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FULL PAPER

A review of cross-sectional imaging, ultrasound and nuclear medicine utilization patterns in paediatric patients in Ireland, 2003–12

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Objective: Recent trends in paediatric imaging have been examined in Australia and the USA. Such literature in Europe is sparse, incomprehensive and outdated. This research investigated (1) population-based trends in the use of advanced medical imaging in children in Ireland from 2003 to 2012; (2) its use across age and gender; and (3) the most commonly performed examinations within each modality.

Methods: A retrospective cohort analysis study was carried out within Irish paediatric hospitals. All CT, MRI, ultrasound and nuclear medicine (NM) annual examination data from 2003 to 2012 was obtained from radiology information systems.

Results: 224,173 imaging procedures were carried out on 84,511 patients, 68% of which were ultrasound, 15% were MRI, 11% were CT and 6% were NM. Between 2003 and

2012, MRI (+280%) and CT (+80%) saw the largest increases in use, followed by ultrasound (+67%) and NM (+10%). Almost half of the study population were less than 3 years old. CT imaging was more frequent than MR in 2005. By 2012, MR rates were twice that of CT. CT imaging rates were the lowest in the youngest age categories.

Conclusion: Advanced imaging use, particularly MRI, has risen substantially over the past 10 years. The utilization of non-ionizing modalities increased between 2003 and 2012, especially in brain, spinal and abdominal imaging. MR is now used at twice the frequency of CT.

Advances in knowledge: Longitudinal advanced imaging utilization trends, including CT trends, have been established in the Irish paediatric population.

The use of advanced diagnostic imaging has increased considerably over the past two decades, particularly amongst the paediatric population.^{1–3} Advanced imaging modalities used in paediatric radiology include ultrasound, CT, MRI and nuclear medicine (NM).⁴ The quest for safer, more accurate and interpretive-efficient diagnoses has driven technological advances in imaging.⁴ As a result, the quality of information that imaging can provide has significantly improved; this has led to a higher quality of care and reduced patient morbidity and mortality.⁴

While there are many benefits to diagnostic imaging, there are also some risks worth considering. Some advanced imaging modalities such as CT and NM involve ionizing radiation and radioactive material that can be detrimental to patient's health. CT represents just 10% of all imaging modalities that use ionizing radiation; yet, it delivers >50% of the total collective dose in diagnostic imaging.^{5,6} The radiation burden of CT and NM is a major concern, particularly when imaging children.^{6,7} Children are at higher

risk of developing radiation-induced cancers than are adults because their developing tissues are more sensitive to radiation.⁸ Their likelihood of repeat examinations and longer life expectancy allows additional time for the emergence of detrimental effects.^{9–11}

To date, initiatives such as the Image Gently campaign by the Alliance for Radiation Safety in Paediatric Imaging have been established to increase awareness of the opportunities to promote radiation protection when imaging children.¹² The European Society of Radiology recently launched a similar campaign, the EuroSafe Imaging Campaign 2014, to further promote quality and radiation safety in medical imaging. To successfully develop further initiatives and to monitor the success of existing initiatives, it is necessary to analyse the trends in diagnostic imaging over time.

Longitudinal studies on the use of paediatric imaging involving radiation have been examined in Australia² and the USA.^{3,13} Such literature in Europe is sparse and outdated.

The Irish healthcare system currently consists of three tertiary referral paediatric hospitals, located in county Dublin. While paediatric imaging does take place infrequently in regional hospitals, these three specialist centres perform the vast majority, owing to the expertise available therein. This study aimed to investigate the trends in advanced paediatric imaging in Ireland from 2003 to 2012, its use across paediatric age groups and genders, and the most commonly performed procedures in each specialist modality.

METHODS AND MATERIALS

An exemption from ethical review was obtained from the local institution on the basis that no identifying patient data were being collected and that the participating sites would be anonymized.

Permission was obtained from each hospital prior to data collection. A retrospective cohort analysis study was carried out within each paediatric hospital in Ireland ($n = 3$). The following advanced imaging modalities were included: CT, MRI, ultrasound and NM, as these were available in each centre, with none currently having a positron emission tomography (PET)/CT facility. Data were obtained from the radiology information systems (RIS) within each hospital. CT, MRI, ultrasound and NM data were collected for each year between 2003 and 2012. The retrieved data included the type and number of imaging procedures performed in each modality per annum, the number of patients who underwent each imaging procedure and the patient demographics at the time of examination (age and gender). Each modality was categorized anatomically using the Abington Radiology Ordering Guide (Table 1).¹⁴

Whether these examinations were performed with or without contrast did not change the categorizations. Using patient and examination count data, the rate of examinations per patient was calculated for each age group, gender, anatomical location and modality individually.

