

Hungarian Pediatrics



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Child health protection

Child protection is of paramount importance because it safeguards the physical, mental, and social well-being of children. One of its primary objectives is to create a safe environment that provides the conditions necessary for healthy physical, psychological, and emotional development. Prevention involves recognizing potential risks in a timely manner and taking steps to avoid harm. Community cooperation and social responsibility are not solely the responsibility of authorities; rather, all adults share a responsibility to pay attention to children's well-being.

Child protection also encompasses child health protection, which includes several key areas. These include supporting healthy physical development through proper nutrition, including an adequate intake of vegetables, fruits, and water. Regular physical activity, sports, and outdoor play are also important components. Prevention, including vaccination, is another essential aspect, as discussed in our previous issue.

Mental and emotional well-being depend on a safe environment and a stable, supportive family and community background. Attention, communication, and listening to children's feelings can help reduce stress and promote emotional security. Adequate sleep and age-appropriate rest are also essential for healthy nervous system development and functioning.

Child protection and health protection should begin from the neonatal period. Several articles in this issue address health protection, particularly in infants. In our commemorative section, we remember our colleague who dedicated his work to premature and newborn infants. In addition, our Iraqi colleague, *Mohanad Abdulhamid* (Al-Hikma University, Iraq), presents a study on infant incubators. The study aims to improve the quality of care provided to vulnerable infants. Infant incubators are designed to precisely control temperature, humidity, and oxygen levels, thereby creating environmental conditions that approximate those of the womb. The main objective of the study is to develop an autonomous monitoring device specifically designed to assist midwives and other healthcare professionals responsible for monitoring multiple incubators.

Andrea Fogarasi Grençzer presents the basic principles of caring for premature infants, focusing on developmental care, family-centered perinatal intensive care (PIC), specialized nutrition, and close multidisciplinary follow-up. Preterm infants represent a vulnerable population with specific needs, and their care at home is influenced by numerous risk factors. Following hospital discharge, their developmental trajectory requires continuous follow-up,

monitoring, and early intervention. The article provides detailed data on Hungarian mothers of preterm infants, which may support the early identification of high-risk groups and the development of appropriate communication and care strategies. Members of the healthcare team assist parents in recognizing problems associated with prematurity, both in the hospital setting and in primary care.

The following article, by *Lajos Réthy*, discusses the immunology of the first thousand days of life. The first thousand days, from conception to two years of age, represent one of the most critical periods for the structural and functional maturation of the immune system. During this sensitive developmental window, immunological tolerance develops, inflammatory responses undergo long-term regulation, and fundamental patterns of immune-metabolic and neuroendocrine regulation are established. Early environmental influences, nutrition, microbiome colonization, and epigenetic mechanisms collectively shape the later risk of allergic, autoimmune, and other chronic inflammatory diseases.

Adrienne Nagy discusses the treatment of allergic rhinitis, which has a global prevalence of approximately 30%. Avoiding allergens and relying on continuous symptomatic medication do not necessarily result in lasting improvement in quality of life or disease remission. Allergen immunotherapy aims to restore the disrupted immune tolerance. Its effects may persist for years after treatment has been discontinued, allowing patients to tolerate exposure to pollens, animal dander, molds, and house dust mites in their natural environment with few or no symptoms over the long term. This causal treatment has already become an integral part of modern allergic rhinitis management.

Judit Tasi presents the role of the Department of Family Care Methodology at the Faculty of Health Sciences of Semmelweis University in the education of students enrolled in the Health Care and Prevention program and the Child Health Nurse specialization. The education and professional activities of child health nurse students encompass a wide range of complex responsibilities. One of the key tasks of school and youth health nurses working in school health care is health promotion, and all students must be adequately prepared for this role during their training. Among the subjects included in the curriculum, Prevention and Health Education is particularly well suited to this purpose and is taught through theoretical and practical classes over two semesters.

The aim of this summary is to present the methods used in this preparation, taking into account the generational characteristics of current university students, as well as approaches that can help them effectively reach children and adolescents in primary and secondary schools. Preparation for health promotion is a complex educational and attitude-forming process aimed at supporting health maintenance, disease prevention, and healthy lifestyle choices. During these programs, participants learn about healthy nutrition, regular physical activity, and maintaining psychological well-being.

The main principles of radiation protection in pediatric radiology are also presented. The primary goal is to avoid unnecessary exposure to ionizing radiation and to keep medically necessary doses as low as reasonably achievable. Because children's tissues are rapidly developing and they have a longer life expectancy, they are more sensitive to the harmful effects of ionizing radiation than adults.

The three basic principles of radiation protection in childhood are: 1. Justification. An examination involving ionizing radiation may only be performed if the expected diagnostic benefit clearly outweighs the potential risk from radiation. 2. Optimization (ALARA principle). Radiation exposure should be kept as low as reasonably achievable while ensuring adequate image quality (As Low As Reasonably Achievable). 3. Dose limits and reference levels. In pediatric imaging, age- and body weight-specific diagnostic reference levels (DRLs) should be used.

Practical radiation protection methods. When examining children, specific technical approaches should be applied in accordance with radiation protection regulations. Preference for alternative imaging modalities. Whenever possible, ultrasound (US) or magnetic resonance imaging (MRI) should be chosen instead of X-ray or CT. These methods do not use ionizing radiation. Physical protec-

tion and shielding. Radiosensitive organs that are not directly exposed to the radiation beam (e.g., the gonads, thyroid gland, and lens of the eye) should be appropriately protected. The radiation beam should be precisely collimated to include only the anatomical region being examined. Optimization of technical parameters. Adult protocols should not be used for children. Tube voltage (kV), tube current (mA), and exposure time should be appropriately adjusted to reduce radiation dose and minimize motion artifacts. In digital systems, modern detectors and appropriate image-processing technologies should be used.

Positioning and fixation. Repeated examinations caused by the child's movement represent an important source of additional radiation exposure. Appropriate pediatric immobilization devices (e.g., shaped foam supports and fixation straps) should therefore be used when necessary. Innovative solutions in pediatrics. Innovative diagnostic technologies, such as the EOS radiological system, are increasingly used in modern pediatric centers. This technology can produce full-body 3D images with up to 90% less radiation exposure in certain applications, such as scoliosis monitoring, thereby substantially reducing the cumulative dose in children requiring repeated examinations.

In a case study, *András Havai* presents *Guillain-Barré syndrome* developing in the setting of severe tetraparesis.

Each of our articles is related to child protection in some way.

We wish you an enjoyable and informative read of our issue.

László Szabó





Commemoration of Dr. Péter Temesvári

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The pediatric community has once again lost one of its distinguished members. Dr. Péter Temesvári (Figure 1), a renowned Hungarian neonatologist and Doctor of Medicine, passed away at the age of 75. Although he was not yet old, he had struggled with numerous health problems in recent years. I first came to know him well in 2004, when, as General Secretary of the Association of Hungarian Pediatricians, I was invited by him to the first Croatian–German–Hungarian Pediatric Congress, which he organized in Kec-

Figure 1. Dr. Péter Temesvári at the age of 68



Figure 2. Croatian–German–Hungarian Pediatric Congress, Kecskemét, Hungary, 2004. From left to right: Dr. Péter Temesvári; Dr. Ivo Barić, University Hospital Zagreb; Dr. Julije Meštrović, Head of the Intensive Care Unit, University Children's Hospital, Split; Dr. Marija Radonić, Head of the Department of Pediatrics, Dubrovnik; Dr. Jürgen Gehler, Head of the Department of Pediatrics, Rüsselsheim; and Dr. Darko Richter, Zagreb



kemét, Hungary (Figure 2). The congress was exceptionally well organized, offering an outstanding scientific program alongside a rich social program. International participants continued to speak enthusiastically for years afterward about both the meeting and the memorable horse show. In the years that followed, we participated together in numerous Croatian–German–Hungarian pediatric congresses, which were held annually in different countries and cities. Figure 3 shows the Hungarian delegation in Cavtat, Croatia, in 2005, and Figure 4 was taken in Bielefeld, Germany, Figure 5 Hévíz, Figure 6 Szeged. Over time, this professional community developed into a close circle of friends. Beyond the scientific sessions, we spent many hours talking and traveling together. Péter was exceptionally well informed, highly intelligent, and a true European intellectual. He was born in Abátfalva on June 1, 1950. He completed his secondary education at the Radnóti Miklós Gymnasium in Szeged and graduated summa cum laude from the Medical University of Szeged. After receiving his medical degree, he began his career at the university's Institute of Pathology. Two years later, he joined the Department of Pediatrics, where he worked for 14 years. He subsequently served as head of the pediatric departments in Makó,

Figure 3. Croatian–German–Hungarian Pediatric Congress, Cavtat, Croatia, 2005. Dr. Péter Temesvári with the Hungarian delegation



Figure 4. Dr. Péter Temesvári in the lecture hall at the Croatian–German–Hungarian Pediatric Congress, Bielefeld, Germany, 2006



Figure 5. Dr. Péter Temesvári and Dr. Ivo Barić (Zagreb) chairing a session at the Croatian–German–Hungarian Pediatric Congress, Hévíz, Hungary, 2013



Kecskemét, and later Orosháza, retiring as department chair in 2016 at the age of 66. He obtained board certification in Pediatrics in 1980 and in Neonatology in 1982. He was awarded a two-year research fellowship at the Institute of Biophysics of the Hungarian Academy of Sciences Biological Research Centre in Szeged. He also spent two years in Germany as a research fellow at the Institute for Experimental Surgery, Klinikum Großhadern, Ludwig Maximilian University of Munich.

He defended his Candidate of Sciences dissertation in 1986 and, in 1996, was awarded the Doctor of the Hungarian Academy of Sciences (DSc) degree for his dissertation entitled *Experimental Models of Neonatal Disorders of Blood–Brain Barrier Permeability*. He obtained his habilitation in 1997. He served as a lecturer at the Department of Pediatrics of the University of Szeged for 16 years and was also responsible for undergraduate education for three years. After leaving the department, he was appointed Associate Professor in 1990 and was awarded the title of Private University Professor in 1997. In addition, he taught at the Department of Nursing of the Szeged Health College from 1990 to 2005. He authored 68 scientific publications, which have received 357 independent citations.

I first met him in 1997, when he organized the annual congress of the European Society for Paediatric Research (ESPR) in Szeged, serving as the Society's President at that time. According to the Society's constitution, the presidency was held by the professor whose institution hosted the annual scientific meeting. From August 31 to September 3, 1997, the ESPR's annual congress was held in Szeged as a major joint meeting with the European Society for Paediatric Hematology and Immunology.

The primary focus of his research was neonatal intensive care, particularly the prevention and treatment of brain injury in preterm infants and newborns affected by perinatal hypoxia. During his decades at the Department of Pediatrics of the University of Szeged, he made important contributions in several major areas of neonatal research:

Blood–Brain Barrier Permeability

This was *Professor Temesvári's* principal area of theoretical and experimental research. Using various animal models, primarily newborn piglets, he investigated how pathological conditions occurring around birth affect the integrity of the blood–brain barrier.

He demonstrated that neonatal pneumothorax selectively disrupts blood–brain barrier integrity, potentially leading to severe neurological complications.

He also investigated the effects of tumor necrosis factor alpha (TNF- α) and other cytokines on the cerebral vasculature and blood–brain barrier permeability.

Neonatal asphyxia and reoxygenation

Professor Temesvári's research focused extensively on the mechanisms of hypoxic–ischemic brain injury occurring at birth, particularly hypoxic–ischemic encephalopathy.

He played a key role in establishing the evidence that resuscitation of asphyxiated newborns with 100% oxygen, compared with room air, may exacerbate early neurological dysfunction and impair cerebral circulation through increased free radical formation. This work contributed to an important international shift in neonatal resuscitation practice.

Neuroprotection and cerebral circulation

Together with his colleagues, including *Professors Ferenc Bari* and *Ferenc Domoki*, he investigated novel therapeutic strategies aimed at reducing brain injury following perinatal hypoxia.

His research demonstrated that inhaled molecular hydrogen exerts neuroprotective effects by preserving neu-

Figure 6. Dr. Péter Temesvári with the Croatian, German, and Hungarian participants at the Croatian–German–Hungarian Pediatric Congress, Szeged, Hungary, 2016.



ronal integrity and maintaining cerebrovascular reactivity in newborns following asphyxia.

He also conducted pioneering studies on cerebral air embolism associated with mechanical ventilation and its effects on neonatal cerebral circulation.

Clinical neonatology and diagnostics

In addition to laboratory research, many practical developments are linked to his name.

Transfontanellar Doppler ultrasonography. He participated in the development and validation of a specialized Doppler ultrasound technique that could be performed through the anterior fontanelle, enabling continuous, low-energy monitoring of cerebral blood flow velocity in very low birth weight preterm infants.

Maternal vitamin supplementation. He investigated the effects of maternal vitamin B₆ (pyridoxine) supplementation during pregnancy on neonatal blood oxygen affinity and prolactin concentrations.

Professor Temesvári's translational research, successfully bridging laboratory discoveries and clinical practice, made a lasting contribution to the development of modern neonatal intensive care in Hungary and influenced neonatal practice more broadly across Europe.

Dear Péter,

Although illness sometimes prevented you from fully participating in our meetings and congresses, your Hungarian, Croatian, and German friends will always remember you with great affection and respect.





Development of a Multi-Incubator Monitoring System for Midwives and Healthcare Professionals

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Abstract

This study aims to improve the standard of care for at-risk infants by facilitating the continuous monitoring of neonatal incubators. Infant incubators maintain temperature, humidity, and oxygen levels that approximate the optimal intrauterine environment. The primary objective was to develop an autonomous monitoring system for midwives and other healthcare professionals responsible for supervising multiple incubators simultaneously. The proposed system uses an ESP32 module and a Raspberry Pi Zero W to transmit real-time monitoring data via the Internet of Things (IoT). Its performance was evaluated using a pretest–posttest experimental design, with measurements compared against those obtained using an incubator analyzer. Analysis of the temperature measurements demonstrated a maximum error of 0.009% (error value: 3). Although some measurement discrepancies remain, the proposed monitoring system has the potential to facilitate the simultaneous supervision of multiple incubators and thereby support improvements in neonatal care.

Keywords: *Infant incubators, IoT, Raspberry Pi Zero W*

Introduction

Premature birth is defined as birth before 37 completed weeks of gestation. Low birth weight is defined as a birth weight of less than 2,500 g, whereas full-term infants are born between 37 and 42 weeks of gestation and typically weigh between 2,500 and 4,000 g. Because the organ systems of preterm infants—including the lungs, heart, kidneys, liver, and gastrointestinal tract—are often functionally immature, prematurity is a major risk factor for neonatal morbidity and mortality. Therefore, maintaining an environment that closely approximates intrauterine conditions, particularly with respect to temperature, humidity, and oxygen concentration, is essential. Neonatal incubators are indispensable devices for the care of preterm infants, providing a controlled environment that supports physiological stability while allowing continuous monitoring by healthcare professionals. In addition to preventing hypothermia, incubators contribute to reducing neonatal mortality by maintaining stable environmental conditions. The incubator air temperature

is typically maintained between 32°C and 36°C, while environmental conditions are carefully regulated to support an infant body temperature of approximately 37°C (1–5). Adequate humidity is essential to warm and humidify inspired air before it reaches the lungs. Because preterm infants have limited subcutaneous fat and immature thermoregulatory mechanisms, they are particularly susceptible to hypothermia. Consequently, relative humidity should generally be maintained above 70%, with adjustments made according to the infant's gestational age and stage of care. Inadequate humidity increases evaporative water and heat loss, thereby increasing metabolic demand and oxygen consumption. Conversely, excessively high humidity may promote the growth of bacteria and other microorganisms. Effective incubator management therefore requires careful regulation of both temperature and humidity to minimize heat loss and maintain thermal stability. The principal environmental parameters controlled within an incubator include temperature, humidity, oxygen concentration, and lighting. In addition, noise levels in the neonatal intensive care unit (NICU),

largely generated by life-support equipment, should be minimized and carefully monitored. Healthcare personnel must continuously monitor incubator conditions to ensure that temperature and humidity remain within the recommended ranges. Excessively low temperatures may result in hypothermia, increasing the risk of serious morbidity or death, whereas excessive heat may lead to overheating and, in severe cases, thermal injury (6–9).

A review of the literature (10–15) indicates that monitoring of infant incubators is still largely performed manually, highlighting the need for routine monitoring by midwives and other healthcare professionals. Consequently, there is a need for a centralized Internet of Things (IoT)-based monitoring system capable of continuously monitoring multiple infant incubators. Such a system should monitor key parameters, including incubator air temperature, infant skin temperature, relative humidity, and ambient noise levels. In the proposed system, monitoring data are displayed through a web-based interface that provides real-time visualization on a computer. To improve the accuracy of skin temperature measurements, the DS18B20 sensor was selected because of its accuracy and cost-effectiveness. The DHT22 sensor is used to measure the incubator's internal temperature and relative humidity, with a reported measurement accuracy of approximately $\pm 2\%$. One limitation of the DHT22 is its relatively slow sampling interval of approximately 2 s compared with the DHT11, which can acquire humidity measurements at shorter intervals. The Internet of Things (IoT) enables real-time monitoring, analysis, and management of physical parameters through interconnected sensors communicating via standardized protocols. In this study, a Raspberry Pi Zero W serves as the central computing platform.

The aim of this system is to improve the efficiency of midwives and other healthcare professionals responsible for supervising multiple infant incubators. The web-based interface enables users to monitor infant skin temperature, incubator air temperature, relative humidity, and ambient noise levels in real time. This enhanced monitoring capability may help reduce the risk of adverse events by facilitating the early detection of deviations from predefined environmental conditions. Timely identification of such abnormalities allows prompt intervention, helping to maintain a safe and optimal environment for infants receiving incubator care. By leveraging IoT technology, the proposed system enables seamless communication between the monitoring devices and the central computer. This architecture supports efficient data acquisition, storage, analysis, and visualization, thereby assisting healthcare professionals in making informed clinical decisions. Overall, implementation of this IoT-based central infant incubator monitoring system has the potential to improve workflow efficiency, patient safety, and the quality of neonatal care in the neonatal intensive care unit (NICU) and pediatric intensive care unit (PICU). The primary objective of this study was to develop an autonomous monitoring system for infant incubators that

integrates an ESP32 module with a Raspberry Pi Zero W to facilitate real-time data transmission via the Internet of Things (IoT). The system was designed to support the care of vulnerable infants by continuously monitoring environmental conditions within the incubator. Its performance was evaluated by comparing its measurements with those obtained using an incubator analyzer in a pretest–posttest experimental design.

