0.001

SD, standard deviation

Table 3. Assessment of Pain and Discomfort Progression Through Objective Scale Scores in Group A (PNB) and Group B (CB)

	Pudendal nerve block Group A (Mean ± SD)	Caudal block Group B (Mean ± SD)	Cohen d test value	*P* value
15 mins after the operation	0	0	0.0	-
6 h after the operation	0.20±0.41	0.1±0.2	0.52	0.066
12 h after the operation	0.65±0.59	1.65±0.67	1.26	<0.001
18 h after the operation	1.30±0.57	2.40±0.82	2.58	<0.001
24 h after the operation	0.65±0.49	4.25±0.79	3.26	<0.001
Subgroup analysis of children up to 2 years of age				
15 mins after the operation	0	0	0	-
6 h after the operation	0	0	0	-
12 h after the operation	0.75±0.43	2.25±0.433	3.464	<0.001
18 h after the operation	1.75±0.43	2.5±0.5	1.603	<0.001
24 h after the operation	1.25±0.43	3.25±0.433	4.618	<0.001

SD, standard deviation; PNB, pudendal nerve block; CB, caudal block

Table 4. Assessment of Perioperative Changes in Heart Rate and Blood Pressure Conducted Between the Two Studied Groups

	Group A Pudendal nerve block (Mean ± SD)	Group B Caudal block (Mean ± SD)	Test value	*P* value
1) Heart rate (beats per min)				
- Preoperative	101.05±9.51	105.55±8.86	1.548	0.130
- Intraoperative	98.85±9.82	105.10±8.65	2.136	0.039
- Postoperative	100.1±8.05	107.85±8.69	2.926	0.006
2) Mean arterial pressure (mmHg)				
- Preoperative	57.5±2.52	55.85±3.13	1.834	0.074
- Intraoperative	57.4±3.53	55.5±4.32	1.523	0.136
- Postoperative	59.15±3.58	58.13±3.97	1.667	0.104

SD, standard deviation

pain relief by directly targeting the pudendal nerve, along with its perineal branch, which supplies the ventral region of the penis (Figure 2). This ensures localized perineal anaesthesia and minimises systemic effects, in contrast to CB, which covers a broader area, including sacral and lumbar regions. The use of a specific method results in a reduced risk of hemodynamic instability or respiratory compromise, compared to a CB, which has a higher potential for systemic absorption, leading to a small risk of hemodynamic changes. PNB preserves motor function in the lower extremities due to targeted blockade, unlike CB, which may cause transient lower limb weakness due to involvement of sacral motor fibers. Therefore, the pudendal block is a more precise and appropriate peripheral block for targeted anaesthetic applications such as hypospadias surgery.[15] However, there can be some sparing at the base in cases of penoscrotal hypospadias, as this area is innervated by the ilioinguinal nerve (L1 nerve root). Figure 2 illustrates the pudendal nerve course in relation to the bony landmarks. Naja et al.[12] were the earliest to study the utilization of the pudendal block in paediatric patients undergoing surgical correction for hypospadias and circumcision. Traditionally, pudendal blocks were performed via blind injections, but techniques such as nerve stimulators, fluoroscopy, and CT scans have since been developed to guide the procedure. Our method of administering the pudendal block differed from that used in previous studies.[12,16] We employed a combined approach using ultrasound guidance combined with peripheral nerve stimulator (PNS), whereas earlier studies used either ultrasound or a nerve stimulator alone. The drawback of using ultrasound alone is the difficulty in clearly identifying the pudendal nerves or vessels, which complicates locating an accurate endpoint for the needle. A nerve stimulator provides a clear endpoint, such as penile bobbing or the anal wink, which improves precision. Therefore, we used a combined approach. We employed a transverse plane ultrasound to visualize the lateral aspect of the ischium within the sciatic notch, using a 2-5 MHz curvilinear transducer. Sliding the probe downward enabled clear visualization of the ischial spine, along with medial identification of the pudendal artery and nerve, ensuring accurate guidance for different age groups.[17,18]

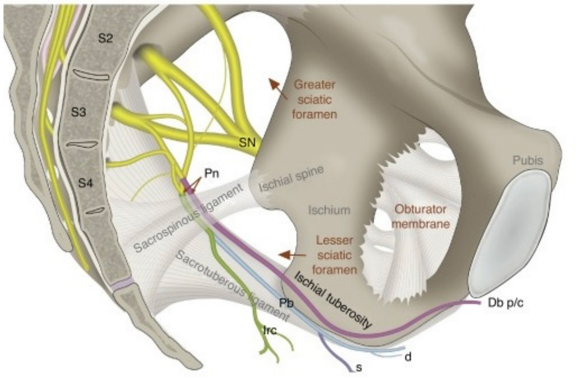

Figure 2. The pudendal nerve's course in relation to the bony landmarks.

Pudendal nerve (Pn), originating from the S2-S4 nerve roots, branches into the dorsal nerve of the penis/clitoris (DBp/c), the perineal nerve (Pb) with its deep (d) and superficial (s) branches, and the inferior rectal nerve (Irb). These branches are anatomically related to the sacrospinous and sacrotuberous ligaments, the greater and lesser sciatic foramina, the ischial spine, and the sciatic nerve (SN). These bony landmarks are critical for accurate localization during the block.

CB is widely regarded as a reliable and safe method for infraumbilical surgeries in children, including hypospadias surgery. However, it is associated with various adverse effects, including motor paralysis, block failure, retention of urine, and the risk of intravascular injection.[19] Additionally, CB becomes unfeasible in cases of sacral anatomical variations or in patients with coagulopathies. More recently, several researchers have implicated CB in the development of urethral fistulas following hypospadias repair surgeries.[20-23]

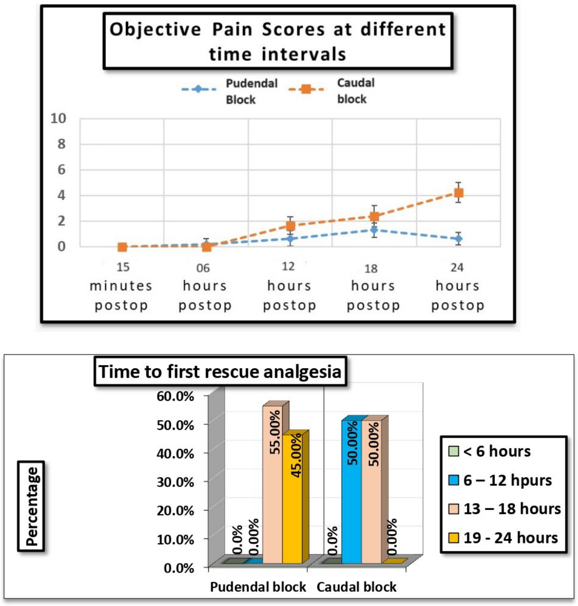

Figure 3. Objective pain score at different time intervals.

Objective pain scores are measured at various time intervals to assess the effectiveness of interventions. X axis denotes the post operative time interval and Y axis denotes the postoperative pain severity. Objective pain score was significantly higher in caudal group than pudendal nerve block group at 6, 12, 18 and 24 hrs.

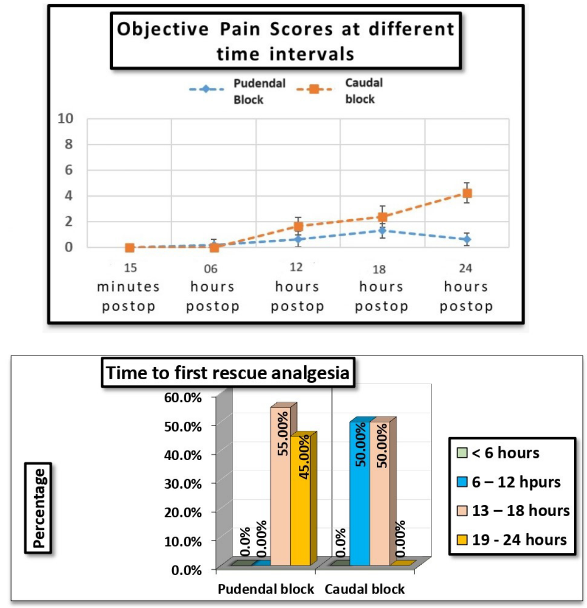

Figure 4. Time to administer the first rescue analgesia in 24 hours.

Time to administer the first rescue analgesia within 24 hours reflects how long a patient remains pain-free after the initial block before needing supplemental pain relief. Time to first analgesia was significantly longer in pudendal nerve block group compared to caudal group.

