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Abstract

Arterial hypertension remains the most significant modifiable risk factor for cardiovascular diseases and is a leading cause of premature mortality worldwide. Evidence from longitudinal studies, spanning early childhood to young adulthood, confirms that elevated blood pressure (BP) in adolescence strongly predicts hypertension (HT) in later life, whereas normal BP values in childhood are associated with a lower risk of developing hypertension in middle age. Increasing attention has been drawn to prenatal and perinatal determinants of cardiovascular health, and numerous studies suggest that the mode of delivery may play an important role in shaping blood pressure regulation in later life.

The study ultimately included 747 children and adolescents aged 4–15 years. Anthropometric assessments, blood pressure measurements, and comprehensive evaluation of prenatal and perinatal factors were conducted.

Delivery by caesarean section (C-section) was associated with a higher likelihood of elevated blood pressure. Among children born via C-section, 43.5% presented with increased BP values, compared with 38.8% in the group born naturally. This difference was statistically significant ($p = 0.015$*). Additionally, arterial hypertension was diagnosed in 23.5% of children delivered vaginally.

C-section can increase the risk of elevated blood pressure during childhood, suggesting that mode of delivery may be an important early life determinant of cardiovascular health.

Keywords: childbirth, delivery, caesarean section, blood pressure

Introduction.

High blood pressure (BP) in children is a growing health problem, closely linked to changing lifestyles and the rising prevalence of overweight and obesity in the pediatric population. Although for many years considered rare in young children, it is now known that primary hypertension (PHT) is the most common form of hypertension (HT) in school-age children and adolescents. It is characterized by a lack of a clear organic cause, and its development is the result of an interaction of genetic, environmental, and behavioral factors.

Early diagnosis and control of blood pressure are crucial, as elevated blood pressure levels in childhood can persist into adulthood, increasing the risk of cardiovascular diseases, such as myocardial infarction and stroke, atherosclerosis, and chronic kidney disease [1,2,3.]

Data from repeated blood pressure measurements (from early childhood to early adulthood) support the association of elevated BP in adolescence with hypertension in adult life and normal BP in childhood with absence of hypertension in middle age [4].

One of the directions of cardiological prevention is the detection of subclinical symptoms affecting children and adolescents. It is children and young people who are the most flexible and susceptible to favorable changes, among whom the principles of a healthy lifestyle should be introduced as early as possible. Measurements of BP and body weight and height are among the basic, simplest and cheapest, though often underestimated, methods of early prevention.

Epidemiological studies have shown that the incidence of high blood pressure in children and adolescents has increased significantly in recent years [5,6]. Studies suggest that 5–8% of children and adolescents have hypertension, and an additional 10–14% have elevated BP, often referred to as prehypertension [7]. BP measurement in younger children is associated with a high risk of failure due to the lack of cooperation on the part of the patient.

Based on a systematic review by Song et al., it can be estimated that HT affects 4–6% of the pediatric population aged 0–18 years, with varying frequencies in individual age groups. [8],The phenotype of PHT can present as early as 3 years of age and is the predominant form of hypertension in children after age of 6 years [9].

According to the data of the Polish Society of Hypertension from 2015, with the increase in obesity in children and adolescents, the frequency of primary hypertension increases and among all children diagnosed due to hypertension, its frequency is about 50% [10.] From the research carried out in the team of Wyszyńska, shows that 68% of children with prehypertension develop persistent hypertension within 4 years [11,12.]

Researches show that the kind of birth vaginal and cesarean section (C-section), has some association with blood pressure in infancy and childhood, although the effects are generally modest and can depend on the other factors too.

Vaginal delivery is a natural way of childbirth and brings many physiological and microbiological benefits that affect the development of the cardiovascular system. During

natural birth, the baby experiences stress related to contractions and passage through the birth canal, which triggers the release of catecholamines, more effective cleansing of the lungs of fluid and adaptation of the circulatory system immediately after birth [13.] This early response to stress helps the cardiovascular system mature and regulate blood pressure more effectively.

These microbes affect gut health, metabolism, and immune regulation, which affects inflammation control, endothelial function, and blood pressure regulation.

Babies born vaginally are exposed to maternal vaginal and gut microbiota and can affect the development of the immune and cardiovascular systems, potentially leading to slightly lower BP later in life [14.] Better insulin sensitivity and a lower risk of obesity, which also helps maintain normal blood pressure [15.]

