

RESEARCH REPORT

Temperature change in children undergoing magnetic resonance imaging—An observational cohort study

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Section Editor: Prof Francis Veyckemans

Abstract

Aim: An increasing number of children undergo magnetic resonance imaging requiring anesthesia or sedation to ensure their immobility; however, magnetic resonance imaging may increase body temperature whereas sedation or anesthesia may decrease it. We investigated changes in body temperature in children who underwent sedation or anesthesia for magnetic resonance imaging.

Methods: Children aged 12 weeks–12 years undergoing anesthesia and magnetic resonance imaging were included in this prospective observational study. Tympanic body temperature was measured before and after magnetic resonance imaging, and the difference between measurements was calculated. Associations between the temperature difference and patient- or procedure-related factors were evaluated with linear and logistic regression analysis.

Results: A total of 74 children were included, of whom 5 (7%) had a temperature increase $\geq 0.5^{\circ}\text{C}$. Mean temperature difference was -0.24°C (SD 0.48) for the entire group and -0.28°C for the youngest children (0–2 years). The temperature difference correlated positively with the duration of imaging (unadjusted coefficient 0.26, 95% confidence interval (CI), (0.01; 0.52)).

Conclusion: In this study of sedated or anesthetized children undergoing magnetic resonance imaging, clinically relevant increases in body temperature above 0.5°C were only found in a few patients. However, longer imaging duration tended to be associated with increased body temperature.

KEYWORDS

body temperature, general anesthesia, magnetic resonance imaging, pediatrics

1 | BACKGROUND

An increasing number of children undergo magnetic resonance imaging (MRI),¹ during which radio waves and magnetic fields form images of the body, for the purpose of diagnosing and monitoring diseases.² Due to difficulties lying still in a noisy and enclosed scanner, many children require anesthesia to achieve acceptable

picture quality.^{1,3} However, sedation and general anesthesia reduce the ability to regulate body temperature. Several factors potentially influence the body temperature during MRI. The optimal functioning of the MRI magnet requires a room temperature of approximately $19\text{--}22^{\circ}\text{C}$ and low humidity, which could contribute to a decrease in body temperature or even hypothermia ($<36^{\circ}\text{C}$) in young children.^{1,3,4} Conversely, MRI generates radio frequencies

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(RF) that are absorbed by the body and converted into heat, which may result in an increase in body temperature, especially in children due to their large body surface area (BSA) relative to body volume.^{2,5,6} The strength of the magnetic field is measured in Tesla (T); most clinical scanners have a magnetic field strength of 1.5 T or 3.0 T. The stronger 3.0 T scanner may potentially increase the body temperature more than the 1.5 T.⁵ If the MRI field temperature increases by $\geq 1^\circ\text{C}$, a heat alarm will appear.⁷ The change in body temperature depends on body composition and the ability to thermoregulate.⁸ Both hypo- and hyperthermia can lead to complications.^{9,10} It has been suggested that children are at risk of overheating during MRI.¹ However, limited research exists in this area and previous studies are ambiguous regarding changes in body temperature.^{1,3,4}

The aims of this study were to (1) measure the incidence and magnitude of changes in body temperature in children undergoing sedation or general anesthesia for MRI, hypothesizing that temperature increases $\geq 0.5^\circ\text{C}$ during MRI, and (2) identify factors associated with temperature changes (ΔT).

2 | METHODS

This study was a prospective, investigator-blinded, observational cohort study including children undergoing MRI in general anesthesia.

2.1 | Study population

All children aged from 12 weeks–12 years undergoing planned or emergency MRI requiring anesthesia from the Department of Neuroanaesthesiology, Rigshospitalet, Denmark, were eligible for inclusion. Children were recruited by referral of the anesthetist prior to MRI between March and June 2020. Parental consent was obtained before enrollment following verbal and written information in Danish or English. According to clinical procedure at the hospital, an initial body temperature above 39°C precluded an MRI.

2.2 | Body temperature measurement

Body temperature was measured before and after the MRI. The temperature was measured in Celsius ($^\circ\text{C}$) with a validated ear thermometer (Braun Thermoscan 7 IRT 6520) with a margin of error of $\pm 0.2^\circ\text{C}$ and adjusted for age (3–36 months or >36 months). Baseline body temperature was measured after sedation of the child within 0–5 min, prior to transportation into the MRI suite. Post-scan measurement was performed 0–5 min after the end of the MRI. The mean temperature of bilateral measurements was calculated unless the temperature difference between the two ear canals exceeded 0.5°C . In this case, the lowest temperature was assumed to be erroneous, for example, due to physical blockage of the ear canal,

What is already known?

- Sedation and general anesthesia reduce the ability to regulate body temperature.
- MRI generates radio frequencies that are absorbed by the body and converted into heat.

