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"Air bubble artefact"

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Title: "Air bubble Artefact": A new type of artefact on CT heads.

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We present a new type of artefact on CT heads due to presence of air bubbles in tube oil cooling system, thereby calling it "Air bubble artefact". It was seen to be present inconsistently and was very variable in its presence, number, location and side. It initially went unexplained and undetected by usual physics checks and caused clinical concerns in several patients. Eventually, it was only confirmed when a scan was instantly repeated in another similar scanner immediately and subsequently confirmed by equipment manufacturer. All patient scanned in this duration were subsequently audited. The technical issues related to this artefact and its global repercussions have been discussed.

1 **“Air bubble Artefact”**: A new type of artefact on CT heads.

2 **Introduction**

3 Artefacts on CT images have been known for decades and have been widely described in literature.
4 These are usually attributed to equipment issues, the physical processes of CT acquisition, such as
5 beam hardening and partial volume effect, and those caused by the patient, such as patient motion.
6 These have been well documented [1-3] and much work has been carried out to reduce these
7 artefacts [3-7]. As a result, these have generally reduced over a period of time and we are not aware
8 of a new artefact described in recent times.

9 We came across a new type of artefact on CT heads in one of our CT scanners, which was
10 inconsistent in occurrence, number and location and mimicked pathologies. Since it was a new
11 artefact, it initially went unrecognised which resulted in inappropriate reports and in some cases,
12 unnecessary clinical concerns and intervention. Despite suspicion, it was initially not identified on
13 quality checks and phantom studies. It was later confirmed by the equipment manufacturer to be
14 due to presence of air bubbles in the tube oil cooling system and the fault was rectified.

15 **Departmental setting**

16 We are a tertiary care 800 bedded Scottish institution including neurosurgical, stroke and neuro-
17 oncology centres, with 18 consultant radiologists (including 2 neuroradiologists) and registrars. We
18 have a dedicated CT scanner for inpatients (GE_Lightspeed VCT) that scans about 300 CT heads each
19 month. We have highly experienced and qualified CT radiographers and dedicated medical physics
20 support from two Medical Physics Experts.

21 **Quality assurance**

22 We have a robust quality assurance program in place to monitor image quality and patient dose. This
23 can be separated into Level A (weekly radiographer led) and Level B (annual physics led) quality

1 control (QC) tests performed according to manufacturer recommendations and published standards
2 [8]. The weekly Level A QC protocol uses the manufacturer specific phantom designed by GE (22cm
3 diameter, water-filled acrylic phantom). These tests cover slice width, CT number, noise, high
4 contrast resolution, and low contrast detectability. CT number and noise (standard deviation) are
5 measured using the measurement tools on the CT console. Four axial images and a single helical
6 image are acquired in the water filled portion of the phantom. For each image an elliptical region of
7 interest (ROI) is selected with a default size of 675mm² and automatically placed in the centre of the
8 image. The mean CT number and standard deviation (noise) are recorded and compared with
9 tolerance levels. The manufacturer tolerance for CT number of water is ± 3 Hounsfield units, the
10 tolerance for standard deviation is baseline $\pm 15\%$. Level B QC is performed as recommended by
11 IPEM Report 91 [8].

12 **Sequence of Events**

13 **A. Initial Clinical Events**

14 In October 2015, **initially** 2 patient scans were brought to the attention of the neuroradiologists by
15 clinical colleagues. These had been performed over the last few days and the patients had presented
16 with headache and neurological deficits. They had several ill-defined areas of low attenuation in
17 cerebral hemispheric white matter (Figures 1 and 2). Subsequently, they had MRI scans within the
18 next few days. MRI of one patient only had a single infarct while other changes were no longer
19 identified (Figure 1). MRI of second patient did not show any of the changes seen on CT (Figure 2).
20 The symptoms had also improved, so it was assumed that the changes represented a “reversible”
21 aetiology such as reversible cerebral vasoconstriction syndrome (RCVS) or posterior reversible
22 encephalopathy syndrome (PRES), complicated by an infarct in 1st patient, although the
23 “improvement” was thought to be “too soon”. **More patients were identified over the next few days,**
24 **some with multiple somewhat similar ill-defined areas of low attenuation in the cerebral**
25 **hemispheres on both sides, while some others had isolated abnormality (Figure 3) without**

1 **corresponding clinical deficits.** A random check of some of the CT heads over a few days was
2 performed which did not show significant changes. A literature review was performed, where
3 despite extensive search, no such artefact was recognised. However, the clinical colleagues were
4 questioned about drug abuse or hypertension history, which was negative. The medical physics
5 department was also contacted.