Some studies have found that children born by C-section may have slightly higher systolic blood pressure during childhood or adolescence [16.] Differences in metabolic and microbiome development, which might contribute to altered BP regulation. Mínguez-Alarcón and co-authors show that adolescents born by C-section have lower levels of adiponectin and higher levels of insulin, suggesting increased insulin resistance, relative to adolescents born by vaginal delivery [17.] C-section was independently associated with increased CVD risk profiles of children, further increased with high BMI trajectory [18].

Over the years global C-section rates has significantly increased from around 7% in 1990 to 21% today surpassing the ideal acceptable C-section rate which is around 10%–15% according to the WHO. However, currently, not all C-section are done for medical reasons with rapidly increasing rate of nonmedically indicated C-section and the so-called “caesarian on maternal request.” These trends are projected to continue increasing with the projected global rate of 29% by 2030 [19.]

More and more women are opting for an on-demand C-section. However, this procedure should be performed in justified cases, when the health of the child or mother is at risk [20.] This is worrying, especially since it does not result in lower maternal and infant mortality quite the opposite [21]. However, there is no evidence of a benefit from C-section in women or infants who do not require surgery. As with any surgery, there are short-term and long-term risks that can last for many years, affecting the health of the mother, baby and subsequent pregnancies. Complications in the mother that occur as a result of caesarean section outweigh the benefits of this procedure [22.]

Compared to naturally born babies, babies born by c-section are more likely to develop autoimmune diseases such as allergies, asthma and diabetes [23]. According to the authors, this treatment may have an impact on the occurrence overweight, although the results are conflicting [24,25]. In a study by Pluymen et al., C-section born babies had a 52% higher risk of being overweight in childhood, but not associated with higher blood pressure during adolescence [26]. During natural delivery, infants are exposed to intense uterine contractions, resulting in significant increases in blood levels of catecholamines, neuropeptide Y, angiotensin and cortisol. Significantly lower concentrations were observed in children delivered by caesarean section [27].

It is important to assess the prevalence of hypertension and to identify a group of factors influencing its development in children and adolescents. A deeper understanding of the relationship between hypertension in children and the level of physical activity and other perinatal factors will allow for the implementation of early prevention of this disease.

1. Aim.

The aim of this study is to examine the relationship between mode of delivery (vaginal vs. c-section) and blood pressure in children and adolescents. The study seeks to determine whether cesarean delivery is associated with higher blood pressure or an increased risk of hypertension, taking into account key perinatal and lifestyle factors.

2. Material and methods.

The study included 1,300 children attending randomly selected primary schools and preschools in the Podkarpackie Voivodeship. Based on written parental informed consent, 1,002 children were enrolled in the study.

Inclusion criteria included:

- consent from the parent/legal guardian and the child to participate in the study,
- child's age 3-15 years,
- attendance at a school/preschool in the Podkarpackie Voivodeship,
- health condition sufficient for testing,
- no diagnosis of hypertension,
- possession of a child health record book containing perinatal parameters.

The exclusion criteria from the study group were:

- lack of consent from the parent/legal guardian or child to participate in the study,
- age of the child under 3 or over 15 years old,
- the presence of contraindications for body mass analysis (metal/electronic implants, implanted pacemaker, epilepsy, pregnancy),
- taking medicines to lower blood pressure.

Out of a group of 1,002 children, 200 respondents did not provide health books, and 55 people did not express their willingness to participate in the study. Ultimately, 747 children and adolescents aged 4-15 years were included in the study. Personal data was secured and the participants were given an appropriate digital code.

The study was approved by the Bioethics Committee of the University of Rzeszów No. 19/12/2015 of December 2, 2015. All methods were performed in accordance with the relevant guidelines and regulations.

2.1. Anthropometric Measurements

A SECA 213 telescopic, portable stadiometer was used to measure body height. The average of three measurements was used in the analysis.

The TANITA BC-420 MA (for children ≤6 years of age) and TANITA BC 418 MA (for children >6 years of age) analyzers were used to measure body composition, meeting all requirements of European standards and directives. The analyzer is certified as a Class III medical device and complies with the EU standard for medical devices MDD 93/42 EEC [28.]