As shown in *Figure 1*, the infant incubator monitoring system incorporates sensors for measuring infant skin temperature, incubator air temperature, relative humidity, and ambient noise levels. These sensors continuously monitor both the infant's physiological and environmental conditions. The ESP32 serves as the data acquisition unit, transmitting the collected measurements in real time to a Raspberry Pi Zero W, which processes the data and displays the results through a computer-based interface. This system enables continuous surveillance of critical incubator parameters, providing healthcare professionals with timely information to facilitate the early detection and management of deviations from the desired environmental conditions.

Methodology of design

A before-and-after experimental design was employed in this study. The experimental monitoring system integrated DS18B20, DHT22, and Analog Sound V2.2 sensors. An ESP32 microcontroller was interfaced with these sensors to convert analog signals into digital data. The system was powered by a rechargeable battery unit supported by a charging module, thereby eliminating the need for frequent battery replacement.

Figure 1. Block diagram of the infant incubator system

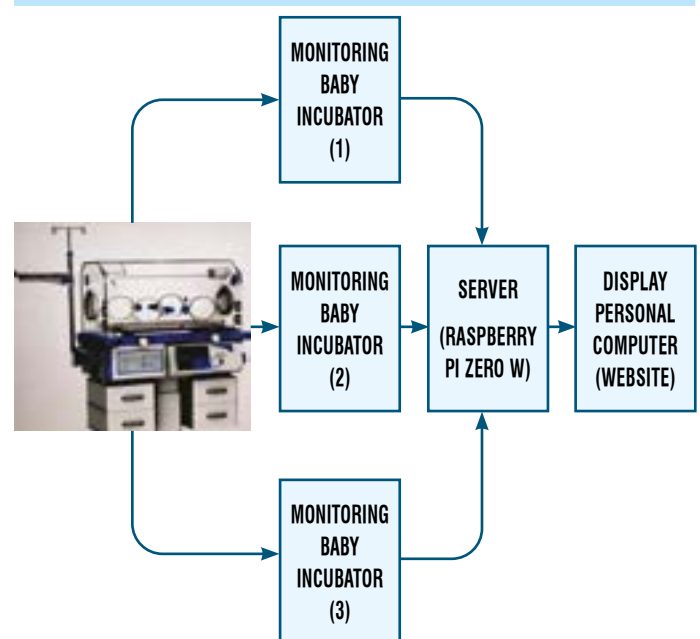
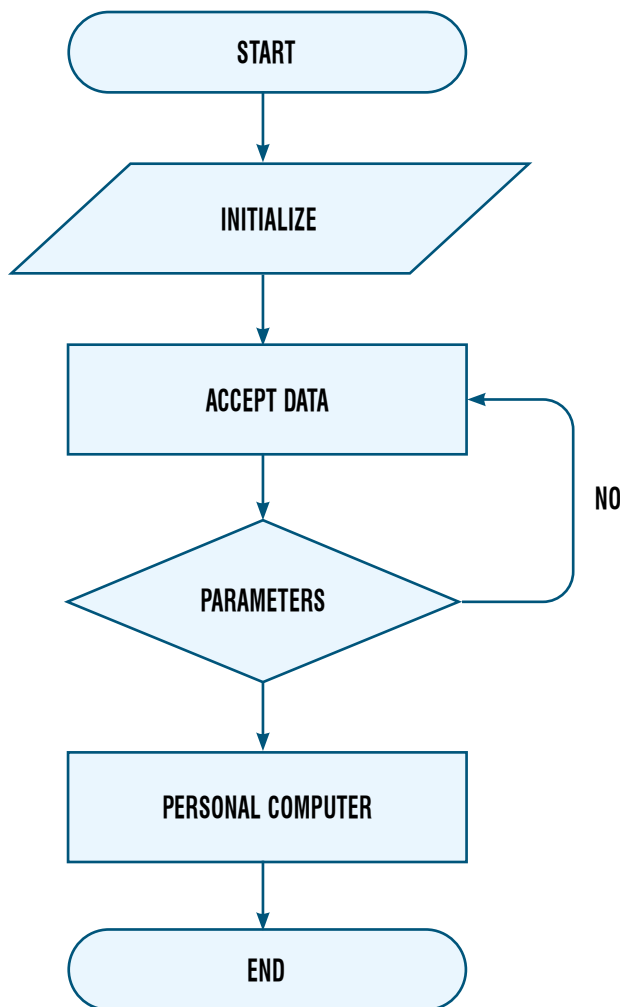


Figure 2. Server flowchart



Three identical infant incubators were used for data collection. After the incubators reached thermal equilibrium, measurements were recorded at 10-minute intervals, with five repetitions per experimental condition. Temperature settings of 32°C, 34°C, and 36°C were evaluated. Both infant skin temperature and ambient incubator temperature were measured. The DS18B20 sensor was used for skin surface temperature measurement, while the DHT22 sensor was used to measure ambient temperature and humidity. The readings obtained from an incubator analyzer, used as the reference standard for calibration and accuracy assessment, were compared with the collected sensor data. This comparison enabled evaluation of the incubator's ability to maintain stable skin and environmental temperatures.

The aim of this study was to assess the accuracy and reliability of infant incubators under different temperature settings. The findings contribute to a more comprehensive understanding of incubator performance and may support manufacturers and healthcare professionals in optimizing care for preterm infants. As illustrat-

ed in *Figure 2*, pressing the power button initiates the system startup sequence, activating all sensors in each client unit. The sensors continuously monitor incubator conditions, including temperature and environmental parameters. The ESP32 module receives and processes the acquired data, after which it connects to the Raspberry Pi Zero W server. In the event of a connection failure, the system automatically attempts reconnection until communication between the monitoring units and the server is re-established. Once the connection is established, sensor data are transmitted to the server for further processing and analysis. This structured data flow enables efficient communication between system components and ensures real-time monitoring. Access to processed data via the server allows healthcare personnel to make timely clinical decisions based on continuous environmental feedback.

The system startup sequence is initiated when the ON button is pressed, as shown in *Figure 3*. Following activation, data acquisition begins across all sensors. The microcontroller processes the collected data and transmits it to the ESP32 module, which functions as the monitoring unit. Subsequently, the Raspberry Pi Zero W, configured as an access point server, establishes communication with the ESP32. Once the Raspberry Pi Zero W receives the data, it processes and manages the incoming information. The measured parameters are displayed on the connected interface, provided they fall within the predefined set points.

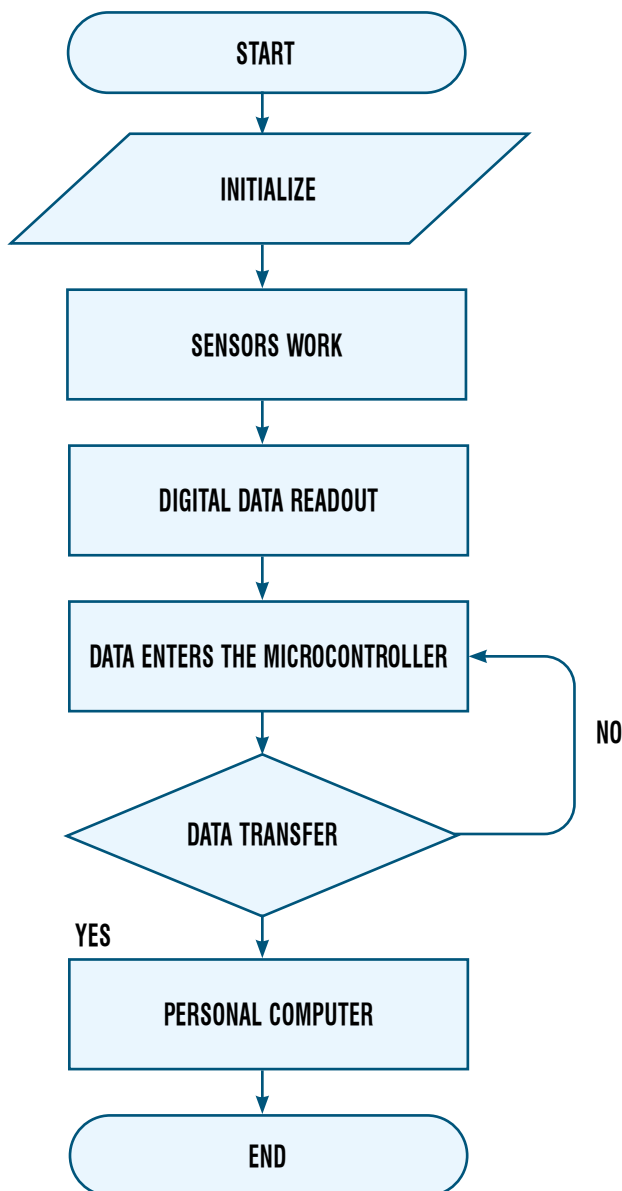
This monitoring system enables continuous assessment of critical parameters within the infant incubator. It supports healthcare providers in the early detection of deviations from established environmental conditions, thereby facilitating timely clinical intervention. The combined use of the ESP32 and Raspberry Pi Zero W provides a reliable and efficient framework for the acquisition, transmission, and visualization of incubator data, including temperature, humidity, and noise levels.

Data measurement

During experiments, the infant incubator was set to 32°C, 34°C, and 36°C, and all variables, including skin temperature and ambient temperature, were recorded. Each measurement was repeated five times to ensure reliability and reproducibility. The mean value was calculated using Equation 1 (*Figure 4*), which defines the arithmetic average as the sum of all recorded values divided by the number of observations. This statistical approach provides a clear representation of the central tendency of the measured temperatures across repeated trials and enables a more robust assessment of system performance.

The calculation of the mean measurement value provides insight into the typical behavior of skin temperature and chamber temperature under different experimental conditions. This information is essential for evaluating the performance of the infant incubator and its ability to

Figure 3. Monitor flowchart



maintain stable and optimal thermal conditions. Percentage error was used as an indicator of system accuracy, representing the deviation of the proposed model from the reference standard. A lower percentage error corresponds to a smaller deviation between measured values and the reference data. The percentage error was calculated using Equation 2.

In this equation, x represents the measured value obtained from the proposed module, while x_n denotes the corresponding reference value obtained from the incubator analyzer (calibration device). This approach allows quantification of the differences between the system measurements and the reference standard. Accordingly, the percentage error provides a measure of the accuracy and precision of the developed module relative to the established benchmark.

Figure 4. Equation 1

$$\bar{x} = \frac{x_1 + x_2 + \dots + x_n}{n} \quad (1)$$

Figure 5. Equation 2

$$\% \text{ERROR} = \frac{(x_n - x)}{x_n} \times 100\% \quad (2)$$

Figure 6. Design of the monitoring module



Results

A comprehensive evaluation of the developed module was performed using an incubator analyzer as the reference comparison tool. *Figure 6* illustrates the implemented monitoring module, which integrates an ESP32 microcontroller with DS18B20, DHT22, and Analog Sound V2.2 sensors. This configuration enables continuous monitoring of key infant incubator parameters, including temperature, humidity, and ambient noise. The system is powered by a lithium battery, supported by a voltage boost (step-up) module to ensure stable operation. The use of a lithium battery improves both the portability and operational reliability of the monitoring unit. The infant incubator monitoring system is accessible through a dedicated web-based interface, as shown in *Figure 7*. This interface provides real-time visualization of monitored parameters, enabling healthcare professionals and caregivers to continuously assess incubator conditions. The integration of these hardware and software components supports efficient monitoring and contributes to improved oversight of critical neonatal environmental parameters.

The average chamber temperature values derived from thermometer readings are presented in *Table 1*. Measurements were performed to determine the mean chamber

Figure 7. Display screen



temperatures after stabilization of three infant incubators set to 32°C, 34°C, and 36°C. Data from three separate monitoring modules were used for the analysis. For each temperature setting, measurements were recorded five times, and real-time reference data were obtained using the Incu Analyzer. At the 32°C setting, the mean temperatures recorded were 31.0°C (Module 1), 29.0°C (Module 2), and 31.0°C (Module 3). At the 34°C setting, the corresponding values were 33.2°C, 33.1°C, and 32.8°C for Modules 1, 2, and 3, respectively. At the 36°C setting, the measured values were 35.0°C (Module 1), 34.9°C (Module 2), and 34.4°C (Module 3). The largest deviation at 32°C was observed in Module 2, while at 36°C, Module 3 showed the greatest deviation. At 34°C, the differences between modules were minimal and comparable across all systems.

Percentage error values were calculated for each module and temperature setting. At 32°C, the errors were 0.001%, 0.006%, and 0.009% for Modules 1, 2, and 3, respectively. At 34°C, the corresponding values were 0.002%, -0.001%, and -0.001%. At 36°C, the errors were 0.001%, -0.004%,

and 0.008% for Modules 1, 2, and 3, respectively. The highest recorded error was 0.009% for Module 3 at 32°C. Overall, measurement deviations remained within an acceptable range when compared with the Incu Analyzer reference values. Minor discrepancies were attributed to limited precision of the incubator control systems and transient delays in temperature stabilization. In addition, intermittent data transmission and buffering between measurement acquisition and server-side processing may have contributed to small temporal discrepancies in the recorded values.

The average skin temperature readings obtained from the measuring devices are presented in Table 2. Measurements were conducted using three infant incubators calibrated to 32°C, 34°C, and 36°C, corresponding to the target chamber temperatures. Data collection commenced after thermal stabilization was achieved. For each temperature setting, measurements were recorded five times, and the average values were calculated using the Incu Analyzer comparison tool in real time. At the 32°C setting, the Incu Analyzer recorded mean values of 31.0°C, 30.0°C, and 30.0°C for Modules 1, 2, and 3, respectively. The corresponding module measurements were 34.0°C (Module 1), 33.7°C (Module 2), and 33.8°C (Module 3). At the 36°C setting, the recorded values were 35.9°C (Module 1), 34.6°C (Module 2), and 34.9°C (Module 3). At 32°C, Module 2 showed the largest deviation from the reference values, whereas at 34°C and 36°C, Module 3 exhibited the greatest deviation.

Percentage error values were calculated for each module and temperature setting. At 32°C, the errors were 0.001%, 0.006%, and 0.009% for Modules 1, 2, and 3, respectively. At 34°C, the corresponding errors were 0.0005%, -0.0005%, and -0.01%. At 36°C, the errors were 0.001%, -0.002%, and 0.01% for Modules 1, 2, and 3, respectively. The highest observed error values were associated with Module 3 across all temperature settings. Although some discrepancies were observed between incubator measurements and Incu Analyzer reference readings, all errors

Table 1. Average Overall Chamber Temperature Measurements

SETTING	INCUBATOR 1	INCUBATOR 2	INCUBATOR 3	MODUL 1	MODUL 2	MODUL 3	ERROR 1	ERROR 2	ERROR 3
32°C	31.2	30.8	30.1	31.2	31	29.8	0.001	-0.006	0.009
34°C	33.3	33	34.1	33.2	33.1	32.8	0.002	-0.001	0.001
36°C	35.1	34.7	34.1	35	34.9	34.4	0.001	-0.004	0.008

Table 2. Skin Temperature Measurements Results

SETTING	INCUBATOR I	INCUBATOR II	INCUBATOR III	MODUL 1	MODUL 2	MODUL 3	ERROR 1	ERROR 2	ERROR 3
32°C	31	30	30	31.8	30.5	30.3	0.0006	-0.01	0.01
34°C	34	33.7	33.4	34	33.7	33.8	0.0005	-0.0005	0.01
36°C	36	34.6	34.4	35.9	34.6	34.9	0.001	-0.002	0.01

remained within an acceptable range. Minor deviations may be attributed to limited resolution of the incubator control system and transient delays during temperature stabilization. In addition, intermittent data transmission between measurement acquisition and server-side processing may have introduced slight delays, preventing fully real-time synchronization of temperature changes.

Conclusion

Through the development of an effective remote monitoring system for multiple infant incubators, the primary aim of this study was to enhance the capabilities of midwives and other healthcare professionals in neonatal care. The collected measurement data demonstrated the accuracy of the proposed monitoring system. For chamber temperature measurements, peak error values varied according to temperature settings. At 32°C, monitoring iteration 3 recorded an error of 0.009%, while at 34°C, monitoring iteration 1 showed an error of 0.002%. At

36°C, monitoring iteration 3 exhibited an error of 0.008%. These findings indicate generally consistent performance of the monitoring system, with small deviations within acceptable limits. Skin temperature measurements also showed minor variations at specific temperature settings. At 32°C, monitoring iterations 2 and 3 both recorded an error of 0.01%. At 34°C, iteration 3 showed an error of 0.01%, while at 36°C it recorded -0.01%. Despite these variations, all measured values remained within an acceptable error range, supporting the reliability of the skin temperature measurements. Overall, the results suggest that the proposed monitoring system provides stable and sufficiently accurate temperature measurements for clinical use. By enabling simplified remote monitoring of infant incubators, the system facilitates early detection of potential deviations in environmental conditions. This may support timely clinical interventions and contribute to improved outcomes for neonates requiring specialized care. The findings of this study indicate the potential of IoT-based monitoring systems to enhance neonatal intensive care practice and reduce the risk of adverse events.

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Most important care considerations for preterm infants

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Abstract

Preterm infants are a vulnerable population with specific healthcare and developmental needs, and their care following hospital discharge is influenced by numerous risk factors. After discharge, these children embark on a unique developmental trajectory that can be supported through continuous follow-up, monitoring, and early intervention. This article presents data on Hungarian mothers of preterm infants, which may contribute to the identification of at-risk groups and the development of appropriate communication and support strategies. Healthcare professionals play an important role in helping parents recognize and address problems associated with prematurity, both during hospitalization and in primary care. Parents should be equipped with the necessary knowledge and skills, which can be fostered through their active involvement in neonatal intensive care and structured parental education. Optimal development of preterm infants can be supported through individualized care plans and early intervention; however, comprehensive family support is also essential, as parental trauma and emotional burden may themselves become barriers to effective care.

Keywords: prematurity, extremely preterm infant, preterm infant follow-up, early intervention

Introduction

Definition of Preterm Birth and Early Life of Preterm Infants

Approximately 134 million preterm infants are born worldwide each year. The significance of preterm birth lies in the fact that complications associated with prematurity remain among the leading causes of mortality in children under five years of age. Survival and morbidity are influenced by several factors, most importantly gestational age, birth weight, and the quality of obstetric and neonatal care (1).

