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Challenges and Peculiarities of Paediatric Imaging

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1. Introduction

Although some, diseases seen among children and infants are similar to those in adults, diagnostic imaging of these category of patients can both be interesting and challenging.

Paediatric imaging therefore requires specific training and certification that guarantees application of thorough knowledge, expertise and a variety of dedicated or adaptable equipment. This is hardly the case in many countries; where there may not be sub specialty training in paediatric imaging and practice may not have specific requirement except interest in children. Historically, there are few recruitment training centers for paediatric imaging specialists, and this area appear to be one of the least subscribed of all radiology sub specialities. It is also difficult, to establish quality imaging service for children defined as 'A service where the child is examined and diagnosis made by specialists with appropriate expertise, is imaged using dedicated facilities and equipment and where the child is at the center of all decisions made' (Report of National Imaging Board, NHS).

It is important to recognise that children are increasingly irritable and unusually aware of strangers and unfamiliar environments. This presents a huge challenge for the radiographer or the clinical care personnel who must try to gain the child's trust and co-operation before and throughout the duration of an examination. This can be a daunting task in children who may both be ill as well as experiencing pain. Coercion and support from parents is usually enough to achieve this, but in some extreme cases (such as MRI and CT), it may be necessary to sedate the child. Even with a quality examination, the accurate interpretation of diagnostic images, also requires a deep knowledge of the intricate and dynamic face of anatomy and some peculiarity in pathological presentations.

This paper seeks to draw attention to the peculiarities of Paediatric Imaging and the need to encourage expertise in this area.

Challenges of paediatric imaging can be discussed as follows:

This chapter will be divided into 3 Major Areas namely service delivery, technical peculiarities and Clinical Applications.

2. Service Delivery

2.1. Lack of Specialist Training

In spite of the vulnerability of this category of patients and obvious need for specialized diagnostic services, there are few training centers or programs dedicated to Paediatric imaging. In Nigeria, there is no specialist training for would be paediatric radiologist, outside the regular fellowship. In some countries like Switzerland, a two year sub specialty Fellowship and certification is available for Radiologist, but nothing specific for Radiographers and Imaging Technologists. There is evidence that enrollment and popularity of paediatric imaging as a speciality is low in United States and Europe. In the United Kingdom, all radiology trainings programs include core paediatric experience, and full adaptation can be achieved after a 6 months of pediatric focused training. Alternatively, a paediatric consultant may need up to 1 year training in radiology, but the short period of rotations during residency is usually not enough to provoke sufficient interest in this category of practitioners.

Among Radiographers, there is no recognition of Pediatrics as an area of specialty or professional registration for pediatric Radiographers. There is no formal training programs dedicated to this area, or career pathways or incentives for Specialist paediatric radiographers. The picture appears to be replicated in most African and SubSaharan countries where lack of manpower may further inhibit the development of this potentially important specialty.

2.2. Lack of Dedicated Children Imaging Centers

This challenge is almost similar to the one earlier described. In practice, there is a wide variation in the provision of specialist imaging centers with services tailored specifically for the children. According to an NHS report, majority of routine, emergency and trauma imaging takes place in district hospitals, equipped with variable degree of local expertise.

2.3. Specialized Equipment

Imaging equipment and facilities suitable for use by children and toddlers require some specialized features. Sometimes, these equipment may differ from the premature to the adult sized teenager. Equipments that are easy to manipulate, while allowing fast acquisition of diagnostic information is the gold standard. Where necessary, image viewing and workflow stations allow fast transfer of images to PACS, for easy reporting and audits by radiologists.

2.4. Environment

Children require stimulating environments that easily catch their attention and make them less suspicious of strangers and their intentions. The environment should usually be friendly and tailored to make the child patient feel relaxed. For instance, the walls should have bright colors, with paintings and designs as well as images with toys, play characters, cartoons and toys.

Provision to allow children run around, play and use murals and stencils can be of immense use.

