TITLE:

Does MR brain scanning at 3.0 Tesla pose a hyperthermic challenge to term neonates?

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Short Title: Thermal safety of neonatal 3T MR brain scanning

Abstract:

Next-generation 3 Tesla MR scanners offer improved neonatal neuroimaging, but the higher associated radiofrequency radiation may increase the risk of hyperthermia. Safety data for neonatal 3T MR scanning are lacking. We measured rectal temperatures continuously in 25 neonates undergoing 3T brain MRI and observed no significant hyperthermic threat.

Introduction:

Magnetic resonance (MR) brain scanning remains the 'gold-standard' imaging modality for neonates with encephalopathy. Hitherto, neonatal MR has been undertaken mainly in 1.5 Tesla (T) strength scanners. Increasingly, higher-field 3T strength scanners are being commissioned with the potential for higher quality neonatal neuroimaging and shorter duration sequences. Higher magnetic field technology also facilitates the use of advanced techniques such as MR spectroscopy, which may ultimately improve the prognostic value of MR. Although MR imaging

does not incur the risks associated with ionizing radiation, it is not hazard-free: infants are exposed to static and time-varying magnetic fields, as well as substantial acoustic noise and radiofrequency radiation.[1,2]

The principal concerns relating to MR radiofrequency radiation are the risks of thermal injury and systemic hyperthermia. Higher-strength magnetic fields require higher radiofrequencies. Radiofrequency radiation increases from 64 to 128 MHz when magnet strength increases from 1.5 to 3T.[2,3,4]. High-field 3T MR scanners thus have the potential to generate a greater intrinsic thermal response and consequently carry a greater risk for hyperthermia and thermal tissue injury.

Neonates are theoretically at higher risk of hyperthermia due to their unique anatomical and physiological characteristics. During MR brain imaging, excess heat generated within the cranial cavity is dissipated by convection through the blood stream. Because neonates have relatively high cranial-to-corporeal surface areas and cranial-to-corporeal volume ratios, their ability to dissipate heat through the body is limited. In addition, infants sedated for scanning and those recovering from encephalopathy may have disturbed thermoregulation and an impaired ability to respond to external heat challenges.[5]

Despite the theoretical risk of overheating, data supporting the thermal safety of 3T MR scanning are lacking in neonates. The most recent safety guidance from the International Commission on Non-Ionizing Radiation Protection references no studies on the thermal stability of neonates during high-field MR.[1] Furthermore, the manufacturer of our hospital's recently commissioned state-of-the-art 3T MR scanner was unable to provide any neonatal temperature safety data.

We have therefore prospectively monitored the core (rectal) temperature of neonates undergoing 3T MR brain scans in our center, with the aims of ensuring their

continued in-scan safety and to establish preliminary safety data. We hypothesized that term neonates undergoing 3T MR brain scans would maintain a core temperature within the safe homeostatic range of 36.0-37.5°C.

Methods:

Between October 2013 and June 2015, we performed core rectal thermometry in the complete cohort of consecutively-enrolled term neonates who underwent 3T brain MR imaging in our center (Norwich) as part of the 'Magnetic Resonance Biomarkers in Neonatal Encephalopathy' (MARBLE) study.[6] All had previously received therapeutic hypothermia for 72 hours for suspected hypoxic-ischemic encephalopathy.

Rectal thermometry was performed using the MR-compatible FOTS100 fiber-optic temperature system with TSD180 high-accuracy fiber-optic temperature probe (resolution 0.1°C, accuracy ±0.2°C, sampling rate 50Hz, calibrated range 20 to 45°C; BIOPAC Systems Inc., CA, USA). MR scans were performed using the Discovery MR750w 3.0 T scanner with the accompanying 21-element GEM suite head and neck unit (GE Healthcare, Bucks., UK).

Clinical and research MR sequences were acquired according to a standardized protocol.[6] In brief, the sequences comprised T1-weighted brain volume imaging, T2-weighted fast spin echo, diffusion-weighted imaging, T2 susceptibility-weighted imaging, T1 and T2 fluid-attenuated inversion recovery, and single-voxel point-resolved spectroscopy of the left thalamus. Table 1 (online) provides full technical details of sequence parameters.

All infants received a single oral sedative dose of chloral hydrate 50 mg/kg before the scan. During scans infants were covered with a single vest and blanket and

had no additional external heating source; they were secured using the Med-Vac™ vacuum infant immobilizer (CFI Medical, MI, USA).

We recorded vital signs, including heart rate and pulse-oximeter saturations, at 5- to 15-minute intervals throughout all scans. Our operating safety protocol stipulated that an MR scan should cease if an infant's core temperature fell <35.5°C or rose >38.5°C during scanning.

We quantified the thermal stability and variability in each infant by assessing: i) the maximal positive and negative temperature excursions from their start-of-scan baseline temperature; ii) the magnitude of the range between their highest and lowest recorded core temperatures during scans, irrespective of start-of-scan baseline temperature; and iii) the magnitudes of their greatest continuous in-scan positive and negative temperature excursions.

Start-of-scan core temperatures were compared using the Mann-Whitney test. Paired start and end-of-scan core temperatures were compared using Wilcoxon's signed rank test. P-values <0.05 (2-tailed) were considered significant.

Results:

We studied 26 consecutive neonates; one was excluded due to rectal thermometer malfunction during scanning. Data from 25 neonates were analyzed. Median postnatal age at scanning was 9 days (range: 5 to 17 days). Birth gestation ranged from 37+6 to 42+0 weeks and median birth weight was 3385 g (range: 2468 to 4480 g). Neonatal encephalopathy grading on postnatal day 1 was severe for n=2, moderate for n=12, and mild for n=11 infants. 14 infants had seizures during therapeutic hypothermia and 15 had previously received anti-convulsants. Only one infant still had an abnormal neurological examination at the time of MR scanning; an infant with a poor suck who

was still on phenobarbital. No infant received heated or humidified medical gases during scanning.