Spontaneous preterm birth is defined as a live birth occurring between 20+0 and 36+6 weeks of gestation. According to the American College of Obstetricians and Gynecologists (ACOG), cervical dilatation of 2 cm is considered diagnostic, whereas several international

guidelines use a threshold of 3 cm. Clinical signs suggestive of spontaneous preterm labor include:

- ♦ Regular uterine contractions associated with progressive cervical dilatation. These may occur 4–12 times per hour and may present as menstrual-like cramps, pelvic pain, or lower back pain.
- ♦ Increased vaginal mucus discharge, which may be accompanied by spotting or light vaginal bleeding.
- ♦ Leakage or rupture of the amniotic membranes, maternal fever, profuse malodorous vaginal discharge, or heavier vaginal bleeding, which may indicate placental abruption.

Spontaneous preterm birth is associated with numerous maternal risk factors, including addictive behaviors such as cigarette smoking, substance use, and alcohol consumption; malnutrition; inadequate antenatal care; social risk factors (e.g., prostitution); extremes of maternal age; and chronic maternal diseases and obstetric comorbid-

List of abbreviations

BPD: Bronchopulmonary Dysplasia; **CP:** Cerebral Palsy; **FTG:** Developmental Supportive Care; **IVH:** Intraventricular Hemorrhage; **NEC:** Necrotizing Enterocolitis; **NIC:** Neonatal Intensive Care Unit (NICU); **PDA:** Patent Ductus Arteriosus; **PIC:** Perinatal Intensive Care Center; **PVL:** Periventricular Leukomalacia; **PTSD:** Post-Traumatic Stress Disorder; **ROP:** Retinopathy of Prematurity; **RSV:** Respiratory Syncytial Virus; **WHO:** World Health Organization

ities, particularly hypertension, preeclampsia, diabetes mellitus, and autoimmune disorders.

During antenatal education and routine prenatal care, pregnant women should be informed about the warning signs of spontaneous preterm labor. Emphasis should also be placed on the importance of regular antenatal care and participation in recommended screening examinations, as early recognition may contribute to preventing or postponing preterm birth. Nevertheless, approximately 50% of women admitted to hospital with threatened preterm labor give birth within a few days, while a further 10% deliver within one week. Timely administration of antenatal corticosteroids, tocolytic therapy, appropriate pharmacological treatment, and antibiotics when indicated can reduce maternal and fetal complications, improve neonatal survival, and decrease neonatal morbidity. However, neonatal outcomes remain strongly dependent on gestational age, birth weight, and, consequently, the degree of fetal maturity (2).

An increasing proportion of preterm births are medically indicated rather than spontaneous. Medically indicated preterm birth may be associated with advanced maternal age, infertility treatments, multiple pregnancies, maternal medical conditions, placental disorders, and fetal abnormalities (3).

Key Epidemiological Data on Preterm Birth in Hungary

An overview of the epidemiology of preterm birth in Hungary and the characteristics of parents of preterm infants is essential, as these factors may influence future opportunities, parental cooperation, and ultimately the child's long-term developmental outcomes.

In 2023, the national preterm birth rate in Hungary was 8.1%, with considerable regional variation across counties. The highest rates were reported in Somogy County (11.1%), followed by Borsod-Abaúj-Zemplén County (11.0%), Baramya County (9.8%), Heves County (9.4%), and Bács-Kiskun County (9.3%). The lowest rates were recorded in Komárom-Esztergom and Győr-Moson-Sopron counties (6.7–7.0%), while the rate in Budapest was 7.2% (4).

Several additional epidemiological findings are relevant, as they may substantially influence family circumstances and the ability of parents to cope with the crisis associated with preterm birth:

- ♦ In 2023, 2,612 twin deliveries were recorded in Hungary (4). Multiple pregnancies are strongly associated with preterm birth, with approximately 55% resulting in preterm delivery (5).
- ♦ A total of 6,903 preterm births occurred, including 39 live births before 23 weeks of gestation, representing 0.05% of all live births (4).
- ♦ Among mothers who gave birth, 11 were aged 14 years or younger, while eight were aged 50 years or older (4).
- ♦ 66.8% of mothers of preterm infants were married, compared with 76.5% of mothers of term infants. Mar-

riage may represent a protective factor during the psychological crisis associated with preterm birth (4, 5).

- ♦ 10.5% of mothers of preterm infants were unmarried and living without a partner (5).
- ♦ 60.1% of preterm infants had a birth weight below 2,500 g (4).
- ♦ Regarding birth order, 42.6% of preterm infants were first-born children, 29.6% were second-born, and 27.8% were third-born or later-born children (4).
- ♦ According to data from the Hungarian Central Statistical Office (HCSO) Birth Cohort Study, based on self-reported financial status, mothers in the lowest socioeconomic category were almost three times more likely to experience preterm birth than those in the highest socioeconomic category (11.5% vs. 4.0%). Financial deprivation may also limit access to developmental and rehabilitation services (5).
- ♦ Preterm birth occurs more frequently among families living in rural areas and smaller settlements, which may adversely affect access to follow-up care and early intervention services (5).
- ♦ Maternal age shows a U-shaped association with the risk of preterm birth, with substantially higher rates among mothers younger than 20 years and those older than 35 years (5).
- ♦ The prevalence of preterm birth is considerably higher in settlements with fewer than 1,000 inhabitants, particularly in those with populations below 500, potentially limiting access to specialized healthcare professionals (5).
- ♦ According to the Hungarian preterm birth cohort study, 84% of mothers smoked before pregnancy, 99% smoked during the first trimester, and 10.7% continued smoking throughout both the first and second trimesters (5).

The educational attainment of mothers of preterm infants is presented in *Table 1*, as maternal education represents an important indicator when planning and providing comprehensive care.

Overall, from the perspectives of both preterm birth prevention and subsequent follow-up care, the highest-risk group comprises mothers who are younger than 20 years

Table 1. Educational attainment of mothers of preterm infants in Hungary, 2023 (N = 6,903). Source: Hungarian Central Statistical Office (HCSO), Statinfo Database (4)

EDUCATIONAL ATTAINMENT	NUMBER OF MOTHERS WITH PRETERM BIRTHS (N)	PROPORTION OF MOTHERS WITH PRETERM BIRTHS (%)
Primary education (Grades 0–7)	210	3
Completed primary education (8 grades)	1450	21
Completed vocational school or trade school	693	10
Completed secondary education	2057	29.8
Completed higher education	1771	25.7
Unknown	683	9.8

Table 2. Prevalence of major neonatal morbidities during hospitalization, and morbidity among surviving children at the 2-year follow-up assessment

MAJOR NEONATAL MORBIDITIES DURING HOSPITALIZATION	PREVALENCE %	MORBIDITY AMONG SURVIVING CHILDREN AT THE 2-YEAR FOLLOW-UP ASSESSMENT	PREVALENCE %
Necrotizing enterocolitis (NEC)	8.9	Moderate-to-severe cerebral palsy (CP)	84
Early-onset sepsis	24	Bilateral blindness	15
Late-onset sepsis	19.9	Requirement for a hearing aid or cochlear implant	2.5
Severe intraventricular hemorrhage (IVH)	14.3	Hospital readmission with a median of 1–3 hospitalizations, depending on gestational age	49.9
Severe retinopathy of prematurity (ROP)	12.8	Need for mobility aids	154
Severe bronchopulmonary dysplasia (BPD)	8.0	No or only mild neurodevelopmental impairment	48.7
		Moderate neurodevelopmental impairment	29.3
		Severe neurodevelopmental impairment	21.2

of age, single, have a low level of educational attainment, and reside in small rural communities. These factors should be considered when planning targeted preventive interventions and long-term family support (5).

Classification of Preterm Infants According to Gestational Age

The classification of preterm birth varies slightly across international guidelines; however, the World Health Organization (WHO) classification is applied in Hungary:

- ♦ Extremely preterm infants: born before 28 completed weeks of gestation.
- ♦ Very preterm infants: born between 28+0 and 31+6 weeks of gestation.
- ♦ Moderate to late preterm infants: born between 32+0 and 36+6 weeks of gestation (1).

Some publications also use the term “micro preemie” to describe infants born before 26 weeks of gestation or with a birth weight below 700–800 g (6).

Early and Late Complications in Preterm Infants

Because preterm infants are born before completing normal fetal maturation, their adaptation to extrauterine life is frequently compromised.

Among late preterm infants, the most common complications include respiratory distress, hypothermia, hypoglycemia, hyperbilirubinemia, and feeding difficulties. In contrast, extremely and very preterm infants are additionally at increased risk of developing necrotizing enterocolitis (NEC), intraventricular hemorrhage (IVH), periventricular leukomalacia (PVL), sepsis, bronchopulmonary dysplasia (BPD), patent ductus arteriosus (PDA), retinopathy of prematurity (ROP), anemia, hypotension, and impaired postnatal growth and development (2).

A large American cohort study investigating mortality and morbidity among more than 10,000 extremely preterm infants born between 22+0 and 28+6 weeks of gestation reported an overall hospital discharge survival rate of 78%. Survival increased markedly with advancing gestational age, ranging from 10.9% among infants

born at 22 weeks to 94% among those born at 28 weeks. Among survivors, 49.9% were readmitted to the hospital during the 2-year follow-up period, while 21.2% were diagnosed with severe neurodevelopmental impairment (7). These findings underscore the importance of actively involving parents in neonatal care and providing comprehensive education, psychological support, and family-centered counseling throughout hospitalization and subsequent follow-up (8).

Prevalence of Major Conditions Requiring Treatment in a Large Cohort of Extremely Preterm Infants

According to a large international cohort study of extremely preterm infants born between 22 and 28 weeks of gestation, the prevalence of major neonatal morbidities during hospitalization is presented in *Table 2* (7).

Assessments and Procedures Prior to Hospital Discharge

Before discharge from the neonatal unit, the following assessments and interventions should be completed, as presented in *Table 3* (8).

Table 3. The following assessments and interventions should be completed, before discharge from the neonatal unit (8)

Comprehensive neurological examination, including assessment of muscle tone, cranial nerve function, primitive reflexes, feeding ability, sleep–wake patterns, vision, and hearing
General physical examination
Ophthalmological examination
Newborn hearing screening
Cranial ultrasonography
Information regarding the recommended schedule of follow-up examinations
Explanation of the discharge summary and its clinical implications
Information on available social benefits and financial support
Prescription of infant formula, when medically indicated
Communication and transfer of relevant information to the primary care pediatrician and the health visitor.

Developmental Characteristics in Early Childhood and Developmental Support for Preterm Infants

Typical development refers to the expected developmental trajectory observed in most children, whereas atypical development describes developmental patterns that differ significantly from age-appropriate norms. A thorough understanding of typical developmental milestones is essential for the early recognition of developmental deviations.

In children between 1 and 3 years of age, atypical (or divergent) development refers to significant delays or abnormalities affecting one or more developmental domains compared with the expected developmental pattern for a given age. It is important to recognize that every child develops at an individual pace, and minor variations are considered part of normal development. Atypical development is diagnosed when developmental differences are persistent, involve multiple developmental domains, or interfere with the child's adaptive functioning and subsequent developmental progress (9).

Developmental milestones in preterm infants should be assessed using corrected age rather than chronological age. For infants born before 28 weeks of gestation, corrected age should be used until 2 years of age. For those born between 28 and 34 weeks of gestation, age correction is recommended until 12 months, whereas for infants born between 34 and 37 weeks of gestation, corrected age should be used until 6 months of age.

If a preterm infant does not undergo a developmental neurological assessment and subsequent follow-up at a neonatal outpatient clinic or a Perinatal Intensive Care Center (PIC), referral to a pediatric neurologist for evaluation and long-term follow-up may become necessary.

In primary healthcare, monitoring the development of preterm children is a shared responsibility of the community health visitor and the primary care pediatrician. However, developmental surveillance should always be conducted in close collaboration with the parents or other primary caregivers.

During the initial home visits, the community health visitor performs a comprehensive assessment, including visual inspection, clinical observation, parental interview, review of the medical history, and evaluation of the family's overall circumstances.

This assessment is complemented by ongoing family-centered support addressing all aspects of the infant's care, including monitoring vital signs at home, bowel and bladder function, nutrition and feeding, administration of prescribed medications, sleep patterns, physical activity, safe outdoor exposure, safety throughout all phases of care, emotional security, social support, environmental health considerations, hygiene, appropriate clothing, implementation of home-based developmental activities, and reinforcement of the importance of attending scheduled follow-up appointments.

If developmental delay, abnormal developmental patterns, or behavioral concerns are identified, referral to

Table 4. The main domains of psychomotor development

Gross motor skills
Fine motor skills
Language and speech development
Cognitive development
Adaptive skills
Social and emotional development
Independence and self-care skills
Feeding skills

the primary care pediatrician is recommended for further evaluation.

Community health visitors also complete standardized parent-reported developmental screening questionnaires together with the parents. These questionnaires, based on parental observations of the child in the home environment, provide valuable information about the child's developmental progress (10).

Between 0 and 3 years of age, psychological development is closely embedded within motor development; therefore, this developmental period is commonly referred to as psychomotor development. Psychomotor development encompasses not only motor abilities but also communication, social interaction, movement patterns, neuromuscular function, and sensory processing.

The main domains of psychomotor development are seen in *Table 4*.

The developmental trajectories of preterm children are characterized by considerable heterogeneity. Developmental self-correction and neuroplasticity play an important role during early childhood, and neurological impairments may, in many cases, improve over time. Numerous studies have investigated why some preterm infants demonstrate remarkably favorable developmental outcomes, achieving substantial improvement and eventually reaching age-appropriate developmental milestones across multiple domains.

One of the most important protective factors is the quality of the parent-child interaction, which has been shown to positively influence self-regulation, cognitive development, behavioral outcomes, and later academic achievement.

The developmental risks associated with prematurity arise from multiple interacting factors, including biological immaturity, intrauterine growth restriction (IUGR), the consequences of intensive medical interventions required to support survival, parental stress, or a combination of these factors (9).

Preterm Infants as a High-Risk Population

The long-term consequences of prematurity extend beyond neonatal diagnoses and chronic medical conditions requiring ongoing follow-up. Difficulties in cognitive,

social, and emotional development are also common, particularly among infants at the highest biological risk. Preterm children may experience intellectual impairment, learning disabilities, behavioral difficulties, mental health problems, and persistent physical health issues later in life. Delays in expressive language development, together with poorer performance in mathematics, reading, and spelling, are frequently reported. Consequently, preterm children are more likely to enter school at a later age and require special educational support. Motor impairments, delayed motor development, prolonged tube feeding or long-term enteral nutritional support, and breastfeeding difficulties may further compromise communication and overall developmental outcomes (9).

Whenever a child's development deviates from the expected developmental trajectory (i.e., atypical development) or fails to meet age-appropriate milestones, healthcare professionals have a responsibility to communicate these concerns to the parents. Within the limits of their professional competencies, clinicians should provide objective yet sensitive counseling, emphasizing that developmental functions build upon one another and that timely referral to early intervention services may be necessary (11).

During follow-up care, assessment of motor function should ideally be performed by a multidisciplinary rehabilitation team, including conductive education specialists, physical therapists, and movement therapists, whenever available (8).

Following referral to the Educational Support Service, children undergo a comprehensive diagnostic assessment, on which individualized therapeutic and intervention plans are based. The responsibilities of these services include developmental screening, functional assessment, and longitudinal monitoring of the child's development both within the family environment and in educational settings, including preschool, elementary school, and secondary school (11).

Until independent walking and speech have been established, developmental follow-up is provided by regional and national pediatric neurology outpatient clinics. When indicated, these specialist services recommend appropriate early intervention programs tailored to the individual needs of preterm children. For children with severe motor impairment, they also provide guidance regarding rehabilitation and the use of assistive devices. Parents should receive clear information about the objectives, expected benefits, and long-term importance of participating in early intervention programs (8).

Sensory Impairments

Visual and hearing impairments occur considerably more frequently among preterm infants than among term-born children. Common complications include retinopathy of prematurity (ROP), hearing impairment, and

sensory processing disorders, in which visual, auditory, and tactile stimuli may be processed atypically, resulting in difficulties integrating sensory information.

Sensory screening is an integral component of routine follow-up care for preterm infants. Early identification and timely intervention are essential to minimize the severity of visual and hearing impairments and sensory processing disorders. Such interventions optimize sensory, perceptual, and developmental outcomes, thereby improving the long-term quality of life of children born preterm (8).

Nutrition

Prematurity is one of the major factors complicating breastfeeding. Neurological immaturity, impaired pharyngeal innervation, prolonged tube feeding, abnormalities in muscle tone and coordination, prolonged neonatal jaundice, medical interventions, and maternal stress may all interfere with successful breastfeeding and the provision of human milk (10).

Breastfeeding and feeding with the mother's own milk are strongly recommended for preterm infants. Preterm milk provides substantial benefits owing to its higher protein, lipid, and immunological component content compared with mature breast milk. Nevertheless, despite the use of colostrum and early breast milk, human milk fortification may still be required to meet the increased nutritional demands of preterm infants (8).

Nutritional management requires close clinical monitoring throughout infancy. Because preterm infants have an immature gastrointestinal tract, a thin intestinal wall, reduced intestinal motility, limited nutrient stores, and a rapid rate of postnatal growth, they are unable to tolerate large feeding volumes and therefore require smaller, more frequent feeds. Brain development is particularly rapid during this period, making an adequate supply of energy and nutrients essential. In addition, fluid balance is unstable, increasing the risk of dehydration. Fluid requirements vary considerably among preterm infants and should be individualized, while energy and protein intake require careful medical supervision.

Monitoring of body weight, body length, and head circumference – and, when indicated, other anthropometric parameters – may be necessary on a daily basis, as adequate nutritional support has a profound impact on growth and all domains of neurodevelopment (12).

Successful breastfeeding also depends on comprehensive maternal support, including education and stress management. The involvement of lactation consultants is highly beneficial in establishing and maintaining lactation. Community health visitors provide guidance on the introduction of complementary feeding in accordance with current national and international recommendations. Unlike developmental assessment, the timing of complementary feeding is based on chronological age rather than corrected age (8,10).

Infection Prevention and Control

In preterm infants, particular emphasis should be placed on infection prevention and maintaining a hygienic home environment. Preventive measures should extend beyond household cleanliness to include proper cleaning and disinfection of infant care equipment, safe food and feeding practices, and meticulous personal hygiene among caregivers, particularly regular hand hygiene.