The designs can also be such that allows a lot of natural lighting into the room. This can be achieved with glass panels and windows and special lightings.

2.5. Safety and Radiation protection

With the advent of CT and fluoroscopy, the amount of radiation doses available to paediatric patients has become increasingly significant. Consequently, issues of radiation protection are more stringent in paediatric imaging and both local rules and international standard must be maintained.

It is recommended that low dose imaging systems be deployed using digital detection components, optimized for paediatric use to ensure dose reduction.

Imaging systems that are ultra fast are often needed to reduce the time of investigation while optimizing image quality, and this comes with a huge financial burden to hospital authority, since they cost higher. It is also important to ensure the physical safety of the child while in the department.

2.6. Extended Work Hours

The need to have immediate intervention in children especially following trauma and emergencies, may necessitate the extension of working hours and off peak availability of personnel. This means placing Radiographers and Radiologists with pediatric experience on call, to handle such cases. This obviously places most departments under work pressure to keep this category of workers.

2.7. Quality Assurance

The need to obtain images of optimum quality requires that the imaging equipment function to their maximal capacity. Diagnosis of many paediatric ailments depend on exquisite demonstration of anatomical detail, and subtle changes. Quality assurance programs are tailored towards ensuring optimum performance, often requiring constant calibration of these equipment.

Double check protocols are necessary to ensure there is no missed diagnosis, through proper clinical audits.

2.8. General Guidelines for Paediatric Imaging Departments

The standard protocols should be adopted as a general rule:

1. There must be a clinical justification for any imaging procedure
2. The clinical benefits should outweigh any potential risk
3. When possible, children should not be examined with facilities dedicated to adults

4. The protocols for each investigation must be specific and tailored to meet individual patient situations.
5. Service hours and sessions must be sufficient to cover both booked and emergency cases.
6. Radiation protection services must be available and optimization principles such as ALARP (As Low As Reasonably Practical) should be applied.
7. There should be care providers with sound understanding of the anatomical and pathological processes in the paediatric age group.
8. A thorough knowledge of various diagnostic and imaging techniques by practitioners, including indications, contraindications and complications.
9. Knowledge of the advantage as well as limitations of each imaging modality, is necessary to make informed choice and guide clinical management.
10. Good communication and interpersonal skills are needed to deal with children.
11. Access to interventional and emergency care must be ensured at all times.
12. All protocols must take into consideration, the personal or physical safety of the children while in the imaging department.

3. Technical Peculiarities

Conventional X-ray

There are existing policy guidelines regarding acceptable quality and criteria for diagnostic radiography in the pediatric population. Such guidelines like that of the European Commission, sets out to ensure the triple objectives of producing adequate and uniformly acceptable image quality, providing accurate radiological interpretation of the image and using a reasonably low radiation dose per radiograph. A typical guideline will take into account a specific image criteria, taking into consideration anatomical, patho-physiological, size and degree of cooperation expected of a child. It will emphasize good Radiographic technique and patient dose limitations. The general requirements include but not limited to the list below

1. High quality images produced by computed or digital radiography is recommended, so that exposure factors can be optimized and repeats are avoided.
2. Films of high contrast and capable of yielding high resolution images are recommended.
3. Low absorption cassette or image plates, grids, tabletops should be used. While the use of grids may often be unnecessary, the introduction of digital or computed Radiography has reduced the use and importance of some of these accessories)

4. Exposure Parameters should be stringent, with appropriate combination of KV, MA and Time. Due to a likelihood of motion blur, short exposure times is compensated for by slight increase in KV and MA.
5. The technique with positioning, centering, collimation, side markers, image identification, restraining methods are carefully chosen.
6. There should be proper collimation devices with fine focus techniques necessary to reduce radiation dose without loss of detail. Protective radiation shields should be used whenever necessary.
7. Radiographs should show both soft tissue and bony detail.
8. Comparison films are often necessary to make accurate diagnosis.
9. Where possible, effort should be made to produce the area of interest with minimal projections. For example, A single projection showing chest and abdomen would be preferable in an eight month old baby, rather than two view of the chest and abdomen respectively.
10. In acute injury, two projections (Ap and Lateral) should be done as an emergency.