The number and types of imaging procedures performed in the study population were described using simple descriptive

statistics. Study population-based rates of use were calculated where the numerators were the cumulative number of imaging procedures performed in an individual category and the denominators were the total number of children in that particular category. For these analyses, children were categorized based on their age at the time of the examination (ages 0 to <3, 3 to <6, 6 to <9, 9 to <12, 12 to <15 and 15–18 years) and gender. Imaging rates for each age group were reported per 1000 eligible patients, that is, the CT imaging rate for 0–3 year olds was calculated by dividing the number of CT examinations performed on 0–3 year olds by the total number of 0- to 3-year-old children in this study. Population-based rates were also calculated using Irish population data obtained from the Central Statistics Office census population database to allow for further comparison of trends internationally.¹⁵

RESULTS

Between 2003 and 2012, 224,173 advanced imaging procedures were carried out on 84,511 patients. Of these imaging procedures, 68% were ultrasound, 15% were MRI, 11% were CT and 6% were NM (Figure 1).

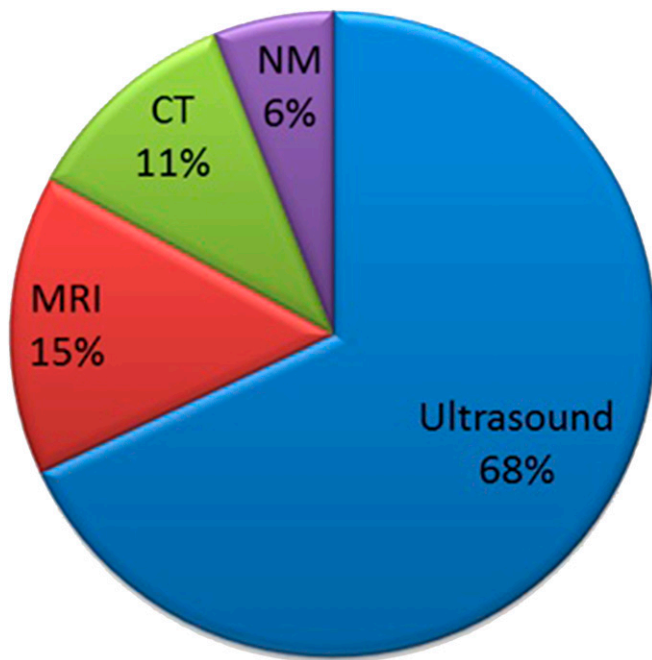
While the use of each modality increased between 2003 and 2012, MRI (+280%) and CT (+80%) saw the largest increases, followed by ultrasound (+67%) and NM (+13%) (Figure 2). The average annual increase in the number of examinations over 10 years was MRI (+17.8%), CT (+8%), ultrasound (+6%) and NM (+2%). At the beginning of the study (in 2003), one hospital had a CT scanner but no MRI scanner, while a second hospital had a MRI scanner but no CT scanner. The third hospital had both a CT and MRI scanner. In 2006 and 2007, the number of both CT and MRI scanners across hospitals increased from two to three scanners. At this time, there was a dramatic annual increase of 53% in CT examinations and 72% in MRI.

The number of examinations carried out using CT, MRI, NM and ultrasound was the highest in 0–3 year olds and the lowest in 15–18 year olds; 30% of all CT, 31% of all MRI, 50% of NM and 49% of all ultrasound examinations were performed on children

Table 1. Anatomical categorization of each modality

CT	MRI	Ultrasound	Nuclear medicine
Head	Head	Head	Bone
Neck	Neck	Neck	Renal
Chest	Chest	Chest	Lung
Abdomen	Abdomen	Abdomen	Thyroid
Pelvis	Pelvis	Pelvis	Gastrointestinal
Spine	Spine	Spine	Hepatobiliary
Extremities	Extremities	Extremities	Cardiovascular
Cardiovascular	Cardiovascular	Cardiovascular	Lymphatic
Other	Spectroscopy	Other	Other
	Other		

Figure 1. Imaging procedures carried out over a 10-year period. NM, nuclear medicine.



aged 0–3 years (Table 2). A large proportion of the study population (44%) was under the age of three, as seen in Figure 3.

Population-based imaging rates differed between modalities and age groups (Table 3). The rate of imaging per patient increased

with age in CT and MRI, as seen in Table 3. Imaging rates in NM were the highest for the youngest age category and decreased with age. Ultrasound imaging rates were the highest in the youngest age category and decreased with age until the age of 15 years, where another peak arose (Table 3).

The ratio of male to female patients was approximately 50:50 for all modalities and age groups. Population-based rates are presented in Table 4, where rates were calculated in terms of national paediatric population.

Regions most frequently imaged in each modality included the abdomen (64%) and pelvis (24%) in ultrasound, head (57%) and spine (13%) in MRI, head (49%) and chest (15%) in CT, and renal (69%) and bone scans (21%) in NM. The most common imaging procedures in each modality are displayed in Figure 4.

Figures 5–8 below demonstrate the rate of use of each modality per anatomical region.

DISCUSSION

Longitudinal data are valuable for monitoring and developing best practice guidelines and policies as they provide a description of phenomena and relationships that are intrinsically longitudinal whereby age and cohort effects can be distinguished.¹⁶ There is very little longitudinal data depicting advanced imaging trends in paediatric populations. Two longitudinal paediatric imaging studies have been carried out in the USA.^{3,13} Older studies have published national paediatric CT data from Australia, the UK, Israel and Germany.^{2,17–19} To date, we present the

Figure 2. Advanced imaging trends in the paediatric population. NM, nuclear medicine; US, ultrasound.