The proposed mechanism involves a vascular tone reduction which results in engorgement of the penile venous sinuses and excessive microvascular oozing from the surgical site after a CB. However, there is also conflicting evidence regarding this theory.[24]

In our study, baseline demographic characteristics were comparable between the groups, with no significant differences observed. We used 0.5 mL kg^{-1} of bupivacaine (0.25%) with clonidine (1 µg kg^{-1}) for the pudendal block and 1 mL kg^{-1} of bupivacaine (0.25%) with clonidine (1 µg kg^{-1}) for the CB.

The OPS is employed to evaluate pain and discomfort in children (8 months to 13 years of age) after procedures or surgeries by measuring behavioural changes and physiological parameters. Our investigation revealed that OPS scores were reduced in the PNB group at 12, 18, and 24 hours after surgery with $P < 0.001$ (Figure 3). The duration for the 1st rescue analgesia was between 13 and 18 hours for 55% of patients in the PNB group, while the remaining 45% did not require rescue analgesia until 19-24 hours after surgery. In the CB group, Unlike the PNB group, 50% of patients required their first dose of rescue analgesia within 6-12 hours after surgery (Figure 4). Thus, PNB proved more effective in providing denser analgesia, decreasing the need for analgesic medications, and prolonging pain-free duration after surgery. The superior performance of PNB can be attributed to the administration of the anaesthetic directly at the target location, adjacent to the nerve, unlike the CB, which is a central neuraxial technique. Administering the anaesthetic near the target nerve avoids distortion of surgical planes and prevents complications such as penile engorgement or erection, which are sometimes observed after CB.

Performing an ultrasound-guided PNB with PNS requires more time than a CB due to the need for precise anatomical visualization and accurate needle placement. Performing the block in the PNB group took considerably more time, averaging 22 minutes, while the CB group achieved completion in only 6 minutes ($P < 0.001$). This prolonged duration is primarily due to the extra time required for proper positioning, particularly in older children. However, the authors believe that approximately 15 minutes of extra operating room time is justified by the superior quality and extended duration of pain relief after surgery (18-24 hours) offered by PNB, as evidenced by notable variations in OPS scores and the timing of the first rescue analgesia between the groups.

None of our patients showed signs of motor block during PACU assessment, and no technical difficulties, major complications, or neurological issues arose during the procedure. Three patients experienced transient faecal incontinence following PNB, though follow-up assessments showed no signs of anal sphincter motor dysfunction. While transient sphincter dysfunction can occur with PNB, it did not persist into the postoperative period, and no postoperative sphincter dysfunction or faecal incontinence was observed.

We successfully administered PNB in all patients, likely due to the combined ultrasound and PNS technique. Previous studies using either ultrasound or a nerve stimulator alone have reported a higher incidence of block failure.[25,26] Most previous studies administering PNB have focused on children ranging in age from 6 months to 2 years or from 2 to 6 years.[27] These studies found no notable variation in the quality or duration of the analgesia between PNBs and continuous blocks in children under 2 years. However, our findings indicated that the PNB group had markedly lower OPS scores and longer-lasting analgesia than the CB group, even in children under 2 years. At 12, 18, and 24 hours after surgery, the OPS scores were significantly lower in the PNB group compared to the CB group (P < 0.001, subgroup analysis, Table 3).

A notable prolongation in the time to the first administration of rescue analgesia was observed in the PNB group compared to the caudal group (P < 0.001).

Study Limitations

There were only a few patients in each group (only 20). Further randomized controlled studies with larger sample sizes are needed to measure pain and compare the efficacy of the two analgesic techniques. Also, we did not record surgeon satisfaction regarding variations in the surgical field, and post-operative surgical complications like fistulas. Overall, this study serves as a preliminary exploration, providing a foundation for future research with larger cohorts to validate and expand upon these findings.

Conclusion

The results demonstrate that PNB is effective for a longer time than CB at these selected doses with significantly decreased pain scores and a reduced need for analgesics after surgery.

Ethics

Ethics Committee Approval: Ethical approval was obtained from the Institutional Ethics Committee of King Edward Memorial Hospital Seth Gordhandas Sunderdas Medical College (approval no.: EC/OA-186/2022, date: 27.02.2023).

Informed Consent: Written informed consent was obtained from parents for their children's participation in the study.

Footnotes

Author Contributions: Surgical and Medical Practices - N.K., R.D.; Concept - H.S., N.K.; Design - N.K.; Data Collection and/or/Processing - H.S., N.K.; Analysis and/or/Interpretation - H.S., R.D.; Literature Review - H.S., R.D.; Writing - H.S., N.K., R.D.

Declaration of Interests: The authors declare no conflicts of interest.

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Original Article

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National Trends in Hospitalizations for Appendectomy in Children, 2001-2017

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Abstract

Objective: Appendectomy for acute appendicitis is the most common acute surgical procedure in children. Recent changes in appendicitis management have likely modified the nature and cost of hospitalizations for this condition.

Methods: Using data from the National Inpatient Sample from 2001 to 2017, we performed a cross-sectional study and identified the temporal changes in hospitalization for appendectomy. Changes in relative hospitalization cost and length-of-stay were also studied to assess their associations with the changes in procedure incidence. Patient and hospital characteristics were considered to understand outcome disparities between groups. Geographic variation in the outcomes was also identified at the United States region and division levels.

Results: The incidence of appendectomy hospitalization decreased from 11.2 to 6.4 per 10,000 person-years between 2001 and 2017. Conversely, the median procedure cost increased 61% during this same period. The temporal changes in appendectomy hospitalization varied according to patient and hospital characteristics, as well as geographic locations.

Conclusion: The overall incidence of appendectomies in children decreased substantially from 2001 to 2017, yet the trend for costs was in the opposite direction. The data on the clinical factors driving these trends can be useful in guiding policies with evidence-based guidelines that help optimize clinical decisions and the effective use of resources in the management of appendicitis.

Keywords: Appendicitis, cross-sectional studies, epidemiology, perioperative care, public health

Main Points

- In this nationwide database analysis, we demonstrated the incidence of appendectomies among children decreased dramatically between 2001 and 2017.
- We found evidence, however, that associated costs are rising, suggesting that despite the reduction in incidence, modifications in the approach to appendicitis have made the procedure itself more expensive, even after appropriate cost adjustments.
- By improving the understanding of patterns of cost distribution, the described trends may help identify potential disparities in resource utilization in the management of acute appendicitis in children and provide data that could affect future research, practice, and health policy.

Introduction

Pediatric hospitalizations accounted for approximately 15% (5.2 million) of all hospital stays in the United States (U.S.) in 2019, with an aggregate cost of more than $46 billion.[1] Between 2010 and 2016, there was a 20% decrease in pediatric hospitalizations, but a rise in 30-day readmissions, with a higher proportion of chronic complex comorbidities.[2] The annual pediatric hospitalization cost has increased over the years, largely due to the increase in the mean hospital costs per day, a rise particularly marked for surgical stays.[1-4]

Hospitalization for acute appendicitis, the most common acute pediatric surgical condition,[1,4] decreased by 27% from 2000 to 2012.[1,5] During this time, total index pediatric admissions similarly decreased by 21% from 2000

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to 2016.[1,2] Yet, pediatric healthcare expenses are growing faster than in other age groups.[6,7] Appendicitis-related hospitalizations cost approximately $3 billion a year within the U.S.,[2,4] and appendicitis remains the 5th most common reason for hospitalizations among children.[3,4]

Even though the improvements in pediatric health care reduce childhood morbidity and mortality,[8] they do not come without a cost, and limited data are available about the continued trends in the surgical management of appendicitis, especially with the emerging non-surgical approach.[9] Therefore, we investigated temporal trends in national inpatient appendectomies among children to better understand resource utilization and patterns of cost distribution, including potential disparities in the management of acute appendicitis in children. The use of data from 2001 to 2017 for our study brings a dataset that is representative of a stable pre-pandemic period, offering a more consistent and reliable baseline for analysis compared to more recent data. The coronavirus disease-2019 pandemic significantly disrupted healthcare systems and patient behaviors, potentially skewing data on hospital admissions and surgical procedures. Additionally, the extensive timespan of our dataset allows for the identification of long-term trends and patterns in appendectomy practices.

Methods

This study was developed with de-identified, publicly available national data. Local ethics committee review was waived.