6 **B. Initial Physics Check**

7 The medical physics experts (MPE) attended the scanner and discussed the Level A QC with the Lead
8 Radiographer. No issues had been reported with the Level A QC which had passed all quantitative
9 tests. The results of the Level A QC were reviewed and found to be within tolerance. Further tests
10 were performed using a CATPHAN 424 Series (The Phantom Library Incorporated, NY) and CTDI
11 Perspex head phantom (16cm diameter). CT number, noise and uniformity were tested using the
12 water-filled portion of the CATPHAN (Table 1). The mean CT number and standard deviation were
13 recorded for elliptical ROIs (350mm²) placed at the centre, 12, 3, 6, and 9 o'clock positions. To
14 calculate the uniformity, the difference in the mean CT number between each of the peripheral ROIs
15 and the central ROI was calculated. The uniformity was then defined as the maximum difference in
16 the mean CT number at the peripheral ROIs versus the centre ROI. The values measured were then
17 compared to baseline and checked against tolerances. All results were measured to be within
18 tolerance.

19 As the suspected artefact was seen on clinical images which are acquired helically the artefact was
20 investigated further using the CTDI Perspex head phantom scanned using the clinical acquisition
21 protocol. These images were visually inspected at various window levels and widths; however, the
22 artefact was not originally identified on these images. It was assumed that there was no technical
23 issue with the scanner.

24 **C. Subsequent Clinical events**

1 Since no evidence of a technical issue with the scanner was found, it was decided that the scanner
2 would continue to be used for CT heads. Over the next few days, some further similar cases **were**
3 **identified and** brought to the attention of clinical colleagues about potential, yet uncertain artefacts.
4 A couple of these had subsequent MRIs which did not show these changes, however, there was
5 again a few days gap and it was still uncertain if these changes were real and “reversible”, or
6 artefactual. The CT radiographers were therefore requested to bring to immediate notice, any
7 further instance while the patient was still on table. **Eventually,** one such patient was identified with
8 a similar area of low attenuation in left cerebral hemisphere (Figure 3). **Following discussion and**
9 **verbal consent, the patient** was rescanned on the outpatient scanner (GE Lightspeed VCT) within 15
10 minutes. The second CT was normal and it was therefore confirmed that the appearances must be
11 artefactual (Figure 4). As this artefact was only being seen on CT heads, it was immediately decided
12 to stop using the scanner in question for CT Heads pending further investigations.

13 **D. Reporting to Equipment manufacturer**

14 The site immediately contacted GE **engineers** who were able to access the scanner logs and
15 determine through remote monitoring that air was present in the tube oil cooling system. This could
16 result in an artefact on clinical images if the air bubble was within the primary beam at the x-ray
17 tube output window at any point during the rotation. GE identified that the scanner had exceeded
18 the tolerance level measuring air in the tube oil cooling system 4 weeks previously.

19 **E. Subsequent Physics Checks**

20 Following this information from GE, all images relating to the investigation of the artefact were
21 reviewed by the Lead Radiographer and MPE. The Level A QC images were reviewed for the four
22 week period. As is routine, these images were viewed on the CT console at the default window level
23 of 40 with a width of 400. The artefact was found to be visible in at least one image on two of the
24 four Level A QC image series. In one case the presentation was subtle and was unlikely to be

1 identified without cause to suspect that an artefact may be present. However, in the second case
2 the artefact was clearly identifiable even at the wide window width used for default viewing of the
3 Level A QC.

4 The CATPHAN and CTDI Perspex head phantom images were also reviewed. The artefact was not
5 identifiable on the CATPHAN images but could be seen on images of the Perspex head phantom
6 acquired using the clinical CT Head protocol (Figure 5). In this case the motion of the air in the tube
7 oil cooling system could be seen in the phantom as the tube rotated when scrolling through the
8 images. This required a narrow window width of 40 in order to clearly identify the artefact on the CT
9 console.

10 Table 2 demonstrates that while the artefact was visible in the image when viewed using a narrow
11 window width, this image would pass the quantitative test based on the current tolerance level. The
12 small variation in CT number caused by air in the tube oil cooling system is sufficient to cause the
13 artefact to appear in clinical CT Head images which may then be mistaken for pathology.

14 **F. Resolution**

15 The air was removed from the tube oil cooling system by a service engineer.

16 **G. Review of CT Images of potentially affected patients**

17 Since the air bubbles were potentially present in the system for about 4 weeks, all CT head scans
18 performed over that period (315) were **urgently** reviewed by a group of radiologists led by
19 neuroradiologists. **It was required by the organisation as part of standard care and to deal with any**
20 **outstanding clinical issues and no ethical approval was deemed necessary.** It was identified that
21 there were 56 scans, where either potential artefacts were present or the background white matter
22 changes may have appeared exaggerated due to artefacts. An addendum was added in such reports,
23 requesting clinical colleagues to review those patients and request further investigations if necessary
24 **to address any outstanding clinical issues.** The matter was discussed by management and felt that

1 the response of the radiology department was adequate and commendable and that any clinical
2 governance issues that may arise will be appropriately dealt with by the responsible clinical
3 colleagues on a case to case basis.

4 **H. Further governance and review of QC**

5 Since there was no automatic alarm that may have indicated this specific technical issue, it has been
6 strongly felt that the equipment manufacturers must review the system checks. We are discussing
7 tolerance levels and timely intervention with GE to minimise the likelihood of future artefacts
8 caused by air in the tube oil cooling system.