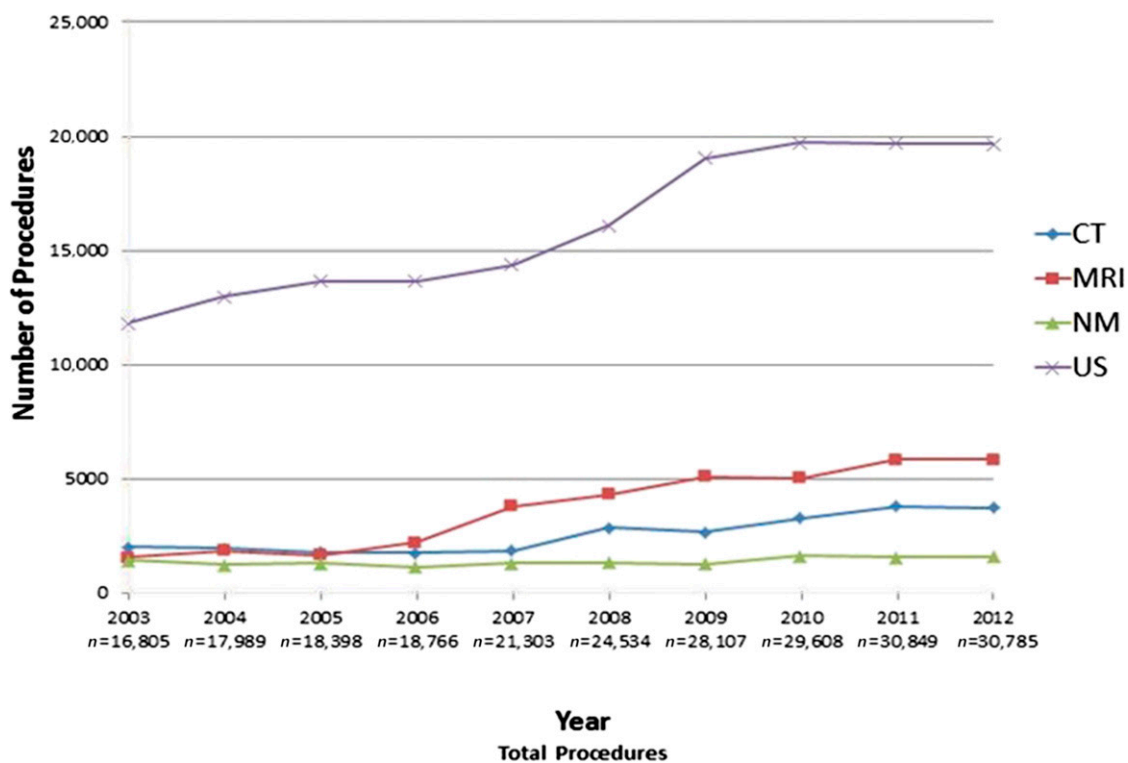


Table 2. The number of examinations carried out in each age group (percentage of total)

Imaging modality	0–3 years	3–6 years	6–9 years	9–12 years	12–15 years	15+ years	Total (%)
CT	9189 (30)	4516 (15)	3960 (13)	4547 (15)	5476 (18)	3248 (10)	30,936 (100)
MRI	8884 (32)	4456 (16)	3779 (13)	3722 (13)	4314 (15)	3046 (11)	28,201 (100)
Nuclear medicine	7655 (50)	2938 (19)	1797 (12)	1309 (9)	974 (6)	548 (4)	15,221 (100)
Ultrasound	73,159 (49)	21,473 (14)	16,339 (11)	14,392 (10)	14,694 (10)	9758 (7)	149,815 (100)

first longitudinal population-based study in Europe examining the use of advanced imaging in paediatrics.

Over a 10-year period, 224,173 advanced imaging examinations were carried out, an average of 2.7 examinations per person. As expected, ultrasound was by far the most utilized modality in our study, followed by MRI, CT and NM. Ultrasound is known to have many advantages: ultrasound scanners are portable and comparatively low in cost; and scanning is quick, painless and safe (the absence of ionizing radiation). In a combined adult and paediatric population (1996–2010) in six large integrated health-care systems in the USA, ultrasound was the most commonly utilized modality, followed by CT, MRI and NM.¹

