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Place de l'IRM corps entier sans le dépistage des lésions traumatiques d'origine indéterminée chez l'enfant : étude PEDIMA

Solène Vacheresse

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THÈSE D'EXERCICE / UNIVERSITÉ DE RENNES 1
sous le sceau de l'Université Bretagne Loire

Thèse en vue du

DIPLÔME D'ÉTAT DE DOCTEUR EN MÉDECINE

présentée par

Solène VACHERESSE

Née le 26/06/1988 à Quimperlé

**Place de l'IRM corps
entier dans le
dépistage des lésions
traumatiques
d'origine
indéterminée chez
l'enfant. Etude
PEDIMA.**

**Thèse soutenue à CHU de Rennes
Le 17/04/2018**

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Table des matières

Liste des PU-PH et MCU-PH	2
Remerciements	6
Liste des documents annexés	9
Liste des tableaux et figures	9
Préambule.....	10
1. Introduction et historique	10
2. Définition de la maltraitance physique de l'enfant et contexte légal	10
3. Epidémiologie de la maltraitance physique de l'enfant	12
4. Diagnostic de maltraitance physique de l'enfant.....	12
5. Résumé des résultats des essais non cliniques et des essais cliniques disponibles et pertinents au regard de la recherche biomédicale concernée	16
6. Bibliographie.....	24
Résumé	28
Abstract	29
Article scientifique	30
1. Introduction	30
2. Materials and methods.....	31
3. Results.....	35
4. Discussion	43
5. Conclusion.....	51
Références bibliographiques.....	52
Liste des abréviations.....	56
Annexe	57

Liste des documents annexés

<i>Annex: Whole Body Magnetic Resonance Imaging (STIR) in suspected child abuse: a pictorial review from the PEDIMA study</i>	57
<i>Abstract</i>	58
<i>Introduction</i>	59
<i>Pedima study</i>	60
<i>Specific lesions in child abuse on WB-MRI</i>	63
<i>Traps to avoid</i>	74
<i>Discrepant cases</i>	77
<i>Conclusion</i>	83
<i>References</i>	83

Liste des tableaux et figures

Table 1: <i>Definition of true negative, false positive, false negative and true negative lesions according to the consensus for each body part unit. For example, SS, WB-MRI and the combination [SS+WB-MRI] are used in this table (resp SS, BS and [SS+BS]).</i>	34
Table 2: <i>Number of children with lesions detected by each imaging modality separately or by combination of SS with MRI or BS.</i>	36
Table 3: <i>Detail of true positive (TP), false positive (FP) and false negative (FN) lesions according to the imaging modality and localization (body part unit).</i>	37
Table 4: <i>Detail of discrepancies between different imaging modalities according to the localization of lesions.</i>	39
Table 5: <i>Statistical characteristics of each imaging modality and combinations of SS with BS or MRI versus consensus</i>	40
Fig 1: <i>Population study. SS= Skeletal survey, WB-MRI= Whole-Body Magnetic Resonance Imaging, BS= Bone scintigraphy.</i>	35
Fig 2: <i>A 2-years-old child admitted for multiple bruises on the face and lameness of the right leg. Notion of domestic violence.</i>	41
Fig 3: <i>A 14-months-old child admitted for violence.</i>	42

Préambule

1. Introduction et historique

La maltraitance physique de l'enfant est un problème de Santé Publique majeur. Le diagnostic de maltraitance sous-tend un abord pluridisciplinaire. La fréquence, l'urgence de la prise en charge, les difficultés du diagnostic radiologique et de la datation des lésions placent le radiopédiatre au centre du diagnostic. Ils justifient la mise en œuvre de moyens permettant un diagnostic de certitude en raison des implications thérapeutiques et judiciaires qui en découlent.

La maltraitance à nourrissons et enfants est un sujet préoccupant, connu depuis les travaux d'Ambroise Tardieu publiés en 1860^[1]. Le corps social n'était pas prêt à la révélation des brutalités parentales qui retombèrent dans l'oubli. Il faut attendre la description par le radiopédiatre Silverman dans les années 1940, de lésions osseuses traumatiques évoquant des mauvais traitements et surtout l'article collaboratif d'un pédiatre, d'un radiopédiatre et d'un pédopsychiatre, en 1962, intitulé le « syndrome de l'enfant battu » pour provoquer une prise de conscience de la communauté scientifique et souligner la nécessité d'une enquête médico-socio-psychologique^[2]. Le « syndrome du bébé secoué », autre forme de maltraitance, a ensuite été décrit par le radiopédiatre Caffey en 1972^[3] sur un tableau encéphalique spécifique, qui peut s'associer à des anomalies squelettiques ou s'observer isolément. Toutes ces descriptions initiales ont été largement complétées ensuite, en particulier par les travaux de P. Kleiman.

2. Définition de la maltraitance physique de l'enfant et contexte légal

Les définitions proposées par l'Observatoire national de l'action sociale décentralisée (ODAS) sont actuellement les plus consensuelles.

On entend par « enfant maltraité » tout mineur victime, de la part de ses parents ou d'adultes ayant autorité sur lui, de violences physiques, de cruauté mentale, d'abus sexuels et/ou de négligences lourdes, ayant des conséquences graves sur son développement physique et psychologique.

On entend par « enfant en risque » tout mineur qui connaît des conditions d'existence risquant de mettre en danger sa santé, sa sécurité, sa moralité, son éducation ou son entretien, mais qui n'est pas pour autant maltraité.

On entend par « enfants en danger » l'ensemble des enfants maltraités et des enfants en risque.

Sur le plan légal, on peut se référer à la Loi n° 2007-293 du 5 mars 2007 réformant la protection de l'enfance^[4]. Cette loi vise à donner de nouveaux moyens aux Conseils Généraux pour exercer cette responsabilité essentielle. Elle met en œuvre les trois objectifs prioritaires suivants: renforcer la prévention, organiser le signalement des situations à risque et diversifier les actions et les modes de prise en charge des enfants^[5]. Afin de renforcer la prévention, la loi organise des bilans réguliers aux moments essentiels du développement de l'enfant (entretiens systématisés au 4ème mois de grossesse, visite à domicile dans les premiers jours suivant la sortie de maternité, bilans systématiques à l'école maternelle, puis à l'école primaire,...). Pour permettre une réaction fiable et rapide aux informations préoccupantes concernant la situation d'un mineur, la loi organise la procédure de signalement. A cette fin, elle crée dans chaque département une cellule de signalement composée de professionnels de la protection de l'enfance. Enfin, la loi diversifie les modes de prise en charge des enfants. Elle ouvre l'éventail des possibilités entre le maintien de l'enfant dans sa famille et le placement en établissement ou en famille d'accueil : chaque enfant doit pouvoir bénéficier de la solution la plus adaptée à sa situation.

Un diagnostic précoce des lésions osseuses chez un enfant suspect de maltraitance physique est primordial. Avant la loi de 2007 relative à la protection de l'enfance, tout professionnel de santé pouvait, au sens strict de la dérogation légale, et en pratique, devait signaler le cas d'un enfant en danger suspect de maltraitance physique au procureur de la république (signalement judiciaire). En cas de suspicion de maltraitance physique sans danger immédiat (par exemple maltraitance survenue hors de la famille), les professionnels de santé pouvaient signaler le cas aux services du Conseil Général (signalement administratif). Depuis la loi de 2007 renforçant le rôle du Conseil Général en matière de protection de l'enfance, la procédure a été modifiée. En effet, le signalement dit administratif disparaît et tout professionnel concourant à la protection de l'enfance doit (ce n'est plus une dérogation) avertir le Conseil Général de toute situation préoccupante concernant un enfant. En revanche, en cas de danger imminent, la possibilité d'un signalement judiciaire au procureur de la République persiste. Cette obligation de rendre compte de façon obligatoire au Conseil Général de toute situation préoccupante concernant un enfant voire de signaler le cas directement au procureur de la République, souligne l'importance primordiale d'un diagnostic le plus précoce possible.

3. Epidémiologie de la maltraitance physique de l'enfant

L'ODAS publie chaque année les résultats de son enquête sur l'enfance en danger^[4]. Elle fait apparaître que 98000 enfants ont bénéficié en 2006 d'une mesure de protection administrative ou judiciaire, soit 7 mineurs sur 1000 (contre 5 sur 1000 en 1998). L'ODAS fait également état de la diminution du nombre d'enfants effectivement maltraités. Ils représentent 19 % des 98000 enfants signalés, soit une diminution de 5 % sur l'année précédente. Ce recul ramène leur nombre au niveau de 1998, mais le nombre de mineurs s'est accru depuis. Les maltraitements d'ordre physique (33 % des cas) et sexuel (23 %) continuent de dominer, mais leur part a diminué par rapport à 1998.

Cette étude met aussi en avant la meilleure coordination des acteurs, que l'ODAS impute principalement à la mise en place, sous l'égide des Conseils Généraux, des cellules départementales de signalement et des observatoires de la protection de l'enfance, tous deux prévus par la loi du 5 mars 2007. Au 1^{er} novembre 2007, 51 % des départements avaient déjà installé une cellule de signalement. Enfin, l'enquête 2006 montre une progression de la part des suites administratives données au signalement, ce qui correspond à la fois aux souhaits des départements et à une probable amélioration de la détection précoce des situations. Sur les 98000 signalements enregistrés en 2006, 42000 ont reçu une suite administrative et 56000 ont fait l'objet d'une transmission judiciaire, soit un taux de judiciarisation de 57 % contre 59 % en 2005.

4. Diagnostic de maltraitance physique de l'enfant^[6]

a. Les signes de maltraitance

La présentation clinique est extrêmement variable. Parmi les lésions physiques, les lésions tégumentaires sont les plus évocatrices de mauvais traitement. Il peut s'agir de contusions (ecchymoses) de siège particulier; on peut trouver des plaies, dont le siège endobuccal et/ou génital est évocateur ou des brûlures. La présence de plaques d'alopécie en dehors d'affection dermatologique est également évocatrice. Le caractère des lésions, leur topographie, leur aspect multifocal, leur association et leur répétition (lésions d'âges différents) plaident en faveur d'une origine non accidentelle. Il peut s'agir de troubles de l'état général, de retard staturo-pondéral ou psychomoteur en rapport avec des négligences et des carences de soins, de troubles du contact, avec prostration ou état d'agitation.

Les fractures les plus fréquemment constatées sont les fractures des membres dont les signes cliniques et radiologiques sont fonction de l'âge, les fractures de côtes et les fractures du crâne.