2.2. Blood pressure measurement

To classify blood pressure, percentile grids of blood pressure values for children in the age ranges of 3–6 years and 7–18 years by gender and age, as well as by gender and height, developed on the basis of OLA and OLAF projects, based on measurements made using the oscillometric method, were used [29].

Taking into account the guidelines of the European Society of Hypertension report from 2016, the following were classified:

1. Normal blood pressure - systolic pressure and diastolic pressure value below the 90th percentile for sex, age and height; < 130/85.
2. High normal blood pressure - systolic pressure and/or diastolic pressure between the 90 and 95th percentile for sex, age and height or pressure equal to or 130 – 139/85 – 89 mmHg.
3. Hypertension – systolic and/or diastolic blood pressure equal to or greater than the 95th percentile for sex, age and height; ≥140/ 90 [30].

2.3. **Perinatal parameters.**

The values of neonatal parameters such as birth weight and length and other perinatal factors were determined on the basis of information contained in the child's health books. Out of the entire group of 1002 children, 200 respondents did not provide health books, and 55 people did not express their willingness to take part in this part of the study. Finally, 747 people were included in the analysis of perinatal parameters.

3. Results

3.1. Systolic and diastolic arterial pressure in the study group.

The mean systolic blood pressure in the entire study group was 110.6 ± 11.4 mmHg. The average percentile value in the entire study group corresponding to the obtained measurements was over 70, the median was 77. The average value of diastolic blood pressure in the study group was 68.8 ± 9.3 mmHg. The average percentile value in the entire study group corresponding to the obtained diastolic pressure measurements is over 72, the median is 78.

Taking into account the guidelines of the 2016 European Society of Hypertension report, percentile values for systolic and diastolic blood pressure were classified.

The incidence of SBP systolic pressure ≥ the 95th percentile is 8% in both boys and girls in the entire study group. The SBP percentile value ≥ 90, but less < 95 was present in 17.7% of girls and 14.6% of boys. Since the differences between the two sexes in the value of the pressure percentiles are caused by a different frequency of percentiles lower than 90, so there are no statistically significant differences in the classification of blood pressure between girls and boys (Table 1).

Table 1. Classification of systolic blood pressure by percentile in girls boys.

Classification of systolic blood pressure	**Gender (p = 0.410)**				All
	Girls	**%**	**Boys**	%	
< 90 cc	353	74,3%	408	77,4%	761
≥ 90cc < 95cc	84	17,7%	77	14,6%	161
≥ 95 cc	38	8,0%	42	8,0%	80
All	475		527		1002

The prevalence of diastolic blood pressure ≥ the 95th percentile is 16.0% in girls and 13.3% in boys in the entire study group. The prevalence of diastolic blood pressure≥ 90cc but< 95cc is 16% in girls and 13.3% in boys (Table 2).

Table 2.1 Classification of diastolic blood pressure by percentile in girls and boys.

Classification of diastolic blood pressure	**Gender (p = 0.2414)**				All
	Girls	**%**	**Boys**	%	
< 90 cc	343	72,2%	405	76,8%	748
≥ 90cc < 95cc	56	11,8%	52	9,9%	108
≥ 95 cc	76	16,0%	70	13,3%	146
All	475	100%	527	100%	1002

3.2. Methods of delivery

Slightly more than 40% of all deliveries were carried out through caesarean section, while the remaining 58.6% represented natural births, indicating that vaginal delivery continued to be the predominant mode of childbirth. (Table 3).

Table 3. Methods of delivery

Type of birth	Number of births	%
Cesarean section	309	41,4%
Vaginal birth	438	58,6%
All	747	100

3.3. Occurrence of arterial hypertension.

Based on the 2016 criteria of the European Society of Hypertension, the study participants were divided into individuals with normal blood pressure, high normal blood pressure, and hypertension [31.] Based on the 2016 criteria of the European Society of Hypertension, the study participants were divided into individuals with normal blood pressure, high normal blood pressure, and hypertension [30]. 61% of the study participants had normal blood pressure, 19% had high normal blood pressure, and 19.3% had hypertension (Table 4).

Table 4. Classification of blood pressure in the study group.