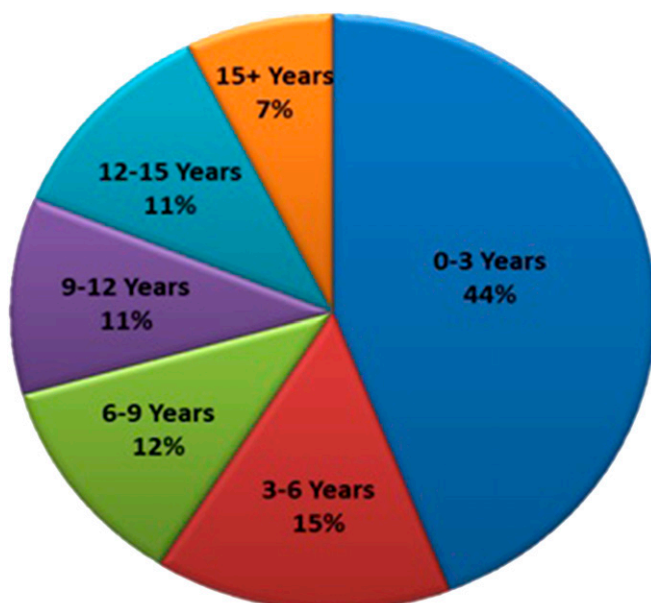
This concurs closely with our findings. Tompane *et al*³ was the only other study to present longitudinal data on CT, MRI, NM and ultrasound (2001–09) in a paediatric population. Contrary to our findings, Tompane *et al* found CT to be most commonly performed, followed closely by ultrasound.

Advanced imaging examinations (CT, MRI, NM and ultrasound) made up just 17% of Tompane's sample of 214,538 examinations. There was also a greater availability of CT scanners in the USA with approximately 32 CT scanners per million

population in the USA compared with 11 scanners in Ireland in 2005.²⁰ Differences in sample size, years in which trends were analysed, hospital types included (specialist paediatric centres only in our study vs a mixture of hospital types) and healthcare systems are likely to have effected differences in imaging trends between these studies.

There was a considerable increase in the volume of advanced paediatric imaging examinations between 2003 and 2012, with the largest increases seen in MRI (+280%) and CT (+80%), followed by ultrasound and NM. Similarly, Tompane *et al* found that MRI (+84%) saw the largest increase in use, followed by CT (+34%). The dramatic increase in CT and MRI in our study was undoubtedly influenced by the introduction of an additional scanner in each of these modalities (53% increase in CT and 72% increase in MRI at the time the scanners were acquired). However, there was an increase in CT use (+22%) in the two hospitals that already had a CT scanner suggesting that the large increase in CT use was not solely owing to the introduction of a CT scanner in the third site. The increase in CT and MRI usage may be attributed to a number of factors: increased staffing, technological advances leading to increased diagnostic efficacy and faster scanning times, patient- and physician-generated demand and defensive medical practices and medical uncertainty.^{4,20–22}

Figure 3. Age of patients undergoing advanced diagnostic imaging.



Although a number of studies support our finding of an increase in the volume of CT performed in the paediatric population over time,^{2,13,17–19} Townsend *et al*²³ recently reported a reduction in the use of CT as a proportion of all cross-sectional imaging studies from 2003 to 2007 in paediatric facilities across North America. However, this study did not provide imaging rates. Miglioretti *et al*²⁴ found that CT use in the USA increased between 1996 and 2005, remained stable between 2005 and 2007 and then began to decline. This decline was attributed to CT referrals being protocolled by paediatric radiologists, increased parental pressure, use of MRI instead of CT where possible and increased awareness about the cancer risks from CT owing to campaigns such as Image Gently. In our study, CT imaging rates peaked in 2008 and have remained consistently lower since then. Simultaneously, there was an increase in MRI rates (Table 4). Both ultrasound and NM imaging rates also decreased over this time. These findings suggest that MRI is being used instead of CT where possible in Ireland, probably owing to increased awareness of the importance of radiation reduction as signified in campaigns such as Image Gently. Such trends may also have been influenced by differing clinical indications, increased availability of MRI and technological advances in imaging.^{12,21}

Table 3. Rate of imaging calculated per 1000 eligible patients in the study population

Rate of examinations, number per 1000 patients in study population				
Age (years)	CT	MRI	Ultrasound	Nuclear medicine
0 to <3	25	24	232	21
3 to <6	32	31	150	20
6 to <9	34	33	126	15
9 to <12	43	35	135	12
12 to <15	53	41	210	6
15 to <18	55	51	163	9

As tertiary referral centres, each centre had access to anaesthetic expertise with both general anaesthesia and sedation being available for patients in the imaging department when required. This in particular affects MRI owing to the long scan times involved and may result in preferential use of CT at times.²⁵ Although this was not specifically investigated here, our results show a consistent increase in MRI scanning suggesting that the availability of anaesthesia did not influence referral patterns.

Ultrasound was the most commonly utilized modality over our entire study period. However, its use did not increase over time to the same extent as other modalities. Ultrasound saw its largest increase from 2007 to 2009, which likely results from an increase in the number of sonographers and a more efficient workflow as reported by staff. No additional ultrasound scanners were introduced over the study period. The plateau seen in Figure 2 may indicate that maximum capacity in ultrasound has been reached. Additional scanners may need to be introduced to facilitate further increases in scanning numbers. However, as exemplified in the period leading up to 2007, the availability of scanners alone is not sufficient for medicoeconomic optimization. Adequate staffing to operate the scanners is necessary to maintain an efficient workflow. In our study, each hospital had access to a CT scanner and CT radiographers but only performed on average 855 scans per year indicating CT scanners are not

being used to their full capacity. This likely reflects the preferential use of non-ionizing modalities such as ultrasound, which was used to maximum capacity, and MRI, which saw a massive increase (+280%) in use over the study period.