When necessary, radiographs may be obtained under mild sedation especially in the very uncooperative patient.

Due to the increasing radiation sensitivity of children compared with adults, balancing radiation protection with image quality is of utmost importance. The dynamic face of the immature growing and partially ossified skeleton, requires experience and good knowledge of the radiological image and developmental variants. Radiation protection should also follow already made guidelines like the ICRP draft report consultation on ' Radiological Protection in Pediatric diagnostic and interventional Radiology' published in the Annals of the ICRP ref 4839-3982-4649 of May 2011 (readers are encourage to view this document for further details).

Paediatric MRI

MRI in children is performed under a variety of settings including neurological, cardiac, musculoskeletal as well as for diagnosis and follow up of malignant disease. The major challenges in imaging children with MRI stem from the following

A. Peculiarity of anatomy

The relatively smaller anatomic structures in children create a challenge in terms of available signal as well as limit of resolution.

These anatomical structures which are smaller than the adult such as inner ear, cranial nerves, brachial plexus, biliary tree, peripheral joints and blood vessels require high resolution. In other words, imaging these structures require high signal to noise ratio. This scenario becomes even more significant in the presence of anomalies or congenital defects, as well as the changing face of structural developments.

This can be achieved with high field strengths, acquisition of thinner slices and improved spatial resolution.

B. Evolving development.

The anatomy in children appear to be evolving as they develop and mature. This is true with cerebral imaging where the corticoculcations, patterns of myelination change rapidly as the child matures. At birth, the water content of brain tissue is significantly higher than that of adults. The abundance of Hydrogen molecules from water and the lack of commensurate fatty signals requires an increase in TE on T2- weighted imaging to achieve good contrast. Also visualization of joints should take into consideration changes in the growth of the epiphyses and and apophyseal cartilage.

C. Patho- Physiological challenges.

The rates of acquisition of images, contrast injection rates may be influenced by physiological changes. For instance, the heart rate, pulse rate, breathing and blood flow rates are different in neonates, necessitating shorter times for image acquisition. Children may also find it difficult to hold their breaths and this may introduce artefacts during the image acquisition process.

It is often difficult to perform an exhaustive clinical examination in children and symptoms may be vague and non- specific. Consequently, MRI request can frequently be non- specific, making the choice of protocols and modification in techniques more cumbersome.

D. Behavioral challenges

Children are increasingly aware of changes in their environment and less likely to co-operate with strangers. Some MRI studies require a reasonable period of cooperation and calm. This poses more difficulties on the time and energy of the staff. To achieve cooperation, the child may be sedated or given general anaesthesia, thereby increasing the inherent risk and often requiring staff with requisite skills.

E. Safety

The thermoregulatory mechanisms in children are poorly developed and children have high basal temperatures, thereby exposing them to higher risk of radiofrequency heating effects. This becomes magnified by the relatively higher surface area to weight ratio in children, increasing the area exposed to RF heating with a concurrent reduction in heat dissipation. The implications of the high specific absorption ratio (SAR) from MRI in children is unclear, but the need for close monitoring in the critically ill child cannot be over emphasised. Further safety concerns stem from possible side effects of anaesthesia like nausea, vomiting, drowsiness, agitation which are exaggerated in the pediatric population.

Generally speaking several issues come to mind

1. Improving signal to noise ratio requires higher field strengths (up to 3T)
2. Achieving the above also means more expensive hardware and sophistication in techniques

3. The use of greater field strength means better spatial and temporal resolution with altered T1 contrast (longer T1 and T2 relaxation times).
4. The likelihood of artifacts are higher especially for cardiac and abdominal imaging.
5. The SAR ultimately increases due to higher fields strengths in addition to introduction of B- field inhomogeneities.
6. Chemical shift, motion and susceptibility artefacts are increased.
7. Safety issues become more stringent as the field strength increases.