Parents should receive education on visitor management and seasonal infection prevention strategies, especially during the fall and winter months. These measures include avoiding crowded public places and limiting unnecessary exposure to individuals with respiratory infections. According to current immunization guidelines, the increased susceptibility of preterm infants to infectious diseases requires all routine childhood vaccinations to be administered according to the recommended schedule without delay. In addition, several optional immunizations are recommended for this high-risk population. For infants born before 32 weeks of gestation, respiratory syncytial virus (RSV) immunoprophylaxis is recommended where available. Other recommended vaccines include those against rotavirus, meningococcal disease (serogroups B and C), seasonal influenza, hepatitis A, and tick-borne encephalitis (8).

The Role of Maternal and Family Support in the Development of Preterm Infants

Mothers of preterm infants face an exceptionally complex and emotionally demanding situation that may significantly influence the establishment of early parent–infant attachment. Although most mothers ultimately develop a strong bond with their preterm infant, numerous factors may interfere with the early stages of attachment, potentially resulting in temporary – and, less frequently, persistent – attachment difficulties.

In Perinatal Intensive Care Centers (PICs), medical treatment is complemented from the earliest stages by Family-Centered Developmental Care (FCDC), an approach that takes into account the individual needs of both the preterm infant and the family. Within the neonatal intensive care environment, excessive light and noise, painful medical procedures, and separation from parents represent substantial sources of stress for preterm infants. Family-centered developmental care seeks to minimize these adverse environmental influences while actively promoting parental involvement.

Continuous parental participation and education are integral components of developmental care. Parents are encouraged to collaborate with healthcare professionals, implement strategies to reduce environmental stressors, and actively participate in their infant's daily care, thereby strengthening the parent–infant relationship.

Developmental care interventions include minimizing environmental noise, maintaining a quiet atmosphere, covering the incubator to reduce light exposure, promoting

skin-to-skin contact (kangaroo care), providing gentle therapeutic touch, careful handling by healthcare professionals, appropriate positioning for comfort and physiological stability, and administering expressed breast milk whenever feasible (8).

Preterm birth represents a profound psychological crisis for the entire family. Mothers of preterm infants are at increased risk of anxiety disorders and postpartum depression, which may manifest as emotional instability, fatigue, feelings of guilt, frequent crying, and difficulties performing infant caregiving tasks. Furthermore, following this traumatic experience, post-traumatic stress disorder (PTSD) may develop in either or both parents, often accompanied by persistent anxiety, fear, intrusive thoughts, and negative cognitive beliefs (3).

The family environment and the quality of caregiving at home play a pivotal role in supporting the cognitive, social, and emotional development of preterm infants. Research has demonstrated that preterm infants exposed to high levels of stress and poor-quality caregiver–infant interactions at 6 months of age show significantly poorer social competence by 12 months. The long-term outcomes of prematurity are strongly influenced by the quality of parental interactions and caregiving.

Overprotective, excessively anxious, or overly restrictive parenting practices may adversely affect subsequent development and contribute to additional developmental difficulties. Therefore, comprehensive psychological support for mothers, fathers, and other family members is of paramount importance. Ideally, this support should involve a multidisciplinary team, including psychologists, perinatal mental health specialists, bereavement counselors, and other mental health professionals, to promote parental well-being and optimize developmental outcomes for the child (9).

The Peter Cerny Foundation Neonatal Ambulance Service: Improving Survival of Preterm Infants

During the transport of extremely preterm infants, neonatal transport teams establish early contact with both the infant and the family. In some high-risk pregnancies, timely in utero transfer to a tertiary perinatal center cannot be achieved. Consequently, urgent postnatal neonatal transport becomes necessary to ensure admission to a Level III Neonatal Intensive Care Unit (NICU).

The specialized neonatal transport service is prepared to receive and transfer critically ill newborns during the so-called “golden hour”, a period during which prompt stabilization and transport are crucial for optimizing clinical outcomes. According to operational analyses, transport teams are typically ready to initiate transfer within approximately 2 minutes to 2 hours and 45 minutes after activation. On occasion, the service is also dispatched to emergency home births requiring immediate neonatal intensive care.

The Peter Cerny Foundation Neonatal Ambulance Service, a unique Hungarian neonatal transport organiza-

tion, has substantially improved the survival of preterm infants through its highly specialized transport system and advanced neonatal care. By ensuring rapid stabilization and safe transfer to tertiary neonatal centers, the service contributes to reducing both short- and long-term complications of prematurity, thereby improving long-term health outcomes.

The Foundation also embraces a family-centered model of care. In addition to providing expert medical treatment, transport teams maintain continuous com-

munication with parents and offer emotional support throughout the transport process. With parental consent, photographs of the infant are taken and shared with the family to help maintain the early parent–infant bond during unavoidable separation. Care is delivered according to the Emotional Presence Protocol, an approach emphasizing mindful attention, compassionate presence, and empathy when caring for critically ill and highly vulnerable preterm infants and supporting their families (13).

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Early prevention of allergic and autoimmune diseases

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Abstract

The period from conception to two years of age – the first 1000 days of life – represents a critical window for the structural and functional maturation of the immune system. During this sensitive developmental phase, immune tolerance is established, long-term inflammatory responsiveness is programmed, and the fundamental patterns of immunometabolic and neuroendocrine regulation are shaped. Early environmental exposures, nutrition, microbial colonization and epigenetic mechanisms collectively determine the later risk of allergic, autoimmune and other chronic inflammatory diseases.

Human milk plays a central role in early immunological programming. In particular, human milk oligosaccharides (HMOs) influence the composition of the infant gut microbiome, promote the development of a tolerogenic immune environment, and indirectly support the differentiation and functional stability of regulatory T cells (Tregs). Microbial fermentation of HMOs leads to the production of short-chain fatty acids and other metabolites that regulate immune responses through epigenetic pathways, including modulation of FOXP3 expression.

Recent systems biology studies have further demonstrated that microbial metabolites can directly influence T-cell differentiation programs in early life, reinforcing the concept of microbiome-driven immune imprinting. In parallel, accumulating clinical evidence indicates that early introduction of allergenic foods supports the development of oral tolerance and may reduce the risk of food allergy. Current European guidelines therefore no longer recommend allergen avoidance diets during pregnancy or breastfeeding for allergy prevention.

Altogether, the HMO–microbiome–metabolite–Treg axis represents a key biological pathway linking early nutrition with long-term immune tolerance. Understanding these mechanisms provides a scientific foundation for early-life preventive strategies aimed at reducing the burden of allergic and immune-mediated diseases.

Keywords: *first 1000 days of life; immune programming; human milk oligosaccharides; microbiome; regulatory T cells; epigenetics; allergy prevention*

Introduction

In recent decades, the incidence of allergic diseases, autoimmune diseases, and other chronic, inflammatory non-communicable diseases has increased significantly worldwide. The rising prevalence of allergic and autoimmune diseases suggests that genetic predisposition alone cannot explain the frequency of these diseases. Research is therefore increasingly focused on environmental influences, especially those during fetal and early infancy (1, 2). The regulation of immune responses during fetal life and the early postnatal period is not yet fully established; therefore, environmental stimuli can significantly influence immune system maturation. Epigenetic regulation, microbiome–immune system interactions, and neuroen-

docrine axis function collectively establish the immunological baseline that determines the long-term balance between tolerance and inflammation (3).

The first 1000 days of life as an immunological window period

The period from conception to the age of two years is uniformly described in the literature as the “first 1000 days of life”. This period is of particular importance not only from a developmental but also from an immunological perspective, as it is the period of regulation of the immune response and the development and program-

ming of immunological tolerance within the organism (4). Several hypotheses have been proposed to explain this immunological programming.

According to the Developmental Origins of Health and Disease (DOHaD) concept, the fetal and early postnatal environment has long-term effects on immune and metabolic regulation. In line with the Barker hypothesis and the “thrifty phenotype” model, early adaptive responses to environmental conditions may later have maladaptive consequences, such as the association between low birth weight and increased risk of obesity and metabolic disease in later life (1, 2). A shift in immunological programming toward a pro-inflammatory profile may subsequently manifest as an increased risk of allergic and autoimmune diseases (3, 4).

Development and immunological significance of the infant microbiome

Colonization of the gut microbiome begins within the first days of life and is closely intertwined with the maturation of the immune system. The gut-associated lymphoid tissue (GALT) represents one of the most important regulatory sites for the development of immunological tolerance, where antigen presentation, T-cell differentiation, and modulation of cytokine networks take place (5).

During vaginal delivery, the newborn is exposed to maternal vaginal and intestinal microbiota, which promotes the establishment of a bifidobacteria-dominant early microbiome. Breastfeeding further supports this process, as bioactive components of human milk – particularly human milk oligosaccharides (HMOs) – selectively promote the growth of bacterial taxa characteristic of early infancy (6, 7).

In contrast, cesarean section, formula feeding, and early-life antibiotic exposure may disrupt normal microbial colonization, leading to dysbiosis. Such alterations can adversely affect immune system maturation and have been associated with an increased risk of allergic and autoimmune diseases (5, 8).

Hygiene hypothesis and environmental microbial exposure

According to the hygiene hypothesis, reduced microbial exposure in modern societies plays a fundamental role in the increasing incidence of allergic and autoimmune diseases (9). Urbanization, smaller family sizes, widespread use of disinfectants, and extensive antibiotic use collectively create an environment in which the developing immune system encounters fewer tolerogenic microbial stimuli.

Epidemiological studies have demonstrated that children raised in farm environments have a lower prevalence of bronchial asthma and allergic sensitization (10). Findings from the GABRIELA and PASTURE studies further suggest that increased microbial diversity and endotoxin exposure promote tolerogenic regulation of both innate and adaptive immune responses (10, 11).

Immunological significance of breast milk

Breast milk provides not only optimal nutritional support for the infant but also actively participates in the regulation and development of the immune system. Immunoglobulins, particularly secretory IgA, along with cytokines, growth factors, living cells, and microorganisms present in breast milk, contribute to the maturation of mucosal immunity (12).

Several longitudinal studies have demonstrated that breastfeeding reduces the incidence of atopic dermatitis, asthma, and certain food allergies, particularly among high-risk infants (13). These effects are not limited to passive immune protection but also reflect active immunological programming.

The role of human milk oligosaccharides (HMOs) in immunological programming

Human milk oligosaccharides (HMOs) constitute the third largest solid component of human milk and exhibit considerable structural diversity (6). These oligosaccharides are not digested by the infant; instead, their primary role lies in shaping the gut microbiome and modulating immune development.

Through their prebiotic effects, HMOs selectively promote colonization by *Bifidobacterium longum* subsp. *infantis* and, to a lesser extent, other infant-associated bifidobacterial species. These microorganisms efficiently metabolize HMOs and produce short-chain fatty acids – acetate, propionate, and butyrate – as metabolic end products (6, 7).

In addition, HMOs can act as soluble decoy receptors that inhibit pathogen adhesion to the intestinal epithelium. They also influence epithelial and antigen-presenting cell function through receptor-mediated mechanisms. Experimental evidence suggests that specific HMO structures may promote tolerogenic polarization of dendritic cells, thereby supporting the induction of regulatory T-cells (14).

Short-chain fatty acids and epigenetic regulation

Short-chain fatty acids (SCFAs) produced by the gut microbiome represent key metabolic regulators of immune function. In addition to their role in providing energy for intestinal epithelial cells, these metabolites exert direct epigenetic effects on immune regulation (15).

Butyrate, in particular, acts as a histone deacetylase (HDAC) inhibitor and thereby enhances transcription of the FOXP3 gene, a central transcription factor required for the differentiation and stable function of regulatory T-cells (Tregs) (16). Both experimental and clinical studies have demonstrated that SCFAs promote the differentiation and long-term maintenance of peripheral Tregs (15–17).

Epigenetic regulation of this type is especially relevant during the first 1,000 days of life, a developmental window in which immune-related epigenetic patterns remain highly plastic and

sensitive to environmental influences. An adverse microbial or nutritional environment may result in unstable FOXP3 methylation patterns, which have been associated with impaired Treg function and enhanced pro-inflammatory immune responses (16, 17). Regulatory T cells are central mediators of the tolerogenic immune environment shaped by the microbiome and bioactive components of human milk. They play a critical role in establishing and maintaining immune tolerance and in regulating inflammatory responses during early life. The differentiation and functional stability of Tregs are closely influenced by early microbial and nutritional exposures. Breastfeeding, human milk oligosaccharides, and microbiome-derived metabolites collectively contribute to a tolerogenic immune milieu by stabilizing FOXP3 expression and supporting Treg survival through epigenetic and metabolic mechanisms. In addition to SCFAs, other microbial metabolites, including certain tryptophan derivatives, have been shown in both animal and human studies to directly influence T-cell differentiation programs and modulate the balance of mucosal immune responses (15–17).

Indole derivatives produced through microbial metabolism of tryptophan, including indole-3-lactic acid, can induce tolerogenic immune responses via activation of the aryl hydrocarbon receptor (AhR) signaling pathway and upregulate expression of galectin-1 (LGALS1). Galectin-1 is an important regulator of T-cell differentiation, promoting suppression of pro-inflammatory Th2 and Th17 responses while supporting the stabilization of regulatory T cells (Tregs) (18, 19).

For an extended period, evidence supporting the relationship between the microbiome and T-cell regulation was primarily indirect. Epidemiological observations, such as the reduced risk of allergic disease in children raised in farm environments, the effects of cesarean section on early microbial colonization, and the impact of early antibiotic exposure, have all suggested that microbiome composition plays a key role in the development of immunological tolerance. In parallel, *in vitro* studies using T-cell cultures and cytokine assays have demonstrated that microbial metabolites can directly modulate T-cell polarization and promote tolerogenic immune responses (18, 19).

Direct human evidence for microbiome-mediated immunological imprinting at the T-cell level has been provided by a comprehensive systems biology study by *Henrick et al.* This longitudinal study, which followed a large cohort of infants, integrated metagenomics, transcriptomics, and mass cytometry to characterize interactions between early-life microbiome composition and immune system development. The results demonstrated that dominance of *Bifidobacterium longum* subsp. *infantis* in the infant gut microbiome was associated with enhanced tryptophan metabolism and increased production of indole derivatives, including indole-3-lactic acid. These metabolites were shown to upregulate expression of the galectin-1 (LGALS1) gene and to modulate T-cell responses toward a tolerogenic profile. Notably, increased LGALS1 expression was primarily observed in T cells, providing direct evidence that early-life microbiome composition

can influence T-cell differentiation programs (20). In this study, colonization with *B. infantis* EVC001 was also associated with reduced levels of pro-inflammatory cytokines, including IL-17A, IL-13, and IL-33, alongside an immune signature consistent with enhanced tolerance. An increasing body of experimental and clinical evidence suggests that human milk oligosaccharides, a bifidobacteria-dominant infant microbiome, and microbial metabolites form an integrated functional axis. The HMO–microbiome–tryptophan metabolite–LGALS1–Treg pathway appears to play a central role in the establishment of early-life immune tolerance. These findings support the concept that early environmental and nutritional exposures can shape immune system function through long-term immunological programming, influencing the balance between inflammatory and tolerogenic immune responses.

The central role of regulatory T cells in the establishment of immunological tolerance and their clinical significance

The differentiation and functional stability of regulatory T cells (Tregs) are closely linked to early microbial and nutritional influences. Breastfeeding, human milk oligosaccharides, and microbiome-derived short-chain fatty acids together contribute to the establishment of a tolerogenic immunological environment that stabilizes FOXP3 expression through epigenetic mechanisms and reduces the long-term risk of allergic sensitization (15–17).

The significance of these basic immunological findings is underscored by the 2025 Nobel Prize in Physiology or Medicine, awarded to *Shimon Sakaguchi*, *Mary E. Brunckow*, and *Fred Ramsdell* for their discovery of the cellular and molecular mechanisms underlying peripheral immunological tolerance. Their work provides a fundamental theoretical framework for a more precise understanding of the central role of regulatory T cells in the early prevention of allergic and autoimmune diseases (21–24).

Early immunological programming and allergy prevention – clinical implications

The balance between tolerance and inflammation plays a critical role in the pathogenesis of allergic diseases. Immunological programming during the first 1,000 days of life is a key determinant of this balance and therefore of long-term disease risk.

During breastfeeding, a bifidobacteria-dominant microbiome induced by human milk oligosaccharides, together with microbiome-derived short-chain fatty acids, contributes to the epigenetic stabilization of FOXP3 expression and supports the tolerogenic function of regulatory T cells (6,15–17). In contrast, cesarean section delivery, early antibiotic exposure, and lack of breastfeeding may disrupt this tolerogenic programming process, thereby increasing the risk of allergic disease development (5, 8).

According to clinical studies, the timely introduction of allergenic foods in early infancy promotes the development of oral tolerance. The LEAP study demonstrated that early exposure to peanut significantly reduces the risk of peanut allergy, an effect that may be mediated, at least in part, by regulatory T-cell responses (25). The tolerance-inducing effect of early allergen exposure is further supported by several randomized controlled trials. In addition to the LEAP study, other intervention studies and meta-analyses suggest that appropriately timed introduction of egg and peanut during infancy may reduce the risk of allergic sensitization and the development of clinically relevant food allergy. Accordingly, current European recommendations, including EAACI and ESPGHAN position statements, no longer support delayed introduction of allergenic foods. Instead, they recommend gradual introduction of potentially allergenic foods after the initiation of complementary feeding. These guidelines also state that allergen avoidance diets

during pregnancy and lactation are not recommended for primary prevention, as such restrictions do not reduce the risk of allergic disease in offspring and may have adverse nutritional consequences (25–27).

Conclusions

The first 1,000 days of life represent a unique window of opportunity for primary prevention from an immunological perspective. Breast milk – particularly human milk oligosaccharides – actively shapes the infant microbiome, contributes to the epigenetic stabilization of regulatory T cell function, and promotes the long-term maintenance of immunological tolerance. Support of the HMO–microbiome–FOXP3–Treg axis represents a biologically plausible strategy that may contribute to the prevention of allergic and autoimmune diseases through the promotion of early-life immune tolerance.

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Allergen immunotherapy as causal treatment of respiratory allergies

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Abstract

Allergic rhinitis affects approximately 30% of the global population. Conventional management, consisting of allergen avoidance and symptomatic pharmacotherapy, does not provide lasting improvement in patients' quality of life or achieve disease modification. Allergen immunotherapy is a causal treatment that aims to restore impaired immune tolerance. By re-establishing immune tolerance, its beneficial effects may persist for years after treatment has been discontinued. As a result, patients may tolerate exposure to pollens, animal dander, molds, and house dust mites in their natural environment with few or no symptoms over the long term. Allergen immunotherapy has therefore become an integral component of the modern management of allergic rhinitis.