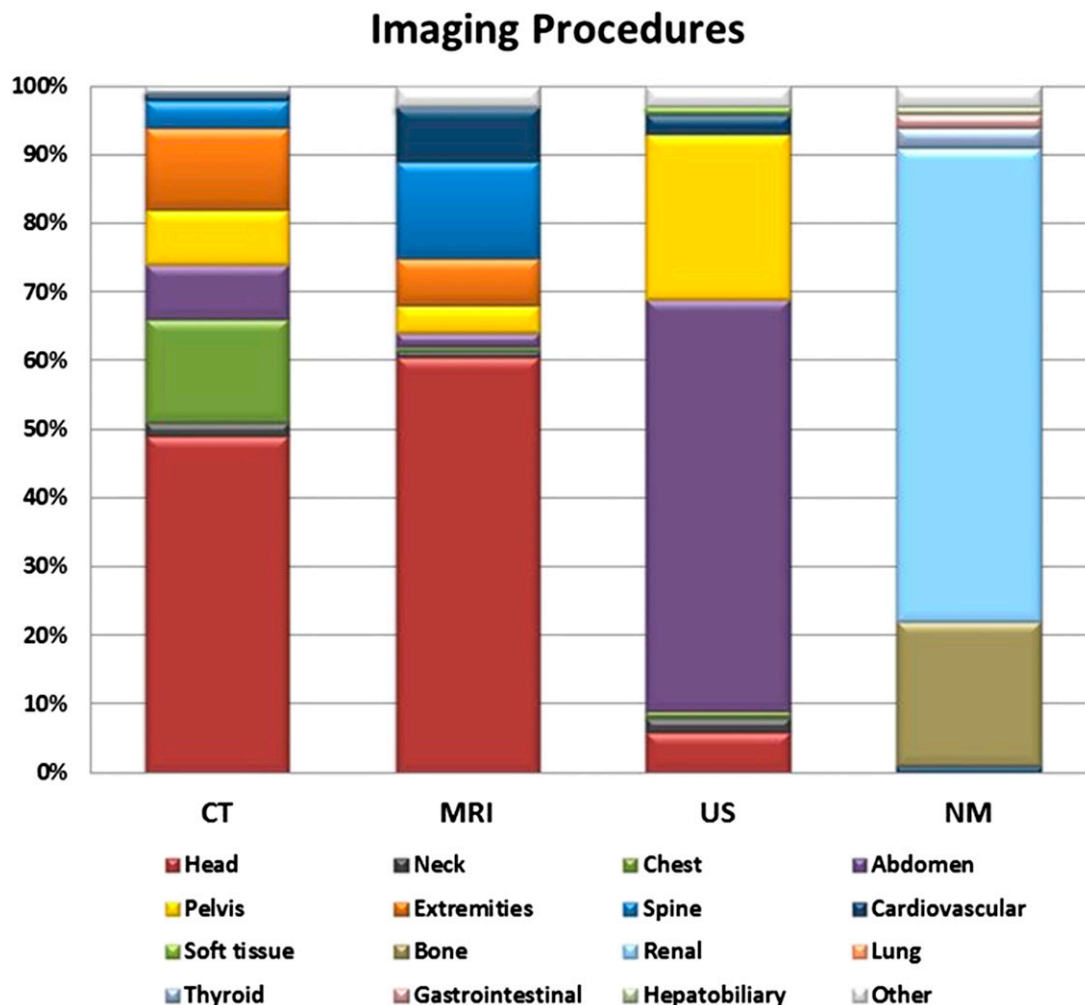
Although other published studies have provided usage rates, it is difficult to compare these accurately as differing denominators were used to calculate these rates. We calculated imaging rates based on the national paediatric population. Some national population rates reported in other studies are based on insurance claims made in the catchment area, while others are based on national population data.

National paediatric CT imaging rates most recently reported were the highest in Australia (9.65 scans per 1000 paediatric patients in 2008) and Israel (6.3 scans per 1000 in 2003), and lower in Ireland (3.85 scans per 1000 in 2012) and Great Britain (3.54 scans per 1000 in 2002).^{2,17,18} The high imaging rates in Australia may be owing to the greater availability of CT scanners in Australia. According to the Organisation for Economic Co-operation and Development Health Statistics, there were approximately 40 CT scanners per million population in Australia in 2003, compared with 6 in Israel and 7 in Great Britain. Despite a similar number of scanners in Israel and Great Britain, CT usage was much higher in Israel at 6.3 CT scans per 1000

Table 4. Rate of imaging per 1000 national paediatric population

Rate of imaging per 1000 national population ≤18 years old				
Year	CT	MRI	Nuclear medicine	Ultrasound
2003	3.53	–	2.1	17.1
2004	3.51	–	1.75	16.36
2005	3.19	–	1.85	18.18
2006	3.28	0.08	1.57	18
2007	3.59	4.87	2.01	17.9
2008	4.38	6.23	1.97	17.79
2009	3.8	5.54	1.42	18
2010	3.73	5.89	1.59	18.74
2011	3.86	6.35	2.37	17.3
2012	3.85	6.32	1.53	16.18

Figure 4. Most commonly imaged regions according to modality. NM, nuclear medicine; US, ultrasound.



paediatric population. This may have been owing to differing radiology referral guidelines, patient- and physician-generated demand, and different levels of radiation awareness.