Les hématomes sous-duraux sont la première cause de mortalité en cas de maltraitance et justifient un bilan radiologique exhaustif à visée encéphalique et squelettique.

b. Les traumatismes squelettiques non accidentels de l'enfant

Les lésions squelettiques élémentaires sont essentiellement des localisations métaphysaires et/ou diaphysaires. Les mécanismes en cause sont fréquemment des arrachements, des torsions, des étirements, parfois associés à des chocs directs. L'enfant « battu » peut être aussi violemment secoué; il s'agit le plus souvent d'enfants de moins de 2 ans. A cet âge, la plaque métaphysaire est fragile et le périoste est faiblement attaché à la corticale osseuse sauf au niveau du coin métaphysaire où son adhérence est très forte. Ainsi, le périoste se comporte comme un ligament et, lors d'un traumatisme, la traction du périoste sur le coin métaphysaire entraîne des lésions d'arrachement. La faible adhérence du périoste au niveau de la diaphyse explique aussi la formation aisée des hématomes sous-périostés.

c. Les fractures métaphysaires

Les lésions métaphysaires posent le problème de leur diagnostic positif, la principale difficulté étant de les reconnaître. Les fractures métaphysaires^[7] des os longs avec arrachement d'un petit fragment en coin (« corner fracture ») sont les fractures les plus fréquentes et les plus spécifiques de l'enfant maltraité. On les observe préférentiellement avant l'âge de 18 mois, et presque jamais après 2 ans. Souvent bilatérales, les fractures métaphysaires se produisent surtout sur l'extrémité distale des fémurs^[8], sur les extrémités proximale^[9] et distale^[10] des tibias et proximale des humérus^[11].

d. Les lésions diaphysaires : lésions périostées isolées ou fractures.

Les lésions périostées sans fracture peuvent répondre à un mécanisme de torsion ou à des coups directs, qui entraînent un saignement et un décollement du périoste. Elles sont plus fréquentes chez le nourrisson et leur diagnostic se fait en général au stade d'appositions périostées, car elles sont peu ou asymptomatiques.

Les fractures diaphysaires n'ont pas d'aspect particulier en elles-mêmes, mais leur découverte, avant l'âge de la marche, sans contexte traumatique parfaitement concordant est inhabituel et est une indication pour la pratique de radiographies de l'ensemble du squelette. Il peut s'agir de fracture spiroïde, notamment sur l'humérus ou le fémur, souvent en rapport

avec un traumatisme par torsion. La présentation clinique des fractures diaphysaires est souvent évidente avec douleurs, tuméfaction voire déformation du membre et impotence fonctionnelle. Le diagnostic en est donc souvent précoce et l'évolution se fait de façon habituelle vers l'apparition d'un cal avec appositions périostées s'incluant progressivement à la corticale. Il est habituel de considérer que les appositions périostées apparaissent environ 7 jours après le traumatisme. La datation précise des lésions est cependant très incertaine et n'est, de toute façon, pas requise au moment du diagnostic. L'élément diagnostique important est de pouvoir déterminer la présence de lésions squelettiques d'âges différents. Certaines localisations de fractures diaphysaires, par exemple sur les phalanges des pieds ou des mains sont suspectes chez le nourrisson ou le jeune enfant.

e. Les fractures du gril costal ^[12]

Du fait de la grande élasticité du gril costal du petit enfant, il est rare de voir des fractures de côtes, même à l'issue de manœuvres de réanimation cardiovasculaire ou de kinésithérapie respiratoire^[13,14]. La littérature rapporte d'exceptionnelles observations de fractures de côtes chez le nourrisson dans les suites d'un accouchement traumatique, chez le prématuré, dans les maladies métaboliques ou osseuses constitutionnelles. En revanche, les côtes peuvent céder à cause des forces d'accélération/décélération dans le cas où l'enfant, en général d'âge inférieur à 2 ans, est tenu au niveau du gril costal et secoué énergiquement^[15]. La valeur prédictive positive de sévices d'une fracture de côte chez l'enfant de moins de 3 ans est estimée à 95%^[16]. Les fractures, le plus souvent multiples, sur des côtes contiguës, bilatérales et symétriques siègent le plus souvent à proximité de la jonction costo-vertébrale ou parfois sur la ligne axillaire moyenne. Le diagnostic des fractures du gril costal est radiologiquement difficile au stade aigu et n'est souvent porté qu'une fois le cal formé, notamment lors du second bilan radiologique répété à J15. La scintigraphie osseuse permet leur détection plus précoce^[17].

f. Les fractures du crâne

Sur la voûte du crâne, certains types de fracture sont évocateurs de maltraitance: les fractures extra-pariétales, en particulier les fractures occipitales, les fractures avec un diastasis de plus de 5 mm, les fractures multiples ou stellaires et les kystes lepto-méningés. Il n'est pas possible de dater une fracture du crâne, sauf s'il existe une tuméfaction des parties molles en regard, indiquant le caractère récent de la fracture.

g. Les fractures des phalanges

Les fractures des phalanges des mains et des pieds sont plutôt rares. Cependant, elles sont fortement évocatrices de maltraitance chez l'enfant qui ne se déplace pas encore. Le plus souvent, il s'agit de fractures distales de métacarpiens, métatarsiens^[18] ou de phalanges suite à une hyperextension forcée^[19].

h. Les fractures vertébrales

Les traumatismes non accidentels de la colonne vertébrale sont moins fréquents que ceux des extrémités ou du crâne, mais leur gravité justifie néanmoins une radiographie de face et de profil de la colonne vertébrale chez un enfant que l'on suspecte victime de maltraitance. La région la plus fréquemment atteinte est la jonction dorso-lombaire^[20]. Les corps vertébraux peuvent être lésés par hyperextension qui peut provoquer une hernie du noyau pulpeux dans la partie antérieure d'un corps vertébral adjacent. Ces fractures touchent souvent plusieurs niveaux. Les lésions les plus fréquentes de l'arc postérieur sont les arrachements de multiples apophyses épineuses. Elles se produisent lors de secousses violentes avec flexion subite^[21].

i. Les autres localisations

Toutes les structures squelettiques peuvent être atteintes : bassin, omoplate, clavicule. La scintigraphie osseuse contribue à leur diagnostic difficile en radiologie conventionnelle.

j. Le syndrome du bébé secoué et l'hématome sous dural (HSD)

Le syndrome du bébé secoué est défini par la présence d'un HSD chez un nourrisson (le plus souvent dans les six premiers mois de vie) pour lequel l'interrogatoire de l'entourage ne retrouve pas de traumatisme crânien ou retrouve un traumatisme minime probablement incompatible avec les lésions constatées. L'HSD se produit lors de la déchirure de veines pontantes qui vont de la surface du cerveau à la dure-mère, ce qui provoque des saignements dans l'espace sous-dural. Le mécanisme - rotation, accélération, décélération - peut aussi être responsable de lésions de cisaillement entre la jonction substance blanche/substance grise responsables de saignements localisés^[22]. Des lésions ischémiques d'hypoxie cérébrale peuvent s'associer à l'HSD, constituant un facteur de mauvais pronostic. Une étude récente unique et très documentée du Pr Adamsbaum souligne dans Pediatrics 2010^[23] l'intérêt d'un dépistage précoce compte tenu des aveux. Les auteurs ont corrélié les résultats de 29 autopsies d'enfants présentant un HSD aux aveux de l'auteur des violences et de 83 cas sans aveux. Il n'y a pas de différence significative entre les groupes : les secousses sont décrites comme extrêmement violentes dans 100% des cas et répétées dans 55% des cas expliquant les

difficultés de datation des lésions. Dans 27% des cas le bilan radiologique mettait en évidence des lésions du squelette.

Le diagnostic repose sur la tomodensitométrie (TDM)^[24]. Tant que la fontanelle est ouverte, l'échographie cérébrale transfontanellaire (ETF) doit être pratiquée chez tous les enfants suspects de maltraitance^[25]. Elle permet de diagnostiquer le double contingent liquidien sous-dural et sous-arachnoïdien ainsi que leur échostructure. L'imagerie par résonance magnétique (IRM) est indispensable car elle permet d'affirmer le diagnostic d'hématome sous-dural et contribue au bilan des lésions encéphaliques associées qui en font le pronostic. Elle ne permet cependant pas une fiabilité totale dans la datation des lésions^[26]. Elle contribue à poser l'indication d'une dérivation sous-duro-péritonéale et à la surveillance thérapeutique sans irradiation de l'enfant. Le fond d'œil fait par un médecin ophtalmologiste ou un pédiatre expérimenté révèle 8 fois sur 10 des hémorragies rétiniennes typiquement bilatérales, très évocatrices si elles sont en flaqes. La normalité du fond d'œil n'exclut pas le diagnostic^[27].

Devant tout hématome sous-dural chez un nourrisson, en dehors d'un contexte accidentel évident, un bilan radiologique exhaustif s'impose à la recherche de lésions osseuses occultes, comme l'illustre le travail récent présenté aux Journées Françaises de Radiologie 2009 par l'équipe du CHU Saint Vincent de Paul. L'étude rétrospective (2003 – 2008) de 75 enfants présentant un HSD reconnu non accidentel rapporte une prédominance masculine (76%), de nourrissons (75% de moins de 6 mois). Au total, 80% étaient admis pour hypotonie, coma ou convulsions et 23% sont décédés. Les lésions associées étaient des hémorragies rétiniennes (85%), des fractures du crâne (11%), des fractures costales (14%) et métaphysaires (17%).

5. Résumé des résultats des essais non cliniques et des essais cliniques disponibles et pertinents au regard de la recherche biomédicale concernée

La présente étude porte sur la place de l'imagerie dans le diagnostic de maltraitance physique de l'enfant ou plus généralement dans le dépistage de lésions traumatiques d'origine indéterminée chez l'enfant. De nombreuses pathologies pédiatriques peuvent être responsables d'anomalies métaphysaires ou de fractures, telles que celles présentes dans un contexte de suspicion de maltraitance physique, par exemple dans les suites d'un accouchement traumatique, dans le cas d'une ostéogénèse imparfaite, ostéomyélite, maladie de Caffey, leucémie, rachitisme, scorbut, syphilis, déficit en cuivre, dysplasie métaphysaire de Schmidt, syndrome de Menkes... posant le difficile problème du diagnostic différentiel^[28,29].

La problématique radiologique est donc d'identifier l'ensemble des lésions présentes et notamment d'identifier précocement les lésions squelettiques qui pourraient échapper au bilan radiologique conventionnel. On distingue deux possibilités pour accroître la détection des lésions en cas de suspicion de maltraitance : soit refaire le bilan radiologique conventionnel deux semaines après le bilan initial, soit faire une scintigraphie osseuse et/ou une IRM en cours d'hospitalisation. La scintigraphie et probablement l'IRM sont susceptibles d'étayer le diagnostic plus précocement que la radiologie conventionnelle qui nécessite un délai de 2 semaines, dans ce contexte d'urgence judiciaire.

Ci-dessous sont présentés les points forts et les limites de chacune des techniques d'imagerie, dans le contexte du diagnostic de la maltraitance physique de l'enfant.

a. La radiologie conventionnelle

La radiologie conventionnelle est capitale pour documenter et dater les lésions squelettiques. On estime qu'un cal osseux apparaît entre le 8^{ème} et le 10^{ème} jour du traumatisme, son épaissement est maximal vers la 10^{ème} semaine, le cal régresse ensuite pour disparaître dans un délai de 6 mois environ. L'imagerie par la radiologie conventionnelle trop précoce peut donc sous-estimer des lésions osseuses.