9 On the local level, the Level A and Level B quality control tests have been reviewed. While inspection
10 of the QC images for artefacts was previously intended to form part of the Level A test, there was no
11 formal system of feedback in place. An additional acquisition has been added to the weekly tests
12 using the water-filled portion of the GE QC phantom to acquire a helical image series which will be
13 visually inspected at the full range of window levels and widths. Radiographers will notify physics of
14 any artefacts that may appear. A similar test will be included in Level B tests.

15 **Discussion**

16 “Areas of low attenuation” in CT heads are a fairly non specific finding and may represent areas of
17 ischaemia, inflammatory conditions such as vasculitis and demyelination, tumours, oedema and
18 reversible changes such as RCVS and PRES. The diagnosis is often guided by the clinical presentation
19 and subsequent course/follow up. While a large number of CT artefacts have been described in
20 literature, the “air bubble artefact” has not been previously reported. We have not come across a
21 similar CT artefact in literature that presents as ill-defined areas of low attenuation, that happen
22 inconsistently (most scans were actually negative for these), can differ in density, are single or
23 multiple, can be unilateral or bilateral. Indeed, various radiology colleagues thought these changes
24 to be real; and based on the number and location, these were mostly labelled as areas of

1 ischaemia/infarcts, but some were thought to be vasculitis, demyelination and tumours, while those
2 that were demonstrated to be reversible were thought to be due to RCVS and/or PRES. The
3 radiology audit performed, focussed on the identification of patients with such artefacts and
4 addition of addenda to inform clinical colleagues for further action, we did not perform a detailed
5 clinical audit of adverse patient outcomes. However, it is clear from discussions with clinical
6 colleagues that some adverse clinical events happened: these included unnecessary treatments such
7 as steroids, inappropriate initial diagnosis, unnecessary further investigations and unnecessary
8 alarms, causing distress.

9 Once the gas bubbles enter the tube oil cooling system, the mechanism of this artefact is thought to
10 be fairly straightforward. The gas bubbles lower the overall attenuation value of the x-ray beam by
11 less than 3HU. Since the number of gas bubbles would be variable and they would unpredictably
12 cross the x-ray beam, it explains the inconsistency of the artefacts in terms of position and number,
13 while majority of CT heads were actually negative for these. Due to low HU values involved, these
14 were visible only on the window setting used for CT heads.

15 During departmental deliberations, we discussed if it was possible to confidently identify these as
16 artefacts earlier. In the absence of any description of such an artefact in the literature, and none of
17 the radiologists able to recall a similar example from experience, it was indeed difficult to
18 confidently call these CT changes as artefacts. While early in the course of events, it was certainly
19 felt that these changes were unusual, the physics checks were reassuring and in retrospect, clearly
20 not tailored to pick these up, despite using standard guidelines.

21 During the review of cases, we did come across a "missed opportunity". Some of the CT heads were
22 performed twice as part of CT head/CT venogram and CT heads (pre and post contrast). While most
23 of these were negative for artefacts, in one instance, we identified it to be present on non contrast
24 images but not on the postcontrast images (Figure 6). However, the changes were very subtle and
25 the reporting radiologist did not recognise it.

1 On a local level, it was surprising that the standard quality control checks did not detect these
2 changes, either because the changes were within tolerance limits or the standard window settings
3 were unsuitable for the purpose. It is important to realise that standard brain interpretation uses a
4 narrow window width and since minor changes in Hounsfield units (HU) can have significant changes
5 in brain images. The tolerance limits should take this factor into account and a wide range of window
6 settings should therefore be used during QC. One of the most important learning points has been
7 the demonstration of the importance of the balance between quantitative and qualitative testing
8 and the realisation that there has to be an element of subjectivity as well as objectivity in the CT QC
9 process. We have since modified our standard quality control checks to be able to detect these
10 changes in future (Section H above). It is likely that other sites across the world have not recognised
11 these shortcomings with their QC and it is important that they review their processes. It is also an
12 opportunity to highlight that the IPEM 91 recommendations for QA are old (2005) and there has
13 been considerable advancement in CT technology since then, both in terms of detector technology,
14 dose control technologies, width of cone beams and reconstruction algorithms. There is therefore a
15 risk that artefacts related to these technologies may not be adequately detected, until such time as
16 adequate procedures are developed. In this instance, it is however unlikely that it would have made
17 any difference to the outcome. It is also important to emphasise that since the artefact has been
18 very subtle, the review of QA images is ideally done in an environment optimised for viewing of
19 images (i.e. the reporting room, with a PACS workstation, calibrated diagnostic monitor and
20 controllable lighting).

21 It was indeed disappointing that there was no automatic mechanism in the scanner, which would
22 have alerted the radiographers to the presence of air bubbles in the cooling oil. We have raised this
23 issue with GE. However, it is likely that other manufacturers have similar shortcomings and it is
24 important that all equipment manufacturers review their systems and suitably modify them.
25 Interestingly, GE informed us that newer GE scanners have an automatic alert system to warn users
26 when there is a danger of bubbles being present in the cooling system, BEFORE they can cause

1 visible artefacts. The issue has been reported to the appropriate regulatory authorities and
2 discussions are ongoing regarding formulation of a process whereby scanners that predate the
3 automatic alert system can be monitored at least as part of the manufacturer's preventative
4 maintenance procedures.