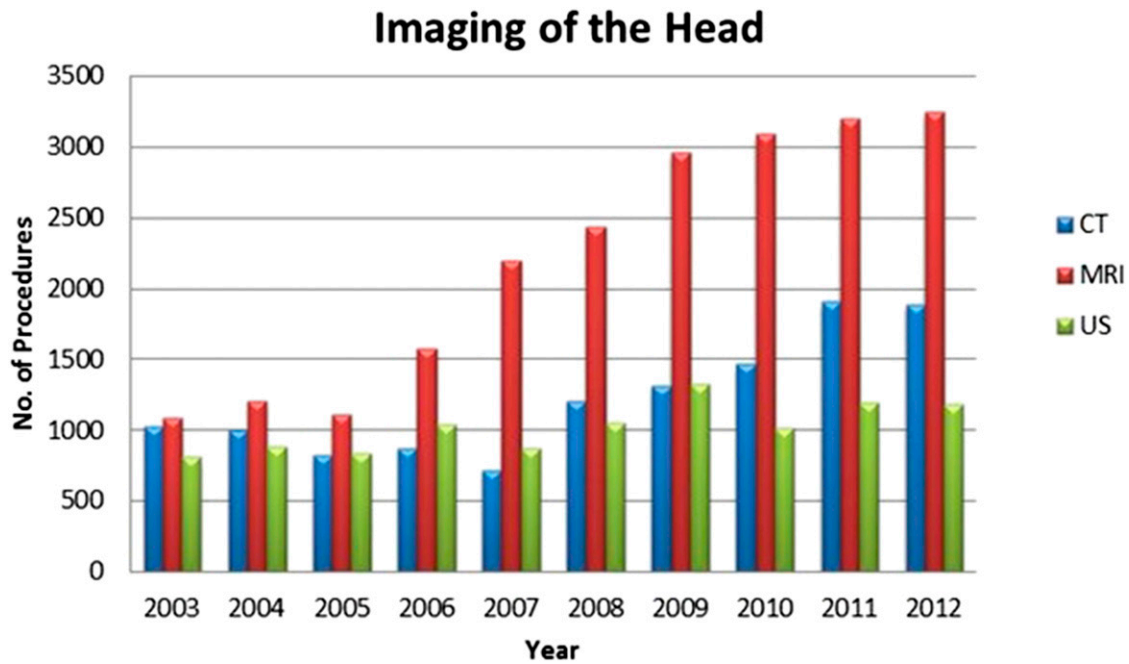
The rate of imaging per patient increased with age in CT and MRI. This is likely influenced by the knowledge of prescribers that risks from radiation are higher in younger children and perhaps the appropriateness of CT/MRI for older children presenting with differing pathologies. Brenner *et al*¹⁰ estimated the risk of fatal malignant neoplasms from radiation exposure with abdominal CT to be 8-fold higher in the 1 year of life as compared with the risk to a 50-year-old adult because their developing tissue is more sensitive to radiation.⁸ The ratio of male to female patients was approximately 50:50 for all modalities and ages indicating that gender was not a factor in imaging trends. Miglioretti *et al*²⁴ projected lifetime attributable risks of solid cancer to be higher for younger patients and girls than for older patients and boys. In our study, CT was less common in younger children and was no more frequent in females than in males.

Anatomical regions most frequently imaged in Irish paediatric centres are portrayed in [Figure 4](#).

Studies in England, Israel, the USA and Germany have also shown that the most common type of CT examination in young people is that of the head or brain, although rates of usage vary with childhood age groups.^{2,17–19} These are similar to adult CT trends in Ireland but contrast with American studies, in which CT scans of the pelvis and abdomen are more common in adults, suggesting varying use of CT imaging in adult populations.^{26–28} To our knowledge, this is the first article to identify the most frequently imaged body regions in MRI, CT and ultrasound in a paediatric population over time.

While the proportion of CT and MRI head scans was relatively similar in 2003, MRI use in brain and spinal imaging has grown to a far greater extent than has CT ([Figures 5 and 6](#)). This is likely owing to the improved resolution and sensitivity of MRI in these anatomical regions, but the lack of ionizing radiation with the modality is certainly a positive in terms of radiation protection. Assuming typical doses for scans in children aged younger than 15 years, cumulative ionizing radiation doses from 2–3 head CTs (*i.e.* approximately 60 mGy) has been reported as having the potential to almost triple the risk of brain tumours, and 5–10 head CTs (approximately 50 mGy) could triple the risk of leukaemia.²⁹ Another study projected that the lifetime excess risk for

Figure 5. Trends in CT, MRI and ultrasound (US) imaging of the head, 2003-12. No., number.



a head CT scan with typical dose levels is about 1 cancer per 1000 head CT scans for young children (less than 5 years), decreasing to about 1 cancer per 2000 scans for exposure at the age of 15 years.³⁰ Abdominopelvic scans were the third most frequently performed examinations in our study (Figure 4). For an abdominal or pelvic CT scan, the lifetime risks for a paediatric abdominal or pelvis scan are higher than that for other CT scans at 1 cancer per 500 scans irrespective of the age at exposure.^{24,30} Our findings indicate that the ultrasound use as a proportion of all cross-sectional imaging modalities has increased more than that of

CT for abdominal and cardiovascular imaging (Figures 7 and 8), which limits detrimental risk to paediatric patients as radiation exposure is avoided by imaging with ultrasound instead of CT.