La radiologie contribue à préciser les mécanismes lésionnels dans le cadre d'une suspicion de maltraitance à enfant^[30,31]. Ainsi, la réalisation de clichés en oblique du gril costal lors du bilan radiologique initial est recommandée par l'American College of Radiology et systématiquement réalisées par la British Society of Pediatric Radiology. Kleinman rapporte une rentabilité diagnostique de 60 % dans une série de 23 enfants en répétant ces clichés 15 jours après le bilan initial^[32].

La radiologie conventionnelle reste la pierre angulaire des explorations pour le diagnostic de maltraitance physique de l'enfance. Cependant, la littérature rapporte qu'elle est mise en défaut dans la détection des lésions périostées et des lésions des structures anatomiques complexes comme le gril costal, le bassin et la scapula^[33]. Il est capital que les clichés du squelette entier soient d'excellente qualité et inscrits dans un protocole précis. Ce sont souvent ces clichés qui apportent les informations à l'origine de l'enquête sociale et/ou du signalement. Au besoin, les clichés doivent être répétés et les incidences multipliées^[34].

Concernant l'irradiation, pour les radiographies de squelette entier, la dose dépend du nombre de clichés et de la technique utilisée. Elle peut varier de 0,16 à 2,76 mSv^[35].

b. La scintigraphie osseuse

Ces dernières années, la médecine nucléaire a fourni un outil supplémentaire, la scintigraphie osseuse, pour diagnostiquer la maltraitance physique de l'enfant^[33,36]. La scintigraphie est une technique d'imagerie très sensible, qui permet de détecter des traumatismes occultes qui sont pourtant bien réels.

La localisation de la fixation osseuse dépend de la physiologie du flux sanguin ainsi que du métabolisme des tissus mous et des structures squelettiques. La bonne compréhension de ce mécanisme est essentielle pour interpréter les résultats de la scintigraphie osseuse. Par exemple, un traumatisme est susceptible de provoquer une hypervascularisation des tissus mous et des structures osseuses avec comme conséquence initiale l'augmentation de la localisation des radioéléments dans les tissus concernés. Secondairement, cette hypervascularisation peut être responsable d'un œdème, puis d'une ischémie des tissus ayant pour conséquence la diminution de la localisation des radioéléments. Le même traumatisme peut donc causer une augmentation ou une diminution de la localisation osseuse des radioéléments en fonction de l'âge de la lésion. C'est pourquoi, les modifications physiologiques au cours du temps au niveau des lésions osseuses et des tissus mous doivent être parfaitement comprises et leurs relations avec la scintigraphie osseuse bien établies, l'interprétation des signes scintigraphiques de ces modifications étant essentielle pour dater le traumatisme. De plus et surtout, la datation du traumatisme a souvent des implications légales.

La scintigraphie osseuse apporte des éléments caractéristiques permettant ainsi de préciser les mécanismes d'un traumatisme^[37]. De plus, la force de la scintigraphie osseuse est de documenter de façon spécifique des sites caractéristiques de maltraitance comme les diaphyses des extrémités et le gril costal, venant ainsi combler les carences de la radiologie conventionnelle. Elle est également très sensible dans la détection des lésions diaphysaires récentes.

Selon la littérature récente, la scintigraphie osseuse, grâce à son intérêt pour caractériser certaines lésions qui peuvent être spécifiques de maltraitance et sa bonne sensibilité, apparaît plutôt comme une technique complémentaire de la radiologie conventionnelle plus qu'en compétition avec elle^[38-40]. Son évaluation fait l'objet d'un PHRC national initié par le CHU de Montpellier en 2006. Les résultats descriptifs de la population de l'étude ont été publiés en 2006^[38]. Outre la description des différentes blessures présentées par les enfants et leurs caractéristiques médico-sociales, ces résultats ont permis de montrer que la réalisation systématique d'un bilan radiographique et d'un bilan scintigraphique

augmentait de façon significative le nombre de suspicion de maltraitance physique par rapport aux seules suspicions retrouvées lors de l'examen clinique. En ce qui concerne les différences inter-observateurs entre relecteurs radiologues, il existait une concordance dans 84% des cas. Les désaccords concernaient principalement le crâne, le rachis ou le gril costal. Ainsi, en cas de suspicion de maltraitance physique, le bilan radiographique devrait être systématiquement interprété par deux radiopédiatres. En cas de désaccord, une troisième relecture commune devrait être proposée. En ce qui concerne les différences inter-observateurs entre relecteurs médecins nucléaires, s'il existait une concordance entre observateurs dans seulement 68% des cas, les situations pour lesquelles une mauvaise interprétation pouvait être délétère quant aux implications judiciaires (situations pour lesquelles un relecteur ne voit aucune hyperfixation et l'autre une très nette hyperfixation) ne représentaient que 6% des cas. Compte tenu de ces résultats, il est là encore recommandé que les scintigraphies osseuses soient systématiquement interprétées par deux médecins nucléaires et qu'en cas de désaccord une troisième lecture soit proposée.

Dans sa méta-analyse, Kemp et collaborateurs^[41] concluent qu'aucune modalité seule ne permettait de détecter l'ensemble des fractures. La sensibilité de la scintigraphie est élevée pour le diagnostic des fractures de côtes et basse pour celui des lésions classiques métaphysaires et des fractures du crâne.

L'expérience rennaise à ce sujet est illustrée par la thèse d'exercice du Dr Samson (non publiée, disponible à la Bibliothèque Universitaire Santé de l'Université de Rennes 1). Sur les 46 dossiers d'enfants inclus dans l'étude dans un contexte de maltraitance physique, la scintigraphie osseuse s'est montrée plus sensible que la radiographie dans 3 dossiers, qui concernaient des images suspectes au niveau d'une scapula, d'une vertèbre et d'un pied. Cependant, dans ces trois dossiers, la relecture multidisciplinaire des images lors d'une réunion d'experts (avec répétition des clichés radiographiques dans le cas de l'image suspecte de la scapula) a permis de conclure à l'absence de lésion osseuse dans chacun des cas, c'est-à-dire qu'il s'agissait de 3 faux positifs. Ces résultats sont en accord avec la littérature. Dans deux dossiers, les radiographies de squelette entier se sont avérées supérieures à la scintigraphie pour diagnostiquer, dans un cas une apposition périostée au niveau d'un tibia, et dans l'autre cas un cal osseux chez un enfant de 3 mois. Ces résultats sont plutôt en contradiction avec les données de la littérature puisque la scintigraphie est censée mieux détecter les appositions périostées que la radiographie. La faible taille de l'échantillon nous empêche de conclure puisque l'analyse statistique tend à montrer la supériorité de la

radiographie par rapport à la scintigraphie osseuse pour le diagnostic final, mais de manière non significative.

En terme d'irradiation, l'équivalent de dose efficace lors de la réalisation d'une scintigraphie osseuse est d'environ 3 mSv pour un enfant de 10 kg, l'irradiation naturelle annuelle étant en moyenne de 3 mSv.

L'irradiation est très variable d'un examen et d'un enfant à l'autre, mais on peut schématiser en disant que l'irradiation délivrée par une scintigraphie osseuse est du même ordre de grandeur que celle des radiographies de squelette entier.

c. La Tomodensitométrie (TDM)

Le scanner thoracique permet une meilleure performance diagnostique dans la détection des fractures de côtes que la radiologie conventionnelle^[42].

Dans une étude rétrospective chez 45 patients âgés de 7 mois à 18 ans, Renton et coll^[43] ont comparé les résultats de la TDM à ceux de la radiologie thoracique standard: 18 patients sur 45, soit 40%, présentaient des lésions dépistées seulement par la TDM. A ce jour, aucune étude n'a validé l'utilisation de la TDM dans le diagnostic des lésions métaphysaires. L'irradiation de ces jeunes patients n'autorise pas actuellement la pratique en routine de cet examen selon Van Rijn^[32].

d. L'échographie

A l'étage encéphalique, l'échographie transfontanellaire est chez l'enfant de moins de 1 an un outil diagnostique fiable dans la détection de l'hématome sous-dural^[25] et des hématomes sous-galéaux.

L'échographie réalisée devant une impotence fonctionnelle d'un membre ou en cas de doute sur un hématome des parties molles peut être également contributive en mettant en évidence des hématomes sous-périostés^[44,45].

Smeets^[46] la recommande en cas de doute pour le diagnostic des fractures de côtes.

e. ¹⁸F-NaF PET

Kleinman a proposé d'évaluer la sensibilité du fluorine 18-labeled sodium fluoride (¹⁸F-NaF) positron emission tomography (PET) pour la détection des lésions traumatiques chez des enfants suspects de maltraitance et de comparer sa performance à celle du bilan radiologique^[47].

Le bilan radiologique et le PET scan étaient réalisées chez 22 patients de moins de 2 ans (septembre 2007 – Janvier 2009). Quatorze enfants ont eu un bilan radiologique de suivi.

Le PET scan était interprété par 2 médecins nucléaires pédiatriques et les radiologies conventionnelles par 2 radiopédiatres différents. Un total de 156 fractures était détecté par la radiologie conventionnelle et de 200 fractures par le PET scan. Le PET scan versus la radiologie conventionnelle avait une sensibilité de 85% / 72% pour la détection de toutes les fractures, 92% / 68% pour les fractures thoraciques, 93% / 73% pour celle des fractures de côtes postérieures et 67% / 80% pour celle des lésions métaphysaires. En conclusion, le PET scan a une sensibilité élevée pour la détection de l'ensemble des fractures mais sa sensibilité moindre pour la détection des lésions métaphysaires rend indispensable le bilan radiologique initial.

f. L'IRM corps entier

La revue de la littérature rapporte seulement 4 études pédiatriques ayant utilisé l'IRM STIR corps entier.

L'étude publiée par Kleinman et al^[48] en 2006 visait à comparer les résultats de la radiologie conventionnelle et de l'IRM corps entier (STIR coronal et sagittal), et portait sur un total de 102 lésions osseuses. Dans 26 % des cas, les résultats étaient concordants, mais 38 % et 35 % des lésions n'étaient pas diagnostiquées, respectivement sur les radiographies et l'IRM. Parmi les 34 lésions métaphysaires classiques et les 40 fractures de côtes visualisées en radiologie conventionnelle, seulement 41% et 42% respectivement n'avaient de traduction en IRM (absence d'anomalie de signal). En conclusion, l'auteur suggérait un défaut de résolution spatiale comme limite au dépistage des anomalies de signal de moelle osseuse, mais des progrès dans ce domaine sont prometteurs ou espérés.