Study Design, Data Source, and Study Population

We performed a cross-sectional study of appendectomy hospitalizations in pediatric patients using the 2001-2017 National Inpatient Sample (NIS) data. NIS is the largest publicly available database for all-payer national inpatient care, developed by the Healthcare Cost and Utilization Project (HCUP). The HCUP divides the U.S. into nine geographic regions.[10] The database is designed to analyze inpatient utilization, access, cost, quality, and outcomes. Before 2012, the database retained all discharge data from a 20% sample of the hospitals in the U.S., stratified by region, hospital location, teaching status, ownership, and hospital size. Beginning in 2012, NIS sampled approximately 20% of discharge data from all HCUP-participating hospitals, excluding rehabilitation and long-term acute care hospitals. A NIS trend weight was applied to our analysis; thus, the estimates are comparable across the study years.[10]

Our study focused on pediatric patients (age <18 years) hospitalized for appendectomy between 2001 and 2017. The hospitalization data for the population was then compared with hospitalizations for other common pediatric surgical procedures (Figure 1). A population with appendicitis diagnosis, (with and without appendectomy) was specified separately to understand its impact on appendectomy hospitalization within the study period. Procedures and diagnoses were identified by Clinical Classifications Software (CCS), which collapses the International Classification of Disease (ICD) codes into clinically meaningful categories (see detailed CCS groups in Supplementary Table 1). NIS

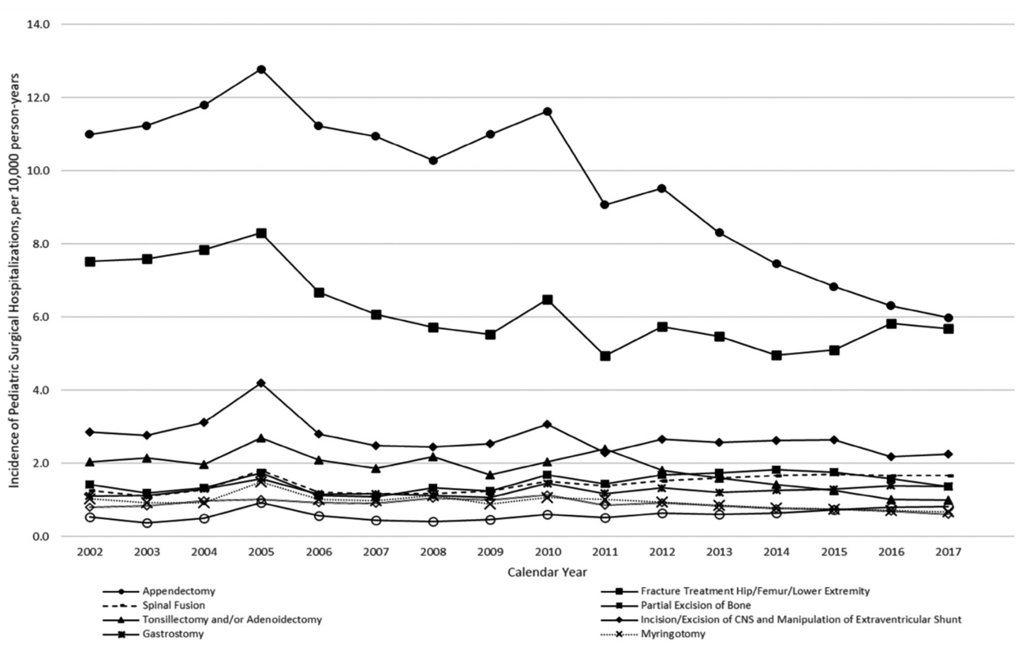

Figure 1. Incidence of pediatric surgical hospitalizations per 10,000 person-years, 2001-2017.

Table 1. Patient and Hospital Characteristics of Appendectomy Hospitalizations in the United States Children, 2001-2017

	2001-2002	2003-2005	2006-2008	2009-2011	2012-2014	2015-2017	Overall weighted frequency	P_{trend}
	Weighted percentage (95% CI)	Weighted percentage (95% CI)	Weighted percentage (95% CI)	Weighted percentage (95% CI)	Weighted percentage (95% CI)	Weighted percentage (95% CI)		
Age, median (IQR)	12 (8-15)	12 (8-15)	12 (8-15)	12 (8-15)	11 (8-14)	11 (7-14)	13,463,915	< 0.001
Female, sex	40.7 (40.1-41.3)	40.7 (40.3-41.1)	40.1 (39.7-40.6)	40.7 (40.2-41.2)	40.7 (40.2-41.3)	40.2 (39.6-40.8)	487,155	0.28
Race/ethnicity								
Non-hispanic white	45 (42-48)	41 (38-44)	42 (39-45)	45 (42-48)	45 (44-47)	42 (41-44)	531,773	0.053
Non-hispanic black	5 (4-6)	5 (4-6)	5 (4-6)	5 (4-6)	5.9 (5.5-6.3)	6.2 (5.7-6.6)	64,603	0.01
Hispanic	20 (17-23)	19 (16-22)	19 (16-21)	27 (24-30)	34 (32-36)	36 (34-38)	306,535	< 0.001
Asian, Pacific Islander, or Native American	2.3 (1.8-2.8)	1.8 (1.4-2.2)	2.2 (1.8-2.5)	2.9 (2.3-3.4)	3.4 (3.1-3.7)	3.6 (3.3-4)	31,996	< 0.001
Other	3.5 (2.6-4.4)	3 (2-4)	3.4 (2.8-4)	4 (3-5)	4.9 (4.5-5.3)	5.2 (4.7-5.7)	47,805	< 0.001
Missing	25 (21-28)	30 (26-34)	28 (25-32)	16 (13-19)	6 (5-8)	6 (5-8)	247,783	< 0.001
Hispanic								
Yes	20 (17-23)	19 (16-22)	19 (16-21)	27 (24-30)	34 (32-36)	36 (34-38)	306,535	< 0.001
No	55 (52-59)	51 (47-54)	53 (50-56)	57 (53-60)	59 (58-61)	57 (55-59)	676,177	< 0.001
Missing	25 (21-28)	30 (26-34)	28 (25-32)	16 (13-19)	6 (5-8)	6 (5-8)	247,783	< 0.001
Length of stay per hospitalization, median (IQR)	2 (1-4)	2 (1-4)	2 (1-4)	2 (1-4)	2 (1-4)	2 (1-5)	4,375,534	< 0.001
Urban teaching	2 (1-5)	2 (1-5)	2 (1-5)	2 (1-4)	2 (1-5)	3 (1-5)	1,227,269	0.50
Rural/urban non-teaching	2 (1-3)	2 (1-3)	2 (1-3)	2 (1-3)	2 (1-3)	2 (1-4)	104,375	0.14
Location/teaching status								
Rural	18 (15-20)	14 (12-16)	13 (11-15)	11 (9-13)	8.7 (8.1-9.4)	6.2 (5.6-6.7)	147,559	< 0.001
Urban non-teaching	39 (35-43)	40 (35-44)	39 (35-43)	35 (30-40)	27 (25-29)	17 (16-19)	418,301	< 0.001
Urban teaching	44 (38-49)	46 (41-51)	48 (43-53)	54 (48-60)	64 (62-66)	76 (75-78)	661,409	< 0.001
Region								
Northeast	19 (15-22)	19 (16-22)	20 (16-24)	16 (12-20)	17 (15-19)	16 (14-18)	221,620	0.30
Midwest	22 (19-26)	20 (16-24)	20 (17-22)	17 (13-20)	16 (15-18)	15 (14-17)	226,701	0.01
South	33 (28-37)	34 (30-39)	33 (28-38)	34 (28-40)	33 (30-36)	34 (32-37)	414,184	0.98
West	26 (22-31)	26 (22-31)	27 (23-31)	33 (27-39)	34 (31-37)	34 (31-37)	367,991	0.004
Bed size								
Small	15 (12-19)	14 (11-17)	15 (12-18)	11 (8-13)	14 (13-16)	16 (14-18)	173,641	0.03
Medium	31 (26-36)	30 (25-34)	25 (21-28)	25 (20-31)	25 (23-28)	25 (22-28)	329,824	0.09
Large	53 (49-58)	56 (51-61)	60 (56-65)	64 (58-69)	60 (58-63)	59 (56-62)	723,804	0.03

CI, confidence interval; IQR, interquartile range switched from the 9th version of the ICD codes (ICD-9) to the 10th version (ICD-10) to identify diagnoses and procedures in October 2015. A new scheme was implemented in CCS to accommodate this change. The 1st three CCS groups were reviewed to capture appendicitis diagnosis and the procedures of interest.

Outcome

The primary outcome was the incidence of appendectomy among hospitalized pediatric patients. Any appendicitis hospitalizations without appendectomy procedures were defined as non-surgical cases. The secondary outcomes included hospitalization costs and hospital length-of-stay for appendectomy. Hospital costs were converted from hospital charges using the cost-to-charge ratio provided by NIS.[11] All hospital costs were adjusted to 2017 U.S. dollars using the consumer price index to facilitate the comparison of costs across years.[12] Costs reflect the actual expenses incurred in the process of delivering hospital services, including wages, supplies, and utility costs.