Blood pressure classification	Number of children	%
Normal blood pressure	619	61,8%
High normal blood pressure	190	19,0%
Hypertension	193	19,2%
All	1002	100

3.4. Methods of delivery and occurrence of hypertension

In the group of children delivered by caesarean section, 43.5% of the subjects presented with elevated blood pressure values, whereas among children born naturally this proportion was slightly lower, at 38.8%. Moreover, hypertension was identified in 23.5% of children born by natural delivery, highlighting that although elevated blood pressure was somewhat more common after caesarean birth, confirmed hypertension occurred more frequently in the group delivered vaginally (Table 5).

Table 5. Type of birth and blood pressure values in children.

Blood pressure classification	**Type of birth (p = 0.015*)**				All
	Cesarean section	**%**	**Vaginal birth**	%	
Normal blood pressure	175	56,5%	269	61,3%	444
High normal blood pressure	73	23,5%	67	15,3%	140
Hypertension	62	20,0%	103	23,5%	165
All	310		439		749

4. Discussion.

It is well known that the likelihood of diagnosing hypertension increases with age. Although children with hypertension do not have the same risk of complications as adults, numerous studies point to the need for early identification of people with hypertension and early intervention to reduce the clinical effects of high blood pressure. Not only the secondary form of hypertension in children, with a specific underlying disease, but also primary hypertension, should be taken seriously by both doctors and parents. Untreated hypertension persists in later years and puts the patient at significant risk. It is now established that primary hypertension is

the most common type of hypertension in young people, especially during adolescence [32.] Research confirms that childhood hypertension occurs worldwide, which is worrying. Between 2000 and 2020, the prevalence of hypertension in children almost doubled, from 3.40% to 6.53% in boys and from 3.02% to 5.82% in girls [nn In the studied population, the occurrence of hypertension was found in 19.3% of the studied children. Contrary to most studies, it was more common in girls than in boys (21.7% and 17.1%) [33,34.] Yaru's study shows similar results. The overall prevalence of prehypertension was 22.1% with a gender-specific prevalence of 21% in men and 23.1% in women. Adolescent girls have a higher prevalence of hypertension, especially prehypertension, compared with men. 2.4% and 1.2% of women had grade 1 and 2 systolic hypertension, respectively, while 1.2% and only 0.1% of girls had grade 1 and 2 diastolic hypertension, respectively [35.]

In the study population of Greek children, girls were more likely to have hypertension than boys, it occurred in 25.3% of girls and 20.8% of boys. Interestingly, prehypertension and stage II hypertension were more common in younger children than in older children 22.4% vs. 13.7% and 8.6% vs. 7.5%, respectively [36.]

The most common type of hypertension was isolated systolic hypertension (ISH), which occurred in 11.9% of the study participants. Furthermore, the risk of hypertension increased with increasing body mass index (BMI) and waist circumference in both boys and girls.

This percentage seems to be very high. However, it turns out that other authors, including Polish researchers, also received very similar results. Kołpa et al. In a group of more than 1000 children aged 10-12 years, they showed a prevalence of hypertension at the level of 18.2%, in 16% of girls and 20.3% of boys [37.] In the studies of Osthegi et al., in a similar age group of children (8-17 years), the incidence of elevated normal blood pressure was about 14% in boys and 6% in girls [38.] Other authors showed that the prevalence of hypertension in the group of children aged 5-18 years was 4.7%. This was significantly related to family history ($p < 0.001$), type of diet ($p < 0.001$) and additional salt intake ($p = 0.008$). A gradual increase in blood pressure was also observed in relation to age [39.]

In the study conducted by Rerkasem and colleagues, the prevalence of abnormal SBP defined as prehypertension or hypertension was found to be significantly higher among children born by caesarean section. In this group, 25.0% of participants exhibited elevated SBP values, which was approximately 2.5 times the prevalence observed among those delivered vaginally (10.3%; $p = 0.003$). After adjusting for potential confounding factors, the risk remained

markedly elevated, with children born via caesarean section demonstrating a 1.9-fold higher adjusted relative risk of abnormal SBP (95% CI 1.15–2.98; p = 0.011). These findings underscore the potential long-term cardiovascular impact associated with mode of delivery [16].