La seconde étude concerne les travaux de P. Evangelista rapportés en 2006 au congrès de l'American Society of Pediatrics^[49] et qui portaient sur l'identification de lésions occultes traumatiques par la radiologie conventionnelle et l'IRM STIR corps entier. Entre 2003 et 2005, 16 enfants (âge moyen 9 mois ; extrêmes 1,5 – 37 mois) suspects de sévices ont été imagés par radiologie conventionnelle et IRM STIR. L'IRM STIR coronal était réalisée avec 3 stations (IRM 1,5 T en utilisant de multiples antennes de surface avec les paramètres suivants: TR/TE/TI=9070/79/130; FOV= 200-300mm; matrice= 230x384; épaisseur de coupes = 3 mm (gap, 0.3mm); Nex= 1-2; acq time= 5.5-7.4 minutes par station. Tous les patients étaient sédatisés. L'intervalle entre le bilan radiologique et l'IRM était de 1,9 jours (extrêmes 0-13 jours). La sensibilité de l'IRM STIR était de 75 % (33/44) pour les fractures de côtes, 67% (2/3) pour les lésions métaphysaires en coin, 100% (1/1) pour les métaphyses, 100% (6/6) pour les diaphyses et 100% (1/1) pour les fractures du crâne. Les 11 fractures de

côtes manquées concernaient des patients avec de multiples fractures de côtes et au moins une fracture de côte avait été diagnostiquée à l'IRM chez chacun de ces patients. Chez 3 patients différents, l'IRM a diagnostiqué une contusion radiale, une fracture de l'ulna et une fracture vertébrale de T2 qui n'avaient pas été identifiées en radiologie conventionnelle. Les 5 patients à IRM STIR normale avaient également un bilan radiologique normal. Enfin, 8 anomalies des parties molles (œdème musculaire ou hématome) étaient détectées par l'IRM STIR, toutes adjacentes à des lésions osseuses. Par ailleurs, l'IRM STIR a mis en évidence un épanchement péritonéal dans 2 cas, pleural dans 1 cas et un anasarque dans 1 cas. Les auteurs concluaient que l'IRM corps entier contribue au diagnostic de fractures et peut démontrer son aide au diagnostic des lésions osseuses et des tissus mous non détectées par la radiologie conventionnelle.

Enfin, Stranzinger et al^[50] ont rapporté en 2007 un cas pédiatrique de maltraitance physique où l'IRM STIR met en évidence un hypersignal dans la moelle osseuse et les tissus mous signant la présence de fractures de côtes postérieures et latérales non détectées par la radiologie conventionnelle.

En 2010, Kleinman et al^[51] rapportent les résultats d'une série concernant 21 enfants (0-12 mois) ayant bénéficié d'une IRM corps entier. Le bilan radiologique initial a concerné tous les enfants et le bilan à distance 16 enfants. L'IRM corps entier à 1,5 T comprenait des séries coronales et sagittales STIR dans les 5 jours qui suivaient le bilan radiologique. L'IRM corps entier et le bilan radiologique ont totalisé 167 fractures : 46 (27.5%) avec les 2 techniques, 68 (40.7%) avec le bilan radiologique seul et 53 (31.7%) avec l'IRM corps entier seule. L'IRM corps entier avait une haute spécificité (95%) mais une faible sensibilité (40%) pour l'identification des fractures ou des anomalies de signal comparativement au bilan radiologique complet. Trente-sept lésions métaphysaires ou anomalies de signal métaphysaires étaient identifiées : 11 (29.7%) avec les 2 techniques, 24 (64.8%) avec le bilan radiologique seul et 2 (5.4%) avec l'IRM corps entier seule. L'IRM corps entier avait une faible sensibilité (31%) pour la détection des anomalies de signal métaphysaires alors que les lésions métaphysaires étaient repérées en radiologie conventionnelle. L'IRM corps entier avait une faible sensibilité (57%) pour la détection des anomalies de signal costales alors que les fractures de côtes étaient repérées en radiologie conventionnelle. L'IRM corps entier a mis en évidence des lésions des tissus mous (œdème musculaire ou épanchement intra-articulaire) qui ont permis alors le diagnostic de fractures additionnelles. L'IRM corps entier apparaît donc peu sensible pour la détection des lésions métaphysaires et des fractures de côtes et ne

peut actuellement remplacer le bilan radiologique mais peut apporter des informations complémentaires en permettant de visualiser des lésions tissulaires.

D'après ces 4 études, l'IRM STIR corps entier semble donc avoir sa place en complément du bilan radiologique conventionnel dans le contexte de la maltraitance physique de l'enfant. Comme les autres imageries corps entier (radiologie conventionnelle, scintigraphie ou PET scan), elle permet d'imager le patient dans sa totalité, mais avec cette fois l'avantage de ne pas exposer l'enfant aux radiations ionisantes.

En cas de suspicion de maltraitance physique de l'enfant, la problématique radiologique est donc d'identifier l'ensemble des lésions présentes et notamment d'identifier précocement les lésions squelettiques qui pourraient échapper au bilan radiologique conventionnel. Ainsi, la scintigraphie osseuse et/ou l'IRM peuvent présenter un intérêt en cours d'hospitalisation. Elles peuvent permettre d'étayer le diagnostic plus précocement que la radiologie conventionnelle dans ce contexte d'urgence judiciaire.

La littérature internationale fait état de l'acuité du problème, comme en témoigne l'intitulé de l'article publié par Van Rijn en 2009^[32]: « How should we image skeletal injuries in child abuse ? » et en France, ce sujet a fait l'objet d'une conférence plénière aux Journées Françaises de Radiologie en 2008 et d'un dossier spécial dans la revue *Pediatric Radiology* en 2014.

L'IRM corps entier permet donc d'imager le patient dans sa totalité de même que les autres imageries corps entier mais avec l'avantage de ne pas exposer l'enfant aux radiations ionisantes. L'IRM corps entier est une technique actuellement utilisable en routine, elle semble prometteuse dans de nombreuses indications en particulier en pathologie tumorale (tumeurs malignes métastatiques, histiocytoses langerhansiennes, lymphomes)^[52-57]. Les applications émergentes incluent l'évaluation de l'ostéonécrose, de l'ostéomyélite multifocale récurrente et des myopathies. M Siegel et col considèrent l'IRM corps entier comme un outil diagnostique d'avenir dans l'autopsie virtuelle et la pathologie traumatique non accidentelle de l'enfant. Dans la mesure où cette technique est possiblement aussi sensible que la scintigraphie et non irradiante, des études multicentriques doivent être mises en place afin d'optimiser son utilisation en pédiatrie.

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Résumé

Place de l'IRM corps entier dans le dépistage des lésions traumatiques d'origine indéterminée chez l'enfant. Etude PEDIMA.

Objectif: Comparer la sensibilité et la spécificité de la radiographie de squelette corps entier (RX), de l'IRM corps entier et de la scintigraphie osseuse (SO) dans le dépistage des lésions traumatiques d'origine indéterminée chez l'enfant.

Matériel et méthode: Il s'agit d'une étude multicentrique prospective (PHRC PEDIMA 2011) ayant inclus des enfants de moins de 3 ans suspects de traumatisme non accidentel. Tous les enfants ont bénéficié des 3 modalités d'imagerie (RX+SO+IRM). Le gold standard était le consensus de l'interprétation collégiale des 3 examens en aveugle par les experts.

Résultats: Au final, 170 enfants ont été inclus. Le délai moyen de réalisation des examens d'imagerie était de 4.4 jours. Soixante-quatre enfants avaient au moins une lésion, avec un total de 146 lésions. La sensibilité et la spécificité de chaque examen étaient respectivement de 88.4% et 99.7% pour la RX, 69.9% et 99.5% pour l'IRM, 54.8% et 99.7% pour la SO. La sensibilité et la spécificité pour le couple RX+IRM étaient respectivement de 95.9% et 99.2% et pour le couple RX+SO de 95.2% et 99.4%.

Conclusion: La RX est l'examen le plus sensible pour détecter des lésions osseuses traumatiques d'origine indéterminée. Sa sensibilité est augmentée si associée à une SO et/ou une IRM corps entier.

Abstract

Whole-body STIR MR imaging in suspected child abuse: comparison with skeletal survey and bone scintigraphy from the PEDIMA multicentric study.

Objective: The purpose of our study was to compare sensitivity and specificity of Skeletal Survey (SS), Whole-Body Magnetic Resonance Imaging (WB-MRI) and Bone Scintigraphy (BS) in the detection of non-accidental injuries in suspected child abuse.

Materials and methods: Our multicentric and prospective study (PHRC PEDIMA 2011) involved children under 3 years old suspected of non-accidental traumatism. All children underwent the 3 imaging modalities (SS+WB-MRI+BS). The gold standard was the consensus of blinded collegial interpretation by experts.

Results: In the end, 170 children were included. The mean delay to realize the 3 imaging modalities was 4.4 days. Sixty-four children had at least one lesion with a total of 146 lesions. Sensitivity and specificity of each exam were respectively 88.4% and 99.7% for SS, 69.9% and 99.5% for WB-MRI and 54.8% and 99.7% for BS. Sensitivity and specificity were respectively 95.9% and 99.2% for the combination SS+WB-MRI and 95.2% and 99.4% for the combination SS+BS.

Conclusion: SS is the most sensitive imaging modality to detect bone lesions suspected of non-accidental origin. This sensitivity is increased when SS is associated with a BS or a WB-MRI.

Article scientifique

Whole-body STIR MR imaging in suspected child abuse: comparison with skeletal survey and bone scintigraphy from the PEDIMA multicentric study.

Introduction

Child abuse is a major issue worldwide that involves a pluridisciplinary approach. It requires an early and reliable diagnosis to lead to a better patient care and to avoid dramatic consequences. The World Health Organization (WHO) estimates that 40 million children aged 0-14 years are abused or neglected worldwide^[1]. This diagnosis mainly relies on detecting high-specificity skeletal injuries thanks to high-quality skeletal surveys (SS)^[2]. These are performed according to the Haute Autorité de Santé (HAS) protocol and American College of Radiology (ACR) standard specifications^[3]. Systematic follow-up SS 10-14 days later to look for additional injuries that may not be seen on initial SS is recommended to improve the diagnosis of occult lesions^[4,5]. The ACR recommends computed tomography (CT) scan and magnetic resonance imaging (MRI) of the head in large indications. The bone scintigraphy (BS) may also be indicated when skeletal survey is negative and that high clinical suspicion remains^[6,7]. Indeed, a recent study showed that BS could aid the confidence of diagnosis or identify new findings in 12% of cases^[8]. Nevertheless, the utility of BS and follow-up SS are controversial in the literature. A recent study that investigated the role of follow-up SS in non-accidental trauma showed that it may be unnecessary without clinical evidence^[9]. Moreover SS and BS cannot diagnose subcutaneous tissues, visceral and muscle injuries.

Whole-Body Magnetic Resonance Imaging (WB-MRI) with Short Tau Inversion Recovery (STIR) sequences has recently emerged as an additional imaging modality. It is currently used for the evaluation of skeletal and extra-skeletal lesions in children affected with infectious or tumoral pathologies^[10]. There is very few data in literature reporting this imaging modality in the context of suspected non accidental trauma. However, some articles show that WB-MRI can help identify soft-tissues injuries such as muscle edema or joint effusions and additional fractures^[11].

Our study aims at comparing skeletal survey, WB-MRI and bone scintigraphy in the detection of traumatic bone lesions on a large cohort of children aged 0-3 years suspected of abuse.