Median ambient temperature in the magnet room during scans was recorded as 21.4°C (range: 20.5 to 21.7°C). Median total scan duration was 55 minutes (range: 41 to 81 minutes). Table 2 (Online) provides typical specific absorption rates of radiofrequency radiation for two representative infants within our cohort. All neonates maintained stable vital signs during scanning and no infant had any significant episode of desaturation, tachycardia, bradycardia or apnea that required scan interruption.

Figure 1 shows recorded core temperature measurements for each neonate. There was no significant change in core temperature between the start and end of scanning: median start-of-scan temperature was 36.8°C (range: 35.8 to 37.6°C) vs. end-of-scan 36.7°C (range: 35.8 to 37.4°C), p=0.09. No infant had a core temperature that exceeded 37.5°C during scanning. The nadir temperature was <36.0°C in four infants, though none fell below the predetermined lower safety threshold of 35.5°C. The four infants with in-scan core temperature nadirs of <36.0°C had significantly lower start-of-scan temperatures compared with those whose core temperatures remained ≥36.0°C (median 36.4°C [range 35.8 to 36.4°C] vs. 36.8°C [range: 36.2 to 37.6°C], P <0.01).

In relation to start-of-scan temperatures, the median greatest positive (or least negative) excursion from baseline at any time during scanning was 0.0°C (range: –0.8 to +0.6°C) and the median greatest negative (or least positive) excursion was –0.4°C (range: –1.0 to +0.2°C). The median value for magnitude of the temperature range between subjects' highest and lowest recorded core temperatures during scans was 0.4ºC (range: 0.0 to 1.1ºC). The median greatest continuous in-scan positive and

negative excursions were: +0.2ºC (range: 0.0 to +1.0ºC) and -0.2ºC (range: 0.0 to –1.1ºC) (**figure 2**). A single infant had both the largest positive and negative in-scan excursions, with a temperature rising from 35.6ºC to 36.6ºC after 10 minutes, followed by a fall to 35.5ºC by 30 minutes (**figure 1**).

Discussion:

We believe these are the first data to demonstrate the thermal safety of high-field 3T MR brain scanning in term neonates. We found that 3T MR brain imaging using the GE Discovery MR750w scanner presented no significant hyperthermic challenge to sedated, recently encephalopathic term neonates. Furthermore, our data suggest that undertaking continuous core temperature monitoring during scanning (using expensive MR-compatible equipment) is superfluous in this population. Neonates maintained a relatively stable core temperature throughout, even during scans lasting up to 80 minutes, and none breached the pre-defined safety range.

The risk of overheating or sustaining thermal injury from exposure to high frequency radiofrequency radiation during 3T MR scanning was real. Two studies within the pediatric population had demonstrated a rise in core body temperature during 3T scanning.[7,8] One reported a statistically-significant 0.5°C increase in core rectal temperature with 3T MR brain imaging, and a 0.2°C increase with 1.5T MR scanning [7]. Average weights/ages of subjects in these two studies were 35 kg/8.3 years[8], and 16 kg/3.8 years[7]; these results cannot be extrapolated to neonatal populations with completely different body weights and proportions.

Contrary to the supposition that a neonate's higher cranial-to-corporeal volume ratio may inhibit the dissipation of thermal energy and lead to overheating, our data reveal a substantial number of negative temperature excursions. The

controlled low humidity and cool ambient temperatures that MR scanner rooms are maintained at may explain this tendency. Smaller and preterm infants will be at particular risk of falls in temperature during scans. Some infants may therefore require pre-emptive additional insulation, particularly if their pre-scan temperature is low.

Our relatively small sample size may limit generalization of our findings. It is also plausible that thermal injury occurs more readily in specific heat-sensitive areas, including in anatomical locations with naturally reduced tissue perfusion such as the lens of the eye. While our study could not specifically assess temperature in such potential 'hot spots', the International Commission on Non-Ionizing Radiation Protection has assessed as low the risk for such thermal injury occurring at 3T.[1] Finally, heating can be very dependent on radiofrequency coil geometry. The 21-element GEM head and neck unit used in this study is a volume coil spanning 49.5 cm in length; it therefore encompassed the entirety of the infant's head as well as a significant proportion of the body. It is unlikely that heating effects would be substantially different with a similar coil produced by another manufacturer, but specialised surface coils could, in theory, produce significant local heating.

Conclusion:

With an increasing number of centers looking to commission 3T MR scanners, neonatologists, radiologists and MR radiographers will rightly demand that basic reassuring neonatal safety data are available before allowing neonates routine access to these higher-field scanners. We have now shown in a small series that 3T scanning did not present a hyperthermic challenge to sedated, recently-encephalopathic term neonates. We hope that these data will go some way to reassuring colleagues

regarding the relative thermal safety of MR brain scanning neonates at 3T, and thereby facilitate wider access for neonates to the enhanced diagnostic potential of these latest MR scanners.

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Abbreviations used:

MR: Magnetic resonance (MR)

T: Tesla

MARBLE: Magnetic Resonance Biomarkers in Neonatal Encephalopathy

Figure legends:

Table 1. (Online Only) Technical parameters for all MR Sequences used within the MARBLE Study MR protocol.[6]

Table 2. (Online Only) Specific absorption rates of radiofrequency radiation in two infants, as typical representative values within this study. Numbers quoted as Watts/kg averaged over 6 minutes. Key:- **SURVEY**: 3 plane localizer Survey, **T1 BRAVO**: T1 Sagittal Fast SPoiled Gradient Recalled echo BRAin VOlume imaging, **T2 TSE**: Axial T2 Fast Spin Echo eXcel, **SWI**: T2 Susceptibility Weighted Imaging, **DWI**: Axial Diffusion Weighted Imaging, **T1 FLAIR**: Axial T1 FLuid Attenuated

Inversion Recovery, **T2 FLAIR**: Axial T2 FLuid Attenuated Inversion Recovery, **MRS 288**: Magnetic Resonance Spectroscopy PROton Brain Exam - Single Voxel [Echo Time 288ms], **MRS 60**: Magnetic Resonance Spectroscopy PROton Brain Exam - Single Voxel [Echo Time 60ms].