5 **Conclusion**

6 We have identified a new type of artefact "the air bubble artefact" due to presence of air bubbles in
7 the tube oil cooling system. It is inconsistent in appearances and can mimic several aetiologies, with
8 the provisional diagnosis being suggested by the clinical presentation resulting in inappropriate
9 clinical interventions. It is likely that the routine QC performed by various organisations worldwide is
10 not adequate to prospectively detect these. It is also possible that several equipment manufacturers
11 are also unaware of this potential problem and there is a lack of automatic alarms in the systems. It
12 is important that the radiologists, CT radiographers, medical physics experts and CT equipment
13 manufacturers become aware of this artefact and take remedial measures wherever necessary, for
14 timely detection and rectification.

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9 diagnostic x-ray imaging systems. York, UK: IPEM; 2005

10 Figure 1: Non contrast CT images (a-d) and MR images: DWI (e) and T2 axials (f-i). Several areas of
11 low attenuation on CT (white arrows from b-d) that were not seen on MRI. A further area of low
12 attenuation on CT (black arrow in a,b), persistent on MRI, as diffusion abnormality in e and T2
13 abnormality on f,g consistent with actual infarct.

14 Figure 2: Non contrast CT images (a-e) and MR images T2 axials (f-i). Several areas of low attenuation
15 on CT (white arrows from a-e) that were not seen on MRI.

16 Figure 3: Non contrast CT (a) shows focal low attenuation (white arrow) in left thalamus, not seen
17 on MRI T2 (b) and FLAIR (c).

18 Figure 4: Initial Non contrast CT images in axial and coronal reconstructions (a,b) showing low
19 attenuation area (White arrow). Repeat CT within 15 minutes on a similar type of scanner (c,d) is
20 normal.

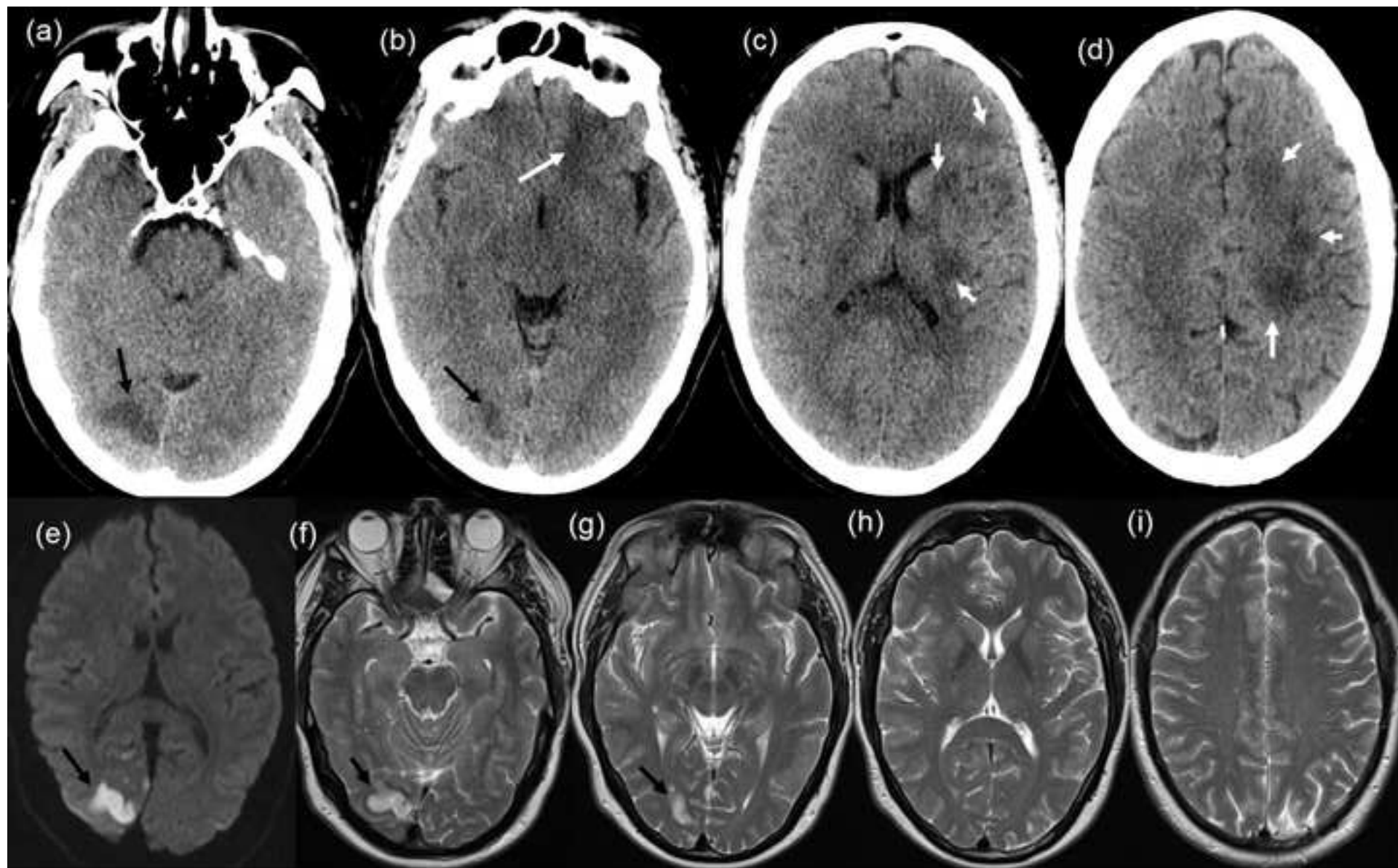
21 Figure 5a)-c) CT images of the CTDI Perspex Head Phantom acquired using the clinical CT Head
22 protocol, viewed at window level 100 and width 40. Image a) no artefact is visible. Images b) and c)
23 the artefact is visible as the air in tube oil cooling system was present in the primary beam at the x-