Material and methods

Study population

This study is a prospective and multicentric study led from August 2011 to February 2015 in 10 French University Hospitals.

Eligible children were aged less than 3 years old and the inclusion criteria were: non-accidental subdural hematoma, bone injuries highly associated with child abuse (metaphyseal lesions, periosteal appositions, bilateral fractures before 2 years old, rib fractures, vertebral fractures, clavicular fracture after birth, diaphysal fractures before 1 year old, fingers and toes fractures), cutaneous or abdominal lesions suspected from non-accidental origin by the pediatrician or the referent forensic scientist. At least one of the parents or legal caregiver should have signed the written consent form.

The exclusion criteria were: subdural hematoma known from accidental origin, accidental fracture and fracture with a consistent mechanism of injury that could explain the clinical and radiological findings.

The clinician who included the child in the protocol completed a form with clinical settings and medical history: facts reported by parents or caregivers, localization and type of traumatic lesions....

Each child underwent imaging examinations within the first days of his hospitalization.

The study was done in accordance with the principles of the Declaration of Helsinki^[12]. Local ethics committees approved the protocol. All children's parents provided written informed consent at enrolment.

Image acquisition

The skeletal surveys were performed according to the protocols of the American College of Radiology^[3], the British Society of Paediatric Radiology^[13] and the SFIPP (Société Francophone d'Imagerie Pédiatrique et Périnatale). For the head, frontal, lateral and Worms views were performed. For the chest, antero-posterior views including the clavicles and oblique views (right and left, to see ribs) were realized. For the limbs, frontal views of both upper arms, both forearms, both femurs and both lower legs were performed. Lateral views were added for long bones. For the pelvis and spine, a frontal view including the lumbar spine and a lateral view of the entire spine were performed. Finally, frontal and dorsoplantar views were performed for hands and feet. In total, there were 16 to 20 radiographs performed per child. The average radiation dose for a full SS was estimated between 0.03 and 0.35 mSv. A

head computed tomography (CT) was realized in each suspected head trauma, especially in case of subdural hematoma, according to recommendations. In this case, head's radiographs were not realized, in order to limit ionizing radiation exposure. The results of head CT were not taken into account. It just helped to enumerate subdural hematomas, so as head MRI did. Follow-up skeletal surveys were not systematically done. It could be performed when there was a discrepancy between SS and WB-MRI results, especially suspected lesions on WB-MRI unseen on SS. However, these results were not taken into account for the statistical analysis because of the few cases gathered.

Bone scintigraphy was performed using an injection of 7.4 to 11.1 MBq/kg (mean activity 8 MBq/kg) of HMDP-99mTc (or equivalent) with a minimum activity of 37 MBq. The early phase (soft tissue uptake) was performed less than 5 minutes after the tracer injection, with static anterior and posterior views (matrix 128x128, time 180s) and optional lateral views, the patient staying in a symmetric position. A delayed acquisition (bone uptake) was performed 2 to 3 hours after the tracer injection with static images (matrix 256x256, time 180s) to obtain a whole-body scintigraphy. Multiple overlapping images were performed, in anterior and posterior views, right and left lateral and oblique anterior or posterior views of the head and the chest. There was a contention of children, without any sedation. Injection sites were noticed for each exam.

The WB-MRI examination was led on a 1,5T or 3T magnet depending on each center. The patients were sedated according to their age, their clinical settings and recommendations^[14]. The body was imaged from the vertex to the feet. Every MR examination included at least coronal STIR sequences and as often as possible sagittal STIR sequences on the spine. The technical STIR parameters were as follows : TR (Repetition Time)= 3761-7520 ms ; effective TE (Echo Time)= 30.3-101 ms ; inversion time= 145-160 ms ; echo-train length= 8-33 ; signal averages= 1-3 ; BW (Bandwidth)= 122-315 Hz/Px ; field of view= between 317x 350 mm² and 530x530 mm² ; matrix= between 169x288 and 512x292 ; section thickness= 4-6 mm ; image acquisition time= 1,5/3 min per station. The average duration of the coronal STIR acquisition was 15 minutes. The coronal STIR sequences were given a quality grading score by visual assessment from 1 (excellent) to 5 (non-interpretable). Patients with non-interpretable exams were excluded from the study. Whole-body diffusion sequences were performed, according to the initial protocol, but not taken into account in the statistical analysis because of too poor quality in most of cases and not interpretable.

Image interpretation

A first review of each exam was realized in a collegial and random order manner. It was blinded from other exams results or clinical settings. SS and WB-MRI were reviewed on consensus by 5 board-certified pediatric radiologists (C.T, C.S-T, P-H.V, B.B, MP; with respectively 20, 20, 15, 15, 10 years of experience). BS were reviewed on consensus by 3 board-certified nuclear doctors (A.D, J.C, C.B; with respectively 25, 30, 15 years of experience). An ultimate review gathering radiologists and nuclear doctors permitted to settle discrepancies and determine “real lesions”. The “truth” was determined by the expert’s consensus.

The settings were collected in a data entry form with a checklist for each exam. Localization of lesions was determined as follows: head, arms, ulna and radius, hands, ribs (right and left), clavicles, spine (cervical, thoracic or lumbar), pelvis, femurs, tibia and fibula and feet. There was a total of 25 body parts.

The skeletal surveys checklist included: localization, number, type (diaphyseal fracture, periosteal appositions, classic metaphyseal lesion) and dating (acute or healing) of the fractures if relevant. The WB-MRI checklist included: presence or absence of high-intensity lesion and their localization and presence of soft-tissues abnormalities. Bone scintigraphy checklist itemized the localization and number of fixations, the presence or not of hyperemia on early phase, the extent and intensity of fixation on the delayed acquisition and the presence of soft-tissues abnormalities.

Statistical Analysis

Sample size was based on the capacity of recruitment of centers. The sample size was set at 200 children. We summarized children’s baseline clinical and demographic characteristics with descriptive statistics.

For each imaging modality and for the combinations SS+WB-MRI and SS+BS, the number and percentage of children concerned by at least one lesion were calculated for the whole body, but also by localization (humerus, radius, ulnas, hands, femurs, tibias, fibulas, cervical spine, dorsal spine, lumbar spine, clavicles, ribs, pelvis and feet), and finally by member segment (upper limbs, lower limbs, spine, clavicles, ribs and pelvis). Descriptive statistics were also realized on the number of body part units affected by at least one lesion per child. For SS, types of lesions were also described. For WB-MRI and BS, soft tissues abnormalities were also described.

Considering the body part unit as a statistical unit, we defined a positive body part unit as a body part for which at least one lesion was detected. A negative body part unit was a body part for which no lesion was detected.

For each exam and for the two combinations of exams SS+WB-MRI and SS+BS, number of body part units + and body part units – were given for the whole body and by localization.

In absence of gold standard giving the truth about the absence or presence of a lesion on a body part unit, a consensus was reached: a lesion on a body part existed (true +), if the three imaging modalities had detected it. A body part unit was negative (true -) if none of the three exams had detected a lesion on the body part. In case of disagreement (a lesion was detected by only one or two of the three exams), the three exams of the concerned child were reviewed one more time by the expert radiologists and nuclear doctors. They collegially agreed on the presence or absence of the lesion on the body part (all disagreements were read during a final review of conflicting results). If a decision could not be taken, the body part unit was removed from the analysis. Sensitivity, Specificity, Positive Predictive value and Negative Predictive Value and their 95% confidence interval were then performed for each imaging modality (SS, WB-MRI and BS), and for the combinations [SS+WB-MRI] and [SS+BS], using the Consensus as the reference. See example for the combination SS + WB-MRI in table 1 (resp. SS + BS).

SS	WB-MRI	[SS+WB-MRI]	Consensus	So [SS+WB-MRI] =
+	+	+	If consensus +	True positive
+	-		If consensus -	False positive
-	+			
-	-	-	If consensus +	False negative
			If consensus -	True negative

Table 1: Definition of true negative, false positive, false negative and true negative lesions according to the consensus for each body part unit. For example, SS, WB-MRI and the combination [SS+WB-MRI] are used in this table (resp SS, BS and [SS+BS]).

The limits of confidence intervals were used to compare sensitivities. Several listings were established, describing disagreements between exams. Statistical analyses were performed with SAS® 9.4 software (SAS Institute Inc., Cary, NC, USA).

Results

Study group description

One hundred and seventy patients underwent the 3 imaging modalities and had images available for the collegial reviewing by experts and finally included for the statistical analysis (Fig. 1). An exam was not available if not performed, not collected or not interpretable. The mean age of children at the inclusion was 8.6 months (range, 0.4 - 35.7). There were 105 boys (61.8%) and 65 girls (38.2%). The mean delay to realize the three imaging modalities was 4.4 days (range, 0 to 32).

Regarding clinical findings, 96 children (56.5%) had at least one cutaneous lesion. There was loss of consciousness after a head trauma in 26 children (15.3%), a convulsive seizure in 30 children (17.8%), a sensorimotor deficit in 42 children (25%) and brutal augmentation of cranial perimeter in 30 children (18%).

Complementary exams found that 58 children had ophthalmologic lesions (34.3%). Most of the time, it was retinal hemorrhage (86.2%). Fifty-eight children had a subdural hematoma on cerebral imaging (34.1%) and 16 had intra-parenchymal lesions (9.4%).