Figure 1. Core rectal temperatures of the 25 participating infants during 3T MR brain scanning. Each plotted coordinate marks the measured rectal temperature at that specified time point.

Figure 2. Greatest continuous positive and negative core temperature excursions occurring in-scan, irrespective of pre-scan baseline temperature. Bars denote medians and inter-quartile ranges.

Ethics approval: These data were collected routinely as part of safe clinical monitoring of patients enrolled in the MARBLE study (UK National Research Ethics Committee Ref. 11/H0717/6).

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Magnetic Resonance Scanning - Sequence Protocols

3 Plane Localizer (3 Plane Loc):

3 Plane Loc

PATIENT POSITION	
Patient Entry	Head First
Patient Position	Supine
Coil Configuration	GEM Head;GEM Neck
Plane	3-PLANE
Series Description	3 Plane Loc
SCAN TIMING	
TE	Minimum
TR	Minimum
Receiver Bandwidth	83.33
IMAGE ENHANCE	
Filter Choice	None
GATING/TRIGGER	
Auto Trigger Type	Off
FMRI	
PSD Trigger	Internal
Slice Order	Interleaved
View Order	Bottom/Up
# of Repetitions REST	0
# of Repetitions ACTIVE	0
SAT	
Tag Type	None
TRICKS	
Pause On/Off	On
Auto Subtract	0
Auto SCIC	Off

IMAGING PARAMETERS	
Imaging Mode	2D
Pulse Sequence	Spin Echo
Imaging Options	Seq, EDR, Fast, SS, ARC
SCAN RANGE	
FOV	24.0
Slice Thickness	10.0
Slice Spacing	0.0
ACQ TIMING	
Freq	256
Phase	128
Freq DIR	Unswap
# of Acq. Before Pause	0
Phase FOV	1.00
Auto Shim	Auto
Phase Correction	No
USER CVS	
User CV1	1.0
User CV2	240.00
User CV13	1.00
MULTI-PHASE	
Seperate Series	0
Mask Phase	0
Mask Pause	0
DIFFUSION	
Recon All Images	On
CONTRAST	
Contrast Yes/No	No

3 Plane Loc

Sagittal Fast SPoiled Gradient Recalled echo BRAin VOlume imaging (SAG FSPGR BRAVO):

SAG FSPGR BRAVO LOW BW

PATIENT POSITION	
Patient Entry	Head First
Patient Position	Supine
Coil Configuration	GEM Head;GEM Neck
Plane	OBLIQUE
Series Description	SAG FSPGR BRAVO LOW BW
SCAN TIMING	
Flip Angle	13
TI	1400
Receiver Bandwidth	8.06
IMAGE ENHANCE	
Filter Choice	None
GATING/TRIGGER	
Auto Trigger Type	Off
MULTI-PHASE	
Seperate Series	0
Mask Phase	0
Mask Pause	0
DIFFUSION	
Recon All Images	On
CONTRAST	
Contrast Yes/No	No

IMAGING PARAMETERS	
Imaging Mode	3D
Pulse Sequence	BRAVO
Imaging Options	EDR, Fast, IrP, ZIP2, ARC
SCAN RANGE	
FOV	21.0
Slice Thickness	1.0
Location per Slab	256
Overlap Locations	0
ACQ TIMING	
Freq	200
Phase	200
Freq DIR	S/I
NEX	1.00
Phase FOV	1.00
Auto Shim	Auto
Phase Correction	No
FMRI	
PSD Trigger	Internal
Slice Order	Interleaved
View Order	Bottom/Up
# of Repetitions REST	0
# of Repetitions ACTIVE	0
SAT	
Tag Type	None
TRICKS	
Pause On/Off	On
Auto Subtract	0
Auto SCIC	Off

SAG FSPGR BRAVO LOW BW

Axial T2 Fast Spin Echo eXcel (Ax T2 TSE):

Ax T2 TSE

PATIENT POSITION	
Patient Entry	*Head First*
Patient Position	*Supine*
Coil Configuration	*GEM Head;GEM Neck*
Plane	*OBLIQUE*
Series Description	*Ax T2 TSE*
SCAN TIMING	
TE	*150.0*
Number of Echoes	*1*
TR	*10000.0*
Echo Train Length	*18*
Receiver Bandwidth	*15.63*
IMAGE ENHANCE	
Filter Choice	*None*
GATING/TRIGGER	
Auto Trigger Type	*Off*
FMRI	
PSD Trigger	*Internal*
Slice Order	*Interleaved*
View Order	*Bottom/Up*
# of Repetitions REST	*0*
# of Repetitions ACTIVE	*0*
SAT	
Tag Type	*None*
TRICKS	
Pause On/Off	*On*
Auto Subtract	*0*
Auto SCIC	*Off*

IMAGING PARAMETERS	
Imaging Mode	*2D*
Pulse Sequence	*FSE-XL*
Imaging Options	*EDR, Fast, ARC*
SCAN RANGE	
FOV	*20.0*
Slice Thickness	*3.0*
Slice Spacing	*0.3*
ACQ TIMING	
Freq	*256*
Phase	*256*
Freq DIR	*A/P*
NEX	*1.00*
# of Acq. Before Pause	*0*
Phase FOV	*1.00*
Auto Shim	*Auto*
Phase Correction	*Yes*
USER CVS	
User CV22	*1.00*
MULTI-PHASE	
Seperate Series	*0*
Mask Phase	*0*
Mask Pause	*0*
DIFFUSION	
Recon All Images	*On*
CONTRAST	
Contrast Yes/No	*No*