Other Factors

Patient and hospital characteristics were evaluated to assess their associations with the temporal trend of appendectomy hospitalization. Patient demographic factors included age, sex, race, and ethnicity. Hospital factors included geographic locations (in regions and in divisions), urbanicity, teaching status, and hospital bed size (small, medium, and large). As NIS sampling was stratified by census region instead of census division before 2012, geographic estimates were reported in regions (Northeast, Midwest, South, and West) in Table 1 to cover the entire study period. Hospital bed size categories are specific to the hospital's region and teaching status. Rural and urban non-teaching hospitals were combined and compared with urban teaching hospitals to identify potential disparities in hospitalization cost and length-of-stay related to the hospitals' teaching status.[13]

Statistical Analysis

All analyses were performed with statistical analysis system (SAS) software, version 9.4 (SAS; Cary, NC). The estimates were calculated using appropriate survey commands in SAS and sample weights provided by NIS. Weighted percentages were reported with a 95% confidence interval. Continuous outcomes were reported as medians with interquartile range. To stabilize estimates, the descriptive results were grouped as 2001-2002, 2003-2005, 2006-2008, 2009-2011, 2012-2014, and 2015-2017. We performed Rao-Scott chi-square test to assess the temporal trend of appendectomy hospitalization, and a linear regression to examine the changes in procedure cost and hospital length of stay. A two-tailed P value < 0.05 was considered statistically significant.

The annual incidence of pediatric hospitalizations was calculated by dividing the estimated number of hospitalizations by the pediatric population from the U.S. Census Bureau.[14] The annual incidence trends were then calculated for appendectomy and other common pediatric surgical procedures. We also examined the incidence trend of hospitalizations diagnosed with appendicitis, grouped by treatment type. The median cost of the appendectomy procedure was calculated in the overall population and stratified by teaching status. An interaction term of linear regression was tested between the year variable and the teaching variable to determine the difference in temporal change in hospitalization cost according to teaching status.

To understand the geographic variation in the outcomes, we mapped appendectomy incidences and hospitalization costs at the division level, as defined by U.S. Census Bureau.[14] Due to NIS sampling strategy changes in 2012, all maps presented division-level outcomes in the earliest available year (2012) and the percentage change in 2017.

Results

Temporal Trends in Overall Incidence of Appendectomy

Overall, we identified 101,581 sampled hospitalizations for appendectomy, representing 256,783 visits. The incidence of appendectomy, the most frequent pediatric surgical procedure, decreased the most compared to other common surgeries, dropping from 11.2 to 6.4 per 10,000 person-years between 2001 and 2017 (Figure 1). A similar pattern was observed for the incidence of appendicitis hospitalization, which decreased from 10.7 to 6.3 per 10,000 person-years (Figure 2). The weighted estimates of non-operative hospitalizations for appendicitis diagnosis appeared stable across the study years (Figure 3).

Trends in Appendectomy Incidence Across the U.S.

While appendectomy incidence declined across the U.S., New England experienced the largest decrease of -59% between 2012 and 2017 (Figure 4) (Supplementary Table 2). The incidence in East South Central (-20%), Pacific (-31%), and West North Central (-34%) experienced smaller but still substantial declines. The incidence of appendectomy in the Pacific division was the highest among all divisions in both 2012 and 2017.

Temporal Trends in Hospital Costs for Appendectomy

The median hospital cost for appendectomy significantly increased between 2001 and 2017 (P_{trend} < 0.001, Figure 5), regardless of hospital location or teaching status. The non-significant interaction term ($P_{interaction}$=1.00) indicated a similar increase in appendectomy cost between urban teaching and rural/urban non-teaching hospitals. Additionally, the overall median length-of-stay for appendectomy hospitalizations was unchanged from 2001 to 2017.

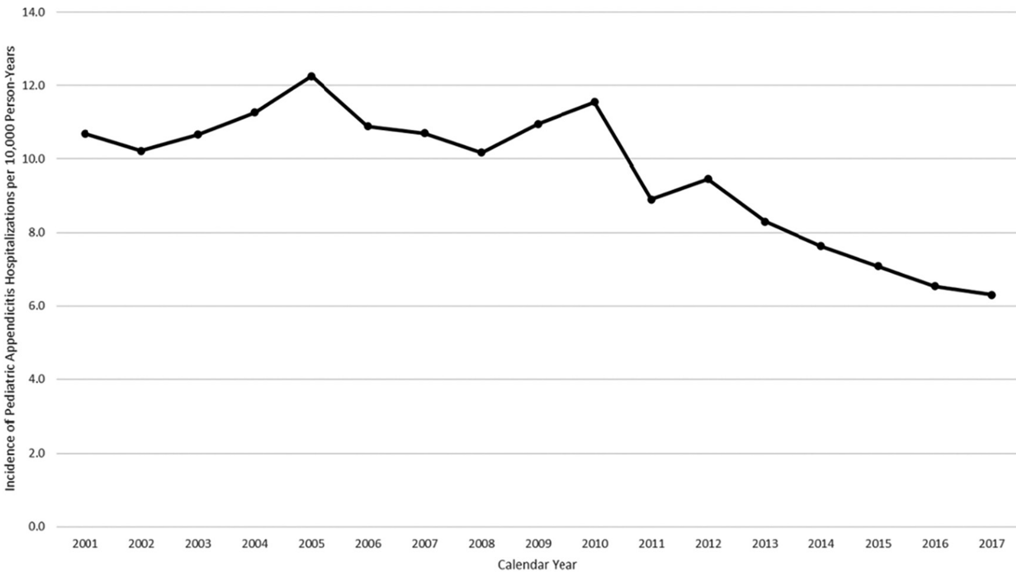

Figure 2. Incidence of pediatric appendicitis diagnosed hospitalizations per 10,000 person-years, 2001-2017

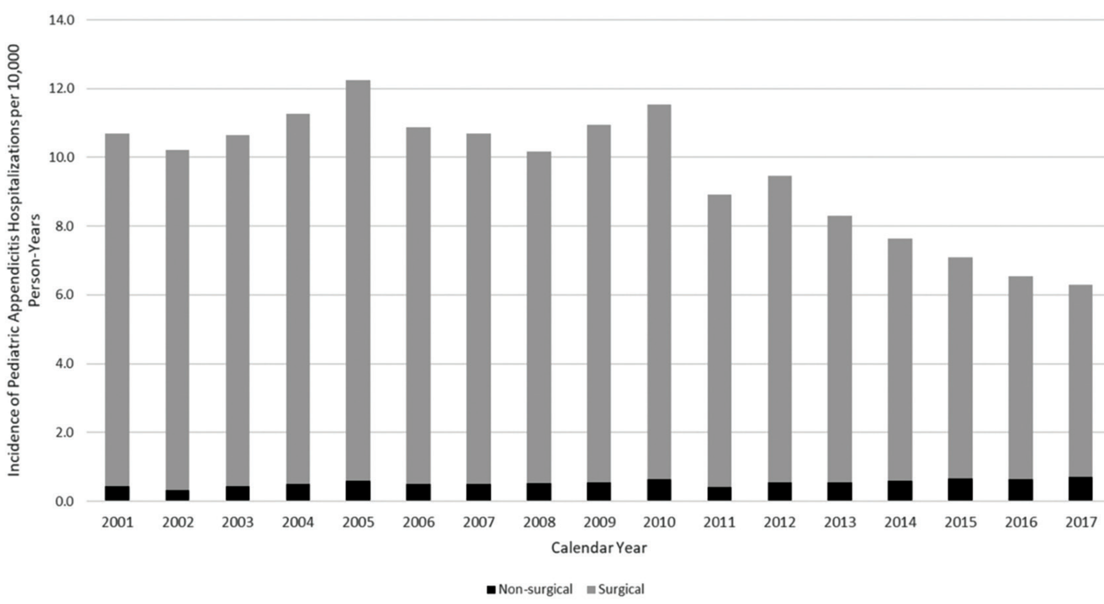

Figure 3. Incidence of pediatric appendicitis diagnosed hospitalizations by procedure type, 2001-2017

From 2012 to 2017, the median hospital cost for appendectomy in West South Central increased by 27% (Figure 6), which was higher than in other divisions. The median cost in East South Central stayed relatively stable. With the highest appendectomy incidence, the median hospitalization cost in the Pacific division was also greater than other divisions in 2012 and 2017 ($9,768 and $11,589, respectively; Supplementary Table 2).

Patient and Hospital Characteristics for Appendectomy Hospitalizations

The median age of pediatric appendectomy hospitalizations decreased slightly from 12 to 11 years over the study period ($P < 0.001$, Table 1). The number of hospitalizations varied by race/ethnicity. The percentage of Hispanic patients significantly increased from 20% to 36% between 2001 and 2017 ($P_{trend} < 0.001$).