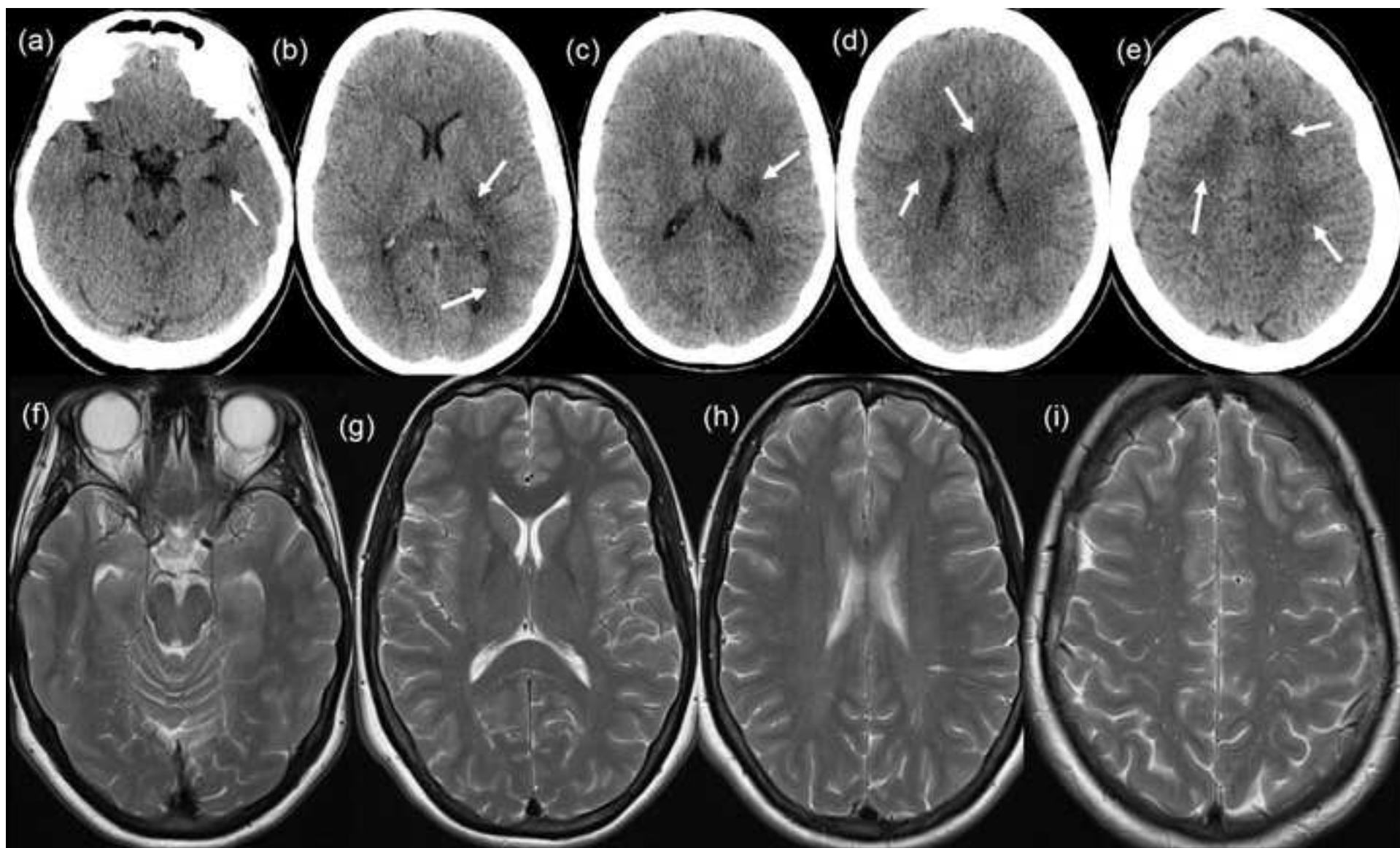
1 ray tube output window during the rotation. The position and degree of artefact varies greatly
2 throughout the series due to the motion of the air bubble.