What this article adds?

- Children undergoing magnetic resonance imaging under general anesthesia are not at risk of overheating.
- Body temperature is more likely to decrease than increase in children during magnetic resonance imaging with general anesthesia.
- Longer magnetic resonance imaging duration is associated with increased body temperature in anesthetized children.

Key notes

- Children undergoing magnetic resonance imaging under general anesthesia are not at risk of overheating.
- Body temperature is more likely to decrease than increase in children during magnetic resonance imaging with general anesthesia.
- Longer magnetic resonance imaging duration is associated with increased body temperature in anesthetized children.

and the highest temperature alone was used for the calculation of mean ΔT (defined as the post-MRI temperature minus the baseline temperature). Staff were blinded to the initial temperature to avoid changes in the clinical management of the child.

2.3 | MRI procedure and anesthesia

All children had a peripheral intravenous cannula inserted. MRI compatible equipment was used for the monitoring of ECG, end-tidal CO_2 , pulse oximetry, and blood pressure. Children were anesthetized with propofol or sevoflurane, some cases supplemented with small doses of opioids. No intravenous fluids were given during MRI. Airway management was done with a tracheal tube, laryngeal mask, or O_2 supplementation at the discretion of the anesthesiologists. Children were transferred to the MRI suite, and earplugs were placed to reduce noise during scanning. Children wore their own or hospital clothes, and approx. 1/3 (25/74) of the children were covered with non-warmed blankets if considered necessary by the staff. The measured duration of the MRI procedure included a short image quality validation by a radiologist.

2.4 | Data recorded

Based on previous studies, several factors were investigated for their potential association to changes in body temperature. Age, weight, and height were registered. The body surface area (BSA) was calculated by the Mosteller Equation.¹¹ The American Society of Anesthesiologists physical status classification system (ASA), which categorizes patients from score 1 (healthy) to 4 (severely ill) defined the children's severity of morbidity, which is known to affect thermoregulation.¹² Sex was registered since it affects thermal responses.¹³ Time since intake of acetaminophen before MRI was registered as acetaminophen may decrease body temperature.¹⁴ These data were obtained from the patients' electronic medical records. Type of anesthesia (general or sedation), magnetic field strength (1.5 T or 3.0 T), use of intravenous contrast agents, and use of blankets during MRI have previously been evaluated for influence on temperature change during MRI and were therefore also included.^{1,3} MRI protocols (cerebrum, neuroaxis, cervical, abdominal, or other) differ in duration and intensity and were therefore included to evaluate their potential influence on changes in body temperature.³

2.5 | Outcomes

The primary outcome was the proportion of children who experienced a ΔT of $\geq 0.5^\circ\text{C}$ during the scan, and the secondary outcome was ΔT measured as continuous variables associated with patient/procedure-related factors.

2.6 | Statistical analysis

2.6.1 | Sample size estimation

The sample size determination was based on a clinically relevant change in body temperature of $\geq 0.5^\circ\text{C}$.¹ With a standard deviation (SD) of 0.4°C found in young children,¹ we found that a sample size of 40 would be necessary to detect such a change at a power of 0.9 (90%) with a significance level of 0.01. However, because of the variable age range in reference studies,¹ we planned to include a minimum of 60 children within the defined inclusion period of 3.5 months. Age was registered as a continuous variable (in years) and categorized in intervals as 0–2, 3–7, and 8–12 years.

2.6.2 | Data analysis

Paired t-tests were used to compare temperature before and after MRI within each age group. Linear regression was performed to determine the association between ΔT and patient/procedure-related factors. Exploratory uni- and multivariable logistic regressions were performed to investigate the association between a positive ΔT and patient/procedural-related factors. A *p*-value of ≤ 0.05 was

considered statistically significant. Data were processed in the SPSS software program (IBM SPSS Statistics Premium Authorized User V 25, version 2019).

2.7 | Ethics considerations

The study was conducted following the Declaration of Helsinki and the Danish legislation. No approval by an Ethics Committee System (no. 20002843) or Health Board (no. 31–1521-149) was needed for this observational study; both parties were consulted. The study was approved by the Danish Data Protection Agency (P-2020-179) and by the Head of the Department of Neuro-Anesthesiology. The study was registered at www.ClinicalTrials.gov before enrollment (NCT 04317378). The ear temperature measurement was a minimally invasive intervention and was not considered to be associated with any risk or discomfort. Parental consent was obtained prior to enrollment.