We also observed variations in temporal hospitalization trends by hospital characteristics. The number of patients admitted for appendectomy to rural or urban non-teaching hospitals decreased during the study period (P_{trend} < 0.001). Meanwhile, the percentage of appendectomy hospitalizations in urban teaching hospitals increased from 44% to 76% (P_{trend} < 0.001). The proportion of appendectomy hospitalizations from the West region was significantly increased (P_{trend}=0.004), while the proportion of hospitalizations from the Midwest region was significantly decreased during the same period (P_{trend}=0.01). Additionally, hospitalizations for appendectomy occurred most often in hospitals with a large number of beds and significantly increased across years (P_{trend}=0.03).

Figure 4. Incidence of pediatric appendectomy hospitalization per division in 2012 (left) and percent of incidence reduced between 2012 and 2017 (right)

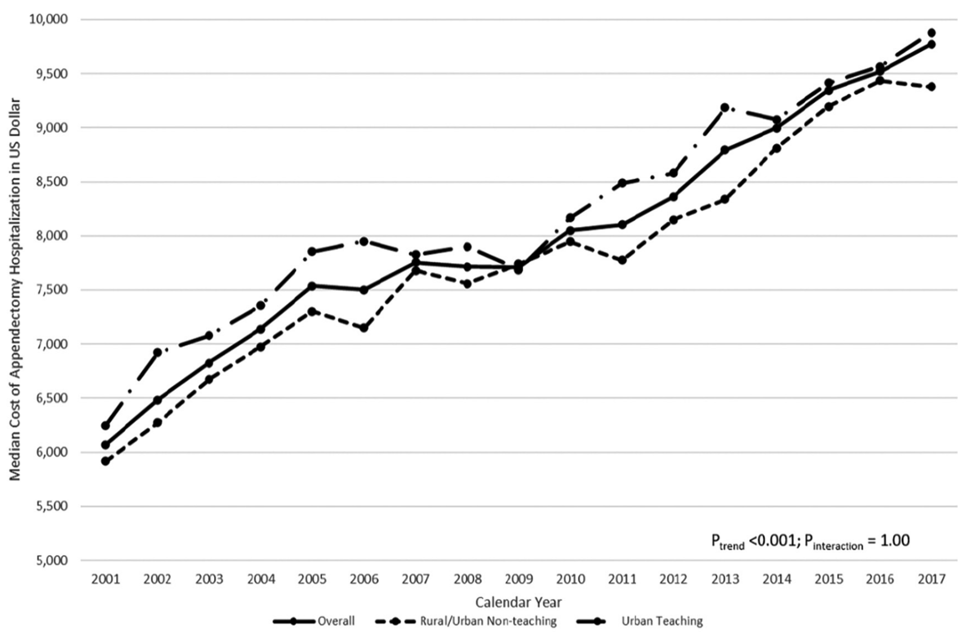

Figure 5. Median cost of pediatric appendectomy hospitalization in United States dollar, by hospital teaching status, 2001-2017

Figure 6. Median cost of appendectomy hospitalization per division in 2012 (left) and percent of cost increased between 2012 and 2017 (right)

Discussion

The results of this multi-year, cross-sectional study indicate that the incidence of appendectomy decreased markedly across the U.S., from 11.2 to 6.4 per 10,000 person-years between 2001 and 2017. There was a similar decline in the incidence of hospitalization for acute appendicitis. The observed reduction in appendectomy incidence may be partially attributed to the increased adoption of advanced diagnostic protocols and imaging techniques, which have improved diagnostic accuracy and potentially reduced unnecessary surgical interventions.[15-18] We identified differences across sociodemographic groups and divisions in the country that may reflect variability in access to or utilization of healthcare.[1,5,7] Despite a decline in overall appendectomies over this period, we observed an increase in costs. While our study did not specifically analyze individual contributors to cost increases, we acknowledge that the trends in increased costs are likely multifactorial. Several potential causes are suggested, including the shift towards laparoscopic procedures, which may have higher initial costs but offer benefits in terms of recovery and complications. The increased use of advanced diagnostic imaging, such as computed tomography (CT) scans, has improved diagnostic accuracy but also contributed to higher overall costs. The more widespread use of antibiotics, both pre- and post-operatively, has also been noted as a factor in cost escalation. Furthermore, studies have identified disparities in healthcare utilization and costs between urban and rural settings, which may influence overall expenditure trends. It's also worth noting that trainee involvement in surgeries, while crucial for medical education, can increase operative time and subsequently affect costs.[15]

Appendectomy remains by far the most common surgical procedure performed among U.S. children in the inpatient setting. We highlight the considerable decrease in its incidence from 2001 to 2017, while the incidence remained roughly stable for other procedures within the same timeframe (Figure 1). This trend can be at least partially attributed to modifications in the diagnosis and management of acute appendicitis in children.[16,17]

Specifically, acute appendicitis management has evolved to include more conservative approaches, such as antibiotic therapy, before operative resection, unless in severe or unstable cases,[18] contributing to the decrease in the appendectomy rate.[16] Classically, acute appendicitis in children was an indication for appendectomy,[17] which reduces the rate of associated complications, especially appendix perforation.[16,17] However, not all appendicitis cases have similar risks of complication if not promptly treated surgically.[19] Indeed, studies have demonstrated that some pediatric patients, particularly those over the age of 5 years with uncomplicated acute appendicitis within 48 hours of symptom onset, could be reasonably treated with conservative antibiotic therapy with a successful treatment rate above 50%.[16,17] Moreover, because uncomplicated acute appendicitis cases are much more common than complicated ones, our results may suggest that a non-operative approach could have been considered to a relatively high number of affected patients, resulting in a downwards trend in the incidence of appendectomy.[16] Meanwhile, some authors have hypothesized reasons for the decreasing trend seen in appendectomies, such as technological changes in diagnostic and treatment techniques, management of complications, implementation of new strategies and protocols, or associations with chronic conditions.[15]

Historically, acute appendicitis has been a clinical diagnosis based on typical abdominal pain features and associated signs and symptoms during physical examination and patient history.[20] Further laboratory evaluation commonly demonstrates leukocytosis, elevated absolute neutrophil count, and C-reactive protein, which have variable performance and predictive values across studies.[21] To increase diagnostic accuracy, tools such as the Pediatric Appendicitis Score (PAS) and the Alvarado score are used as a combination of these variables and provide valuable clinical utility.[21,22] Concurrently, readily available, sensitive imaging methods, ultrasound, and CT scans have emerged as diagnostic tools. These tools increase the reliability of diagnosis and help identify cases and complications of acute appendicitis.[23]

The recent efforts toward non-surgical approaches to appendicitis may also play a role in an increase in hospital length-of-stay (Table 1). Despite the constant rate of non-surgical management of appendicitis over the years, this approach represented a higher proportion compared to a surgical approach, as the overall frequency of these hospitalizations declined. Conservative management could result in longer hospitalizations.[24] When a non-operative approach is proposed, antibiotics are initially administered intravenously in the inpatient setting, and are eventually transitioned to oral medication, with the patient being discharged when feasible.[16,25] Since a conservative approach is not currently recommended by guidelines,[26] clinical reasoning for uncomplicated cases tends to require longer observation periods, with additional imaging and laboratory confirmatory tests increasing the length of stay in the hospital days in the hospital for intravenous antibiotics.

Studies involving adults have demonstrated a similar pattern of overall longer hospital stays for cases treated conservatively, due to variable rates of failure of antibiotic therapy, complications, and reoperation.[16,24,25] Furthermore, approximately one-third of patients initially assigned to receive antibiotic therapy undergo an appendectomy afterwards.[18] Regardless of age, laparoscopic techniques may safely manage uncomplicated appendicitis; however, when complications develop, conventional open techniques tend to be the first choice, and these are associated with longer recovery periods, delayed return to normal activities, and more pronounced psychological effects of hospitalization.[16,17,24-26]

Our nationwide data are also consistent with the previously described decrease in the incidence of appendicitis since the 1940s, with a 14.6% national decrease in the rate observed between 1970 and 1984.[27] Even though a similar nationwide decrease in appendectomies continues to occur, racial and geographic variability seems to play a role in the uneven distribution of this procedure across different regions of the U.S.[28] Disparities in health outcomes have been shown to be affected by many variables beyond the healthcare setting,[28,29] race, income, healthcare access and utilization may influence not only when patients will seek care for one specific condition, but also the success of treatment, rate of complications, availability of follow-up, and overall mortality.[28,30]

For acute appendicitis, many experts have highlighted how crucial it is to ensure that no patients, especially vulnerable populations, are deprived of necessary care, as this can result in an increased likelihood of unfavorable outcomes.[18] This population commonly relies on community hospitals, frequently located in rural areas,[28,30] and such healthcare settings typically have less resources available when compared to urban-teaching hospitals.[13] The increase in costs of appendectomy over the years, in both healthcare settings, illustrates that high-quality, cost-effective management could help optimize resource utilization and lessen the important healthcare burden represented by appendicitis.[2,4] An overall rise in health care costs over the study period most likely reflects the constant incorporation of new medicines, procedures, and technologies.[21,23] With the increasing concern about the affordability of health care, the trends provide an important overview of the incidence and spending associated with the most common emergent surgical procedure in the pediatric population.