Keywords: *relevant allergen, allergen immunotherapy*

Allergic rhinitis is an IgE-mediated disease characterized by a type 2 immune response (1).

The early phase of allergic rhinitis ("hay fever") is mediated by an IgE-dependent reaction in which histamine released from mast cells binds to histamine receptors, triggering the characteristic symptoms of allergic rhinitis, including sneezing, rhinorrhea, and nasal pruritus. Other inflammatory mediators, including proteases, prostaglandins, leukotrienes (LTs), and platelet-activating factor (PAF), further amplify this response. The late-phase response, characterized predominantly by nasal congestion, is maintained by type 2 innate lymphoid cells (ILC2s), myeloid dendritic cells (mDCs), and cytokines released by inflammatory effector cells, including eosinophils, basophils, monocytes, and lymphocytes. Interleukins (ILs), PAF, and LTs also contribute to the persistence of this inflammatory response (1).

In healthy individuals, immune tolerance to environmental substances is established from infancy. These substances include pollens, house dust mites, animal dander, foods, and insect venoms. When immune tolerance fails to develop because of genetic predisposition, environmental factors, or damage to or inflammation of the skin, respiratory tract, or gastrointestinal tract, the immune system may respond with an exaggerated allergic reaction. Consequently, characteristic allergic symptoms

may develop in the upper or lower respiratory tract, the skin, or the gastrointestinal tract. In rare cases, a systemic anaphylactic reaction may occur. In patients with established allergic disease, the therapeutic goal is not only to minimize allergen exposure and provide symptomatic treatment, but also to restore immune tolerance.

In allergic rhinitis, complete avoidance of respiratory allergens is often impossible, particularly in the case of pollens. In other cases, allergen avoidance can only be achieved partially, such as for indoor molds, house dust mites, and animal dander. Symptoms can be effectively controlled with symptomatic treatment. Allergic conjunctivitis can be treated with ophthalmic antihistamines or other antiallergic eye drops, while intranasal corticosteroids, intranasal antihistamines, or their combination are recommended for rhinorrhea, sneezing, and nasal congestion. Second-generation oral antihistamines are indicated for systemic symptom control. However, these medications are effective only while they are being administered. This article focuses on the causal treatment of respiratory allergies with allergen immunotherapy, which is indicated for patients with mild to moderate persistent allergic rhinitis (2).

Allergen immunotherapy (AIT) is currently the only disease-modifying therapeutic approach capable of altering the underlying pathophysiology of allergic disease and inducing immune tolerance to the causative allergen (3–6).

Mechanism of action of AIT

To simplify this complex immunological process, allergen immunotherapy (AIT) gradually introduces the causative allergen to induce immune tolerance, primarily through the activation of regulatory T (Treg) cells. Cytokines released by these cells, particularly transforming growth factor-beta (TGF- β) and interleukin-10 (IL-10), suppress the Th2 immune response that predominates in allergic individuals. Consequently, the production of Th2-associated cytokines, including IL-4, IL-5, and IL-13, is reduced, leading to decreased IgE production by B cells. Mast cell activation is diminished, the release of eosinophils and basophils from the bone marrow and their migration to target tissues are reduced, and tissue inflammation and mucus production are suppressed, thereby attenuating the allergic response. In addition, regulatory T cells stimulate B cells to produce allergen-specific “blocking” antibodies of the IgG, particularly IgG4, and IgA isotypes. Regulatory B cells also contribute to this process by modulating the function of effector, memory, and regulatory T cells. Following the initiation of AIT, mast cell and basophil degranulation decreases within hours. Within days, an increase in the number and activity of regulatory T cells, accompanied by a reduction in effector cell populations, can be observed. Serum allergen-specific IgE concentrations often increase transiently before gradually declining over subsequent months, whereas allergen-specific IgG4 levels begin to rise within weeks. Additional recently identified immunological mechanisms are discussed in reference 1.

Indications

Allergen immunotherapy is indicated for allergic rhinitis, allergic rhinoconjunctivitis, and well-controlled allergic asthma. Commercially available preparations include extracts of tree, grass, and weed pollens, house dust mites, animal dander, and molds, as well as synthetic and recombinant allergens. AIT may be administered from the age of 5 years.

Prick skin testing and measurement of allergen-specific IgE are performed to identify the allergen responsible for a patient's clinical symptoms. It is important to recognize that a positive skin prick test or elevated allergen-specific IgE level alone indicates sensitization rather than clinical allergy. The diagnosis of allergy and identification of the clinically relevant allergen responsible for the patient's symptoms require correlation of the clinical history with the results of *in vivo* and/or *in vitro* allergy testing. In selected cases, molecular allergy diagnostics may also be required to distinguish genuine sensitization from cross-reactivity in patients with respiratory allergies. These tests can support the decision between monocomponent and multicomponent allergen immunotherapy (AIT). For example, in a patient

with confirmed ragweed allergy, sensitization to mugwort pollen may represent either genuine co-sensitization or cross-reactivity with ragweed. Molecular allergy diagnostics can therefore guide the choice between ragweed-only sublingual immunotherapy (SLIT) and a combined ragweed–mugwort preparation.

Contraindications

Allergen immunotherapy is contraindicated in patients with severe immunodeficiency, severe cardiovascular disease, uncontrolled autoimmune disease, active malignancy, or severe neurological disease. Another contraindication is hypersensitivity to epinephrine or β_2 -adrenergic agonists (e.g., salbutamol), as these medications are essential for the management of potential systemic adverse reactions. AIT should not be initiated during pregnancy; however, treatment that has already been started may be continued during pregnancy if clinically appropriate. Although oral immunotherapy for food allergy is contraindicated in patients with eosinophilic esophagitis (EoE), the use of SLIT requires careful consideration rather than absolute avoidance. Earlier meta-analyses considered EoE a contraindication to SLIT; however, the 2024 recommendations are more permissive. In patients with EoE receiving SLIT for respiratory allergens, expectorating the sublingual allergen extract after the recommended sublingual exposure period may substantially reduce the risk of worsening esophageal inflammation (7).

Drug forms

Allergen immunotherapy (AIT) was originally introduced in the form of subcutaneous immunotherapy (SCIT). Currently, sublingual tablets, as well as sublingual drops or sprays (SLIT), represent the most widely used routes of administration. In recent years, allergen preparations have been modified to minimize adverse effects while maintaining therapeutic efficacy. The most commonly used active substances include purified allergen extracts, chemically modified allergoids, recombinant allergens, and peptide fragments of allergens. The efficacy of these preparations may be enhanced by various adjuvants. The incidence of side effects can be further reduced through adjunctive therapy, such as monoclonal anti-IgE antibodies or anti-IL-4 receptor alpha (anti-IL-4R α) antibodies.

Treatment course

Ideally, allergen immunotherapy should be prescribed and initiated by an allergist. In the case of subcutaneous administration, the preparation is administered by a physician. For sublingual formulations, the first dose should be taken under medical supervision, during which the

specialist demonstrates the correct administration technique, informs the patient about possible adverse reactions, and explains indications for treatment discontinuation. Subsequent doses of SLIT can be self-administered at home. Treatment consists of an initiation (dose-escalation) phase followed by a maintenance phase. For pollen allergens, this is typically administered in a pre-seasonal and co-seasonal regimen, usually for 4–6 months per year over three consecutive years. In the case of perennial allergens, treatment is generally continuous for three full years, with daily, weekly, or monthly dosing schedules depending on the specific product instructions.

When should pollen immunotherapy be started?

The timing of pollen exposure (“pollen season”) depends on geographic location, climate, and current meteorological conditions.

In Northern and Central Europe, sensitization to birch and grass pollen is most common. In Southern Europe, grass and olive pollen are the predominant aeroallergens. In Central and Eastern Europe, including Hungary, the main causes of respiratory allergic symptoms are birch, grass, and ragweed pollens (8).

Pollen release occurs during the flowering period of the respective plant species. In Hungary, early flowering trees such as hazel, alder, and birch release pollen from late January to the end of April. Grasses pollinate mainly in May and June, mugwort (*Artemisia vulgaris*) from mid-July to October, and ragweed (*Ambrosia artemisiifolia*) from August to the end of October. Allergen immunotherapy (AIT) should ideally be initiated at least two months before the expected onset of the relevant pollen season and continued throughout the season. *Table 1* provides guidance for planning pollen immunotherapy schedules. Clinical studies have generally demonstrated that higher cumulative allergen doses are associated with greater clinical efficacy.

Importantly, the indication for AIT is not based on the size of the skin prick test reaction or the level of allergen-specific IgE alone, but rather on the clinical relevance of symptoms caused by the specific allergen. In pa-

tients sensitized to multiple pollens, treatment should be initiated with the allergen responsible for the most severe symptoms (the clinically relevant allergen). In subsequent years, immunotherapy may be expanded to include up to two, and in selected cases three, allergens. Due to climate change, pollen seasons are shifting and often beginning earlier, which may necessitate adjustments in the timing of immunotherapy initiation. During the summer humid period, fungal spores, particularly *Alternaria alternata*, may increase in the air and can trigger hay fever symptom similar to pollen allergens. Because of their prolonged presence, they are often included in aerobiological monitoring reports. Occasionally, these spores may also be detected in the air during spring.

AIT can be started at any time for perennial allergens

For perennial allergens, allergen immunotherapy may be initiated at any time of the year. House dust mites, animal dander, and indoor molds are present throughout the year; therefore, treatment is not seasonally restricted. Nevertheless, environmental control measures should be implemented to reduce allergen exposure as much as possible. In selected cases, air purifiers equipped with HEPA filters may help reduce airborne allergen load in both home and occupational environments.

Side effects

SCIT may cause transient local reactions at the injection site, including erythema, swelling, and pruritus. In rare cases, systemic reactions such as asthma exacerbation or anaphylaxis may occur. Therefore, injectable preparations must always be administered in a medical setting equipped with the personnel and infrastructure required for the immediate management of anaphylactic reactions.

With SLIT, adverse effects may include oral pruritus, throat irritation, itching of the ears or eyes, and sublingual edema. Mild gastrointestinal symptoms may occur rarely.

1. Table: Planning Allergen Immunotherapy for Pollens and Outdoor Fungal Spores in Hungary

POLLEN, FUNGAL SPORES	EARLY FLOW-ERING TREES (HAZEL, ALDER, BIRCH)	BIRCH	GRASSES	RAGWEED	MUGWORT (BLACK WORM-WOOD)	ALTERNARIA
Period of flowering / highest airborne concentration	Late January–April	Late March–late April	May–June	August–late October	Mid-July–October	May–October
Latest recommended visit at allergist	October	December	January	March	March	January
Recommended start of AIT	November (end), December	January	February	April (end)	April (end)	February
Minimum recommended treatment duration per year (months)	4.5	4–4.5	4–4.5	6	6	8

Severe systemic reactions are extremely uncommon. These local adverse effects typically resolve within minutes after administration and tend to diminish as immunological tolerance develops. SLIT for respiratory allergens has been associated with eosinophilic esophagitis (EoE) in fewer than 0.1% of cases. Discontinuation of therapy generally leads to resolution of symptoms. In such cases, switching to SCIT may be considered. Patients should be informed about the symptoms of EoE and instructed to report them promptly to their physician (7, 9).

Efficacy and its measurement

This disease-modifying treatment gradually retrains the immune system to tolerate the allergen responsible for symptoms. As a result, patients experience progressive improvement in quality of life, with a reduction in both symptom severity and the need for symptomatic medication. These beneficial effects may persist for years after completion of therapy. In optimal cases, patients may achieve long-term remission of symptoms. Allergen immunotherapy has also been shown to reduce the risk of developing new sensitizations and to decrease the progression from allergic rhinitis to asthma in pediatric patients. It is well established that allergic asthma coexists with allergic rhinitis in approximately 30% of cases; following AIT, asthma symptoms may improve or, in some cases, remit. In this sense, allergen immunotherapy may be regarded as a form of “allergy vaccination.” Symptomatic medications may be used concurrently during AIT when needed, as no clinically relevant interactions affecting efficacy have been demonstrated. The improvement in skin prick test reactivity and serum allergen-specific IgE levels typically lags behind clinical improvement. Therefore,

the most reliable indicators of treatment efficacy are the reduction in symptom scores and the decrease in medication use. Immunological biomarkers reflecting treatment response exist but are primarily used in research settings.

Compliance, adherence, support

A disadvantage of allergen immunotherapy is its long treatment duration, which requires sustained patient co-operation. Failure to maintain adherence often results in treatment discontinuation. Patient and parent personality factors, as well as the quality of the physician–patient relationship, also influence adherence and compliance with AIT. The relatively high cost of medications may represent a barrier to access (approximately 20,000–45,000 HUF per month). According to economic analyses, this initial investment is typically recouped within 6–7 years, as the patient’s symptoms and need for symptomatic medications decrease; consequently, the use of symptomatic drugs and their social insurance support also declines. Medicinal products registered in Hungary may be prescribed via standard prescription. Medicinal products registered in the European Union may be obtained through individual importation by an allergist or by a physician experienced in allergology, following prior approval by the National Centre for Public Health and Pharmacy.

The Hungarian Society of Allergy and Immunology strives to ensure that allergen immunotherapy products are included in social insurance reimbursement schemes. Instead of decades of deteriorating quality of life and prolonged use of costly symptomatic medications, supporting a therapy that induces immune tolerance and offers the possibility of long-term disease modification is considered beneficial both for individual patients and for society as a whole.

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Preparing for health promotion – presenting a good practice (summary study)

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Abstract

The Department of Family Care Methodology at the Faculty of Health Sciences of Semmelweis University is responsible for the training of students in the Health Care and Prevention program, including the Child Health Nurse specialization. The education and professional activities of child health nurse students encompass a wide range of complex and diverse areas. One of the key responsibilities of school and youth health nurses working in school health care is health promotion, and all students must be adequately prepared for this role during their training. Among the subjects included in the curriculum, Prevention and Health Education is particularly suited to this purpose and is taught through theoretical and practical classes over two semesters. The aim of this summary is to present the methods used in this preparation, taking into account the generational characteristics of current university students, as well as how they can effectively reach students in primary and secondary schools. Following their theoretical and practical training, health promotion students deliver a health promotion presentation at a high school. Their performance is evaluated based on feedback from the school's teachers, the participating students, and the students themselves.

Keywords: *health promotion, health education, digital educational tools and methods*

Training of health care nurses

Health care nurses are part of the Hungarian university-level training system in medical and health sciences. The training of health care nurses became a college-level program 50 years ago, in 1975, initially as a 3-year program and, from 1993, as a 4-year program. It is currently offered at the BSc level over 8 semesters.

After graduation, health care nurses can work in hospitals and clinics as hospital nurses, or in community and school settings. In community care, they primarily provide family health services, including care for pregnant women, postpartum mothers, and children from birth to 6 years of age. Within the school health care system, they work as full-time school health nurses or, in mixed districts, as nurses who provide school health services in addition to community care. Like all healthcare professionals, health care nurses play an important role in protecting and promoting the health of the population.

Health promotion knowledge of school health nurses

One of the key responsibilities of school health nurses, particularly those working in primary school health care, is to participate in health promotion and promote healthy lifestyles, as stipulated in Decree 26/1997. (IX. 3.) NM. Annex 8, paragraph 8, regulates the following:

“Independent tasks to be performed by the health visitor of the educational institution: Participation in health education (1).” The most important topics are listed in *Table 1*.

Table 1. The most important topics in health education (1)

Basic knowledge about health (personal hygiene, healthy lifestyle, patient care, first aid)
Family planning and contraception
Parental role and infant care
Knowledge of self-examination
Prevention of addictive behaviors and substance use disorders

The final task of the course, which also forms the basis of assessment, is to conduct a health promotion lesson combined with a presentation at a secondary school. For many students, this is their first opportunity to practice their presentation skills in a real-life setting. It is only the beginning, as they are subsequently required to participate in health promotion programs several times during their community health nursing practice. For several years, we have maintained contact with the management of Kanizsai Dorottya Catholic High School, Health Technical School and Vocational School in Budapest, which has welcomed our students to deliver health promotion lectures for the past three years. The health promotion lessons are tailored to the needs of the school and individual classes, as well as to the students' age and prior knowledge. Since some students already participate in health promotion activities as volunteers, it is necessary to bring their knowledge and presentation skills to a consistent level.

In the Community Care Methodology course, students learn about the planning process according to the PDCA (Plan, Do, Check, Act) cycle (2), while SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis (3) is used to assess available resources. Both methods form part of the initial planning stage.



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consumption, alcohol consumption, internet use, sexually transmitted infections, HPV infection and the importance of vaccination, contraceptive methods, effective time management, skin health, healthy nutrition, and the role of sports and physical activity.

Since both current university students and a large proportion of high school students belong to Generation Z, generally defined as those born between 1995 and 2010 (4), it is particularly important to present information that they perceive as relevant and interesting and that they can apply quickly and effectively. This generation is characterized by a practical approach to thinking and working, strong technological skills, and the ability to divide attention between multiple tasks (multitasking) without necessarily experiencing a significant decline in performance. At the same time, they tend to read fewer printed materials and books and generally prefer speed and immediacy in various areas of life (5).

This generation also responds strongly to visual content, so during the lessons we look for short videos related to the topics being discussed. These are then analyzed together to determine which videos could be effectively incorporated into a health promotion lesson and why (e.g., Smart Box and Comprehensive School Health Promotion short videos). We discuss the basic principles of an effective presentation, including thorough knowledge of the subject, visual appeal, the ability to capture attention, credibility, and a clear “take-home message.” Visual elements, a well-designed PowerPoint presentation, and appropriately selected humorous images can all help maintain the audience’s attention and facilitate information retention.

During the class, students first select their topic in small groups and then prepare a mind map, as shown in *Figure 1*. This helps students focus on the selected topic and identify the key points that should be included in the presentation. The small groups then prepare the presentation for the health promotion lesson they have chosen. For this purpose, we provide a laptop and internet access, and all models and presentation tools available in the Department are at their disposal. These can be used to take photographs or create short videos for their presentations (e.g., Smart Plate, MyPlate, breast and testicular self-examination models, smoker’s lungs and healthy lungs; *Figure 2*).

We determine how much time is available for preparing the lesson and presentation, how much audiovisual content is required, and which digital tools they will use, such as Kahoot, Canva, or PowerPoint. We also review Semmelweis University’s “Health to Take Away” program, a thematically structured health promotion program (6).