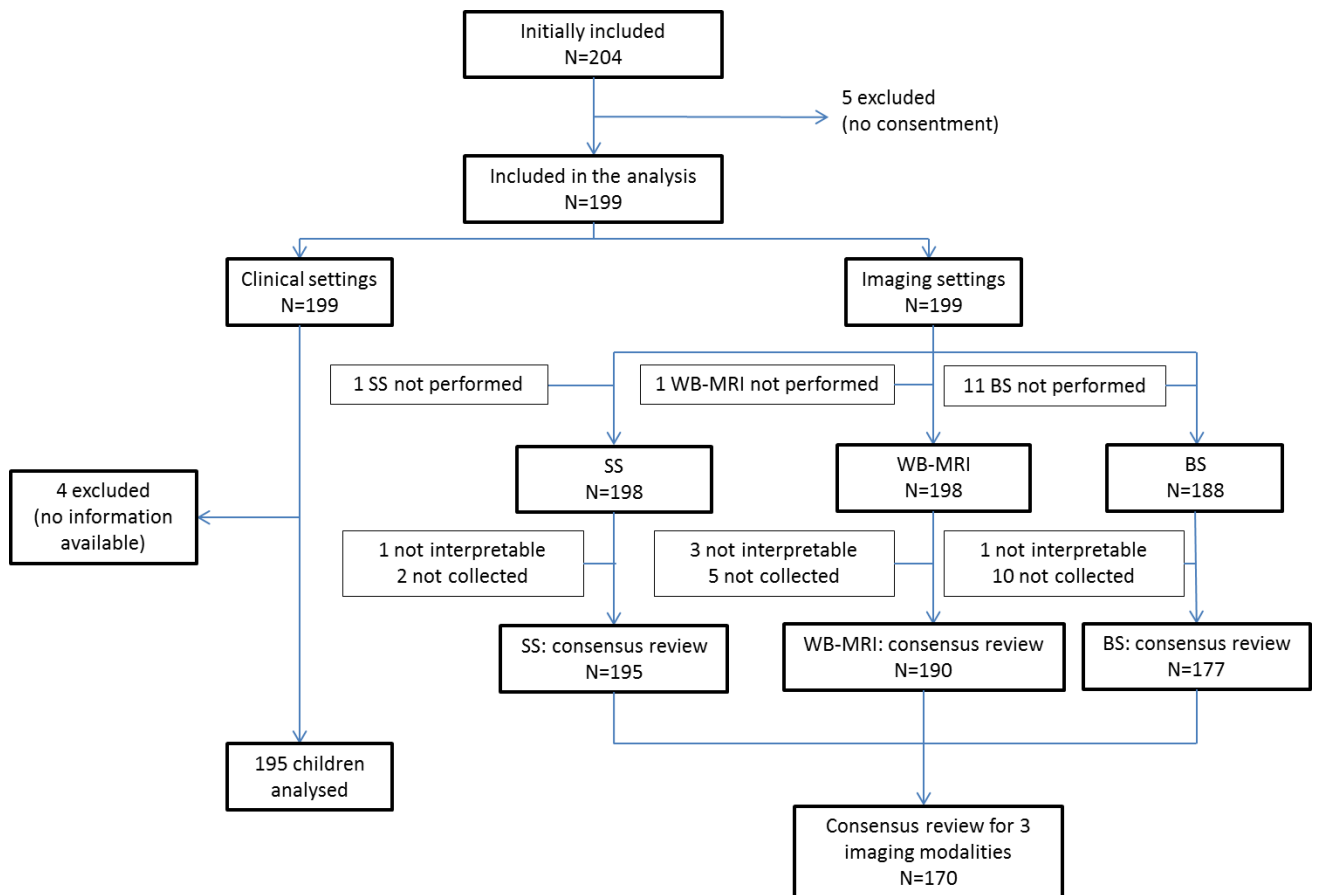


Fig. 1: Population study. SS= Skeletal survey, WB-MRI= Whole-Body Magnetic Resonance Imaging, BS= Bone scintigraphy.

Imaging results

There were a total of 4250 body part units analyzed for 170 children. Among them, the 3 imaging modalities were in agreement for 4114 body part units. They were discrepant for 136 body part units (concerning 58 children). These 136 examinations have been reviewed by experts to agree on a consensus. A consensus could not be obtained for 11 body part units that were removed from the final statistical analysis. At the end, statistical analysis concerned 4239 body part units.

After consensus, 64 (37.6%) children had at least one lesion with a total of 146 body part units affected (positive body part unit = with at least one lesion). The number of children with lesions at consensus is detailed for each imaging modality in the Table 2. The SS was negative for 5 children that had one lesion at consensus. Among them, 4 children had a foot lesion that was diagnosed on WB-MRI for 2 of them and on BS for the 2 others (*Fig.2*). The 5th child had a clavicle lesion that was diagnosed on BS (*Fig. 3*). Therefore, 1 clavicle lesion and 2 feet lesions were “missed” by the combination SS + WB-MRI and 2 feet lesions by the combination SS+BS.

	SS N (%)	WB-MRI N (%)	BS N (%)	SS+WB-MRI N (%)	SS+BS N (%)
All lesions detected	51 (79,7)	39 (60,9)	36 (56,3)	59 (92,2)	57 (89,1)
At least one lesion undiagnosed	8 (12,5)	16 (25)	18 (28,1)	2 (3,1)	5 (7,8)
No lesion diagnosed on the exam	5 (7,8)	9 (14,1)	10 (15,6)	3 (4,7)	2 (3,1)

Table 2: Number of children with lesions detected by each imaging modality separately or by combination of SS with WB-MRI or BS. n= 64 children with at least one lesion.

Line 1: number of children with all lesions detected on the exam;

Line 2: number of children with at least one lesion undetected on the exam;

Line 3: number of children with no lesion detected on the exam.

The number of lesions (including true positive, false positive and false negative) for each body part unit and each imaging modality is detailed in the Table 3. The 17 body part units that were false negative on SS concerned 13 children. Two FN were spine lesions in the same child detected on BS, 4 were lower legs lesions (2 periosteal appositions in a single child) detected on WB-MRI and BS, 1 was a hairline fracture of the femur detected on WB-MRI and BS. In 14 children (8.2%), there were lesions of different age on SS. Among the 44 false

negative body part units on WB-MRI, 9 were spine lesions including 6 lesions that appeared as shape abnormalities without high-intensity signal, so unnoticed. Ten WB-MRI FN were periosteal appositions of long bones and 10 others were classic metaphyseal lesions (CML). Among the 66 body part units that were FN on BS, 9 were periosteal appositions, 20 were CML and 8 were recent fractures.

	SS			WB-MRI			BS			SS+WB-MRI			SS+BS			Total of lesions
	TP	FP	FN	TP	FP	FN	TP	FP	FN	TP	FP	FN	TP	FP	FN	
Humerus	20	1	1	19	5	2	15	0	6	21	6	0	20	1	1	21
Radius	14	2	0	12	1	2	9	0	5	14	3	0	14	2	0	14
Ulna	12	1	0	10	1	2	8	0	4	12	2	0	12	1	0	12
Hand	0	1	0	0	0	0	0	1	0	0	1	0	0	2	0	0
Femur	28	0	1	24	2	5	20	2	9	29	2	0	29	2	0	29
Tibia	16	2	4	14	1	6	11	5	9	20	3	0	18	7	2	20
Fibula	5	1	0	2	1	3	1	0	4	5	2	0	5	1	0	5
Feet	2	0	5	4	0	3	2	1	5	5	0	2	4	1	3	7
Spine (Cervical)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spine (Dorsal)	5	1	1	2	0	4	1	0	5	5	1	1	6	1	0	6
Spine (Lumbar)	4	0	1	0	0	5	1	0	4	4	0	1	5	0	0	5
Clavicle	8	1	1	4	2	5	3	0	6	8	2	1	9	1	0	9
Ribs	14	3	3	10	9	7	8	1	9	16	11	1	16	3	1	17
Pelvis	1	0	0	1	0	0	1	1	0	1	0	0	1	1	0	1
Total	129	13	17	102	22	44	80	11	66	140	33	6	139	23	7	146

Table 3: Detail of true positive (TP), false positive (FP) and false negative (FN) lesions according to the imaging modality and localization (body part unit). SS= Skeletal Survey, WB-MRI= Whole-Body Magnetic Resonance Imaging and BS= Bone Scintigraphy.

Among the 13 body part units appearing as FP on SS, most of them were CML falsely diagnosed. Periosteal appositions on the arm were also falsely diagnosed. Three concerned suspected ribs fractures. One of them also appeared as FP on WB-MRI, but involved different parts of the chest (ribs numbers were not taken into account in the statistical analysis). The last one concerned a clavicle lesion and appeared as a FP also on WB-MRI. This lesion was finally considered as clavicle congenital pseudarthrosis so considered of non-traumatic origin. In the end, only 2 body part units appeared as FP on both SS and WB-MRI.

Among the 22 body part units that were FP on WB-MRI, 2 lesions of ulna and fibula were a mistake regarding the bone involved (ulna instead of radius and fibula instead of tibia). One lesion of the tibia was in fact soft tissues high-intensity signal due to perfusion. Some suspected bone lesions (3 humeral, 1 clavicle and 2 ribs) were in fact only soft tissues signal abnormalities. Some suspected lesions (2 humeral, 1 rib and one femoral) were due to positional artefacts. Five suspected ribs lesions were due to thin pleural effusion and one was mistaken with an anterior cartilage. Finally, one suspected femoral lesion was due to vascular artefacts along the diaphysis.

Among the 11 body part units that were FP on BS, one suspected femoral lesion was due to movement artefact, one rib lesion and one pelvis lesion were due to positional artefacts. Finally, one femoral fixation was considered of non-traumatic origin.

Table 4 describes discrepancies between different imaging modalities according to the localization of lesions.

There were a total of 29 CML diagnosed on SS, concerning 13 children. Among them, 15 (51.7%) were detected on WB-MRI concerning 9 children and 9 (31%) were detected on BS, concerning 7 children. One more CML was detected only on WB-MRI.

There were a total of 20 periosteal appositions diagnosed on SS, concerning 9 children. Among them, 11 (55%) were detected on WB-MRI concerning 7 children and 7 (35%) were detected on BS concerning 5 children. Two more periosteal appositions were diagnosed on both WB-MRI and BS and one more only on WB-MRI.

There were 4 epiphyseal lesions described on SS, 3 were detected on WB-MRI and 4 on BS. WB-MRI identified soft tissues abnormalities in 85 children (50%), including muscular edema in 60 children (35.3%), sub-cutaneous edema in 47 (27.6%), peritoneal effusion in 8 (4.7%), articular effusion in 7 (4.1%), pleural effusion in 6 (3.5%) and spine ligament injury in 2 (1.2%). Among the 60 children that had a muscular edema, 7 did not have any associated bone lesion. There was no visceral lesion diagnosed.

	SS + / WB-MRI -	SS - / WB-MRI +	SS + / BS -	SS - / BS +	WB-MRI + / BS -	WB-MRI - / BS +	Total of lesions
Humerus	2	1	5	0	4	0	21
Radius	2	0	5	0	3	0	14
Ulna	2	0	4	0	2	0	12
Hand	0	0	0	0	0	0	0
Femur	5	1	9	1	4	0	29
Tibia	6	4	7	2	5	2	20
Fibula	3	0	4	0	2	1	5
Feet	1	3	2	2	4	2	7
Spine (Cervical)	0	0	0	0	0	0	0
Spine (Dorsal)	3	0	5	1	2	1	6
Spine (Lumbar)	4	0	4	1	0	1	5
Clavicle	4	0	6	1	3	2	9
Ribs	6	2	8	2	5	3	17
Pelvis	0	0	0	0	0	0	1
Total	38	11	59	10	34	12	146

Table 4: Detail of discrepancies between different imaging modalities according to the localization of lesions. SS= Skeletal Survey, WB-MRI= Whole body Magnetic Resonance Imaging and BS= Bone Scintigraphy.

Sensitivity, specificity, VPP and VPN

Table 5 shows that SS has the best sensitivity with a significant difference, comparing to other imaging modalities. Combining a second imaging modality with the SS, either BS or WB-MRI, adds confidence at the non-accidental trauma diagnosis even if this difference is non-significant. There was no significant difference of sensitivity, specificity, VPP or VPN when comparing SS+WB-MRI and SS+BS.