Due to the absence of radiation exposure, whole body MRI is considered a useful sequence in the evaluation of children with systemic abnormality or bone metastases.

Some general rules to achieving a successful MRI in children would include engaging them to become aware and participate in the procedure, allowing considerable distractions with audiovisual aids, puzzle tasks and relaxation breathing techniques. In addition to this, conscious effort to separate intravenous cannulations from the main MRI exam as well as carefully planning the sequences and protocols to include only the necessary ones are techniques that ultimately help.

3.1. Paediatric CT

There are general concerns about the amount of radiation exposure from paediatric CT due to the radio sensitivity of developing and immature tissues in children. Evidence abound to prove that pediatric CT will result in significantly increased lifetime radiation risk for cancer over adult CT, due to increased dose per milliamperes second and the increased lifetime risk per dose. There are also issues with who makes appropriate decisions for the referral of children, clinical benefit of the procedure, dose information and poor knowledge and compliance to laid down guidelines.

In a particular survey, there is poor compliance to guidelines in imaging children with torticollis, ventriculoperitoneal shunt and sinusitis. Sometimes, unnecessary examinations may be seen in cases of uncomplicated headache, suspected Pulmonary embolism, pre- op chest survey, and in the evaluation of appendicitis.

The use of Helical CT techniques for volume acquisition during CTA (CT Angiography), also has several challenges in children. To perform successful CTA's in children, factors like reduced contrast volume, injection rates, timing of scans, radiation dose minimization and breath holding abilities must be considered. For most indications, helical CT of the chest using low dose techniques provides adequate image quality without a significant loss of diagnostic information. Modifications in equipment design has allowed optimization of scan parameters to achieve desired results. These include reduction in the rotation time (0.4 to 0.5seconds), reduced detector coverage commensurate to body size, reduced slice thickness and pitch especially with multiple slice facility. Others are reduced field of view (FOV), KV and use of smart MA/ auto MA options to optimize exposure levels.

When used, CT facilities should be equipped to accommodate ventilated neonates and appropriately trained medical and nursing staff must accompany such patients.

3.2. Paediatric Ultrasound

The procedure for paediatric ultrasound does not differ significantly from that of children. Equipment and facilities may not differ significantly except for the choice of transducers. Most ultrasound machines come with options for paediatric probes. This is especially true for transcranial and cardiac work. Most paediatric probes would be relatively smaller than adult probes and may have adjustable usually higher frequencies to cope with various depths and patient needs. The compromise is usually between the degree of penetration and resolution required for each case.

Patients may either be awake or sleeping, but there is usually no need for sedation in most circumstances.

Ultrasound is relatively safe with no risks of radiation, cheap and readily available. Ultrasound scans may be repeated over and over again, without any significant risks. The challenges for the care giver is similar to that in most other modalities; getting the cooperation of the child.

A warm friendly environment, good interpersonal skills will help the sonographer perform the investigation with ease. The practice of warming the gel and towels is often desirable for the child patient. The cooperation of the parents or guardian is usually solicited as this helps the child to remain calm during the investigation. As a general rule, most pediatric ultrasound scans are performed in the presence of accompanying adult.

For neonates in intensive care units, portable scanners may be used, equipped with transducers with various frequencies, and Doppler to perform the investigation at the bedside. Special care and aseptic procedures must be maintained to prevent risk of infection to infants.

The general rule is to get an ultrasound whenever possible, as it can be repeated over and over again.

4. Clinical Applications

The clinical implications of the above challenges are highlighted below for the various regions.