This study had a number of limitations. It was not possible to categorize examinations by clinical indications as this information was not available in a concise code format and thus could not be efficiently obtained from the RIS. Therefore, the appropriateness of imaging examinations and justification cannot be commented on, although it would be worthy of further

Figure 6. Trends in CT, MRI and ultrasound (US) imaging of the spine, 2003-12. No., number.

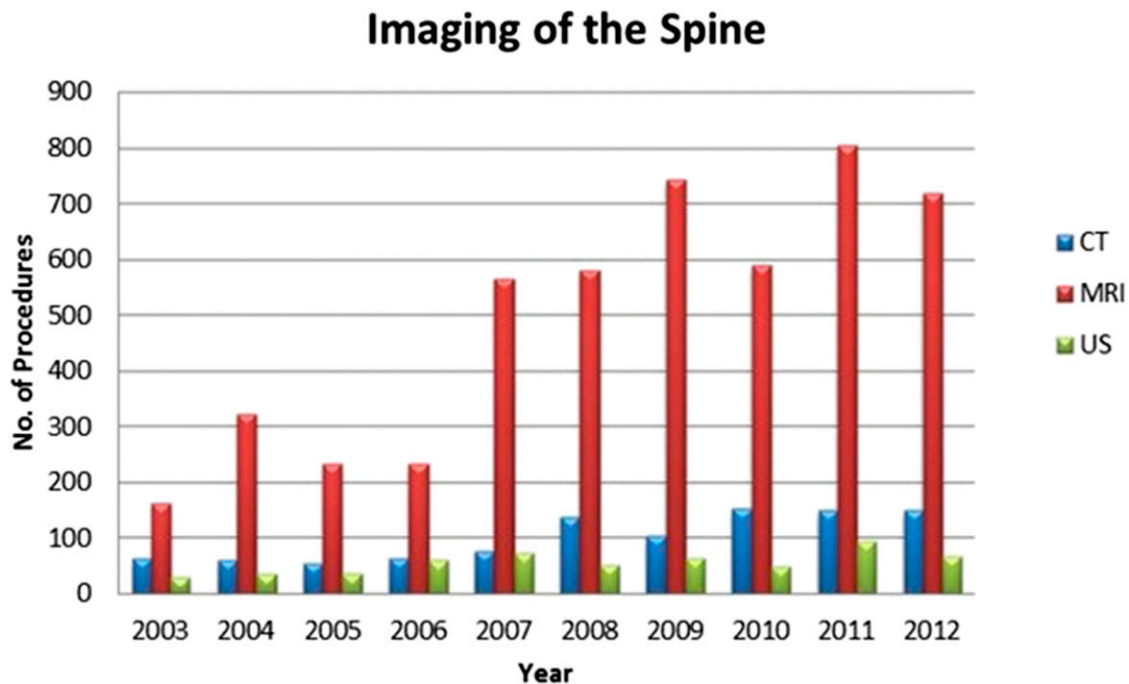
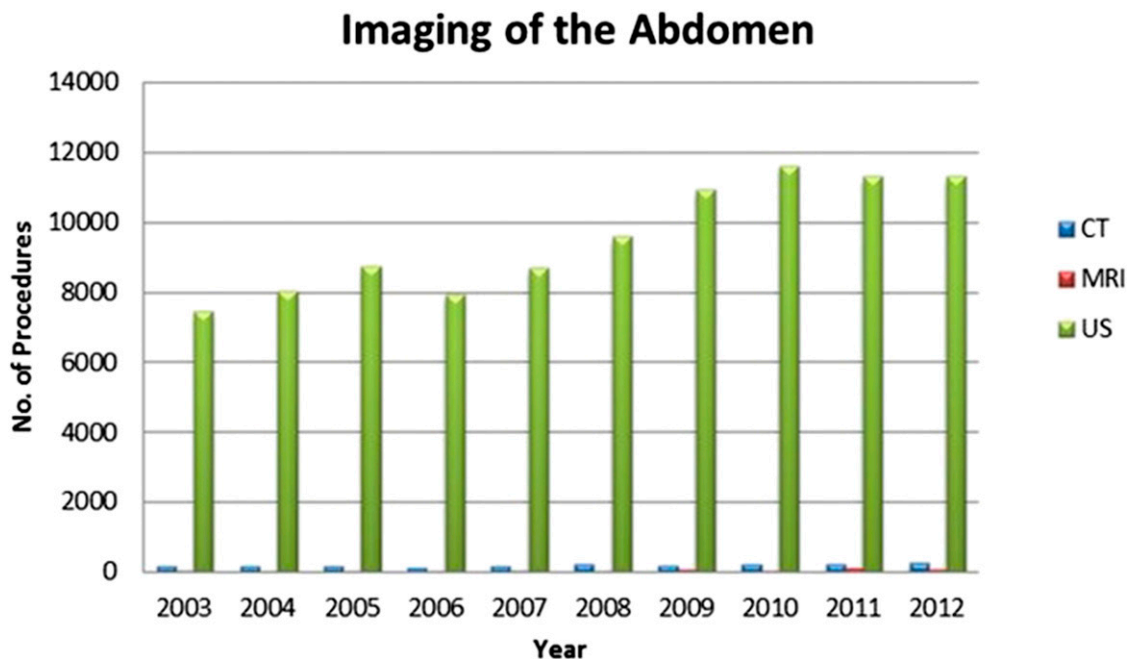