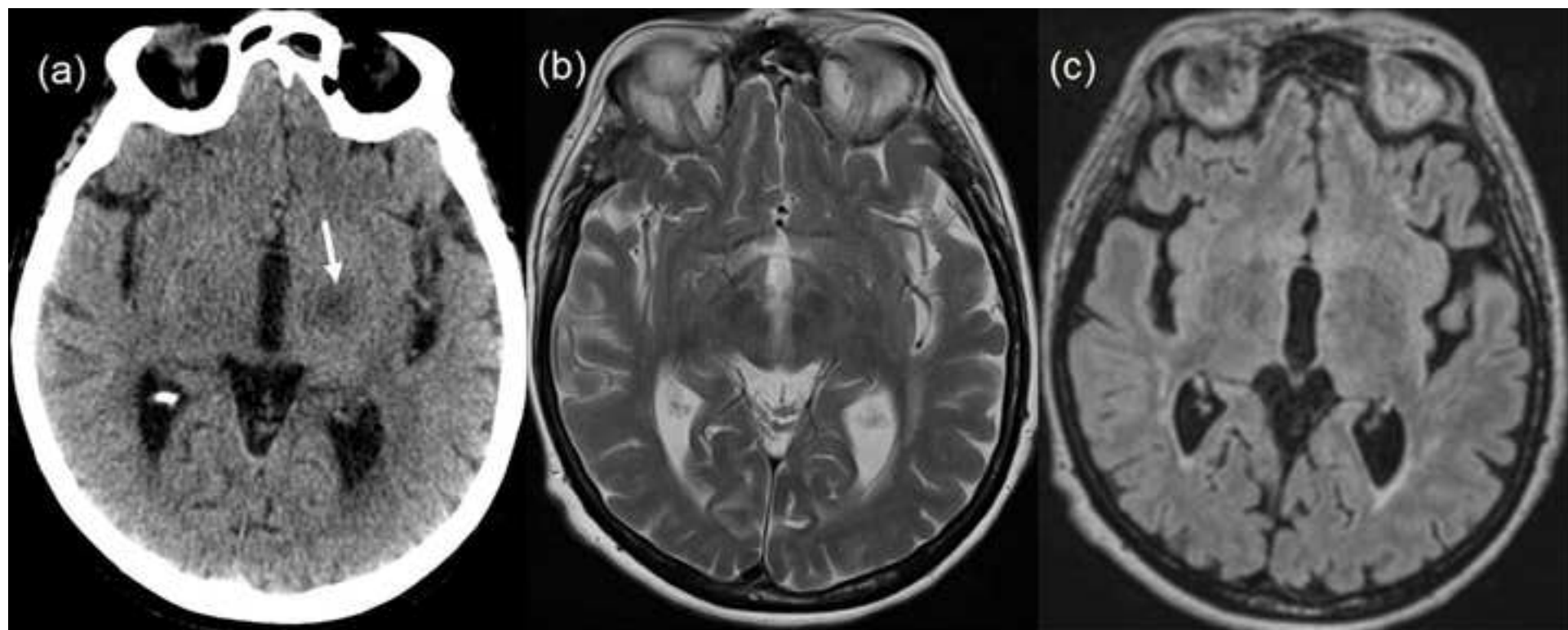
3 Figure 6: Missed opportunity. Initial non contrast CT (a) showing area of low attenuation on left side
4 (white arrow). It is not seen on the corresponding post contrast image (b)