Pediatric chest: The chest radiograph is the most common imaging technique employed for pediatric thoracic abnormalities. Pediatric chest radiography presents peculiar challenges due to the wide range of tissue densities present in the thorax. This is complicated by the need to minimise radiation dose, the varying thoracic sizes, difficulty in achieving inspiration and likelihood of motion blur. The continuous improvement in screen-film technology and development of digital systems produce a wider dynamic range and linear response to x-ray exposure. This ensures that useful images can be obtained in a wide latitude of expo-

tures and digital processing allows adequate contrast and detail to be achieved. This means a better control of radiation exposure as repeats are almost eliminated. The neonatal chest radiograph will most undoubtedly include portions of the abdomen and appendicular skeleton. The ABC approach typically is to examine the whole radiograph and not just the chest. This can be put in this simplified format

A- Abdomen region is examined for abnormal gas patterns, calcification and situs

B- Bone to exclude fractures, metabolic diseases eg rickets or definite bone lesions

C- Chest for position of the mediastinum, cardiac size and contours, vascular markings, abnormal air spaces, pneumothorax or atelectasis, determine positions of central venous line, umbilical venous catheter and endotracheal tube, pleural effusions.

In addition, soft tissue appearance to exclude abnormal swellings, or loss of body mass like in malnutrition and wasting states. Rapid advancement in imaging technologies has widened the opportunities provided to more specifically explore pathologies of the chest by the introduction of CT, MRI, PET CT. In conjunction with tremendous input of digital techniques has improved acquisition of morphological and functional information regarding the chest. Helical CT scans allow short acquisition times, reduce motion artefacts and with dynamic contrast injection can produce remarkable information of the thoracic bony cage as well as vascular and pulmonary architecture, simultaneously.

MRI holds a high promise in the evaluation of thoracic disease. It has ability to clearly distinguish between mediastinal fat, blood vessels and soft tissues. Cardiac anomalies, mediastinal masses, and chest wall lesions can be delineated with MRI. The emphasis on the possibility of acquiring dynamic and functional information of the lungs has led to introduction of many techniques such as Functional MR, He- enhanced MR, and Fluorodeoxyglucose (FDG)PET studies. MR techniques hold much promise in the examination of obstructive airways disease including cystic fibrosis, by allowing excellent delineation of lung parenchyma and patterns of ventilation.

PET studies appear to be increasingly useful in lymphoma imaging in children.

Pediatric Abdomen

The plain abdominal radiograph can provide variable degree of information allowing initial assesment of disease processes. Similar to the approach adopted for chest interpretation, plain films of the abdomen require specific methodology.

The plain abdomen radiograph typically includes the lower chest and thus the bases of the lungs and diaphragm are examiained for pneumonia and abnormal gas appearance beneath the dome respectively. The erect abdomen radiograph appears to be the most vital single projection, allowing tremdous insight into chest and abdominal changes.

Bones are examined to exclude fractures, osteomyelitis and abnormal changes due to metabolic or neoplastic disease.

The psoas muscles, retro-peritoneal fat lines, calcification or abnormal gas patterns are visualized within the abdominal cavity. This can be interpreted as CBA (chest, bone, abdomen), a reversal of the pattern described earlier.

In suspected intestinal obstruction, a plain radiograph may be sufficient to differentiate low from high obstruction, by providing information on the presence, extent and level of gas in the bowel. A water soluble contrast examination of the upper gastrointestinal tract will help to determine cause, for example pyloric stenosis and gastric outlet obstruction. Barium enema may be necessary to differentiate the possible causes of low intestinal obstruction especially in equivocal cases of ileal atresia, meconium plug or ileus.

Ultrasound is both safe and reliable to assess intrabdominal organs and to determine origin and perhaps vascular extension of a potential abdominal mass. Initial assessment of the liver, spleen, kidneys are best performed with ultrasound. Ultrasound would equally be useful to differentiate medical from obstructive jaundice and initial suggestion of biliary atresia. In an experienced hand, abdominal ultrasound can provide a tremendous amount of information in cases of suspected intestinal obstruction. Diagnosis of pyloric stenosis and gastric outlet obstruction, hiatus hernia, intussusception can comfortably be made with ultrasound.