The next step is for the students to present their completed presentations to one another in small groups, with each student presenting a part of the material. The presentations are then analyzed together with the other students and the course instructor.

Step 2: ...Let’s Go!

Following the interactive preparation and small-group sessions, the students work in pairs and select the class in which they will deliver the lesson. They then prepare their own presentation. The presentation intended for the actual session is reviewed separately with the course instructor outside the regular class, if necessary, and revised and corrected before the students begin teaching the high school classes.

Step 3: Feedback, evaluation

At the high school, students are escorted to their assigned classes with the assistance of the deputy principal and class teachers. Computers, internet access, and a projector are also available for use during the sessions. Following the lessons, each student is required to prepare an individual report, the required components of which are presented in *Table 2*.

At the end of the semester, students receive a grade based on their individual reports and the joint evaluation pro-

Table 2. Suggested points for a report prepared after a health promotion lesson

In which class and on what topic was the health promotion lesson given?
How was the lesson structured?
Audiovisual tools used, internet applications (e.g. online voting, feedback)
How did you feel during the lesson?
What went well, and what caused difficulties?
How do you evaluate your own preparation and lesson delivery?
What questions did you receive from the students?
To what extent did you manage to make the lesson interactive?

Figure 2. Smart Plate Recommendation of the National Association of Hungarian Dietitians <https://okostanyer.hu>



vided by the class teachers and the participating students. Student self-reflection perhaps best demonstrates where we currently stand in the field of health promotion and which areas require greater emphasis during the mentoring and preparation of students throughout their health visitor training.

Below are some examples of feedback from the students: “I was very nervous before the presentation, as I usually am. I was worried about how receptive the students would be and whether they would pay attention to us. We discussed that even if they were not particularly attentive, we still needed to present our material confidently and find ways to engage their interest. Fortunately, I think there were no major problems: almost everyone listened, responded to our questions, and we were able to convey the information we had planned. Personally, I tend to get very stressed when I have to give a presentation, and that may not change completely, but I feel that this opportunity helped me. It was a step toward becoming a little more confident, and I realized that despite being very nervous, I can still do it.”

“Overall, despite the nervousness before the presentation, we left the school with positive feelings. We had a good experience, and the students were friendly. We are happy that we can look back on this occasion as a success.”

“Unfortunately, the students were very tired, but we tried not to overload them. They listened to us patiently throughout the lesson. We tried to make the session interactive, but this was made more difficult by the fact that they were waiting to go home at the end of the day. The presentation was nevertheless instructive in terms of how to respond and present in such situations, how

to maintain the audience’s attention even when they are very tired, and when it is worth organizing such a session. I think it was useful.”

“Overall, this presentation was a very positive experience for me. Despite how nervous I was at the beginning, I got into it relatively quickly and felt that I could easily connect with the students, although I also needed their participation. What I learned is that it is very difficult to allocate time appropriately and put together a presentation that meets the expectations of today’s generation while also being suitable for health promotion.”

“The health promotion class was a valuable experience for me. Not only did we inform the students about the harmful effects of smoking, but I also had the opportunity to develop my own skills. Although there were difficulties and I was nervous, through preparation and teamwork we managed to deliver an informative and insightful presentation. This opportunity strengthened my confidence in my future professional work, and I believe I will be able to contribute effectively to developing health-conscious attitudes among young people.”

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Assessment of radiation protection knowledge based on a questionnaire

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Abstract

Diagnostic imaging methods are widely used in pediatric care. However, the use of ionizing radiation in children raises additional concerns, as their longer life expectancy and greater radiosensitivity increase the risk of radiation-induced malignancies. The primary aim of this thesis was to assess parents' awareness and knowledge of radiation protection and diagnostic imaging procedures involving ionizing radiation in children. An anonymous, self-developed questionnaire comprising 16 targeted questions on ionizing radiation was used for the study. A total of 63 respondents completed the questionnaire. The ages of the children concerned ranged from newborns to adolescents. Conventional X-ray examinations were the most frequently reported imaging modality, selected by more than three-quarters of respondents, followed by ultrasound. From a radiation protection perspective, the frequency of examinations is a fundamental consideration, as the effects of ionizing radiation are associated with cumulative lifetime exposure. According to the results, the majority of respondents correctly identified conventional X-rays (95.2%) and CT scans (73%) as imaging modalities that use ionizing radiation. However, a substantial knowledge gap was identified regarding magnetic resonance imaging (MRI): 21% of respondents incorrectly believed that MRI involves X-rays. In our study, 60% of respondents correctly recognized the restrictions regarding the presence of a pregnant accompanying person during radiation exposure; however, a significant proportion still considered remaining in the examination room while wearing a protective apron to be permissible. The results indicate that although parents are generally familiar with diagnostic imaging modalities, significant gaps remain in their knowledge of radiation exposure and associated risks. These findings highlight the importance of providing parents with clear and accessible information on radiation protection in pediatric imaging.

Keywords: *ionizing radiation, MRI, pediatrics, radiation protection*

Introduction

Nowadays, diagnostic imaging is an essential component of healthcare. Between 1997 and 2007, more than 3.6 million diagnostic radiological examinations were performed worldwide each year (1, 2). X-rays and CT scans, which use ionizing radiation, play a particularly important role. Radiation exposure is associated with potential biological effects resulting from cellular damage (3). Diagnostic imaging methods are also widely used in pediatric care, as they enable the early and rapid detection of diseases and more effective treatment planning (4–6). Cross-sectional imaging techniques, such as computed tomography (CT), have contributed substantially to the diagnosis and management of pediatric patients (7). With the rapid development of imaging technology, the use of these

modalities in the pediatric population has also increased (1, 8, 9). According to the 2013 UNSCEAR report, approximately 3–10% of medical diagnostic radiological procedures were performed in children (1, 10).

However, the use of ionizing radiation in pediatric care raises additional concerns, as children have a longer life expectancy and are more sensitive to radiation, resulting in a higher risk of developing certain radiation-induced malignancies (1, 11–15). Minimizing radiation exposure to the developing body is therefore of paramount importance. Children are more sensitive to the effects of radiation due to their anatomical, biological, and physiological characteristics. It is therefore important to emphasize that technological advances cannot replace human attention and appropriate radiation protection. Knowledge of the biological effects of radiation and compliance

with radiation protection regulations are not only professional but also ethical obligations. A study by *Ria F et al.* (17) reported that patients had limited knowledge of radiation-based imaging procedures (17–20). Patients' knowledge and understanding of radiation exposure can influence their consent to diagnostic imaging procedures (21–23).

In addition to patients, several studies have also demonstrated low levels of awareness among healthcare professionals. This includes knowledge of medical radiation exposure and its associated risks, as well as radiation protection for both patients and healthcare professionals (18–20, 22).

Effective communication between healthcare professionals and patients is crucial for improving the patient experience and facilitating informed decision-making (1, 24). Studies have shown that patients do not receive adequate information and that discussions about the benefits and risks of radiation exposure associated with medical imaging are often insufficient (25–27).

The primary aim of my thesis research is to assess parents' awareness and knowledge of radiation protection in childhood and of diagnostic imaging procedures involving ionizing radiation. The topic was chosen because significant information gaps and misconceptions exist among the general population regarding the risks and necessity of diagnostic examinations, which may also influence the successful performance of these examinations. The aim of this research is to highlight that parents' knowledge in this area is often incomplete or inaccurate, underscoring the importance of clear and appropriate information provided by healthcare professionals.

Material and method

A self-designed, anonymous questionnaire comprising 16 targeted questions related to ionizing radiation was used for the study. To ensure the validity of the research and accurately assess the level of knowledge among the general population, individuals with a healthcare qualification were excluded, so that the results would reflect the knowledge of parents without professional medical training. During data collection, the questionnaire did not contain any personally identifiable information. Participation was voluntary, and the results were processed exclusively in aggregated statistical form.

Results

A total of 63 participants completed the questionnaire in an evaluable manner. The ages of the children concerned ranged from newborns to adolescents. Participation in diagnostic imaging examinations is shown in detail in *Figure 1*. Multiple answers were permitted. Ac-

Figure 1. Distribution of imaging modalities. Multiple answers were possible

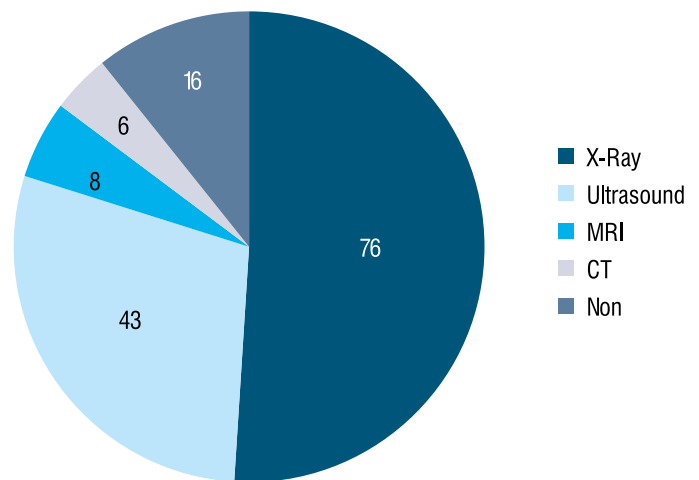
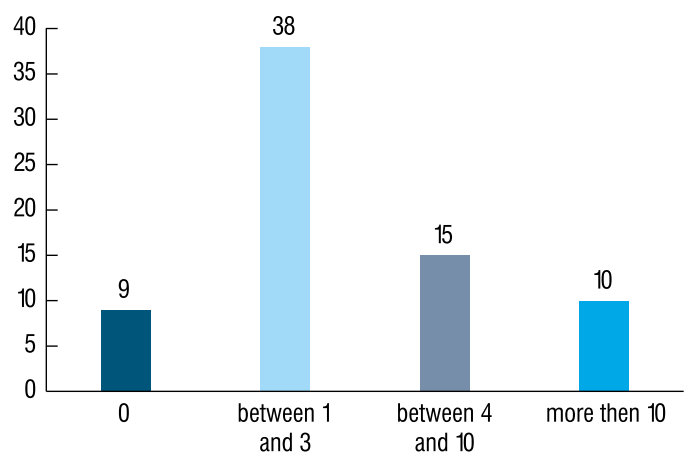


Figure 2. Frequency of participation in imaging examinations in the study population



cording to the results, conventional X-ray examinations (RTG) were the most frequently selected diagnostic modality, with 46 respondents (more than three-quarters) choosing this option. Ultrasound (US) was the second most frequently selected procedure, reported by 26 respondents.

The frequency of examinations and their distribution by number of examinations are presented in *Figure 2*. According to the results, 14% of respondents' children had not undergone any imaging examinations, while 60% had undergone 1–3 examinations. A further 24% of respondents reported that their children had undergone 4–10 imaging examinations, indicating a more extensive medical history and more frequent medical evaluations. Only one respondent (1.6%) reported that their child had undergone more than 10 examinations.

The questionnaire also assessed respondents' theoretical knowledge regarding the use of ionizing radiation in different imaging modalities. The results are presented in

Figure 3. According to the data, the majority of respondents correctly identified conventional X-ray examinations as involving X-rays (60 respondents), while 43 respondents correctly identified CT scans as using X-rays. Two respondents selected ultrasound. However, 13 respondents incorrectly indicated that magnetic resonance imaging (MRI) involves X-ray radiation.

Less than half of the respondents (47.6%) correctly indicated that CT involves a higher radiation exposure than conventional X-ray examinations. A further 27% believed that CT involves a lower radiation exposure, while 12.7% considered the radiation exposure to be the same as that of a conventional X-ray examination. Another 12.7% were unable to answer the question. The results are presented in Figure 4.

The next section of the questionnaire assessed parents' knowledge of the biological effects of radiation and radiation protection measures. According to the results, 87.3% of respondents were aware that children are more sensitive to radiation than adults. Regarding the nature of the risks, the majority (58.7%) were concerned about long-term health effects, while nearly one-third of respondents were uncertain about the potential harmful effects of radiation.

The results also indicated a relatively high level of awareness of practical radiation protection measures: 88.9% of respondents agreed that an accompanying person in the examination room should wear a lead apron. However, opinions were divided regarding the presence of pregnant women during examinations involving ionizing radiation. While 60.3% of respondents were aware that pregnant women should not be present during radiation exposure, a significant proportion (31.7%) would still consider remaining in the examination room while wearing a protective apron. The majority of respondents (81%) correctly identified the purpose of the lead apron as protecting non-examined, radiation-sensitive organs. Only 22.2% of parents correctly knew that the presence of metal objects is specifically prohibited during MRI examinations.

The questionnaire also assessed parents' emotional responses to examinations involving ionizing radiation. On a scale of 1 to 5, a substantial proportion of respondents reported some degree of anxiety. Overall, 41.2% of respondents experienced moderate or greater anxiety (levels 3, 4, or 5) when their child was recommended to undergo an X-ray or CT examination. Regarding the main reasons for concern, the most common concern was the potential adverse effects of the examination (44.4%). Other important factors included the child's lack of cooperation, particularly the inability to remain still (27%), and concerns that the examination might be frightening or painful (14.3%). A further 14.3% of respondents reported that they were not concerned at all.

In the final section of the questionnaire, parents' knowledge of the limitations of imaging examinations was assessed. According to the results, 71.4% of respondents were aware that there is no theoretical upper limit to the num-

Figure 3. Percentage distribution of parents' knowledge of radiation exposure associated with individual imaging modalities. Multiple answers were possible

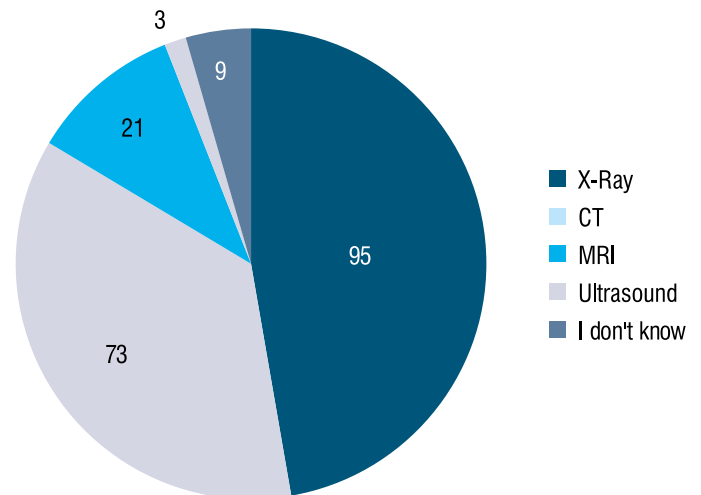
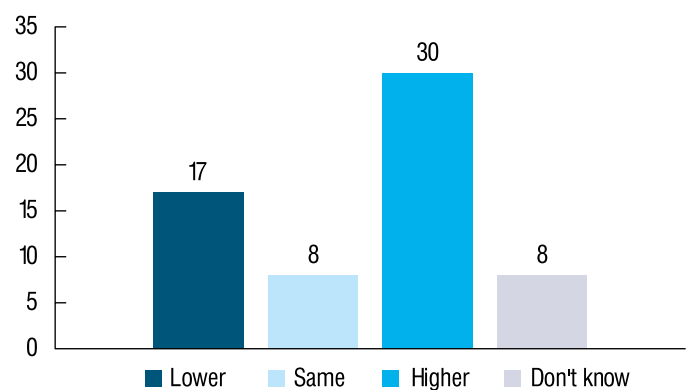


Figure 4. Parents' opinions on radiation exposure from CT compared with conventional X-ray examinations



ber of X-ray examinations a patient may undergo, provided that each examination is medically justified. Regarding the age at which X-ray examinations can be performed, half of the parents (50.8%) correctly knew that X-rays can be performed from the neonatal period, including as early as one hour after birth. Almost one-quarter of respondents (23.8%) were uncertain about this issue.

Finally, we assessed parents' views on the appropriate interval between two X-ray examinations. More than half of the respondents, 57.1% (36 people), correctly knew that, if medically justified, multiple examinations may be performed within the same day. In contrast, 22.2% of parents believed that at least one year should elapse between two X-ray examinations.

Discussion

The ages of the children included in the study varied widely, from newborns to adolescents. This diversity clearly illustrates that children may undergo imaging examina-

tions involving ionizing radiation from a very young age. It also highlights that radiation protection is relevant across all pediatric age groups. Among the imaging modalities, conventional X-ray examinations (RTG) were the most frequently reported, with more than three-quarters of respondents selecting this option. Ultrasound (US) was the second most frequently reported modality. As ultrasound does not use ionizing radiation, it plays an important role in pediatric screening and in the differential diagnosis of acute conditions. It is also noteworthy that CT examinations were less frequently reported by respondents. This finding may represent a practical example of the conscious application of the ALARA principle (As Low As Reasonably Achievable) (28) by healthcare professionals.

The third question of the questionnaire examined the frequency of imaging examinations, which is an important factor in determining cumulative radiation exposure in children. This question assessed the proportion of respondents' children who had undergone repeated imaging examinations. According to the data, 14.3% of respondents reported that their children had undergone an imaging examination 1–3 times. This finding is consistent with the previous results, indicating that diagnostic imaging is an integral part of pediatric healthcare, although it is not routinely required on a daily basis. A further 23.8% of respondents reported that their children had undergone 4–10 imaging examinations, which is noteworthy, as this group may reflect a more extensive medical history and more frequent medical evaluations. Only one respondent (1.6%) reported that their child had undergone more than 10 examinations, suggesting that most children in the sample did not have chronic conditions requiring frequent repeated imaging.

From a radiation protection perspective, the frequency of examinations is a fundamental consideration, as the potential effects of ionizing radiation are related to cumulative lifetime exposure. The more frequently examinations are performed, the more important it becomes to carefully manage radiation doses and critically assess the medical necessity of each examination.

The fourth question of the questionnaire assessed respondents' theoretical knowledge of the radiation exposure associated with individual imaging modalities. According to the results, the majority of respondents correctly identified conventional X-ray examinations (95.2%) and CT examinations (73%) as procedures involving X-ray radiation. In Manzor's study, the majority of parents were unaware that CT examinations involve a higher radiation exposure than conventional X-ray examinations (4). In our study, the results regarding ultrasound were reassuring, with only slightly more than 3% of respondents incorrectly identifying it as involving ionizing radiation. However, a significant knowledge gap was identified regarding magnetic resonance imaging (MRI), with 20.6% of respondents incorrectly indicating that MRI involves X-rays. This finding suggests that many parents are unaware that MRI uses non-ionizing radiation.