3 | RESULTS

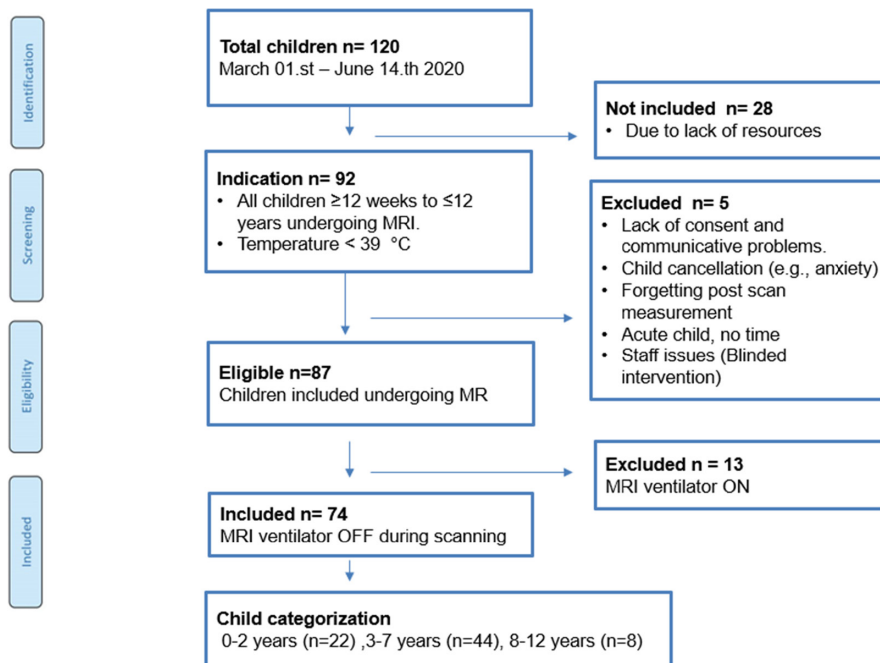
A total of 120 children aged from 4 months to 12 years underwent MRI during the inclusion period (Figure 1). Of these, 74 were included, and 46 were excluded for the following reasons: 28 children were excluded due to lack of resources or previous participation in the study, 5 were excluded due to lack of consent and a need for emergency MRI, while 13 were excluded due to uncertainty whether an MRI ventilator fan had been used (please also see Limitations in the Discussion section). The children were categorized in the three age groups as follows: 0–2 years ($n = 22$, 30%), 3–7 years ($n = 44$, 59%), and 8–12 years ($n = 8$, 11%). Thirty-eight (51.4%) children were female (Table 1).

3.1 | Temperature

In four children, the temperature of the two ears differed by $\geq 0.5^\circ\text{C}$, and the higher temperature was used as previously mentioned. Mean baseline and post-MRI temperature were 36.9°C (SD 0.40) and 36.7°C (SD 0.48), respectively; the highest baseline temperature was 38.2°C . For the total group, mean ΔT was -0.24°C (SD 0.48). For children aged 0–2 years, mean ΔT was -0.28°C (SD, 0.42), compared to -0.24°C (SD 0.54) for children aged 3–7 years and -0.16°C (SD 0.33) for children aged 8–12 years (Table 2, Figure 2).

Only five (7%) children (all boys) had a ΔT of $\geq 0.5^\circ\text{C}$ (range, 0.65 – 1.50°C); none of these was in the oldest age group (8–12 years). A positive ΔT ($>0.0^\circ\text{C}$) was found in 15 children (20%), all of whom received general anesthesia rather than sedation during imaging. Among the children, the most frequent imaging protocol was cerebrum ($n = 45$). Ten of these children had a positive ΔT (22%). Furthermore, 10 (22%) children receiving an intravenous contrast

FIGURE 1 Flowchart of inclusion



agent ($n = 46$) had a positive ΔT . A total of 59 children had a negative ΔT ($\leq 0.0^\circ\text{C}$), while three (4%) had an unchanged temperature.

3.2 | Duration of MRI scan

The mean duration of the MRI was 47 min (SD 22.3) (range, 32–87). Most scans had a duration of less than 60 min ($n = 55$; 74%), and $n = 19$ (26%) had an MRI duration ≥ 60 min. Of the 19 children with a MRI duration ≥ 60 min, six (32%) had a positive ΔT compared to nine (16%) of the children with a MRI duration of 60 min or less. Duration of MRI was less than 60 min in most cases ($n = 55$) for Tesla 3.0 T and 1.5 T scans: in these cases, mean ΔT was -0.25°C (SD 0.54).

The shortest protocol was the MRI of the cerebrum (mean 39 min, SD 17). MRI of the neuroaxis had the longest duration (mean 70 min, SD 25) and a mean ΔT of 0.20°C (SD 0.46).