Ax T2 TSE

3 Plane Localizer (3 Plane Loc):

3 Plane Loc

PATIENT POSITION	
Patient Entry	*Head First*
Patient Position	*Supine*
Coil Configuration	*GEM Head;GEM Neck*
Plane	*3-PLANE*
Series Description	*3 Plane Loc*
SCAN TIMING	
TE	*Minimum*
Number of Echoes	*1*
TR	*Minimum*
Receiver Bandwidth	*83.33*
IMAGE ENHANCE	
Filter Choice	*None*
GATING/TRIGGER	
Auto Trigger Type	*Off*
FMRI	
PSD Trigger	*Internal*
Slice Order	*Interleaved*
View Order	*Bottom/Up*
# of Repetitions REST	*0*
# of Repetitions ACTIVE	*0*
SAT	
Tag Type	*None*
TRICKS	
Pause On/Off	*On*
Auto Subtract	*0*
Auto SCIC	*Off*

IMAGING PARAMETERS	
Imaging Mode	*2D*
Pulse Sequence	*Spin Echo*
Imaging Options	*Seq, EDR, Fast, SS, ARC*
SCAN RANGE	
FOV	*24.0*
Slice Thickness	*10.0*
Slice Spacing	*3.0*
ACQ TIMING	
Freq	*256*
Phase	*128*
Freq DIR	*Unswap*
# of Acq. Before Pause	*0*
Phase FOV	*1.00*
Auto Shim	*Auto*
Phase Correction	*No*
USER CVS	
User CV1	*1.0*
User CV2	*240.00*
User CV13	*1.00*
MULTI-PHASE	
Seperate Series	*0*
Mask Phase	*0*
Mask Pause	*0*
DIFFUSION	
Recon All Images	*On*
CONTRAST	
Contrast Yes/No	*No*

3 Plane Loc

Magnetic Resonance Spectroscopy PROton Brain Exam - Single Voxel; Echo Time 288 (PROBE-SV 288):

PROBE-SV 288

PATIENT POSITION	
Patient Entry	*Head First*
Patient Position	*Supine*
Coil Configuration	*GEM Head;GEM Neck*
Plane	*OBLIQUE*
Series Description	*PROBE-SV 288*
SCAN TIMING	
TE	*288.0*
Number of Echoes	*1*
TR	*2288.0*
IMAGE ENHANCE	
Filter Choice	*None*
GATING/TRIGGER	
Auto Trigger Type	*Off*
FMRI	
PSD Trigger	*Internal*
Slice Order	*Interleaved*
View Order	*Bottom/Up*
# of Repetitions REST	*0*
# of Repetitions ACTIVE	*0*
SAT	
Tag Type	*None*
TRICKS	
Pause On/Off	*On*
Auto Subtract	*0*
Auto SCIC	*Off*

IMAGING PARAMETERS	
Imaging Mode	*MRS*
Pulse Sequence	*Probe-P*
Imaging Options	*EDR*
SCAN RANGE	
FOV	*24.0*
Slice Thickness	*15.0*
Slice Spacing	*15.0*
Location per Slab	*1*
ACQ TIMING	
Freq	*1*
Phase	*1*
Freq DIR	*A/P*
NEX	*8.00*
Auto Shim	*Auto*
Phase Correction	*No*
USER CVS	
User CV3	*1.00*
User CV4	*128.00*
User CV18	*7.00*
MULTI-PHASE	
Seperate Series	*0*
Mask Phase	*0*
Mask Pause	*0*
DIFFUSION	
Recon All Images	*On*
CONTRAST	
Contrast Yes/No	*No*

PROBE-SV 288

Magnetic Resonance Spectroscopy PROton Brain Exam - Single Voxel; Echo Time 60 (PROBE-SV 60):

PROBE-SV 60

PATIENT POSITION	
Patient Entry	*Head First*
Patient Position	*Supine*
Coil Configuration	*GEM Head;GEM Neck*
Plane	*OBLIQUE*
Series Description	*PROBE-SV 60*
SCAN TIMING	
TE	*60.0*
Number of Echoes	*1*
TR	*2060.0*
IMAGE ENHANCE	
Filter Choice	*None*
GATING/TRIGGER	
Auto Trigger Type	*Off*
FMRI	
PSD Trigger	*Internal*
Slice Order	*Interleaved*
View Order	*Bottom/Up*
# of Repetitions REST	*0*
# of Repetitions ACTIVE	*0*
SAT	
Tag Type	*None*
TRICKS	
Pause On/Off	*On*
Auto Subtract	*0*
Auto SCIC	*Off*

IMAGING PARAMETERS	
Imaging Mode	*MRS*
Pulse Sequence	*Probe-P*
Imaging Options	*EDR*
SCAN RANGE	
FOV	*24.0*
Slice Thickness	*15.0*
Slice Spacing	*15.0*
Location per Slab	*1*
ACQ TIMING	
Freq	*1*
Phase	*1*
Freq DIR	*A/P*
NEX	*8.00*
Auto Shim	*Auto*
Phase Correction	*No*
USER CVS	
User CV3	*1.00*
User CV4	*64.00*
User CV18	*7.00*
MULTI-PHASE	
Seperate Series	*0*
Mask Phase	*0*
Mask Pause	*0*
DIFFUSION	
Recon All Images	*On*
CONTRAST	
Contrast Yes/No	*No*