	Sensitivity [IC95%]	Specificity [IC95%]	PPV [IC95%]	NPV [IC95%]
SS	88,4 [82,0 - 93,1]	99,7 [99,5 - 99,8]	90,8 [84,9 - 95,0]	99,6 [99,3 - 99,8]
WB-MRI	69,9 [61,7 - 77,2]	99,5 [99,2 - 99,7]	82,3 [74,4 - 88,5]	98,9 [98,6 - 99,2]
BS	54,8 [46,4 - 63,0]	99,7 [99,5 - 99,9]	87,9 [79,4 - 93,8]	98,4 [98,0 - 98,8]
SS+WB-MRI	95,9 [91,3 - 98,5]	99,2 [98,9 - 99,4]	80,9 [74,3 - 86,5]	99,9 [99,7 - 99,9]
SS+BS	95,2 [90,4 - 98,1]	99,4 [99,2 - 99,6]	85,8 [79,5 - 90,8]	99,8 [99,6 - 99,9]

Table 5: Statistical characteristics of each imaging modality and combinations of SS with BS or WB-MRI versus consensus (n=170)

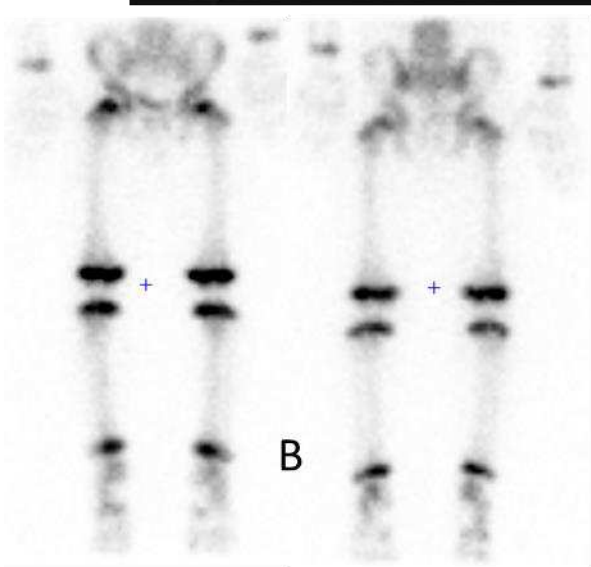
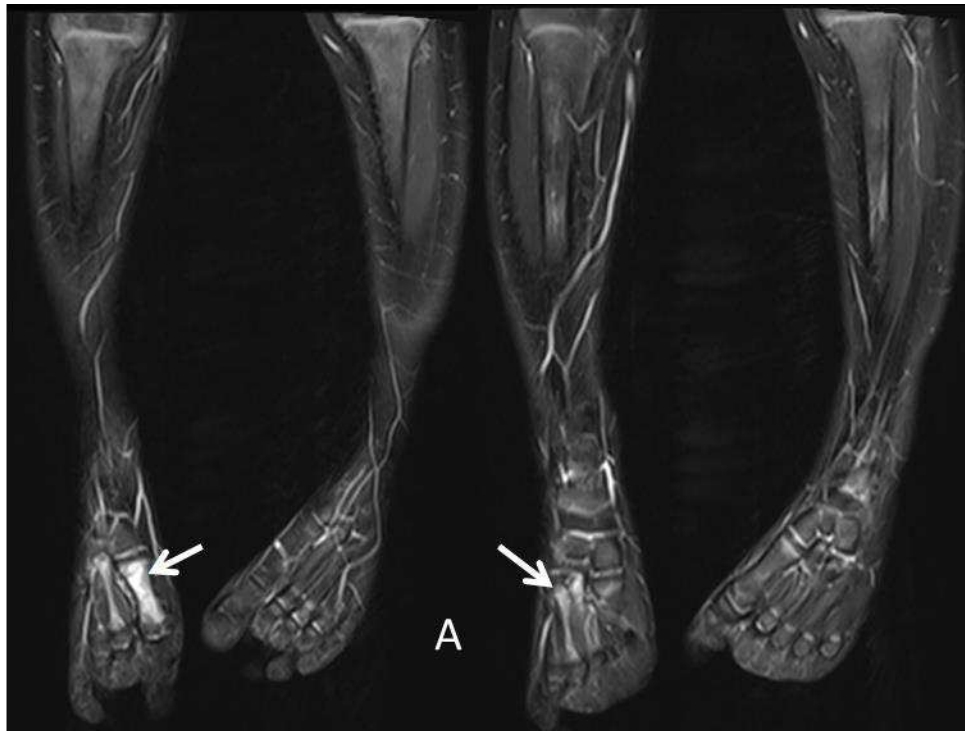


Fig 2: A 2-years-old child admitted for multiple bruises on the face and lameness of the right leg. Notion of domestic violence.

A- Coronal STIR WB-MRI shows high-intensity signal of the 1st, 2nd and 3rd metacarpus of the right foot (arrows).

B- Bone scintigraphy does not show any abnormal uptake

C- Radiographs, dorso-plantar view of the feet does not detect any abnormality.

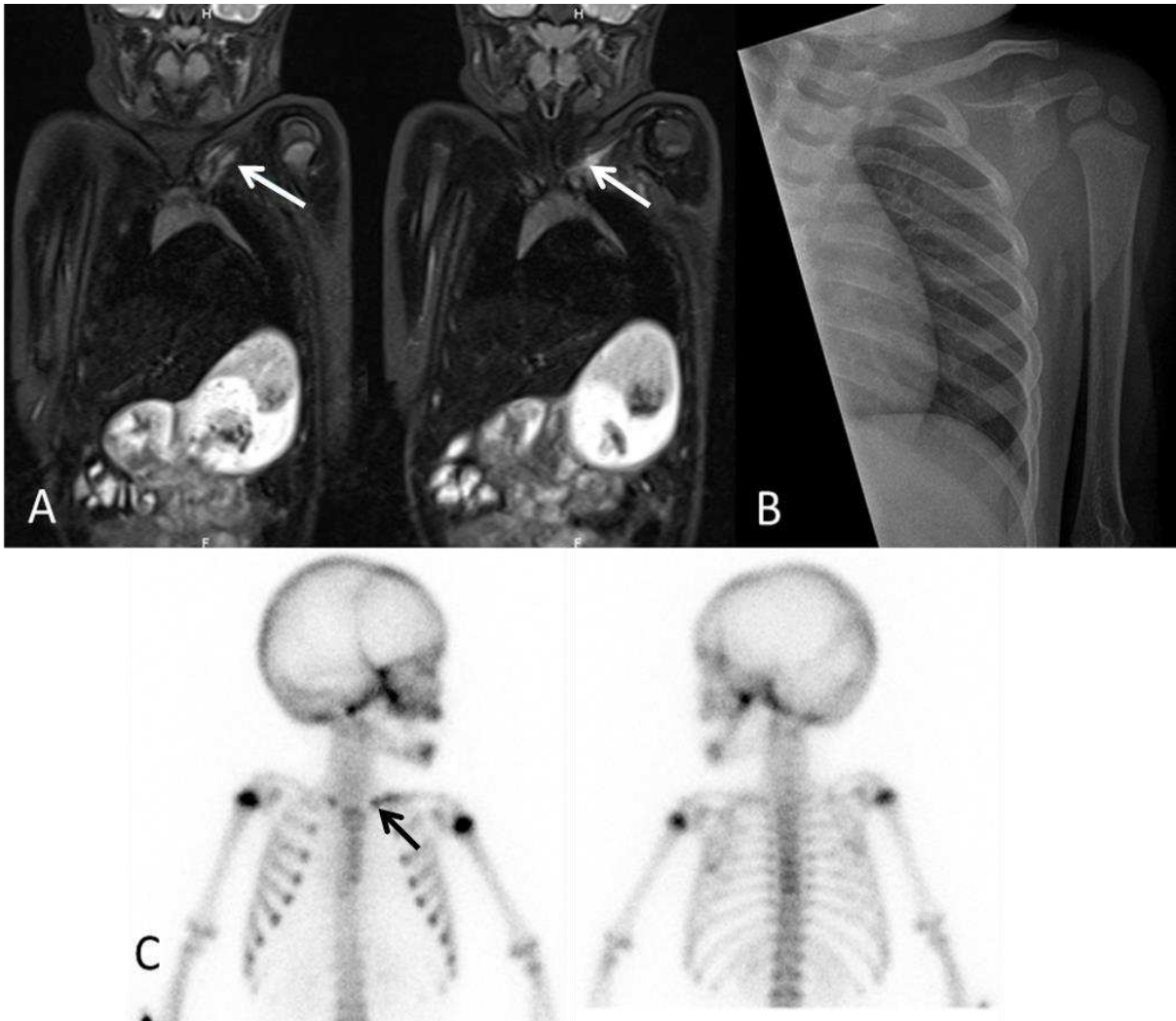


Fig 3: A 14-months-old child admitted for violence.

A- Coronal STIR WB-MRI examination shows high-intensity signal lesion of the proximal left clavicle both in bone marrow and in surrounding soft tissues (arrows). This lesion was missed initially.

B- Radiograph, frontal view of the left clavicle, does not allow seeing the fracture.

C- Bone scintigraphy, anterior and posterior views shows uptake of the medial side of left clavicle (arrow).

Discussion

Fractures are the most common findings in child abuse after cutaneous lesions such as bruises and contusions. That is why their detection is a crucial component of the final diagnosis of non-accidental trauma. The main imaging modality for imaging skeletal injuries in child abuse is the conventional radiography with a complete SS. The ACR has published guidelines on how the skeletal survey should be performed. In 2008 the Royal College of Radiologists and the Royal College of Paediatrics and Child Health also published guidelines. In this last one, the main difference is the use of oblique chest radiographs. Indeed, oblique chest radiographs have been shown by Ingram et al^[15] to increase the sensitivity for the detection of rib fractures, highly specific of child abuse, by 17% (95% CI 2–36%) and the specificity by 7% (95% CI 2–13%).

Even if the skeletal survey is performed properly, occult fractures can be missed and equivocal lesions can be found. In these cases, a follow-up SS performed 14 days after the initial SS can be advised. Some studies show that the FUSS can diagnose new findings in 61%^[16], 46%^[17], 37.6%^[18], 14%^[19], 21.5%^[20] and 8 to 28%^[21] children in different studies published respectively in 1996, 2005, 2009, 2010, 2013 and 2015. Most of initially undiagnosed fractures concerned ribs and CML. Some studies also demonstrated that the FUSS should not include views of pelvis, spine and hands because of extremely rare lesions in these localizations^[19]. However, a recent study published in 2017 showed that the FUSS may be unnecessary without clinical evidence^[9]. Indeed, in this study published by Powell-Doherty and al, among 110 children under the age of 4 years old, 87 (79%) had one or more positive findings on initial SS. Those with negative initial imaging had no missed injuries on the FUSS.

Bone scintigraphy is ‘... indicated when clinical suspicion of abuse remains high and documentation is still necessary’ according to the ACR appropriateness criteria. It is an alternative to the follow-up SS (FUSS), especially to prevent a delayed diagnosis. BS is known to have an increased sensitivity for detecting ribs fractures, subtle shaft fractures and early periosteal thickening. On the contrary, it has low sensitivity for detecting CML, particularly when bilateral, and subtle spinal injuries^[7]. However, practice varies according to geographic location. A European survey reported that 29% of centers throughout Europe perform the BS, 56% do not and 15% did not answer^[8].