3.3 | Field magnetic strength

Most MRI scans took place at 1.5 T, but cases with a positive ΔT were seen with both scanner types, ten children (22%) were in the 1.5 T, and 5 (17%) in the T 3.0. The range of ΔT was -1.35°C to 0.70°C in the 1.5 T scanner compared to -1.20°C to 1.50°C in the 3.0 T scanner. ΔT increased with longer duration in the 3.0 T scanner (Figure 3).

Through unadjusted linear regression analyses, MRI duration ≥ 60 min correlated positively with ΔT (regression coefficient 0.26; 95% CI, 0.01; 0.52; p -value .039). By contrast, a negative correlation was found between female sex and ΔT (-0.25 , 95% CI, -0.47 ; -0.03 , p -value .028), interpreted as a more pronounced decrease in girls. A negative correlation was also found for baseline temperature (-0.51 ;

95% CI, -0.76 ; -0.25 ; p -value $<.001$); however, this finding likely represents regression toward the mean (Table 3, Figure 4). Logistic regression analysis did not show any statistically significant associations between ΔT and patient/procedural-related factors (Table 4).

4 | DISCUSSION

In the present study, we found no clinically relevant changes in body temperature in anesthetized children undergoing MRI. The observed number of children with a positive ΔT of $\geq 0.5^\circ\text{C}$ was less than expected ($n = 5^7$). In a large proportion of the included children, a small decrease in body temperature was measured, which was most pronounced for the youngest children in the age group 0–2 years old.

The presence of cancer did not affect ΔT , and neither did the use of blankets or contrast agents. In fact, only three of the investigated factors were associated with a positive ΔT : male sex, baseline temperature, and a longer duration of the scan.

Previous studies have reported increases in body temperature of 0.2 – 0.5°C during MRI^{1,3}; Machata et al. found a median ΔT of 0.2°C (interquartile range [IQR], 0.1°C to 0.3°C) in children aged <6 years who were scanned at 1.5 T and a median ΔT of 0.5°C (IQR, 0.4°C to 0.7°C) at 3.0 T, using ear temperature and propofol sedation.³ However, a more recent study found that several infants and children under the age of 8 turned hypothermic ($<36^\circ\text{C}$).⁴ Bryan et al. reported a ΔT of 0.5°C (95% CI; 0.3 – 0.7) in 30 children undergoing MRI at a mean age of 14.9 months (SD 8.6).¹ In that study, sedation was achieved using chloral hydrate, which is a less effective hypnotic drug than propofol.¹⁵ Insufficient sedation may lead to longer scan duration due to movements prompting a need to repeat sequences. Longer procedural time leads to an increase in body temperature.¹ In the present study, all children received either deep sedation or

TABLE 1 Demographic and clinical characteristics by age group of 74 children undergoing MRI

	0 to 2 years		3 to 7 years		8 to 12 years		All	
	N	%	N	%	N	%	N	%
Total	22	29.7	44	59.5	8	10.8	74	100
Sex								
Female	14	63.6	21	47.7	3	37.5	38	51.4
Male	8	36.4	23	52.3	5	62.5	36	48.6
Age (years)								
Mean (SD)	1.4 (0.7)	-	5.0 (1.5)	-	10.5 (1.3)	-	4.5 (3.0)	-
Range (min ^a , max)	(0.4 ^a ; 2.9)	-	(3.1; 7.9)	-	(8.9; 12.5)	-	(0.4; 12.5)	-
Body mass Index (BMI) (kg/m ²) ^a								
<18.5	16	72.7	38	86.4	4	50.0	58	78.4
18.5–25 (number [%])	6	27.3	6	13.6	4	50.0	16	21.6
Percentiles (BMI) ^a								
Mean (SD)	1.74 (2.0)	-	0.54 (1.22)	-	0.33 (1.13)	-	-0.87 (1.60)	-
Range (min ^a , max)	-2.05; 5.35	-	-3.39; 3.11	-	-1.61; 1.89	-	-3.39; 5.35	-
Body surface area BSA(m ²) ^a								
Mean (SD)	0.48 (0.09)	-	0.76 (0.13)	-	1.16 (0.13)	-	0.72 (0.23)	-
Range (min; max)	(0.33; 0.68)	-	(0.54; 1.10)	-	(0.94; 1.33)	-	(0.33; 1.33)	-
ASA group								
ASA 1	4	18.2	5	5.7	0	-	9	12.1
ASA 2	16	36.4	25	29.1	3	20.0	44	59.5
ASA 3	2	9.1	14	31.8	5	62.5	21	28.4
ASA 4	0	-	0	-	0	-	0	-
MR Protocol								
Cerebrum	17	89.5	26	60.5	2	25.0	45	60.2
Neuroaxis	2	10.5	7	16.3	2	25.0	12	16.2
Abdomen	0	-	4	9.3	3	37.5	7	9.5
Cervical	1	4.5	0	-	1	12.5	2	2.7
Other	2	9.1	6	14.0	0	-	8	10.8
Use of contrast								
Yes	12	54.5	26	59.1	8	100.0	46	62.2
No	10	45.5	18	40.9	0	-	28	37.8
Use of blanket								
Yes	10	45.5	11	25.0	4	50.0	25	33.8
No	12	54.5	33	75.0	4	50.0	49	66.2
Use of Acetaminophen								
Yes	0	0.0	2	4.5	1	12.5	3	4.0
No	22	100.0	42	95.5	7	87.5	71	96.0
Cancer								
Yes	11	50.0	13	29.5	4	50.0	28	37.8
No	11	50.0	31	70.5	4	50.0	46	62.2