Computed tomography or MRI is usually necessary to determine the exact extent of a mass and to exclude spread, especially when the need to have a sectional information arises. CT has its use in the determination of injuries to organs following trauma, perforated viscus, abscesses, appendicitis. The use of spiral CT techniques encourages better evaluation of the liver for acquired vascular abnormalities, vascular masses, pre operative evaluation of renal tumors. The advances in MR techniques have significantly altered the investigation of abdominal and pelvic disease in children. MRI will profoundly help in the visualization of the biliary tract, pancreas as well as intra and extra- luminal bowel disease. MR urography is especially useful for anatomical and functional assessment of the urinary system.

Pediatric Brain

The use of ultrasound in the imaging of neonatal brain has tremendous advantages. Ultrasound is safe, cheap and available and therefore is the preferred modality at this stage. In older children, ultrasound is no longer useful once the fontanelles are closed.

Brain CT is usually recommended for children with traumatic brain injury, which is relatively common. The recommendation takes into account traditional clinical guidelines for determining the at risk patient and the risk of radiation and possible sedation for the critically ill. Such a guideline would ultimately depend on the clinical scenario and age of the patient. The problem typically lies in the ability to determine this category of patients who clinically qualify for the procedure and to differentiate them from those at low risk for serious treatable head injury for whom cranial CT would be unnecessary.

Structural and functional MR techniques are invaluable in investigating brain tissue development. Practical and technical constraints exist in MR imaging in children and have been discussed in the technical section. Some peculiar techniques employed in Paediatric MRI include susceptibility-weighted Imaging (SWI) which is useful in imaging trauma, vascular

disease, telangiectasia, cavernous and venous angiomas, tumors and epilepsy and Diffusion Tensor Imaging allowing changes in the developing brain, trauma, and white matter disease. Other techniques include arterial spin labeling useful in identifying perfusion changes in the brain.

Paediatric Skeleton

Hussain et al (2007) noted that the unique features of children's growing skeletons create challenges in imaging and specifically result in injuries and fractures. The imaging of skeletal structures following trauma in children typically start with plain film radiography. Additional modalities include MRI and CT which are used as Adjunct procedures. MR imaging has evolved as the most important diagnostic tool for the local staging of primary bone and soft tissue tumors, for monitoring response to chemotherapy and also in the detection of postoperative tumor recurrence. MR imaging provides accurate postoperative staging of local tumor extension and helps to obtain adequate safety margins and planning of successful limb- salvage surgery.

Bone scintigraphy with ^{99m}Tc -polyphosphate or ^{99m}Tc -pyrophosphate can be carried out in children with suspected bone disease. Scintigraphy is effective to demonstrate skeletal metastases, primary osteosarcoma, fibrous dysplasia, and osteomyelitis. Abnormal accumulation of radioactivity in soft tissue lesions can also be demonstrated in primary adrenal neuroblastoma, Hodgkin's granuloma, and metastatic Burkitt's lymphoma.

Radionuclide bone scintigraphy is also highly sensitive and specific for diagnosing the musculoskeletal disorders of childhood. Conditions such as neonatal osteomyelitis, septic arthritis, diskitis of childhood, Legg-Calve-Perthes disease, the osteochondroses, the toddler's fracture, sports injuries, spondylolysis, myositis ossificans, and reflex sympathetic dystrophy can easily be made. Risks may include allergic reactions and exposure to radiation.

5. Conclusion

The challenges and peculiarities discussed so far underscores the need for expertise and care during paediatric imaging procedures.

This expertise can be acquired through structured training as well as experience.

There is need to encourage Pediatric radiology as a sub specialty, as well as the training of Radiographers specifically for this purpose. There is need to encourage separate registration and licensing with career pathways and incentives to would be pediatric Radiographers. This may involve a review of the current training curriculum for Radiographers and radiologists.

There is need to have a joint commitment and responsibility towards achieving quality service delivery to the pediatric patient population.

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