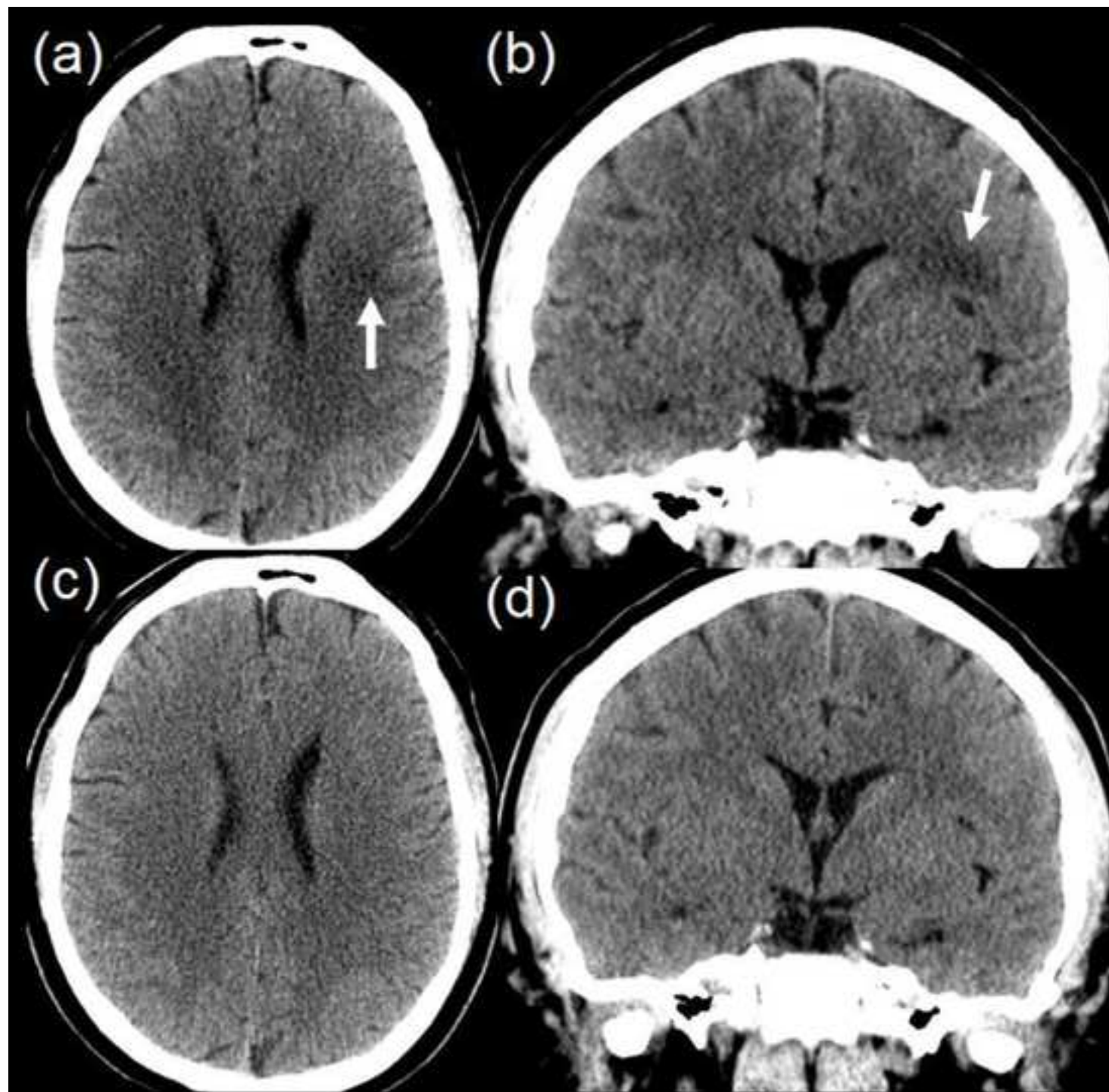
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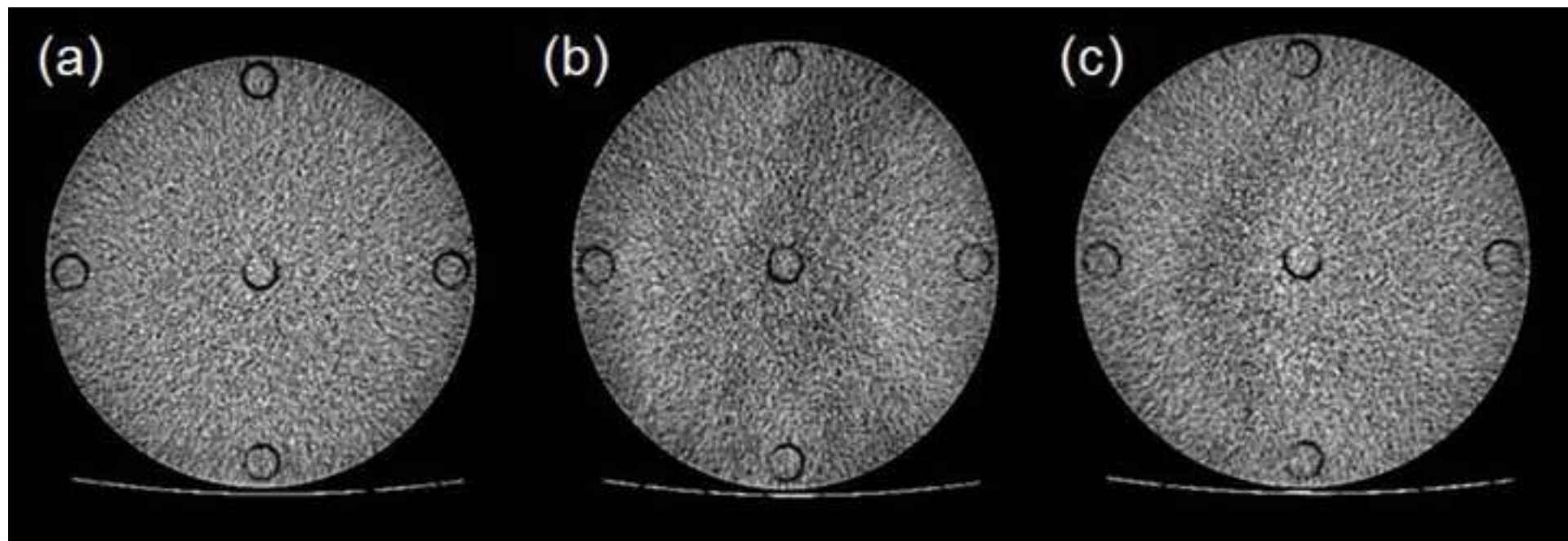
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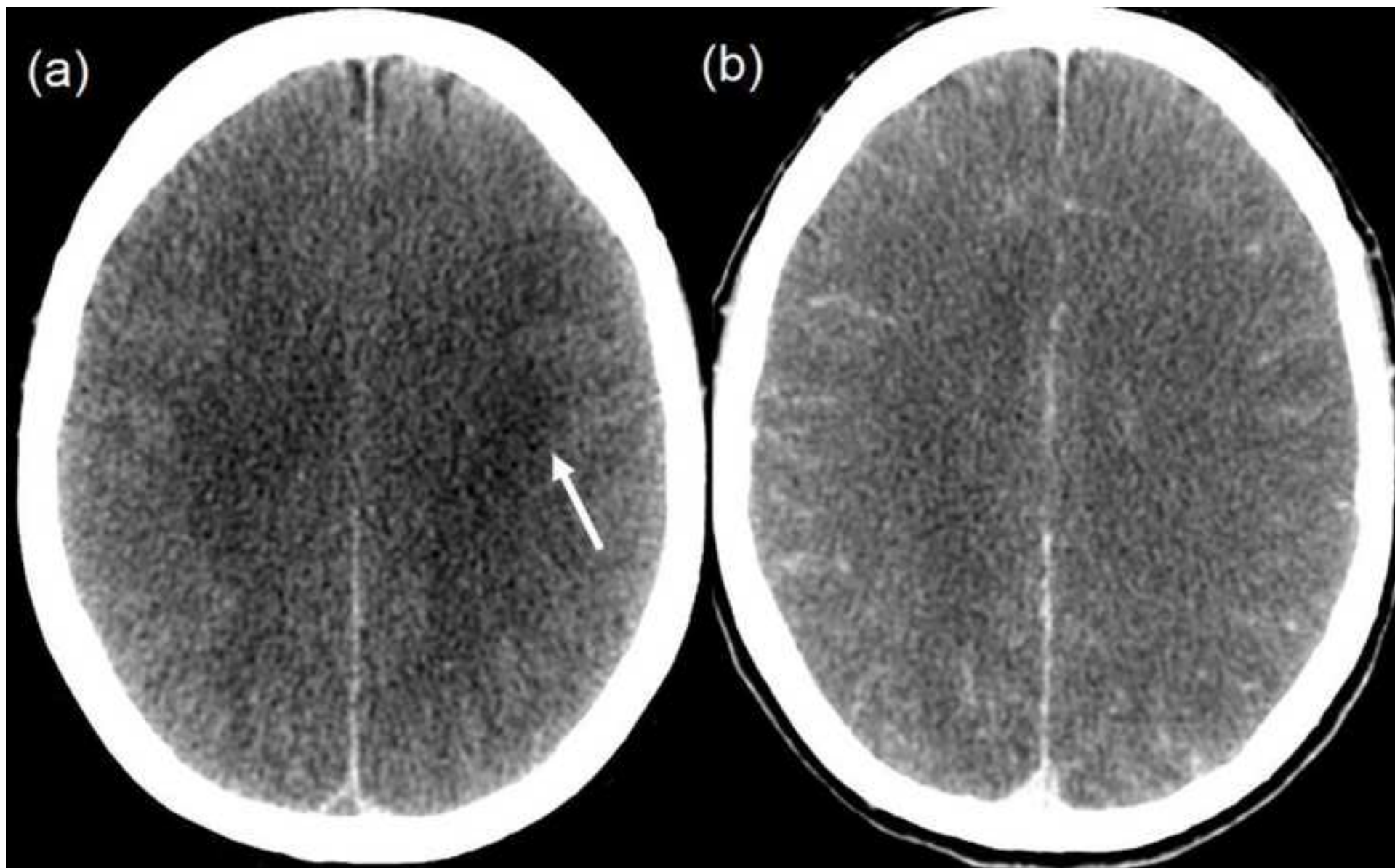