PROBE-SV 60

3 Plane Localizer (3 Plane Loc):

3 Plane Loc

PATIENT POSITION	
Patient Entry	*Head First*
Patient Position	*Supine*
Coil Configuration	*GEM Head;GEM Neck*
Plane	*3-PLANE*
Series Description	*3 Plane Loc*
SCAN TIMING	
TE	*Minimum*
Number of Echoes	*1*
TR	*Minimum*
Receiver Bandwidth	*83.33*
IMAGE ENHANCE	
Filter Choice	*None*
GATING/TRIGGER	
Auto Trigger Type	*Off*
FMRI	
PSD Trigger	*Internal*
Slice Order	*Interleaved*
View Order	*Bottom/Up*
# of Repetitions REST	*0*
# of Repetitions ACTIVE	*0*
SAT	
Tag Type	*None*
TRICKS	
Pause On/Off	*On*
Auto Subtract	*0*
Auto SCIC	*Off*

IMAGING PARAMETERS	
Imaging Mode	*2D*
Pulse Sequence	*Spin Echo*
Imaging Options	*Seq, EDR, Fast, SS, ARC*
SCAN RANGE	
FOV	*24.0*
Slice Thickness	*10.0*
Slice Spacing	*3.0*
ACQ TIMING	
Freq	*256*
Phase	*128*
Freq DIR	*Unswap*
# of Acq. Before Pause	*0*
Phase FOV	*1.00*
Auto Shim	*Auto*
Phase Correction	*No*
USER CVS	
User CV1	*1.0*
User CV2	*240.00*
User CV13	*1.00*
MULTI-PHASE	
Seperate Series	*0*
Mask Phase	*0*
Mask Pause	*0*
DIFFUSION	
Recon All Images	*On*
CONTRAST	
Contrast Yes/No	*No*

3 Plane Loc

Optional Sequences:

---OPTIONAL SEQUENCES---

PATIENT POSITION	
Patient Entry	*Head First*
Patient Position	*Supine*
Coil Configuration	*GEM Head;GEM Neck*
Plane	*AXIAL*
Series Description	*---OPTIONAL SEQUENCES---*
SCAN TIMING	
TE	*150.0*
TR	*8000.0*
Receiver Bandwidth	*83.33*
IMAGE ENHANCE	
Filter Choice	*None*
GATING/TRIGGER	
Auto Trigger Type	*Off*
FMRI	
PSD Trigger	*Internal*
Slice Order	*Interleaved*
View Order	*Bottom/Up*
# of Repetitions REST	*0*
# of Repetitions ACTIVE	*0*
SAT	
Tag Type	*None*
TRICKS	
Pause On/Off	*On*
Auto Subtract	*0*
Auto SCIC	*Off*

IMAGING PARAMETERS	
Imaging Mode	*2D*
Pulse Sequence	*Spin Echo*
Imaging Options	*EDR, Fast, SS, Asset*
SCAN RANGE	
FOV	*25.6*
Slice Thickness	*3.0*
Slice Spacing	*0.3*
ACQ TIMING	
Freq	*128*
Phase	*128*
Freq DIR	*A/P*
# of Acq. Before Pause	*0*
Phase FOV	*1.00*
Auto Shim	*Auto*
Phase Correction	*No*
USER CVS	
User CV1	*1.0*
User CV2	*240.00*
User CV13	*1.00*
MULTI-PHASE	
Seperate Series	*0*
Mask Phase	*0*
Mask Pause	*0*
DIFFUSION	
Recon All Images	*On*
CONTRAST	
Contrast Yes/No	*No*

---OPTIONAL SEQUENCES---

Axial Diffusion Weighted Imaging (Ax DWI):

Ax DWI b1000

PATIENT POSITION	
Patient Entry	*Head First*
Patient Position	*Supine*
Coil Configuration	*GEM Head;GEM Neck*
Plane	*OBLIQUE*
Series Description	*Ax DWI b1000*
SCAN TIMING	
TE	*Minimum*
Number of Echoes	*1*
TR	*8000.0*
Number of Shots	*1*
IMAGE ENHANCE	
Filter Choice	*None*
GATING/TRIGGER	
Auto Trigger Type	*Off*
FMRI	
PSD Trigger	*Internal*
Slice Order	*Interleaved*
View Order	*Bottom/Up*
# of Repetitions REST	*0*
# of Repetitions ACTIVE	*0*
SAT	
Tag Type	*None*
TRICKS	
Pause On/Off	*On*
Auto Subtract	*0*
Auto SCIC	*Off*

IMAGING PARAMETERS	
Imaging Mode	*2D*
Pulse Sequence	*Spin Echo*
Imaging Options	*EPI, DIFF, Asset*
SCAN RANGE	
FOV	*20.0*
Slice Thickness	*4.5*
Slice Spacing	*0.0*
ACQ TIMING	
Freq	*128*
Phase	*128*
Freq DIR	*R/L*
Phase FOV	*1.00*
Auto Shim	*Auto*
Phase Correction	*Yes*
USER CVS	
User CV0	*1.00*
User CV5	*1.00*
MULTI-PHASE	
Seperate Series	*0*
Mask Phase	*0*
Mask Pause	*0*
DIFFUSION	
Optimized TE	*Yes*
Diffusion Directions	*128*
Number of Diffusion Directions	*4*
Number of T2 Images	*1*
Dual Spin Echo	*Off*
Recon All Images	*On*
CONTRAST	
Contrast Yes/No	*No*

Ax DWI b1000

Axial Susceptibility Weighted ANgiography (Ax SWAN):