Study Limitations

This study comes from the analysis of a large nationally representative database over a long study period. Despite the widely generalizable results, these trends presented here were obtained based on procedure codes, which is a system prone to error, and which can lead to misclassification of the outcome. Considering the study period, we also need to acknowledge that administrative data transitioned from ICD-9 to ICD-10 codes in October 2015, which may affect trends, and that there were data-structure changes in NIS elements that occurred in the same year.[10,11] Furthermore, NIS implemented a sample redesign in 2012 to better represent U.S. hospitals. As the old design was stratified by regions instead of divisions, it would be inaccurate to calculate division-level estimates before 2012. Therefore, the maps in our study focused on the change in incidence in the later years by division. Additionally, some secondary diagnoses codes might still refer to surgical inpatient outcomes but do not necessarily differentiate between complications and comorbid conditions, limiting our ability to specify costs related to the main procedure.

Conclusion

Between 2001 and 2017, we identified a significant decline in the incidence of appendectomies among U.S. children and overall hospitalizations for acute appendicitis. By contrast, costs for hospitalizations for appendectomy have increased, suggesting that modifications in the approach to appendicitis, including utilities and supplies used in its management, have made the procedure itself more expensive, even after adjusting for inflation. The differences in patient characteristics and geographic distribution of the incidence of this procedure emphasize the multitude of components involved in the surgical approach to appendicitis. Future analyses of clinical data could consider whether the increase in costs translates into better outcomes such as fewer complications and readmissions, aiming to provide improvements in care for patients with appendicitis. Previous data have shown that access to healthcare, and ultimately outcomes, vary considerably by sociodemographic factors, and these aspects are useful in generating evidence-based guidelines valuable in the evaluation and management of appendicitis. Our findings emphasize the importance of standardized care protocols to reduce variability and improve outcomes, while also suggesting that lessons from international practices, such as broader adoption of non-operative management, could further enhance pediatric appendicitis care in the U.S. Finally, the overall rising costs and disparities seen in the approach to appendicitis should call for the development of treatment strategies and policies that consider clinical factors in the decision-making process of managing pediatric appendicitis.

Ethics

Ethics Committee Approval: Waived (analysis of de-identified, publicly available national dataset).

Informed Consent: Not applicable.

Footnotes

Author Contributions: Concept - L.C.S., J.G., C.A.C.; Design - L.C.S., J.G., R.C.F.F., P.F.M., L.B.R., C.A.C.; Data Collection and/or/Processing - J.G.; Analysis and/or/Interpretation - L.C.S., J.G., R.C.F.F., P.F.M., L.B.R., C.A.C.; Literature Review - L.C.S., R.C.F.F., P.F.M.; Writing - L.C.S., J.G., R.C.F.F., P.F.M., L.B.R., C.A.C.

Declaration of Interests: The authors declare no conflicts of interest.

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Click for Supplementary Table 1 and 2 access link:

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Case Report

Paediatric Anaesthesia

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Neonatal Severe Hyperparathyroidism: Anaesthetic Considerations for Removal of Pea-size Glands in Children

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Abstract

Neonatal severe hyperparathyroidism (NSHPT) is an extremely rare disorder with uncontrolled severe hypercalcemia and its clinical manifestations. It is caused by a mutation in the *calcium-sensing receptor (CaSR)* gene, which modulates the negative feedback of parathormone. We present anaesthetic management of two children with NSHPT who were posted for total parathyroidectomy as a life saving procedure. Both patients presented with lethargy, failure to thrive, and hypotonia. Intraoperative anaesthetic challenges include susceptibility to bradycardia, prolonged QT interval, precipitation of hypercalcemic crisis in the form of renal failure, hyperkalemia and electrocardiography changes, unpredictable response to neuromuscular blockade, susceptibility to recurrent laryngeal nerve injury, refractory hypocalcemia, which may start developing within six hours after surgery. Anaesthetic goals include preoperative optimisation of serum calcium with subcutaneous. Calcitonin, intravenous pamidronate and tablet cinacalcet, which are calcimimetics, maintenance of hydration and readiness to deal with intraoperative hypercalcemic crises. Anaesthetic management of NSHPT posted for total parathyroidectomy is challenging. To the best of our knowledge, there is no anaesthetic literature published to this day and only four surgical cases have been reported. Genome sequencing in both patients showed a *CaSR* gene mutation that is homozygous for a suspected pathogenic variant. Management requires a preoperative multidisciplinary approach for severe hypercalcemia and postoperative refractory hypocalcemia. These patients need lifelong calcium and vitamin D supplementation.

Keywords: Calcimimetics, hypercalcemia, neonatal severe hyperparathyroidism, parathyroidectomy

Main Points

- Neonatal severe hyperparathyroidism is an extremely rare disorder which is caused by inactivating mutations of calcium-sensing receptors present on the parathyroid gland.
- Parathyroidectomy is the definitive treatment.
- Pre-operative optimization of serum calcium is extremely challenging to prevent an intraoperative hypercalcemic crisis.
- Management requires preoperative multidisciplinary approach for severe hypercalcemia and postoperative refractory hypocalcemia. These patients need lifelong calcium and vitamin D supplementation.

Introduction

Neonatal severe hyperparathyroidism (NSHPT) is an extremely rare disorder with prevalence of 2-5 cases per 100,000.[1,2] It is caused by inactivating mutations of calcium-sensing receptors (CaSR) present on parathyroid gland which modulates the inhibitory feedback of parathormone (PTH) release thus resulting in uncontrolled hyperparathyroidism with severe hypercalcemia.[3,4] Parathyroidectomy is a definitive treatment.[5] We report anaesthetic management of two children with NSHPT, scheduled for total parathyroidectomy.

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Case Reports

Case 1

A 40-day-old term male infant weighing 2,840 kg was diagnosed with NSHPT on day-10 of life. The child presented with lethargy, excessive crying and failure to thrive. Subsequent investigations were done and revealed hypercalcemia [serum calcium of 18 mg dL^{-1}, ionized calcium (iCa^{2+}) 4.08 mmol L^{-1}, serum PTH 971 pg mL^{-1} (range 15-65 pg mL^{-1})], and hyperkalemia (serum potassium 6.3 mEq L^{-1}). The patient was treated in the neonatal intensive care unit (NICU) according to the hyperparathyroid protocol, which includes a first saline bolus (10 mL kg^{-1}) followed by intravenous furosemide (1 mg kg^{-1}), and then calcitonin 4 U kg^{-1} (every 12 hours) subcutaneously for the initial 48 hours. Hypercalcemia was still uncontrolled, hence three doses of intravenous pamidronate 1 mg kg^{-1} and tablet cinacalcet 0.5 mg kg^{-1} day-1 in three divided doses were given. Pre-operative electrocardiography (ECG) was suggestive of short QT interval. Ultrasonography neck revealed a parathyroid adenoma 4x2x4 mm in the right inferior parathyroid lobule with no displacement of the upper airway structures (Figure 1). The patient was planned for total parathyroidectomy due to uncontrolled hypercalcemia. On the day of surgery, the morning dose of cinacalcet was omitted as postoperative hypocalcemia was expected. Emergency drugs were kept ready, such as insulin for hyperkalemia, inhaled β2 agonists for hyperkalemia, and furosemide and calcitonin for hypercalcemic crisis. Intraoperative monitoring included non-invasive blood pressure (BP), pulse oximetry, ECG, temperature, and end tidal carbon dioxide ($EtCO_2$). Baseline heart rate (HR) was 124 min^{-1} and BP 74/42 (54) mm Hg (50^{th}-90^{th} centile). Near infrared spectroscopy (NIRS, INVOS™ Somanetic Corp. Troy, MI) was monitored. Anaesthesia was induced with incremental doses of sevoflurane (2-6%), with oxygen and nitrous oxide (50/50). Intravenous fentanyl 2 µg kg^{-1} and intravenous cisatracurium 0.15 mg kg^{-1} were given, and the infant was intubated with a 3.5 mm uncuffed endotracheal tube. Anaesthesia was maintained with oxygen/nitrous oxide/sevoflurane minimum alveolar concentration (MAC-1-1.2). Under ultrasound guidance, the right radial artery was cannulated for intraoperative hemodynamic monitoring, blood gas, and serum PTH levels. Intraoperative train of four (TOF) monitoring was done for neuromuscular blockade. Plasmalyte was chosen as the intravenous fluid of choice as it is devoid of calcium, and was given at a maintenance rate of 10 mL kg^{-1} hr^{-1}. Prior to surgical incision, 1 µg kg^{-1} fentanyl and intravenous Paracetamol 15 mg kg^{-1} were given. Intraoperatively, PTH levels were sent at the following time intervals i) Pre-resection (levels were 1,900 pg mL^{-1}) ii) 20 minutes after removal of all four parathyroid glands (levels to 83 pg mL^{-1}), this post resection drop in serum PTH along with pathological frozen sections confirmed successful resection of all four parathyroid glands (Figure 2). Post resection serum sodium was 134 mEq/L, potassium -5.6 mEq L and iCa^{2+}>4 mmol L^{-1}. Patient hemodynamics was stable throughout the surgical procedure without Inotropic support and NIRS values were within 20% of baseline (NIRS baseline values=75). At the end of the surgical procedure, the TOF count was >0.9 vocal cords were adducting and abducting well under C-MAC videolaryngoscope guidance following which trachea was extubated. Post extubation, the patient (post conceptional age >47 weeks) was shifted back to NICU for observation in view of risk of post-anaesthetic apnea. On postoperative day-1, serum PTH was 22 pg mL^{-1} serum calcium was 8.6 mg % and iCa^{2+} reduced to 1.93 mmol L^{-1} and patient was started on cap calcitriol 0.125 µg 12 hourly, vitamin D3 drops 2,000 IU day-1. The patient was discharged on postoperative day-13 with oral vitamin D3 and calcium supplementation.