TABLE 1 (Continued)

	0 to 2 years		3 to 7 years		8 to 12 years		All	
	N	%	N	%	N	%	N	%
Anesthesia								
General anesthesia	22	100.0	40	90.9	6	75.0	68	91.9
Sedation	0	0.0	4	9.1	2	25.0	6	8.1
MRI duration								
Mean (SD)	40.2 (12.5)	-	48.5 (24.4)	-	61.1 (26.1)	-	47.4 (22.3)	-
MRI type								
Tesla 1.5	12	54.4	27	61.4	6	75	45	60.8
Tesla 3.0	10	45.5	17	38.6	2	25	29	39.2

^aAge minimum: 0.37 years = 4.4 months.

$$^b\text{BMI} = \frac{\text{weight (kg)}}{\text{height (cm)} \times \text{height (cm)}}$$

$$^c\text{Mostellar formula BSA (m}^2\text{)} = \frac{\sqrt{(\text{Height (cm)} \times \text{Weight (kg)})}}{3600}$$

^dPercentiles: Child's height compared to children of same age and sex <https://cran.r-project.org/web/packages/childsds/childsds.pdf>.

TABLE 2 Paired t-test

	Pre Tp	Post Tp	ΔT	ΔT (95% CI)	p-value
Age					
0–2 years (n = 22)	36.9	36.6	-0.28	(- 0.4; - 0.1)	.006
(SD)	(0.3)	(0.4)	(0.4)		
3–7 years (n = 44)	37.0	36.8	-0.24	(- 0.4; - 0.1)	.005
(SD)	(0.4)	(0.5)	(0.5)		
8–12 years (n = 8)	36.9	36.7	-0.16	(- 0.4; 0.0)	.208
(SD)	(0.7)	(0.7)	(0.3)		

Note: Pre- and post-MRI tympanic temperature and ΔT in 74 children undergoing MRI.

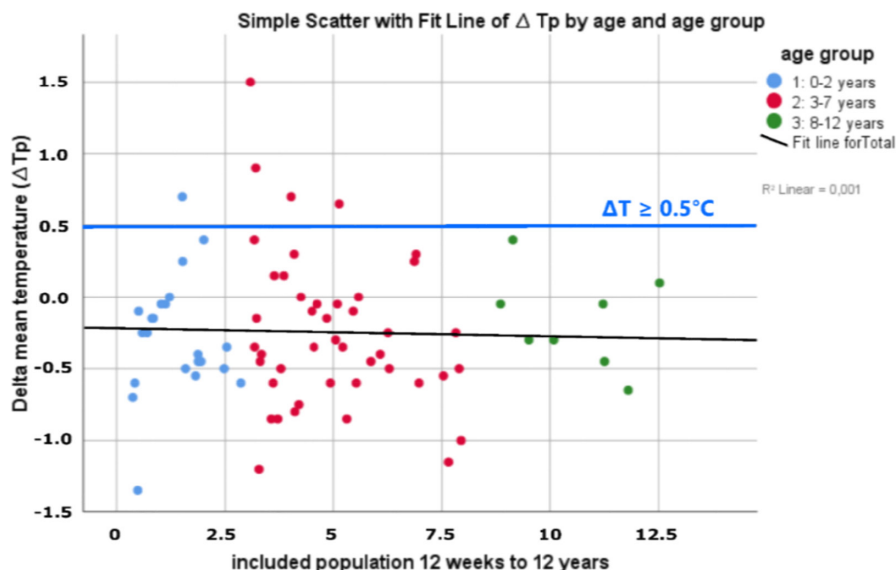
Abbreviations: SD, Standard deviation, 95% CI, 95% confidence interval.

general anesthesia. Propofol and sevoflurane may both decrease temperature due to vasodilation, lowered metabolism, and possibly to an effect on hypothalamic function. This effect is especially relevant for younger children.¹⁰

Under normal circumstances, body temperature is maintained around 37°C even in cold conditions due to thermoregulation, but after the induction of anesthesia, a decrease of 0.5°C to 1.5°C within 30–40 min is not unusual.^{10,16} Younger children have a higher BSA, reduced body fat, and immature thermoregulation, which may affect their ability to generate heat by shivering, leading to a higher risk of heat loss than in older children and adults.⁴ Thus, we expected that high BSA would correlate negatively with ΔT but analysis of our data did not confirm this.