Ax SWAN

PATIENT POSITION	
Patient Entry	*Head First*
Patient Position	*Supine*
Coil Configuration	*GEM Head;GEM Neck*
Plane	*OBLIQUE*
Series Description	*Ax SWAN*
SCAN TIMING	
Flip Angle	*15*
TE	*24.9*
Number of Echoes	*6*
TR	*Minimum*
Receiver Bandwidth	*62.50*
IMAGE ENHANCE	
Filter Choice	*None*
GATING/TRIGGER	
Auto Trigger Type	*Off*
MULTI-PHASE	
Seperate Series	*0*
Mask Phase	*0*
Mask Pause	*0*
DIFFUSION	
Recon All Images	*On*
CONTRAST	
Contrast Yes/No	*No*

IMAGING PARAMETERS	
Imaging Mode	*3D*
Pulse Sequence	*SWAN*
Imaging Options	*FC, Fast, ZIP2, Asset*
SCAN RANGE	
FOV	*20.0*
Slice Thickness	*2.0*
Location per Slab	*54*
Overlap Locations	*0*
ACQ TIMING	
Freq	*320*
Phase	*224*
Freq DIR	*A/P*
Phase FOV	*0.70*
Auto Shim	*Auto*
Phase Correction	*No*
FMRI	
PSD Trigger	*Internal*
Slice Order	*Interleaved*
View Order	*Bottom/Up*
# of Repetitions REST	*0*
# of Repetitions ACTIVE	*0*
SAT	
Tag Type	*None*
TRICKS	
Pause On/Off	*On*
Auto Subtract	*0*
Auto SCIC	*Off*

Ax SWAN

Axial T1 FLuid Attenuated Inversion Recovery (Ax T1 FLAIR):

Ax T1 FLAIR

PATIENT POSITION	
Patient Entry	Head First
Patient Position	Supine
Coil Configuration	GEM Head;GEM Neck
Plane	OBLIQUE
Series Description	Ax T1 FLAIR
SCAN TIMING	
Flip Angle	142
TE	24.0
TR	2700.0
TI	1112
Echo Train Length	8
Receiver Bandwidth	41.67
IMAGE ENHANCE	
Filter Choice	None
GATING/TRIGGER	
Auto Trigger Type	Off
FMRI	
PSD Trigger	Internal
Slice Order	Interleaved
View Order	Bottom/Up
# of Repetitions REST	0
# of Repetitions ACTIVE	0
SAT	
Tag Type	None
TRICKS	
Pause On/Off	On
Auto Subtract	0
Auto SCIC	On

IMAGING PARAMETERS	
Imaging Mode	2D
Pulse Sequence	T1flair
Imaging Options	FC, Seq, EDR, TRF, Fast, Asset
SCAN RANGE	
FOV	20.0
Slice Thickness	3.0
Slice Spacing	0.3
ACQ TIMING	
Freq	320
Phase	288
Freq DIR	Unswap
NEX	1.00
# of Acq. Before Pause	0
Phase FOV	1.00
Auto Shim	Auto
Phase Correction	No
Flow Direction Compensation	Slice
USER CVS	
User CV12	1.00
User CV22	1.00
MULTI-PHASE	
Seperate Series	0
Mask Phase	0
Mask Pause	0
DIFFUSION	
Recon All Images	On
CONTRAST	
Contrast Yes/No	No

Ax T1 FLAIR

Coronal Fast SPoiled Gradient Recalled echo BRAin VOlume imaging (COR FSPGR BRAVO):

COR FSPGR BRAVO

PATIENT POSITION	
Patient Entry	*Head First*
Patient Position	*Supine*
Coil Configuration	*GEM Head;GEM Neck*
Plane	*OBLIQUE*
Series Description	*COR FSPGR BRAVO*
SCAN TIMING	
Flip Angle	*13*
TI	*1400*
Receiver Bandwidth	*8.06*
IMAGE ENHANCE	
Filter Choice	*None*
GATING/TRIGGER	
Auto Trigger Type	*Off*
MULTI-PHASE	
Seperate Series	*0*
Mask Phase	*0*
Mask Pause	*0*
DIFFUSION	
Recon All Images	*On*
CONTRAST	
Contrast Yes/No	*No*

IMAGING PARAMETERS	
Imaging Mode	*3D*
Pulse Sequence	*BRAVO*
Imaging Options	*EDR, Fast, IrP, ZIP2, ARC*
SCAN RANGE	
FOV	*21.0*
Slice Thickness	*1.0*
Location per Slab	*150*
Overlap Locations	*0*
ACQ TIMING	
Freq	*200*
Phase	*200*
Freq DIR	*S/I*
NEX	*1.00*
Phase FOV	*0.80*
Auto Shim	*Auto*
Phase Correction	*No*
FMRI	
PSD Trigger	*Internal*
Slice Order	*Interleaved*
View Order	*Bottom/Up*
# of Repetitions REST	*0*
# of Repetitions ACTIVE	*0*
SAT	
Tag Type	*None*
TRICKS	
Pause On/Off	*On*
Auto Subtract	*0*
Auto SCIC	*Off*

COR FSPGR BRAVO

If lots of movement:

---if lots of movement---

PATIENT POSITION	
Patient Entry	*Head First*
Patient Position	*Supine*
Coil Configuration	*GEM Head;GEM Neck*
Plane	*AXIAL*
Series Description	*---if lots of movement---*
SCAN TIMING	
TE	*150.0*
TR	*8000.0*
Receiver Bandwidth	*83.33*
IMAGE ENHANCE	
Filter Choice	*None*
GATING/TRIGGER	
Auto Trigger Type	*Off*
FMRI	
PSD Trigger	*Internal*
Slice Order	*Interleaved*
View Order	*Bottom/Up*
# of Repetitions REST	*0*
# of Repetitions ACTIVE	*0*
SAT	
Tag Type	*None*
TRICKS	
Pause On/Off	*On*
Auto Subtract	*0*
Auto SCIC	*Off*