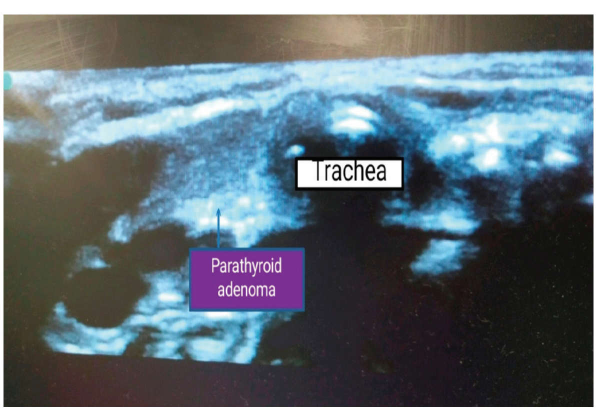

Figure 1. Ultrasound of neck showing parathyroid adenoma

Case 2

A two year female child weighing 4.2 kg, with history of poor weight gain and delayed milestones was diagnosed as NSHPT on. Day-33 of life. The child received two doses of intravenous pamidronate for: high serum calcium 19.4

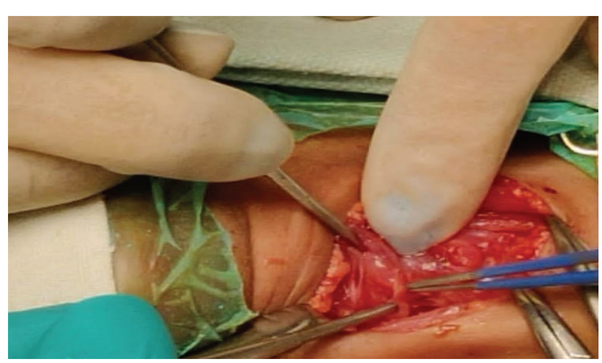

Figure 2. Right parathyroid lobule during surgical dissection

mg dL^{-1}, iCa^{2+} 1.84 mmol L^{-1} and PTH 586 pg mL^{-1}. Child was started on tab cinacalcet 7.5 mg. Preoperatively, serum calcium was 11.0 mg dL^{-1}; iCa^{2+} 1.2 mmol L^{-1}; and PTH 1,900 pg mL^{-1}. Ultrasonographic evaluation of parathyroids showed two enlarged glands one at right midpole measuring 2*7 mm and in left lower pole measuring 2*4 mm. On the day of surgery, the morning dose of cinacalcet was omitted. The child was premedicated with intravenous midazolam 0.1 mg kg^{-1}, and standard American Society of Anesthesiologists monitors, including non-invasive BP, pulse oximetry, ECG, and $EtCO_2$, were attached. Baseline HR was 122 min^{-1} with BP 82/35 mmHg, NIRS values of 73 and ECG showed sinus rhythm. Child was induced with intravenous fentanyl 2 µg kg^{-1}, intravenous propofol and intravenous atracurium 0.5 mg kg^{-1} and intubated with 3.5 mm microcuff® (AVANO, Roswell, GA) tube and maintained with oxygen/nitrous oxide and desflurane 4-6 (0.8 to 1.0 MAC). Intravenous paracetamol, 15 mg kg^{-1}, was given as a part of multimodal analgesia. Ultrasound-guided vascular access was secured via the left brachiocephalic vein. All four parathyroids were excised and confirmed by frozen section and fall in PTH (Pre-resection PTH >1,900 pg mL^{-1}, and 20 minutes post excision was 166 pg mL^{-1}). Plasmalyte was given at the maintenance rate of 10 mL kg^{-1} h^{-1}. Intraoperative hemodynamics were stable. Post-extubation, the patient was transferred back to intensive post-cardiac care unit for observation. On postoperative day-1, serum PTH was 11.2 pg mL^{-1}, serum calcium was 8.8 mg dL^{-1}, and iCa^{2+} was 1.13 mmol L^{-1}. Patient was started on tab calcitriol 0.25 µg and was discharged on postoperative day-10 with calcium and vitamin D supplementation.

Genome sequencing in both patients showed *CaSR* gene mutation homozygous for suspected pathologic variant.

Discussion

NSHPT requires emergency parathyroidectomy due to life-threatening manifestations like failure to thrive, anorexia, vomiting, irritability, lethargy, hypotonia, and seizures.[6,7] Bradycardia, short QT interval, and hypertension are other findings due to hypercalcemia. Long-term metabolic consequences include nephrocalcinosis that may cause permanent renal damage, skeletal muscle weakness, osteoporosis, and neurodevelopmental impairment. Our patients presented with hypercalcemia, hyperkalemia, lethargy and intolerance to feeding. Only four surgical cases have been reported so far. Calcitonin is given subcutaneously for the first 48 hours, as tachyphylaxis develops after that.[8] Intravenous pamidronate (0.5-1 mg kg^{-1}) inhibits macrophage and osteoclastic activity. Subsequent doses are repeated at 7-10 days interval. Cinacalcet is a calcimimetic drug and therefore increases the sensitivity of calcium receptors on parathyroid cells, thereby reducing PTH levels and thus decrease in serum calcium levels.[9,10] Pre-operative optimization of serum calcium is extremely challenging to prevent intraoperative hypercalcemic crisis.

Intraoperative anaesthetic challenges include susceptibility to bradycardia, prolonged QT interval, precipitation of hypercalcemic crisis in the form of renal failure, hyperkalemia and ECG changes, unpredictable response to neuromuscular blockade, and refractory hypocalcemia, which may start developing within six hours after surgery. Additional challenges include recurrent laryngeal nerve injury leading to vocal cord palsy, stridor, and tracheomalacia. Maintenance of hydration is important perioperatively to prevent hypercalcemic crisis. We used NIRS monitoring for cerebral oxygenation as a marker to rule out great vessel compression during neck dissection. Intraoperatively, the values were within 20% of baseline. TOF >0.9 was accepted for extubation and reversal. Neuromuscular blockade was antagonized using intravenous neostigmine 50 µg kg^{-1} and intravenous glycopyrrolate 10 µg kg^{-1} after generating adequate tidal volume and respiration with no signs of airway obstruction. In both cases, the intraoperative and postoperative course was uneventful.

Conclusion

Anaesthetic management of NSHPT undergoing total parathyroidectomy is challenging. To the best of our knowledge, there is no anaesthetic literature published to this day. Management requires preoperative multidisciplinary approach for severe hypercalcemia and postoperative refractory hypocalcemia. These patients need lifelong calcium and vitamin D supplementation.

Ethic

Informed Consent: The patients provided consent for the clinical information pertaining to the case to be published in a medical journal.

Footnotes

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Letter to the Editor

Turkish Journal of Anaesthesiology & Reanimation

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Comment on "Can Artificial Intelligence Be Successful as an Anaesthesiology and Reanimation Resident?"