This study found that female sex correlated negatively with a positive ΔT . This is similar to findings in adult females, who in general have a smaller body size, BSA, and muscle mass compared to males, and therefore tend to lose heat more easily than males.¹³

FIGURE 2 Scatterplot showing the individual values of a ΔT for all ages and the mean of -0.24°C (SD 0.48) (black line) for the whole population (n = 74). The blue line shows a $\Delta T \geq 0.5^\circ\text{C}$ (MRI)



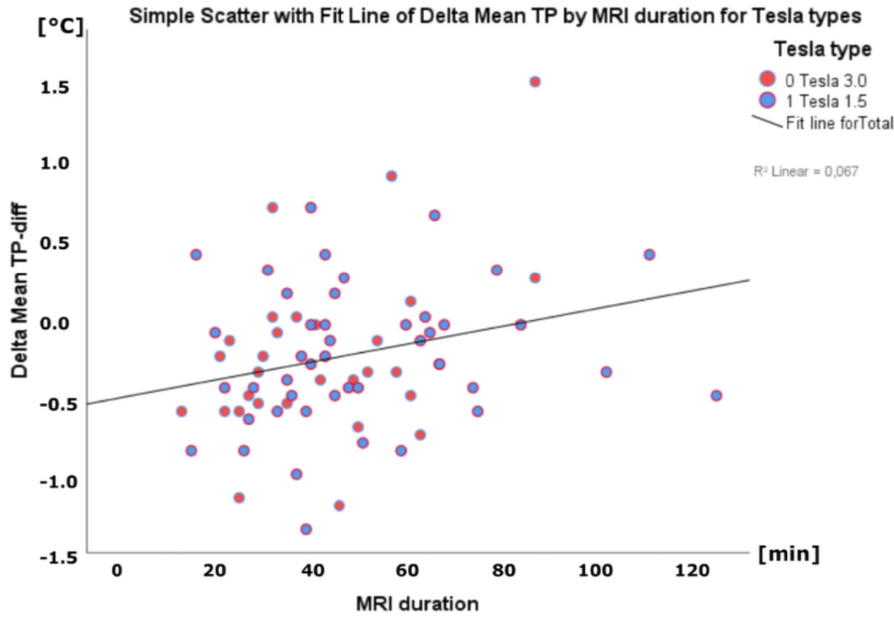


FIGURE 3 Scatter plot with fit line for ΔT by MRI duration for 1.5T and 3.0 T ($n = 74$)

Predictors	Unadjusted coefficient	95% Confidence interval (CI)	p-value
Age (years)			
0-2	-0.046	(-0.294; 0.203)	.716
3-7	0.002	(-0.229; 0.243)	.984
8-12	0.093	(-0.273; 0.459)	.615
Female sex (Male ^a)	-0.248	(-0.468; -0.028)	.028
No use of blanket (Blanket used ^a)	-0.044	(-0.280; 0.190)	.715
Body surface area (BSA) (m ²)	0.100	(-0.389; 0.589)	.684
Baseline temperature	-0.506	(-0.763; -0.250)	<.001
3T scanner (1.5 T ^a)	0.004	(-0.230; 0.240)	.976
Imaging duration <60 (≥60) min	0.266	(0.013; 0.519)	.039

TABLE 3 Uni- and multivariable linear regression analysis of associations between body temperature and patient/procedural factors among 74 children undergoing MRI

^aReference category, A negative coefficient indicates a decrease in temperature from baseline to post-magnetic resonance imaging (MRI).