In the presented studies, on the other hand, at the level of the entire community, it can be concluded that the incidence of hypertension decreases with age. This relationship occurs both in the group of girls and boys considered separately, so it is independent of gender. The highest incidence of hypertension was recorded in the group of children aged 4-6 years (23.8%), in children 7-11 years of age this frequency was 21.5%, and in the oldest group 11.9%. The result of the presented study is absolutely consistent with the observations of Młodzianowski et al. By assessing blood pressure in a large population of 3232 children aged 9.8-16.5 years and using the same three-measurement methodology, it showed an increase in blood pressure and/or diastolic pressure ≥ the 95th percentile in 26.1% of girls and 23.5% of boys. In younger children, the percentage of measurements exceeding the 95th percentile was significantly higher [40].

Many studies have attempted to describe the relationship between the child's birth parameters, birth weight and length, and the occurrence of hypertension.

There are few reports in the available literature showing the effect of the type of birth on the incidence of primary hypertension in children. The presented results indicate that childbirth by c-section increases the risk of increased blood pressure. Among babies born by c-section, 43.5% had elevated blood pressure. This is a statistically significant relationship (*p=0.0152).* Nevertheless, more cases of hypertension have been reported in the group of children born naturally. Morley showed in her studies that children born by caesarean section had significantly lower systolic blood pressure compared to children born naturally (99.3 ± 10.0 vs. 104.4 ± 9.4 mm Hg, p = 0.003) [41]. This result indicates the need for further research in this area.

C-section, including medically unrequired ones, slightly increases the risk of overweight in children compared to natural childbirth. As shown by Li et al. Odds ratio was 1.18 [42]. The prevalence of persistent pulmonary hypertension in newborns was about 0.37% among newborns born by caesarean section, almost five times higher than in natural delivery. These results should be a guideline for informed consent before cesarean section and increased supervision of newborns after cesarean section [43]. In Pluymen's studies, babies born by caesarean section (8.9%) are mostly babies born before 37 weeks of gestation. As the results showed, they were 5 times more likely to have low birth weight and 2 times more likely to have

high birth weight compared to children born naturally. Mothers, on the other hand, were more likely to be overweight and gain excessive weight during pregnancy before pregnancy, compared to mothers of children born by the forces of nature [44].

Undoubtedly, further studies are needed in different populations, including adults, to confirm the relationship between the type of birth and blood pressure. This will allow for prevention to cover potentially endangered people.

5. Results.

In the study population, children delivered by caesarean section, 43.5% of the subjects presented with elevated blood pressure values, whereas among children born naturally this proportion was slightly lower, at 38.8%.

Systolic blood pressure was found to be ≥ 95th percentile in 8% of children (8% of girls and 8% of boys), while diastolic blood pressure ≥ 95th percentile in 14% of children (16% of girls, 13.3% of boys). Caesarean section can increases the risk of increased blood pressure in childhood.

6. Limitations.

This study has several limitations that should be taken into consideration when interpreting the findings. First, its cross-sectional design does not allow establishing causal relationships between mode of delivery and elevated blood pressure; therefore, the observed associations should be interpreted as correlational rather than causal. Second, although a broad range of prenatal and perinatal factors was evaluated, the possibility of residual confounding cannot be excluded. Factors such as diet, levels of physical activity, socioeconomic status, or parental cardiovascular health may have influenced blood pressure outcomes but were not fully controlled for in the analysis.

Third, blood pressure measurements were performed at a single time point, which may increase the risk of misclassification due to natural variability in BP values, measurement errors, or situational factors such as the “white-coat effect.” Repeated measurements over several visits would provide a more accurate assessment. BP measurement in younger children is associated with a high risk of failure due to the lack of cooperation on the part of the patient: in children in the first year of life, BP measurement is unreliable in the age group of 3-6 years, approximately 9% of children fail to measure correctly.

Additionally, the study sample was limited to children and adolescents from a specific geographical region, which may restrict the generalizability of the results to broader populations. Important delivery related distinctions, such as elective versus emergency caesarean section, were also not examined and may have different implications for early life physiological development. Finally, factors strongly associated with longterm cardiovascular risk, such as birth weight, gestational age, and breastfeeding patterns, while included in the broader assessment, may not have been sufficiently controlled for to fully eliminate their potential confounding effects.

Overall, these limitations indicate the need for prospective, longitudinal studies to more precisely clarify the impact of delivery mode on blood pressure regulation throughout childhood and adolescence.

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This research did not receive any funding.

8. **Data availability**

The datasets used and analysed during the current study available from the corresponding author on reasonable request.

9. **Informed consent** was obtained from all parents after they were fully informed about the study prior to their children's participation.

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