IMAGING PARAMETERS	
Imaging Mode	*2D*
Pulse Sequence	*Spin Echo*
Imaging Options	*EDR, Fast, SS, Asset*
SCAN RANGE	
FOV	*25.6*
Slice Thickness	*3.0*
Slice Spacing	*0.3*
ACQ TIMING	
Freq	*128*
Phase	*128*
Freq DIR	*A/P*
# of Acq. Before Pause	*0*
Phase FOV	*1.00*
Auto Shim	*Auto*
Phase Correction	*No*
USER CVS	
User CV1	*1.0*
User CV2	*240.00*
User CV13	*1.00*
MULTI-PHASE	
Seperate Series	*0*
Mask Phase	*0*
Mask Pause	*0*
DIFFUSION	
Recon All Images	*On*
CONTRAST	
Contrast Yes/No	*No*

---if lots of movement---

Single Shot T2 Turbo Spin Echo (SS T2 TSE – MOTION TOL):

SS T2 TSE - MOTION TOL

PATIENT POSITION	
Patient Entry	Head First
Patient Position	Supine
Coil Configuration	GEM Head;GEM Neck
Plane	AXIAL
Series Description	SS T2 TSE - MOTION TOL
SCAN TIMING	
TE	150.0
TR	8000.0
Receiver Bandwidth	83.33
IMAGE ENHANCE	
Filter Choice	None
GATING/TRIGGER	
Auto Trigger Type	Off
FMRI	
PSD Trigger	Internal
Slice Order	Interleaved
View Order	Bottom/Up
# of Repetitions REST	0
# of Repetitions ACTIVE	0
SAT	
Tag Type	None
TRICKS	
Pause On/Off	On
Auto Subtract	0
Auto SCIC	Off

IMAGING PARAMETERS	
Imaging Mode	2D
Pulse Sequence	Spin Echo
Imaging Options	EDR, Fast, SS, Asset
SCAN RANGE	
FOV	25.6
Slice Thickness	3.0
Slice Spacing	0.3
ACQ TIMING	
Freq	128
Phase	128
Freq DIR	A/P
# of Acq. Before Pause	0
Phase FOV	1.00
Auto Shim	Auto
Phase Correction	No
USER CVS	
User CV1	1.0
User CV2	240.00
User CV13	1.00
MULTI-PHASE	
Seperate Series	0
Mask Phase	0
Mask Pause	0
DIFFUSION	
Recon All Images	On
CONTRAST	
Contrast Yes/No	No

SS T2 TSE - MOTION TOL

Axial T1 FLuid Attenuated Inversion Recovery PROPELLER (Ax T1 FLAIR PROPELLER):

Ax T1 FLAIR PROPELLER

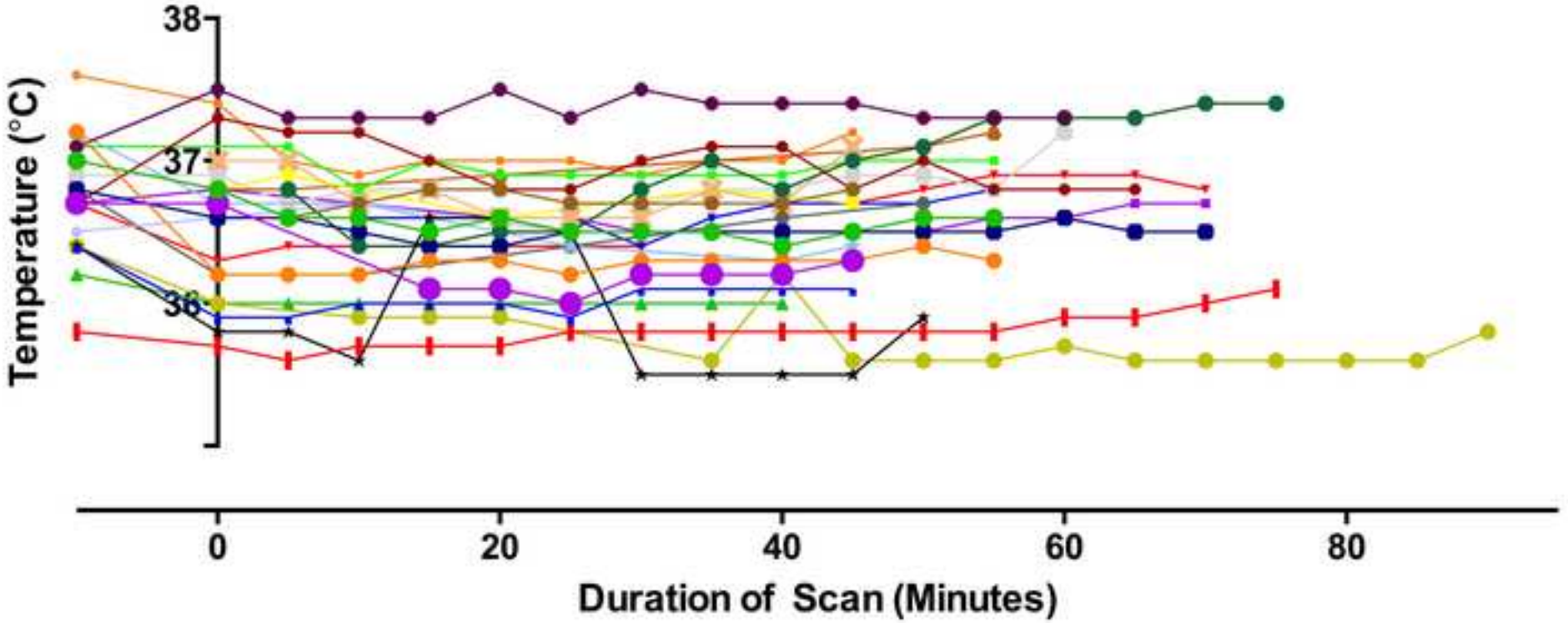
PATIENT POSITION	
Coil Configuration	*CT Spine 48*
Plane	*Oblique*
SCAN TIMING	
Flip Angle	*110.0Degrees*
TE	*36.48ms*
TR	*1.572s*
TI	*565.0ms*
Echo Train Length	*12*
Receiver Bandwidth	*50.0KHz*
ACQ TIMING	
Freq	*256*
Phase	*16*
NEX	*2.0*
Phase FOV	*21.0cm*