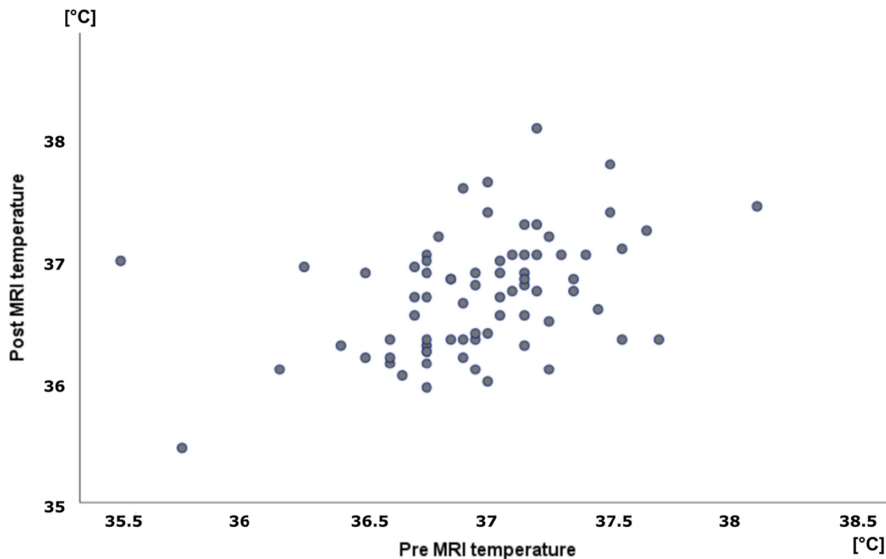


FIGURE 4 Scatterplot pre- and post-MRI temperature measurement

TABLE 4 Multivariable logistical regression analyses of associations between positive ΔT ($\geq 0.0^\circ\text{C}$) and patient/procedural factors ($n = 74$)

Predictors	Univariable Model		Multivariable model	
	OR (95% CI)	<i>p</i>	OR (95% CI)	<i>p</i>
Age (Years)				
0–2	0.54 (0.131; 2.192)	.386	–	–
8–12	1.13 (0.917; 6.514)	.888	–	–
Age	1.03 (0.852; 1.246)	.757	0.97 (0.784; 1.215)	.830
Body mass index (BMI)	0.45 (0.130; 1.612)	.224	1.01 (0.820; 1.260)	.879
Female	1.26 (0.406; 3.940)	.685	1.33 (0.353; 5.015)	.672
Blanket YES	0.71 (0.221; 2.292)	.570	1.77 (0.451; 6.951)	.413
Cancer YES	2.94 (0.750; 11.534)	.122	0.23 (0.050; 1.137)	.072
Contrast YES	0.78 (0.237; 2.583)	.687	1.66 (0.424; 6.563)	.465
MR Type 3.0	1.37 (0.416; 4.520)	.604	0.96 (0.260; 3.560)	.954
MR duration start _finish	1.02 (0.992; 1.045)	.110	1.01 (0.963; 1.062)	.649

Note: Acetaminophen was not included due to small sample size.

Abbreviations: BMI = $\frac{\text{weight (kg)}}{\text{height (cm)} \times \text{height (cm)}}$; CI, confidence interval; OR, odds ratio.

The results from our study agree with a study by Lo et al., who found an overall negative ΔT of -0.28°C (95% CI; -0.36 ; -0.19) in 193 children aged 3 months–6 years, who underwent MRI under general anesthesia.² Several studies, including the present, suggest that a higher baseline temperature, not surprisingly, reduces the risk of developing hypothermia during MRI.^{1,2} A recent study by Cronin et al. found hypothermia ($< 36^\circ\text{C}$) in 63% of children undergoing MRI (mean age of 3.6 years [SD 2.1]).⁴ In their study, the temperature was measured prior to MRI and continuously, using an axillary device during MRI, in contrast to a pre- and post-temperature measured in the ear in our study.⁴ The accuracy of an axillary temperature differs by $\pm 0.45^\circ\text{C}$ and the use of a fan in the MRI suite led to significant limitations and a high incidence of hypothermic children. In this study, a small decrease in temperature was also found in children undergoing MRI, but all stayed normothermic. This could be due to covering the body with a blanket reducing heat loss by convection. A decrease in temperature in most of the children occurred despite the use of clothes, blankets, and heat generated from the MRI by RF.

Cronin et al. did not find any association between hypothermia and demographic factors or anesthesia duration.⁴ By contrast, we found an association between ΔT and longer MRI duration, female sex, and pre-procedural temperature. However, we speculate that the latter finding, that is, the relationship between ΔT and pre-temperature may be due to so-called mathematical coupling or “regression toward the mean,” since ΔT was calculated by post-temperature minus pre-temperature.

Body temperature increased more in children with a longer MRI duration (> 60 min) and post-scan temperatures were higher in 3.0 T compared to 1.5 T, which is similar to the study by Machata et al.³ However, one outlier with a ΔT of 1.5°C during scanning at 3.0 T may have had a disproportionate effect on the mean in the present study. An analysis was therefore conducted excluding this outlier, stating that the highest ΔT was seen in 3.0 T with a duration of > 60 min. An increase in temperature was found with both scanner types when

the duration exceeded 60 min, but this result did not reach statistical significance.