A previous review by *Ribeiro et al.* (25) showed that patients generally have limited knowledge of radiation exposure and radiation safety. A study by Ng (29) found that only 40% of respondents had a satisfactory level of knowledge regarding radiation exposure and safety in medical imaging, while more than 41% did not know that radiography involves radiation. Parents may also have insufficient knowledge of the risks associated with pediatric imaging (16). One survey found that 75.34% of parents in Jordan were unaware of the risks associated with ionizing radiation (30). These findings demonstrate significant knowledge gaps regarding the potential risks of ionizing radiation, particularly in the pediatric population, which is more sensitive to its effects (31).

According to the results, less than half of the respondents were aware that CT examinations involve greater radiation exposure than conventional X-rays. Particularly concerning, more than half of the respondents provided an incorrect answer or were uncertain. Specifically, 27% believed that CT examinations involve lower radiation exposure, 13% considered the exposure to be the same as that of conventional X-rays, and a further 13% were unable to answer the question. This discrepancy highlights a significant gap in public knowledge. Although the previous question showed that most parents were aware that CT examinations use X-rays, these results suggest that many do not understand the magnitude of the associated radiation exposure or the implications of the examination. The radiation dose from a CT examination can often be tens or even hundreds of times higher than that from a conventional X-ray examination. Nevertheless, many parents remain unaware of the radiation-related risks associated with pediatric imaging. A study conducted in Malaysia found that fewer than 50% of parents correctly identified CT as a high-radiation procedure, while only 42% were aware that nuclear medicine and fluoroscopy involve ionizing radiation (4, 32). Other studies have shown that 68–98% of parents answered questions about radiation incorrectly, regardless of whether their child had previously undergone such imaging examinations (33, 34).

The next section of the questionnaire assessed parents' knowledge of the biological effects of radiation and radiation protection measures. The results showed that 87% of respondents correctly understood that children are more sensitive to radiation than adults. Regarding the nature of the associated risks, the majority were concerned about long-term health effects, while nearly one-third of respondents were uncertain about the potential harmful effects of radiation. The literature clearly demonstrates that children are more radiosensitive and have a higher risk of developing radiation-induced malignancies (1, 11, 12).

According to the results, parents demonstrated awareness of practical radiation protection measures. The vast

majority agreed that an accompanying person in the examination room should wear a lead apron. However, opinions were divided regarding the presence of pregnant women during radiographic examinations. In Ng's study, more than 70% of respondents understood that pregnant women should not accompany their children during radiography (29). In our study, 60% of respondents correctly recognized that pregnant women should not be present during radiation exposure; however, a significant proportion still considered it permissible to remain in the examination room while wearing a protective apron. This finding indicates that more comprehensive information is needed on this issue.

The majority of respondents correctly identified the function of the lead apron as protecting non-examined, radiosensitive organs. Interestingly, only 22.2% of parents knew that particular precautions regarding metal objects apply specifically to MRI examinations. Most respondents incorrectly believed that leaving jewellery or metal clips in place would be equally hazardous during other imaging procedures, such as X-rays. This finding further supports the trend observed earlier: parents may confuse the technical characteristics of MRI and X-ray examinations and have difficulty distinguishing between them.

The questionnaire also assessed parents' emotional responses to examinations involving ionizing radiation. On a scale from 1 to 5, a significant proportion of respondents reported some degree of anxiety. Overall, 41.2% of respondents experienced moderate or greater anxiety (levels 3, 4, or 5) when their child was recommended to undergo an X-ray or CT examination.

When examining the main reasons for concern, it can be concluded that parents were primarily concerned about the potential adverse effects of the examination. Children are more sensitive to radiation and have a longer expected lifespan than adults, which contributes to their higher lifetime risk of radiation-induced malignancies (35–37). Other important concerns included the child's lack of cooperation, particularly the inability to remain still, as well as the possibility that the examination might be frightening or painful. Only 14% of respondents reported that they were not concerned at all.

These findings indicate that, in addition to providing accurate technical information, emotional support for parents and clear, detailed information about the examination procedure are also important for reducing anxiety and improving the overall experience.

Several studies have highlighted inadequate communication between healthcare professionals and patients regarding medical radiation exposure and its associated risks (25–27). In the final section of the questionnaire, we assessed parents' knowledge of the limitations of imaging examinations. The results suggest that the majority of respondents understood the importance of medical justification. This is supported by the finding that 71% of respondents correctly knew that there is no theoret-

ical upper limit to the number of X-ray examinations a patient may undergo, provided that each examination is medically justified.

Regarding the age at which examinations can be performed, half of the parents knew that X-ray examinations can be performed from the neonatal period, including as early as one hour after birth, while almost one-quarter of respondents were uncertain about this issue. Finally, we assessed parents' views on the appropriate interval between two X-ray examinations. More than half of the respondents correctly knew that, if medically justified, several examinations may be performed even within the same day. In contrast, nearly one-quarter of parents believed that at least one year should elapse between two examinations.

This apparent contradiction suggests that although many parents are concerned about radiation exposure, the majority still trust the physician's clinical judgment and recognize that, alongside safety considerations, establishing an accurate diagnosis is the primary objective. The results also indicate that the extent of information gaps and the level of subjective anxiety did not depend on the age of the child.

Conclusions and recommendations

The analysis of the data shows that although parents are generally familiar with diagnostic imaging modalities, significant gaps remain in their knowledge of radiation exposure and associated risks. One of the most critical findings of the study is the underestimation of the radiation dose associated with CT examinations and uncertainty regarding the radiation safety of MRI. Although respondents expressed a need for professional information, current practice does not provide such information to a satisfactory extent, which may contribute to unnecessary anxiety.

Based on the findings of this survey, several practical measures could significantly improve parents' awareness and reduce their concerns. One of the most effective approaches would be to provide easy-to-understand posters and illustrative diagrams in waiting rooms. These could help parents understand the actual radiation burden associated with different examinations, for example, by comparing it with everyday exposure to natural background radiation. It is also particularly important to emphasize that MRI and ultrasound do not use ionizing radiation. In my view, providing this information alone could significantly reduce parents' uncertainty and anxiety.

This on-site information could be complemented by the detailed online resources already available on hospital websites. Such digital platforms would allow parents to learn more about what to expect before the examination, including information about the procedure, its duration, and its technical background. Providing clear and accessible information in advance may help address concerns and alleviate unnecessary anxiety.

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Basic principles of radiation protection in childhood

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Abstract

Diagnostic imaging is widely used in pediatric care because it enables the early and rapid detection of disease and facilitates effective treatment planning. Knowledge of the biological effects of ionizing radiation and adherence to radiation protection regulations are not only professional responsibilities but also ethical obligations. These responsibilities are particularly important in children. In this review, we summarize the principles and regulatory framework of radiation protection in pediatric practice and demonstrate their application within the Image Gently initiative.

Nowadays, diagnostic imaging is an indispensable component of modern healthcare (1, 2). X-ray examinations and computed tomography (CT), which use ionizing radiation, play a particularly important role. Diagnostic imaging is also widely used in pediatric care because it enables the early and rapid detection of disease and facilitates effective treatment planning (3–7). However, the use of ionizing radiation in children raises additional considerations, as minimizing radiation exposure to the developing body is of particular importance. Children are more sensitive to the effects of ionizing radiation because of their anatomical, biological, and physiological characteristics (1, 8–12).

Therefore, it is important to emphasize that technological advances do not replace careful clinical judgment and appropriate radiation protection measures. Knowledge of the biological effects of radiation and adherence to radiation protection regulations are not only professional responsibilities but also ethical obligations. This responsibility is particularly important in children because the potential long-term consequences of radiation exposure are greater.

Effective radiation protection requires not only specialized expertise but also coordinated teamwork, in which

cooperation among radiologists, referring physicians and other specialists, the child, and the child's caregivers is essential. Optimization of radiation exposure depends not only on technological advances in imaging equipment but also on the ability of healthcare professionals to use these technologies effectively and in accordance with the principles of radiation protection. Dose reduction is a fundamental component of modern radiology, which seeks to achieve the required diagnostic information while keeping radiation exposure to the patient and staff as low as reasonably achievable. Accordingly, increasing attention is being paid to diagnostic methods and technical solutions that can reduce radiation dose. These include modern filtration systems, automatic exposure control, and optimized imaging protocols tailored to children and age-appropriate technical parameters.

Minimizing radiation exposure during diagnostic imaging is a fundamental professional and ethical requirement. The guiding principle is ALARA (As Low As Reasonably Achievable) (13). This principle is particularly important in pediatric care. It does not mean avoiding diagnostic procedures when they are clinically indicated, but rather ensuring that examinations involving ionizing

List of abbreviations

AEC: Automatic Exposure Control; **ALARA:** As Low As Reasonably Achievable; **DRL:** Differential Reference Levels; **ESR:** European Society of Radiology; **ESPR:** European Society of Pediatric Radiology; **EFRS:** European Federation of Radiographer Societies; **EFOMP:** European Federation of Organisations for Medical Physics; **EURATOM:** European Atomic Energy Community; **IAEA:** International Atomic Energy Agency; **ICRP:** International Commission on Radiological Protection;

radiation are performed only when justified. According to the ALARA principle, imaging examinations that use ionizing radiation should be selected and performed in a manner that ensures that the expected clinical information and benefits outweigh the potential risks associated with radiation exposure. Another key aspect is the optimization of imaging parameters to minimize radiation exposure while maintaining adequate diagnostic image quality. This is particularly important in pediatric imaging.

The aim and principles of radiation protection

The aim of radiation protection is to ensure the safe and judicious use of ionizing radiation, particularly in diagnostic imaging. Its primary objective is to minimize harmful biological effects, or prevent them whenever possible, without compromising the information required to establish an accurate diagnosis. In pediatric care, particular emphasis should be placed on minimizing both deterministic tissue effects and long-term stochastic risks. The foundation of radiation protection is the ALARA principle, which is an internationally recognized guiding principle (13). In pediatric practice, appropriate justification of each examination requires particular attention. The primary objective of radiation protection is to avoid unnecessary radiation exposure. An important component of justification is the preferential use of imaging modalities that do not involve ionizing radiation when they can provide the required diagnostic information. This approach ensures that children are exposed to ionizing radiation only when the expected diagnostic or therapeutic benefit justifies the associated risk (14).

If the use of ionizing radiation is unavoidable, the ALARA (As Low As Reasonably Achievable) principle becomes the guiding principle in practice and represents one of the fundamental pillars of radiation protection. Accordingly, the radiation dose should be kept as low as reasonably achievable while maintaining the diagnostic efficacy of the examination (15). The cornerstone of radiation protection is optimization. The aim is not to reduce the radiation dose at all costs, but to achieve an appropriate balance between radiation exposure and the diagnostic information obtained. For example, if the radiation dose is too low to produce an image of sufficient diagnostic quality, the examination may need to be repeated. In such a case, the patient has received unnecessary radiation exposure. In pediatric imaging, this balance can be achieved by individualizing examination parameters.

The ALARA principle is implemented primarily through dose optimization. The radiation dose should be kept as low as reasonably achievable while still achieving the intended diagnostic objective. For this reason, the individual characteristics and clinical circumstances of each patient should be considered in all clinical decision-making

(13). The third principle of the radiation protection system established by the International Commission on Radiological Protection (ICRP) is the application of dose limits. However, it is important to emphasize that patient protection in diagnostic imaging is not based on the application of specific dose limits, but rather on continuous optimization. Consequently, no fixed dose limit is prescribed for an individual patient undergoing a medically justified diagnostic examination. As noted above, every patient and clinical situation is different, making a single universal dose value inappropriate. In diagnostic imaging, the expected clinical benefit of obtaining the necessary diagnostic information must be weighed against the potential risks associated with radiation exposure (13).

Practical application of the ALARA principle

The application of the ALARA principle is of paramount importance in pediatric radiology, as the biological effects of ionizing radiation cannot be completely eliminated but can be minimized. In practice, this means that, while maintaining image quality appropriate for diagnostic purposes, efforts should be made to minimize radiation dose, taking into account the available technical capabilities and the clinical requirements of the examination (16).

Accordingly, radiographers should not rely on a single fixed protocol that is applicable to all patients. During each examination, the patient's individual anatomical characteristics should be considered, and the technical parameters should be selected according to the specific clinical question. The quality of care and the practical implementation of the ALARA principle are strongly influenced by the professional practices of the staff at the institution performing the examination. Experience indicates that, in institutions with mixed patient populations, the same examinations may be performed with higher radiation exposure than in specialized pediatric centers, where pediatric-specific protocols are part of routine practice. When a child must be examined by a specialist with less experience in pediatric imaging, particularly careful selection of imaging parameters is therefore essential.

For these reasons, it is also essential to determine whether the use of ionizing radiation is truly necessary or whether the diagnostic question can be adequately answered using an imaging modality that does not involve ionizing radiation. The practical application of the ALARA principle therefore begins with critically evaluating established routines rather than automatically following them. A good example is traumatic brain injury, in which experienced clinicians recognize that conventional skull radiography has limited diagnostic value compared with other imaging modalities. According to the ALARA principle, appropriate management in selected cases may consist of careful clinical observation, with CT performed when

more severe symptoms or other clinical indications are present. Otherwise, the limited diagnostic yield of conventional skull radiography may not justify the additional radiation exposure to the patient (17).

An excellent example of the practical application of the ALARA principle is the evaluation of suspected osteoid osteoma. In such cases, MRI, which does not involve ionizing radiation, should be considered as the initial imaging modality, with CT performed only when MRI does not provide sufficient diagnostic information. From a diagnostic perspective, an important consequence of applying the ALARA principle is that unnecessary radiographic examinations can be avoided (18).

The EOS 2D/3D system is another good example of the practical application of radiation protection principles and ALARA. The system simultaneously acquires frontal and lateral images in a single scan. In certain orthopedic conditions, such as scoliosis, this technology can therefore reduce the need for conventional radiographic examinations involving multiple exposures. It also allows the entire body or the relevant spinal segment to be assessed simultaneously, facilitating a more comprehensive evaluation. EOS can therefore be a useful option when whole-body or spinal imaging is required, particularly when minimizing radiation exposure is a priority in children and adults (19).

In many areas of radiology, however, the use of ionizing radiation is unavoidable when accurate and timely diagnosis is required. One example is CT in patients with multiple trauma, in whom rapid imaging can be lifesaving. Similarly, CT is essential in selected cases for the detailed assessment of structural abnormalities of the lung parenchyma and for vascular imaging. The latter is commonly performed as CT angiography. In such situations, application of the ALARA principle is crucial to minimize unnecessary radiation exposure. In addition to optimizing the technical parameters, particular emphasis should be placed on avoiding repeat examinations. Patients and, in the case of children, their caregivers should be appropriately informed about the examination and the need to remain still, thereby reducing the risk of motion artifacts. A poor-quality examination may be non-diagnostic and require repetition, resulting in additional radiation exposure. Therefore, after appropriate dose optimization, obtaining a diagnostically adequate image on the first attempt is one of the most effective ways to prevent unnecessary additional exposure (18).

Radiation protection regulation

International guidelines (ICRP, IAEA, EURATOM)

Modern radiology is based on a rigorous system of principles and recommendations designed to ensure that the diagnostic benefits of imaging are proportionate to the associated risks. The fundamental principles of radiation

protection are established internationally through the recommendations and standards of several major organizations. At the highest level of the professional framework is the International Commission on Radiological Protection (ICRP), whose recommendations provide the scientific and professional basis for radiation protection. The ICRP is an independent organization whose members represent a broad range of disciplines within radiation protection. In their work, members do not represent their countries or employers but contribute on the basis of scientific and ethical considerations.

The fundamental principles of radiation protection have been developed by the ICRP, with Publication 103 representing a major milestone. It established the three fundamental principles of justification, optimization, and dose limitation. Its recommendations also incorporate the ALARA principle, which is particularly important in radiological examinations and has special relevance in pediatric imaging (13). From the perspective of pediatric care, ICRP Publication 121 is particularly important (20). This publication provides recommendations specifically addressing the physiological characteristics and increased radiosensitivity of children and provides guidance on the safe use of ionizing radiation in pediatric imaging. The application of these recommendations aims to achieve adequate diagnostic quality while minimizing the potential long-term health risks associated with radiation exposure (21).

To support dose optimization in clinical practice, specific metrics have also been introduced that take into account the characteristics of pediatric patients. One of the most important tools in daily practice is the use of diagnostic reference levels (DRLs). These are not fixed dose limits, but reference values that enable professionals to monitor and continuously optimize examination parameters. They therefore help achieve an appropriate balance between the image quality required for diagnosis and the radiation dose delivered to the patient (22).

The International Atomic Energy Agency (IAEA) is responsible for supporting the practical implementation and international coordination of radiation protection. It translates complex scientific principles into guidelines that can be applied in everyday clinical practice. A major objective of its work is to promote a consistent approach among professionals and ensure that radiation exposure to both patients and staff is kept as low as reasonably achievable (23).

One of the IAEA's most important publications is the Safety Standards Series, which is essentially a three-tiered system of regulations. The highest level, the Safety Fundamentals, sets out the theoretical foundations of protection and safety. The mandatory requirements are described in detail in the Safety Requirements, which form the middle tier. The Safety Guides, at the lowest tier, provide practical methods for implementing the principles and requirements set out in the first two levels. This system covers the full range from fundamental

principles to specific technical guidance. In addition, the IAEA, in collaboration with the International Labour Organization (ILO), has developed Safety Reports as supplementary documents providing guidance for special procedures and new technologies, as well as for worker safety and the dissemination of diagnostic reference levels (DRLs). The dose reference levels (DRLs) defined by the IAEA provide professionals with a metric that enables them to compare their practice with international expectations and identify when a higher-than-necessary radiation dose may be being used for an examination (23). Within the European Union, EURATOM (European Atomic Energy Community) establishes the most important professional and legal frameworks for radiation protection. While international organizations primarily formulate recommendations, EURATOM issues directives that Member States are required to follow and incorporate into their national legal systems. This ensures a uniform and stringent framework for protecting both patients and workers across Europe (24).