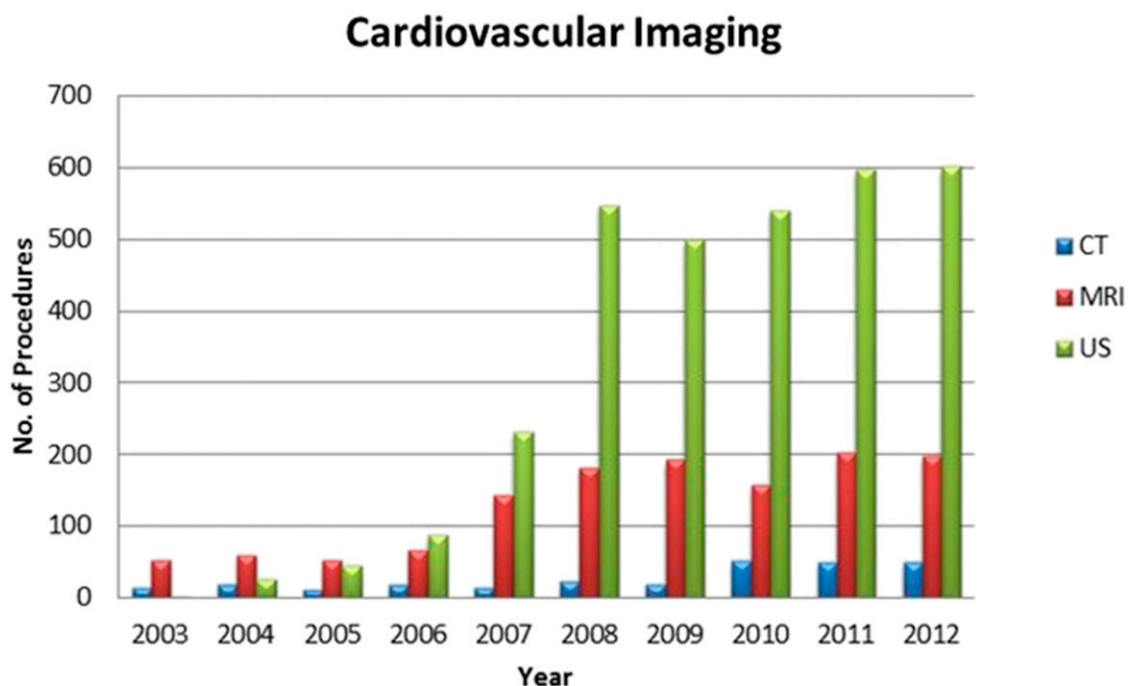
Figure 7. Trends in CT, MRI and ultrasound (US) imaging of the abdomen, 2003–12. No., number.



study. Owing to resources available, it was not possible to collect data on smaller than 3-year age groups. Pathologies and therefore imaging modalities chosen may vary for ages within a 3-year category, for example, between a 6-month old and a 2-year old. Neonatal cranial ultrasound scanning is also performed outside of the three paediatric hospitals (*e.g.* in maternity hospitals). The exclusion of maternity hospitals from this study means that the number of cranial ultrasounds in 0- to 3-year-old category is likely underestimated. PET/CT was not included in this study as the number of paediatric PET/CT scans performed nationally was

deemed too low for analysis and likely accounted for <100 examinations annually. The method of calculating imaging rates is described explicitly in this study. Standardization of the method for reporting modality use across research is recommended to enable accurate comparisons of modality use across studies. National imaging rates based on the Irish paediatric population may be slightly underestimated as children may undergo advanced imaging outside the tertiary specialist paediatric centres. However, the vast majority of children are imaged in the specialist centres included in this study.

Figure 8. Trends in CT, MRI and ultrasound (US) cardiovascular imaging, 2003–12. No., number.



CONCLUSION

This study provides baseline data for the use of imaging in Ireland over a 10-year period and will be a useful benchmark for future analysis and resource planning. Advanced imaging, particularly MRI, has risen substantially between 2003 and

2012. Most advanced imaging was performed on children aged less than 3 years. CT usage rates in Ireland have decreased in recent years and are lower than those in the USA, Israel and Australia. MRI is now used at twice the frequency of CT.

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