4.1 | Strengths and limitations

In four cases, the measured ear temperature of each ear, right and left differed by $\geq 0.5^\circ\text{C}$. The highest measurement was used for analyses; however, the uncertainty regarding the true temperature is a limitation of the current study. This large difference of tympanic temperatures could be caused by the child's head positioning at bedrest. Since the magnet needs a constant and regulated humid environment, the temperature was kept air conditioned to a target around 21°C , which can affect the child's thermoregulation. Due to the small number of scans lasting more than 60 min, we were unable to evaluate the risk of hyperthermia in case of very long MRI. This deserves further studies.

Internal validity was high for the present study since body temperature was measured by the same thermometer for all included children. Moreover, the measurement was blinded for both patients, parents, and staff. Furthermore, the validity of the measurement was increased since only a small number of staff members performed the measurements, and verbal and written information about measurement was repeated throughout the inclusion period. Finally, the sample size allowed us to categorize children in three age groups to distinguish differences in thermoregulation according to age.

The MRI has a fan that can prevent claustrophobia and provide fresh air to comfort individuals. The working mode of the fan is unknown, but it can be assumed that it lowers post-scan temperatures during MRI which was most pronounced in the youngest age group (0–2 years old). A strength in the present study was that the MRI fan was turned off to avoid confounding in contrast to other studies where the MRI fan was noted as a limitation.⁴ However, a control group for comparison of body temperature with and without the MRI fan could have been relevant.

In this study, body temperature was measured in the ears, due to their easy and fast access and without interrupting the sedated child. The Braun ear thermometer has a measurement uncertainty of $\pm 0.2^\circ\text{C}$. Errors may occur in calculation of ΔT and analysis of its relationship with the predetermined patient/procedural-related factors if the probe is not directed properly to the tympanic membrane, which may cause lower temperatures and inaccurate measurements. However, previous studies have shown that compared with the use of a rectal thermometer, ear measurement is a reliable method to monitor temperature in children aged >12 weeks during anesthesia and for screening purposes.¹⁷ Rectal temperature is the gold standard but was considered too invasive, time-consuming and could cause possible discomfort.⁸ Also, the ear thermometer is better suited to detect rapid temperature changes than is the rectal thermometer.¹⁷

An MRI is indicated in both elective and emergency procedures, which makes inclusion of children an organizational challenge. Most children in need of general anesthesia for MRI are preschool children. Almost all eligible children in the inclusion period were included, which was a strength in the study. In future studies, it would be an advantage to include a larger number of children and have an equal number of children in each age group to compare the variation of temperature with age.

Our primary outcome was ΔT of $\geq 0.5^\circ\text{C}$, which was only present in five children, which contradicts our estimated power of inclusion of 40 children for significance. Future studies should perhaps set a more liberal level of relevance or have more focus on the decrease in body temperature rather than increase.

A mean negative ΔT of -0.24°C was found to be statistically significant, but it is not clinically relevant, since this difference was small, and all the children were still normothermic after the procedure.

4.2 | Conclusion

In this study, no general increase in body temperature was found in anesthetized children undergoing MRI. External and internal factors such as MRI protocols, Tesla type, diseases, use of blankets, and contrast agents were not found to influence changes in the body temperature. However, longer duration of MRI trends toward an increase in body temperature.

4.3 | Implications

The risk of hypothermia during MRI needs to be investigated further to initiate interventions for prevention. Some children, where hypothermia poses a specific risk could benefit from systematic or continuous monitoring of body temperature. Guidelines prohibiting MRI scans when temperatures exceed 39°C could be questioned, but we did not examine the effect on any patients with elevated body temperature.

New methods are being developed to reduce the need for sedation during MRI. This will possibly also reduce its impact on changes in temperature.

ACKNOWLEDGMENTS

The authors would like to express their gratitude to all the children and their parents that gave consent to participate in this project. Furthermore, we are grateful to the staff at The Department of Neuroanaesthesiology, who helped with recruiting and collecting data. We are grateful for the help from the Radiological Clinic, all MRI staff at the University Hospital, Rigshospitalet, Denmark for their assistance during MRI procedures.

CONFLICT OF INTEREST

The authors have no conflict of interest to declare.

AUTHOR CONTRIBUTIONS

TMA and KM conceived the study. All authors contributed to the design. TMA and PFC performed the statistical analyses. TMA wrote the first draft of the manuscript. All authors revised the manuscript critically. All have given their final approval of the version to be published.

DATA AVAILABILITY STATEMENT

The data supporting the findings of this study are available from the corresponding author (TMA) upon reasonable request.

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How to cite this article: Madsen TW, Sørensen MK, Cromhout PF, et al. Temperature change in children undergoing magnetic resonance imaging—An observational cohort study. *Pediatr Anesth*. 2022;32:870-879. doi: [10.1111/pan.14450](https://doi.org/10.1111/pan.14450)