Table 1: Local Quality Control tests and tolerances for artefact investigation

Quality Control	Test	Phantom	Tolerance (HU)	Result of Investigation
Level A	Mean CT# Water	GE QC	± 3	PASS
	Noise (standard deviation)	GE QC	3.2 – 4.4 (axial) 9 – 12.1 (helical)	PASS
Level B	Mean CT# Water	CATPHAN 424	± 3	PASS
	Noise (standard deviation)	CATPHAN 424	4.2 – 5.1	PASS
	Uniformity	CATPHAN 424	± 10	PASS (within ± 3 HU)
	Uniformity	CTDI Perspex Head Phantom	Visual inspection - subjective	PASS

Table 1: CT# measurements in CTDI Perspex Head phantom following identification of artefact

Measurement		Difference in mean CT#
Position in phantom	Mean CT# Perspex	from centre
Centre	121.6	
12 o'clock	120.3	-1.3
3 o'clock	121.6	0.0
6 o'clock	122.8	1.2
9 o'clock	121.9	0.3
Artefact	118.9	-2.7

- Air bubble artefact is a new type of CT artefact on CT heads
- It is produced by gas bubbles in tube oil cooling system
- It can cause inconsistent, illdefined areas of low attenuation mimicking pathologies.
- The usual physics checks and QC may be inadequate to confirm these.
- Equipment manufacturers may lack automatic alarms to detect these.