The cornerstone of the current regulatory framework is Directive 2013/59/Euratom. The directive requires equipment to be regularly inspected to ensure safe operation. It also requires radiation exposure to patients to be documented during examinations and the relevant data to be retained in the long term. Particular attention is given to children, recognizing their need for increased protection and specific examination protocols. While the ICRP and IAEA provide predominantly scientific and practical guidance, EURATOM has established diagnostic reference levels (DRLs) within the European regulatory framework. According to the directive, each Member State must conduct its own national review of the most common examinations based on measurement data collected from multiple institutions. Thus, DRLs are not merely theoretical values but reference points derived from practical experience and used within the regulatory framework (24). The harmonized guidelines of these organizations provide a framework for radiation protection that ensures that the benefits of diagnostic radiation exposure outweigh its associated risks (24).

Hungarian legal background

The legal framework of radiation protection in Hungary is essentially defined by EURATOM directives, which are binding on Member States. However, the scientific and ethical foundations of these regulations are provided by the recommendations of the ICRP and the safety standards of the IAEA. Although the latter are not laws in themselves, Hungarian regulations are based on these international principles and follow these professional guidelines (25).

The basis of Hungary's domestic radiation protection regulations is Act CXVI of 1996, commonly known as the Atomic Energy Act. All other relevant regulations

in Hungary are based on this legislation, as the Atomic Energy Act establishes the framework for the safe use of nuclear energy and ionizing radiation. The law defines the framework for the application of these technologies and establishes the rules required for strict and continuous oversight. These provisions enable the safe use of ionizing radiation in everyday medical and industrial practice. In addition, the law incorporates internationally recognized radiation protection principles, such as the ALARA principle and the requirement for dose limitation. The Hungarian Atomic Energy Authority (OAH) is responsible for overseeing compliance with and implementation of the provisions set out in the law (26).

The revision of the radiation protection principles and metrics applied in Hungary was necessitated by EURATOM regulations. Directive 2013/59/Euratom established a uniform European legislative framework that harmonized radiation protection standards across Member States. The directive ensured that radiation protection principles were not merely recommendations to be followed but were also incorporated into legally binding requirements (27). The practical implementation of these principles is facilitated by Government Decree 487/2015 (XII. 30.) and HAEA Decree 2/2022, which form the basis of domestic radiation protection.

These regulations define quality requirements and specify the methods for regularly monitoring the technical condition of equipment. They also establish the maximum radiation exposure limits for the population and workers and require the radiation exposure of all workers to be accurately measured and documented. Importantly, these requirements apply to all radiation sources in Hungary. The regulations also require the workers concerned to complete the radiation protection training and regular continuing education necessary for their work (28).

In the field of diagnostic imaging, EMMI Regulation 21/2018 (VII. 9.) is particularly important because it not only ensures patient safety during medical radiation exposure but also clarifies clinical responsibilities and, through the introduction of clinical audits, establishes a monitoring system to ensure continuous compliance with protocols (28). This regulation is particularly relevant to pediatric care because of its emphasis on the protection of children.

This child-centered approach, based on diagnostic reference levels (DRLs), is further supported by the European Commission's PiDRL (Paediatric imaging Diagnostic Reference Levels) project, which was specifically established for this purpose. The project resulted in Radiation Protection No. 185, a technical guideline designed to provide a harmonized European framework for safe pediatric radiology. Its development was made possible through professional collaboration involving the main European organizations representing radiologists, pediatric radiologists, radiographers, and medical physicists (ESR, ESPR, EFRS, and EFOMP) (25).

Figure 1. Image Gently's "Back to Basics" campaign poster (29)



Table 1. European Diagnostic Reference Levels (EDRL) in radiography and fluoroscopy (25)

RADIOGRAPHY AND FLUOROSCOPY			
EXAMINATION	AGE OR WEIGHT GROUP	EDRL	
		$K_{a,e}^*$ mGy	P_{KA}^* mGy cm ²
Head AP/PA	3 months-<1 y		215
	1-<6 y		295
	≥6 y		350
Head LAT	3 months-<1 y		200
	1-<6 y		250
Thorax AP/PA**	<5 kg		15
	5-<15 kg	0.06	22
	15-<30 kg	0.08	50
	30-<50 kg	0.11	70
	50-<80 kg		87
Abdomen AP	<5 kg		45
	5-<15 kg		150
	15-<30 kg	0.40	250
	30-<50 kg	0.75	475
Pelvis AP	50-<80 kg		700
	15-<30 kg		180
	30-<50 kg		310
MCU	<5 kg		300
	5-<15 kg		700
	15-<30 kg		800
	30-<50 kg		750*

*Based on 4 NDRLs, range 400–2000 mGy cm²; **AP/PA; DRL applies to both AP and PA projections

Radiation protection in pediatric care

Dose values and reference values specific to children

Pediatric imaging differs fundamentally from adult imaging because children are not “small adults”; therefore, simply reducing the radiation dose is not sufficient to ensure adequate radiation protection. This approach is also emphasized by the Image Gently campaign poster, which highlights the principle that “one size does not fit all.” The poster is shown in *Figure 1*.

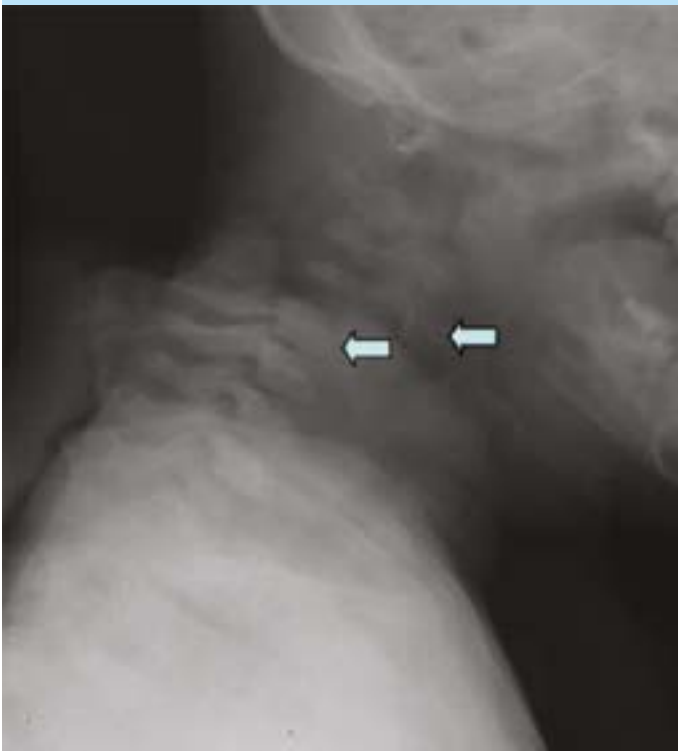
Accordingly, when planning examinations, special attention should be paid to the fact that young patients undergo continuous physical development. Individualized optimization is therefore essential (29). This differentiated approach is supported, for example, by pediatric-specific diagnostic reference levels (DRLs), which are established not only for a single population group but also according to age- or weight-based categories (25). This methodology is illustrated in *Table 1*.

One of the most important aspects of radiation protection in pediatric imaging is the careful and precise selection of technical parameters. This can be achieved by optimizing

the balance between tube voltage (kV) and tube current–time product (mAs). Because children are smaller than adults, less radiation is generally required to obtain diagnostically adequate images, and the same kV settings used for average-sized adults are therefore not necessarily appropriate. Reducing tube voltage can significantly decrease radiation dose and may also increase image contrast, which can be particularly beneficial in pediatric soft-tissue imaging. Literature data support this approach, showing that appropriate optimization of exposure parameters (kVp, mAs, and filtration) can reduce radiation dose by up to 83% in pediatric abdominal imaging (30). It is also important to distinguish between adult and pediatric protocols when optimizing examinations. While the use of higher tube voltage and lower tube current–time product may be an effective dose-reduction strategy in adults, applying the same approach in children can result in diagnostically inadequate image quality. Conversely, poorly selected technical parameters may produce underexposed images that are unsuitable for clinical interpretation and may necessitate repeat imaging (30).

The use of AEC (Automatic Exposure Control), which is standard on modern X-ray equipment, also requires

Figure 2. Motion artifact of lateral cervical spine scan (35)



special attention. This system is designed to ensure adequate diagnostic image quality regardless of the patient's anatomical characteristics. However, careful optimization is necessary because, due to the size and positioning of the sensors, AEC may inaccurately estimate a child's dimensions, particularly when positioning is suboptimal. This can result in a substantially higher radiation dose than necessary (31).

Another important consideration is avoiding the use of an anti-scatter grid when it is not required, as this can significantly reduce radiation dose in children without compromising diagnostic image quality (32). Modern radiology allows imaging protocols and technologies to be designed around these principles from the outset, thereby contributing to the minimization of cumulative radiation exposure in children. Furthermore, modern equipment is often equipped with dedicated, preprogrammed pediatric protocols, including settings based on the recommendations of the Image Gently initiative, which can automatically adjust imaging parameters according to the child's body weight or age (29).

Practical solutions for radiation protection in pediatrics

Figure 3. Image Gently's "Back to Basics" campaign poster (29)



The ALARA principle should be followed in pediatric radiology (16). One of the simplest and most effective methods of radiation protection is precise collimation. Inadequate collimation can result in unnecessary radiation exposure to highly radiosensitive organs located near the area being examined. This is particularly important in children because of their smaller body size and specific anatomy. Since their internal organs are located closer together, an inappropriately large radiation field may expose substantially more healthy tissue and organs to the primary radiation beam than in adults (13).

Another consequence of an excessively large radiation field is increased production of scattered radiation, which can degrade image quality. This can make the image appear grayer and significantly reduce contrast and detail. Precise collimation is therefore not only important for reducing radiation dose but is also essential for maintaining adequate diagnostic image quality (33). The consequences of inadequate collimation are also supported by an international study highlighting the importance of this problem. The study found that, during adult X-ray examinations, the irradiated area was on average twice as large as the diagnostically necessary area. In children, however, this ratio reached 3.7 times the necessary area, demonstrating that inaccurate collimation is an even more significant problem in pediatric imaging (34) (Figure 2).

In the area marked by the arrows, blurring and the double shadow produced by movement of the vertebrae create the misleading impression of cervical dislocation. Because the radiological findings were inconsistent with the clinical presentation, the examination had to be repeat-

ed, at which point normal anatomical conditions were demonstrated. This case highlights that incorrect technical execution can lead not only to an incorrect diagnosis but also to unnecessary repetition of the examination and, consequently, additional radiation exposure (35).

An important element in preventing motion artifacts is creating a sense of safety for the child. This can be facilitated, for example, by a child-friendly examination room that provides a reassuring environment. Calm and reassuring communication is also important, and the presence of a parent or other accompanying person may help to comfort the child. Parents can also provide active assistance with positioning and immobilization. However, adequate radiation protection must be ensured for accompanying persons.

Before an accompanying person enters the examination room, it is essential to determine whether they are pregnant or breastfeeding and to implement appropriate radiation protection measures. To protect the fetus, a pregnant person should not be present in the examination room during radiation exposure. In some cases, however, parental assistance may be insufficient or unavailable, making the use of appropriate immobilization devices essential (36).

Introducing the Image Gently and Image Wisely campaigns

The Image Gently Alliance is an international initiative dedicated specifically to radiation protection in children. Its primary goal is to raise awareness among healthcare professionals of the importance of individualizing radiation doses during pediatric imaging examinations involving ionizing radiation. The initiative seeks to improve clinical practice so that young patients receive the lowest radiation dose that is reasonably achievable while maintaining adequate diagnostic quality. Ultimately, the Image Gently campaign aims to promote safe and effective diagnostic imaging for children worldwide (29).

As part of this initiative, the Image Gently Alliance has published a highly visual and informative eight-part poster series summarizing key radiation protection measures. The series provides an accessible overview of basic principles and professional recommendations for pediatric imaging. *Figures 3 and 4* are part of the organization's "Back to Basics" campaign, which provides a detailed, step-by-step guide to help radiographers systematically

Figure 4. Image Gently's "Back to Basics" campaign poster (29)



evaluate examinations. It covers beam alignment (Beam), artifact assessment (Artifacts), radiation protection and shielding (Shielding), patient immobilization and exposure indicators (Immobilization/Indicators), collimation, and anatomical structures (Structures).

However, *Figure 1* emphasizes that "one size does not fit all" (37), reflecting the increased radiosensitivity of children. It outlines four key practical measures: measuring patient thickness, avoiding the use of grids, accurate field narrowing (collimation), and continuous monitoring of exposure indicators.

The Image Wisely campaign is the adult counterpart to Image Gently. While Image Gently focuses on radiation protection in children, Image Wisely aims to optimize radiation doses in diagnostic imaging for adults. Together, the two initiatives address radiation protection across the full age spectrum, from childhood to adulthood (38).

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In the captivity of tetraparesis

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Introduction

We present the case of a 14-year-old girl who developed symptoms consistent with infectious mononucleosis in December 2025. Initial symptoms included fever, fatigue, sore throat, and cervical lymphadenopathy. Four days later, she developed muscle weakness and paresthesia in the lower extremities, more pronounced on the left side. Two days later, similar symptoms developed in the upper extremities. The following day, she became unable to walk, and by the next morning, peripheral facial nerve palsy had developed.

Case report

Following the onset of peripheral facial nerve palsy, the patient presented to our Emergency Department. Physical examination revealed erythema of the uvula and tonsils and enlarged cervical lymph nodes. Neurological examination demonstrated peripheral facial nerve palsy and tetraparesis, more pronounced on the left side and in the lower extremities, with absent lower-extremity reflexes. During the latent paresis test, she was unable to maintain elevation of all four limbs, with greater weakness on the left side and no pronation. She was able to stand only with substantial assistance.

Following referral to the Neurology Department, a diagnostic evaluation was performed. Laboratory testing showed a mild elevation in CRP and platelet count, with a normal white blood cell count. MRI demonstrated subtle contrast enhancement along the nerve roots of the cauda equina. Lumbar puncture revealed albuminocytologic dissociation in the cerebrospinal fluid (CSF). No viral or bacterial pathogens were detected in the CSF. Electroneurography (ENG) demonstrated sensorimotor polyneuropathy with demyelinating features.

Serological testing was performed to identify a potential infectious trigger. Epstein-Barr virus (EBV) IgM and

IgG were positive, while cytomegalovirus (CMV)-specific IgG was also positive. Anti-Mycoplasma pneumoniae IgM, IgG, and IgA antibodies were detectable in serum, whereas anti-ganglioside antibodies were absent. Despite the presence of anti-Mycoplasma pneumoniae antibodies, no targeted antimicrobial therapy was administered in the absence of clinical signs of an active infection.

Electroencephalography (EEG) was performed because of the patient's slowed responsiveness and difficulty establishing contact with her. The diagnostic findings, together with the overall clinical presentation, fulfilled the diagnostic criteria for *Guillain-Barré syndrome* (GBS).

Discussion

Guillain-Barré syndrome (GBS) is the most common cause of acute flaccid paralysis in children (1–4). Its pathophysiology is based on cross-reactivity between specific epitopes of pathogens causing antecedent infections and epitopes of peripheral nerves (5). This triggers an autoimmune inflammatory response targeting various structures of the peripheral nerves, including axons and myelin sheaths. The most common pathogens associated with antecedent infections are *Campylobacter jejuni*, EBV, CMV, *Mycoplasma pneumoniae*, respiratory syncytial virus (RSV), and influenza virus (2).

GBS is an acute, rapidly progressive peripheral neuropathy (2, 3, 5). Typical symptoms include symmetrical, ascending muscle weakness and paralysis, usually beginning in the lower extremities and subsequently involving the upper extremities (2–4). Hyporeflexia or areflexia is present in most cases and is frequently accompanied by paresthesia, tingling, and pain (3). Autonomic nervous system involvement may manifest as arrhythmias (bradycardia or tachycardia), blood pressure instability, urinary retention, ileus, or increased sweating (2–4).

Cranial nerves may also be affected, resulting in facial nerve palsy, dysphagia, or respiratory impairment. Ap-

proximately 20–30% of patients require mechanical ventilation because of severe respiratory muscle weakness and/or autonomic dysfunction (6). Symptom progression typically continues for 2–4 weeks before reaching a plateau, followed by a period of recovery. Diagnosis is based on a comprehensive assessment of the clinical presentation and disease progression, supported by CSF findings, particularly albuminocytologic dissociation (2, 3) and electrodiagnostic findings (2–4). The main treatment options for GBS are intravenous immunoglobulin (IVIG) and plasma exchange; glucocorticoids are not effective and are therefore not recommended as a treatment for GBS (6, 7).

Our patient received five rounds of plasmapheresis (6), with the first session performed on the day after admission to the Neurology Department, when neurological symptoms had been present for 7 days. She also started physiotherapy and received professional psychological support. Her symptoms worsened during the first few days of hospitalization. Tetraparesis became so severe that she was unable to stand. Autonomic symptoms also developed, including hyperhidrosis, tachycardia, and hypertension. Spironolactone was administered to manage the elevated blood pressure. On the third day of observation, prolonged expiration was noted. Blood gas analysis revealed an elevated $p\text{CO}_2$ level, which resolved spontaneously during continuous monitoring.

We encountered several challenges in providing supportive care during the 3 weeks the patient spent in the Neurology Department. The antecedent infectious mononucleosis caused severe throat pain, resulting in inadequate oral intake. Analgesics provided insufficient relief, leading to self-restrictive eating behavior. Nasogastric tube feeding was therefore initiated; however, mechanical irritation of the pharyngeal mucosa by the tube further exacerbated her throat pain. This vicious cycle persisted for

several days, until the tube was removed to alleviate the pain. Approximately two days later, the patient established an adequate pattern of oral intake. Another major challenge was the patient's family situation. Her divorced parents alternated in staying with her. The mother had a strained relationship with the patient, contributing to intrafamilial conflicts and difficulties. The father spent less time with his daughter and was therefore less able to assist with daily care, including diaper changes and the management of hemorrhoids and pressure ulcers, the latter two having developed as a consequence of prolonged immobilization.

The patient spent 19 days in the Neurology Department. By discharge, the peripheral facial nerve palsy had completely resolved, while her range of motion and muscle strength had improved significantly. On the day of discharge, she was able to sit independently and maintain her balance. She was also able to take a few steps with assistance. Areflexia of the lower extremities persisted at discharge. The patient was subsequently transferred to a rehabilitation center, where she continued physiotherapy and comprehensive rehabilitation.

Conclusions

GBS can affect multiple components of the nervous system, resulting in a complex clinical course that requires multidisciplinary management. Associated complications, such as pressure ulcers and the antecedent infection, can have a substantial impact on quality of life, making appropriate supportive treatment essential. Psychological support is also an indispensable component of care. The importance of continuous physiotherapy and comprehensive rehabilitation cannot be overstated.

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