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Keywords: AI, anaesthesiology, intensive care, resident, technology

Dear Editor,

The publication on "Can Artificial Intelligence Be Successful as an Anaesthesiology and Reanimation Resident?"[1] The purpose of this study was to compare ChatGPT artificial intelligence's (AI) performance with that of anaesthesiology and critical care residents using an exam equivalent to the European Diploma in Anaesthesiology and Intensive Care Part 1. Although the study's design indicates an attempt to examine the possibilities of AI in a complex medical setting, there are various flaws in the research methodology that should be carefully considered. For example, asking ChatGPT the identical questions a day in advance may increase the risk of data leakage, or the model may alter the responses based on context. When contrasted to people who do not have time to prepare in advance, those who do have time exhibit a distinct disparity.

In terms of statistics, non-parametric data should be reported using the median and range. However, the study did not identify the number of test takers, which influenced the statistical analysis. For example, the P value, indicating a significant difference between the training groups of less than and more than 24 months, limited the ability to thoroughly investigate the effect size. Furthermore, within the human group, the ranking of ChatGPT lacked a defined criterion, making it difficult to examine its location in relation to the score distribution in each group.

To encourage in-depth conversation. Questions to consider include: How does ChatGPT employ data sources and processing methods to provide answers? Should there be special criteria or models for assessing AI medical expertise that differ from human knowledge?

Does the fact that ChatGPT performed modestly among trainees imply that AI can replace basic analytical tasks? What are the implications for patient safety if AI is using old or out-of-date data? These questions will spark ethical debates and future regulation of AI therapeutic applications.

Future research should focus on evaluating AI in clinical scenario simulations that demand contextual analysis or time-bound decision-making, rather than answering multiple-choice questions that do not reflect practical skills. Furthermore, AI should be compared to healthcare professionals at various levels of expertise (e.g., senior physicians or specialists) and evaluated in terms of communication, data interpretation, and treatment recommendation

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capabilities to determine AI's true potential and limitations in supporting responsible medical practice.

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Reference

1. Kültüroğlu G, Özgüner Y, Altınsoy S, Kına SF, Erdem Hıdıroğlu E, Ergil J. Can artificial intelligence be successful as an anaesthesiology and reanimation resident? *Turk J Anaesthesiol Reanim*. 2025 Apr 30. Online ahead of print. [CrossRef]

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Letter to the Editor

Perioperative Care

Turkish Journal of Anaesthesiology & Reanimation

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Fluid Selection in Renal Transplant Patients: Considerations for Hyperkalemia Management

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University of Health Sciences Türkiye, Başakşehir Çam and Sakura City Hospital, Clinic of Anaesthesiology and Reanimation, İstanbul, Türkiye

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Keywords: Acid-base balance, balanced crystalloids, fluid selection, hyperkalemia management, perioperative care, renal transplantation

Dear Editor,

I would like to extend my gratitude to the authors for their comprehensive and valuable review on this important topic.[1] Recognizing that appropriate fluid selection may significantly impact clinical outcomes and enhance recovery after surgery (ERAS) in renal transplant recipients, I seek to contribute to their review by providing a more detailed analysis of crystalloid selection.

Metabolic acidosis occurs in the progression of chronic kidney disease as a result of reduced acid excretion capacity combined with increased daily endogenous and exogenous acid production. However, the hyperkalemia observed in these patients is a consequence, not a cause, of metabolic acidosis.[2] And since hyperkalemia is a common challenge in renal transplant patients, clinicians have traditionally favored 0.9% saline infusion due to its lack of potassium. Saline-induced hyperchloremia reduces the strong ion difference, which promotes water dissociation and consequently leads to metabolic acidosis.[3] Acidosis inhibits Na^+-H^+ exchange, one of the key pathways maintaining pH and potassium homeostasis in cells, thereby increasing potassium efflux (see Figure 1).[4] Since 98% of total body potassium resides intracellularly, the disruption of K^+ homeostasis between intracellular and extracellular compartments (e.g., due to saline-induced acidosis) is considered a more critical factor than external potassium intake (e.g., potassium-containing balanced crystalloids).[2] Furthermore, high-chloride solutions, such as saline, may induce renal vasoconstriction and lead to a reduction in glomerular filtration rate.[5] This has led some clinicians to prefer potassium-containing solutions with chloride concentrations more comparable to plasma, such as Plasma-Lyte and Ringer's lactate (RL). The authors state in their review that "The proper fluid type remains controversial and open for research, but balanced crystalloid solutions seem to be the best choice" and cite two references to support this claim.[1,6,7] However, neither of these references discusses the superiority of one crystalloid type over another. One reference merely suggests that the use of crystalloids is appropriate but does not specify which type of crystalloid should be preferred.[6] The other reference reveals an association between overhydration, microinflammation, and endothelial dysfunction, without addressing fluid type selection.[7] Yet, numerous studies have demonstrated the advantages of balanced crystalloids over saline in renal transplant recipients. Studies comparing RL and saline in renal transplant patients have shown that potassium concentrations in the RL group are similar to or even lower than those in the saline group.[8-10] Studies comparing Plasma-Lyte with saline have reported a higher incidence of hyperkalemia, hyperchloremia, and metabolic acidosis in the saline group.[11-13] Additionally, better diuresis and less frequent use of renal replacement therapy early after surgery, as well as better graft function at 3

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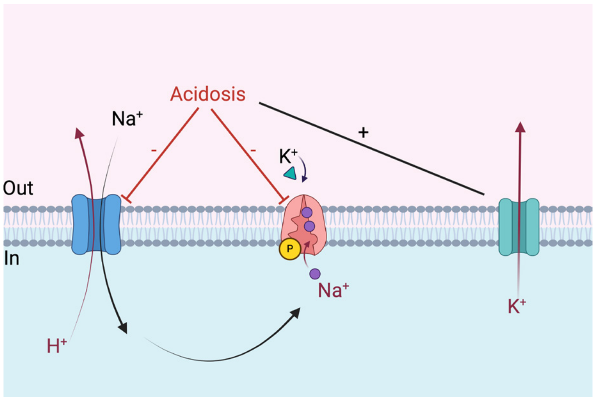

Figure 1. Effects of acidosis on Na^+-H^+ exchange, Na^+-K^+ ATPase pump, and K^+ efflux in a muscle cell [Created in BioRender. Tontu F. (2025) https://BioRender.com/z88e118]

months, were observed in the Plasmalyte group, which may also contribute to ERAS protocols.[11] The American Society of Anesthesiologists Transplantation Committee has stated that, in renal transplant patients, perioperative balanced crystalloid solutions are associated with a better metabolic profile and comparable or lower potassium levels compared to saline. Therefore, their use is recommended (GRADE moderate-quality of evidence, strong recommendation).[14] The 2016 Cochrane meta-analysis reported that balanced solutions are associated with a lower incidence of hyperchloremic metabolic acidosis compared to saline; however, the impact of low-chloride solutions on graft outcomes remains uncertain.[15] However, the BEST-Fluids trial, a multicenter, double-blind, randomized, controlled study published in 2023, yielded striking findings regarding delayed graft function (DGF) in renal transplant patients.[16] The study included 807 patients who underwent deceased donor kidney transplantation, randomized into two groups: saline (n = 403) and balanced crystalloid (n = 404). DGF was observed in 120 patients (30%) in the balanced crystalloid group, compared to 160 patients (40%) in the saline group [adjusted relative risk 0.74 (95% confidence interval 0.66-0.84; $P<0.0001$)]. Based on these findings, the use of balanced crystalloids in deceased donor kidney transplant recipients has been emphasized as the standard of care.[16] In early 2025, a highly recent meta-analysis incorporating data from 10 studies and 1,532 patients was published.[17] According to this analysis, balanced crystalloids significantly reduce the risk of DGF compared to saline in deceased donor kidney transplantation. However, no significant difference was observed between the two groups regarding the risk of hyperkalemia or DGF in living donor kidney transplantation.[17] The authors suggest that targeted fluid therapy and optimized perioperative hemodynamic management can prevent DGF.[1] Additionally, the selection of a crystalloid type may also be crucial in preventing DGF and contributing to ERAS protocols.

In summary, the current literature demonstrates that balanced crystalloids offer several advantages over saline, which may also contribute to ERAS protocols, without posing an additional risk of hyperkalemia.

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"Brennan M, Han SH, Ockerman K, Mehta SD, Furnas HJ, Heath F, Mars P, Klenke A, Sorice-Virk SC. Perioperative Practice Patterns of Anaesthesiologists Surrounding Glucagon-Like Peptide-1 (GLP-1) Agonist Medications. Turk J Anaesthesiol Reanim. 2025 Apr;53(2):42-52. doi:10.4274/TJAR.2025.241653."

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Informed Consent: Survey study.

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