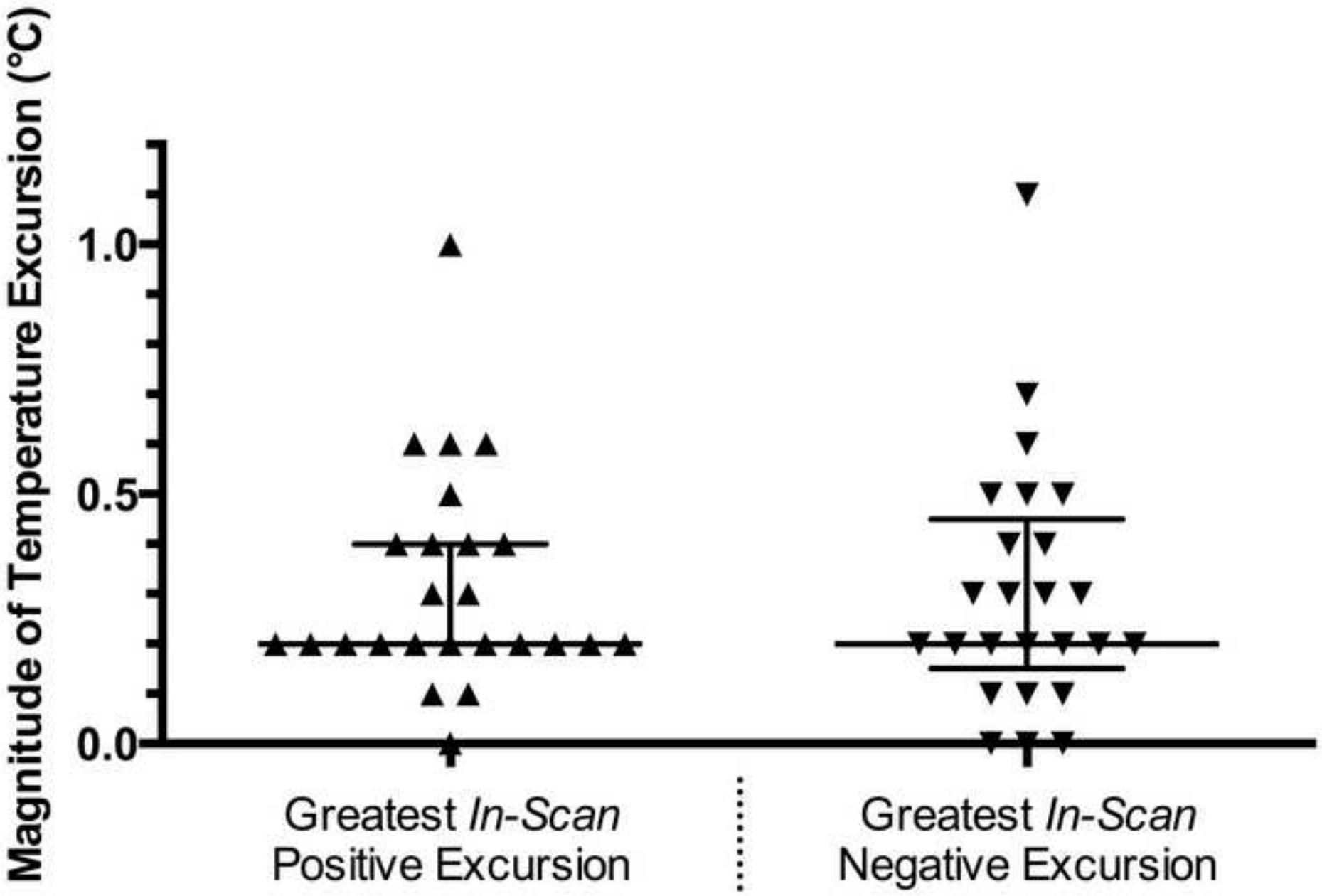
IMAGING PARAMETERS	
Gradient Mode	*NA*
SCAN RANGE	
FOV	*21.0cm*
Slice Thickness	*2.0mm*
Slice Spacing	*1.0mm*

Ax T1 FLAIR PROPELLER

Table 2; online only

MR Sequence	Specific Absorption Rate (Watts/Kg: Averaged over 6 minutes)					
	Infant A			*Infant B*		
	Whole Body	***Local Peak***	***Partial Body***	***Whole Body***	***Local Peak***	***Partial Body***
SURVEY	2.00	4.00	2.00	2.00	4.00	2.00
T1 BRAVO	0.21	0.41	0.21	0.21	0.42	0.21
T2 TSE	1.55	3.10	1.55	1.80	3.60	1.80
SWI	0.20	0.41	0.20	0.22	0.43	0.22
DWI	0.45	0.90	0.45	0.39	0.78	0.39
T1 FLAIR	1.73	3.46	1.73	1.63	3.26	1.63
T2 FLAIR	1.45	2.90	1.45	1.58	3.17	1.58
MRS 288	0.44	0.88	0.44	0.45	0.90	0.45
MRS 60	0.48	0.97	0.48	0.50	1.00	0.50


Temperature (°C)
38
37
36
0
20
40
60
80
Duration of Scan (Minutes)


Magnitude of Temperature Excursion (°C)
1.0
0.5
0.0
Greatest *In-Scan*
Positive Excursion
Greatest *In-Scan*
Negative Excursion