WB-STIR-MRI is widely used as a non-radiating screening exam in paediatric diseases including malignancies due to its high tissue contrast^[10,22,23]. Some radiologists involved in

the field of child abuse explored this imaging modality. The utility of WB-MRI for assessing the extent and cause of traumatic injuries in suspected child abuse has been rarely reported in the literature. Two studies published in 2010 and 2017 by Perez-Rossello^[11] and Merlini^[23] and respectively involving 21 and 16 children suspected of abuse found low sensitivity of WB-MRI in detecting ribs and CML compared to SS. However, no study compared findings of SS, BS and MRI. To our knowledge this is the first published study including a large series of children suspected of no-accidental trauma.

Our study found that among the 3 imaging modalities, the skeletal survey has the best sensibility (88,4%). This sensibility becomes better when combining SS with another imaging modality, without significant difference using either WB-MRI (95,9%) or BS (95,2%).

The main questioning about MRI in previous studies concerned ribs and CML^[11], highly specific of child abuse^[24,25,26,27]. Both SS and BS are known to have a good sensitivity in detecting ribs fractures. In Mandelstam's study^[28] involving 30 children who underwent both SS and BS, there were rib fractures in 16 (62.5%) children: 63% were diagnosed on BS and 73% on SS.

In Perez-Rossello and al's^[11] study involving 21 children who underwent both SS (SS and FUSS for 16 children) and WB-MRI, 46 ribs fractures were diagnosed. Among them, 32 were seen on WB-MRI (69.5%), 28 (61%) on initial SS, 5 (11%) on FUSS and 13 (28%) on WB-MRI only. The sensitivity of WB-MRI to identify signal abnormalities in areas of ribs fractures seen with SS was 57% in this study. In Merlini's study^[23] published in 2017 and involving 16 children suspected of abuse, 5 ribs fractures were missed. However, a case report published by Stranzinger and al^[29] showed that WB-MRI diagnosed more extensive lesions of ribs than the SS. Another case report published by Ruda and al^[30] demonstrated that WB-MRI revealed bilateral rib fractures which were not reported on the initial SS. A FUSS repeated 14 days later confirmed several bilateral healing rib fractures. In these cases, WB-MRI allowed an earlier and reliable diagnosis.

In our study, the diagnosis of ribs fractures was not significantly lower with WB-MRI than with BS. The number of rib fractures detected by WB-MRI was even higher (10 true positive lesions) than with BS (8 true positive lesions). There were 2 rib fractures diagnosed on WB-MRI unseen on SS. One of them was also diagnosed on BS. Among the 17 rib fractures, 3 were not seen on SS, 7 on WB-MRI and 9 on BS. When crossing results, 5 rib fractures were diagnosed on WB-MRI, unseen on BS and on the contrary, 3 rib fractures were diagnosed on

BS and unseen on WB-MRI. This could be explained by the improvement of technologies and image resolution, in particular in magnetic resonance imaging^[10].

On the other hand, there were more false positive lesions detected on ribs with WB-MRI (9 FP lesions). This could be explained by the learning curve that WB-MRI interpretation involves. In fact, some images can mimic rib lesions, such as thin pleural effusion, axillar and sus-clavicular normal lymph nodes or anterior rib cartilages

Concerning metaphyseal fractures, their radiographic appearance is depending on the size of the fragment and the position of the extremity relative to the X-ray beam^[31,32]. In Ignasi Barber and al's study^[2], a total of 124 CML were identified in 50 infants. Among them, 12 fractures were evident only on the FUSS. All patients with CML had a positive SS with additional skeletal injuries including ribs, skull and/or other long bone fractures in 87% children. CML were the only positive survey finding in 6 infants. As CML are a very specific lesion in child abuse, their detection is very important. BS is known to have low sensitivity in their diagnosis. This is because of the physiological uptake of tracer that occurs at the growth plate. In Mandelstam's study^[28], only 35% of CML were diagnosed by BS. In Bainbridge and al's study^[8], involving 166 children who underwent both SS and BS, among the 21 FN cases, 5 had metaphyseal lesions (the others were skull fractures). In Perez-Rossello and al's study^[11], among the 21 children who underwent both WB-MRI and SS, there were a total of 37 CML. Among these, 13 (35%) were seen on WB-MRI, of which 2 (5.5%) on WB-MRI only, 24 (64.8%) were seen on summary SS only and 11 (29.7%) were seen by both techniques. WB-MRI had a low sensitivity (30%) in the identification of signal abnormalities in areas where CML were seen radiographically. This may be partly due to the minimal bone marrow changes and also as a result of lower WB-MRI resolution. In our study, we find quite similar findings for the detection of CML thanks to BS with 31% of lesions detected. However, we found a better sensitivity of WB-MRI concerning the detection of CML with 51.7% of lesions diagnosed. In one case, MRI led to identify an additional metaphyseal lesion of distal humeral extremity, thanks to evident joint effusion, unseen on BS.

Concerning epiphyseal lesions, in particular fracture-separation of the distal humeral epiphysis, they can occur in non-accidental trauma. Nimkin and al^[33] published 3 cases of abused children with humeral physis injuries. More recently, Perez-Rossello and al^[11] showed the case of Salter II epiphyseal separation of the right upper extremity. In all cases, lesions were easily diagnosed with MRI. In our study, we found only 4 epiphyseal lesions. Only one

lesion remained undiagnosed on WB-MRI because of low signal on WB-MRI and the healing character of the lesion.

Concerning periosteal appositions, BS is known to have a good sensitivity in their detection. In a case report article published by Elterman and al^[34], signal abnormalities of bone marrow and soft tissues were diagnosed on MRI in 4 children aged less than 1 year old whereas SS remained normal. For 3 of them, periosteal appositions were diagnosed on FUSS. In our study, periosteal appositions were diagnosed by WB-MRI in 3 cases, while unseen on SS. In one case, there was no abnormality on BS. This finding is interesting as it can lead to an earlier diagnosis of fracture when appositions did not appear yet on the radiography. In these cases, additional radiographs were performed a bit later to confirm the apparition of periosteal appositions.

Concerning extremities lesions, fractures of the hand and feet are subtle but important injuries in abused infants. Nimkin and al^[35] reported a total of 22 extremities fractures in 11 abused children (6 had hands fractures and 5 had feet fractures). Oblique views of the hands and FUSS aided in detection of these injuries. In Mandelstam and al's study^[28], 2 (1.6%) foot injuries among 124 fractures on 30 children were seen only on BS and not on SS. In Harlan and al's study^[18] comparing SS and FUSS, 2 foot lesions were diagnosed only on FUSS among 101 children. In our study, 5 feet lesions remained undiagnosed on SS while 3 of them were diagnosed on WB-MRI and 2 on BS.

There was no lesion of the hands in our study.

Concerning spine lesions, there are few vertebral fractures diagnosed in child abuse in the literature. Harlan and al's study^[18] even suggested removing spine views from the FUSS to decrease the radiation dose. However, Barber and al' study^[36] showed that spinal fractures are not that rare in children with positive SS performed for suspected abuse. They found 22 spinal fractures in 14 infants among 751 children who underwent a SS for suspected abuse. This constituted 1.9% of the total cohort and 9.7% (14/145) of children with a positive SS. In 5 cases, spinal fractures were the only positive skeletal finding. In 71% (10/14) of the children, the spinal fractures were accompanied by intra-cranial injury. Additional imaging (18 F-NaF PET in 7, BS in 1 and MRI in 5 children) confirmed the fractures in 13 of the 14 children and demonstrated 12 additional spinal fractures. In our study, findings are quite similar. We diagnosed 11 spine lesions in 8 children. This constituted 4.7% of the total cohort (8/170) and

12.5% (8/64) of children with at least one lesion. In one child, 2 spinal fractures (dorsal and lumbar) were diagnosed only on BS. Two dorsal fractures in 2 different children were diagnosed on WB-MRI and not on BS thanks to intra-corporeal signal abnormality. We also noticed that WB-MRI could diagnose spinal fractures thanks to shape abnormalities: in 6 cases out of 11, spinal lesions were visible on WB-MRI. As the item “shape abnormality” was not present in the interpretation checklist these results do not appear in the statistical analysis. Finally, there was a lumbar anterior subdural hematoma diagnosed on WB-MRI in one child, which appeared in soft tissues abnormalities in the results. The relatively high prevalence of spinal injuries and their association with intra-cranial injury justify the realization of additional spine imaging.

Concerning clavicle and scapula lesions, they are sometimes difficult to diagnose on SS, especially when acute and undisplaced. Barber and al^[2,25] showed that in 28 clavicle fractures involving 24 infants, the SS was positive in 10 children (42%) and healing fractures were more prevalent in infants with positive SS. In the same way, 13 scapular fractures were noted in 8 infants, 11 (85%) involving the acromion process. All infants with scapular fracture had a positive SS and there was a statistically significant correlation with intracranial injury. In our study, among the 9 clavicles or scapular fractures, one clavicle fracture remained undiagnosed on SS while detected thanks to the BS (*Fig 3*). The lesion was visible on WB-MRI but remained misdiagnosed on the collegial review, because of the learning curve that WB-MRI interpretation involves.

One of the specific strengths of WB-MRI is its capacity to diagnose soft tissues injuries. The case report published by Ruda and al^[30] and involving a 2 weeks-old-girl with bilateral subdural hemorrhage, the initial SS was normal. The WB-MRI performed diagnosed an adrenal hematoma, multiple liver lacerations, and subcutaneous tissue edema of both arms and flank. In Perez-Rossello and al's study^[11] previously mentioned, in 5 cases, soft tissues injuries provided a clue to diagnose occult injury in the SS. As well, in our study, WB-MRI led to identify soft tissues abnormalities in 50% of cases, most of them associated with a fracture. However, among the 60 children that had a muscular edema, 7 did not have any associated bone lesion. That is a really useful tool that can help in this context of suspected non accidental trauma. Even if clinicians perform a physical examination to identify bruises^[37], these are usually lacking in regions overlying non accidental skeletal injuries^[38]. In our study, in one infant, we could see a buttock's signal abnormality, which could be

explained by spanking. We also diagnosed a Lavallée-Morel syndrome on right leg in another child, without abnormalities seen on SS or BS. This appeared as a linear high-intensity lesion into right thigh lateral tissues, reflecting an abrupt and traumatic separation of subcutaneous fatty tissue with underlying fascia^[39,40]. Most of children who had medical reanimation presented diffuse signal abnormalities (subcutaneous edema, hydrops...).

Another specificity of WB-MRI is that it is a free-radiation imaging modality. That is all the more important since children are more sensitive to the effects of radiation exposure. There is a “as low and reasonably achievable (ALARA)” principle dose of radiation that must be respected in children’s care^[41]. In the literature, the radiation dose in a SS performed for suspected child abuse is variably estimated to be 0.2 mSv-0.5 mSv, congruent with our study’s findings.

This is approximatively 7%-17% of the average annual exposure from natural background radiation in the US (3 mSv)^[42]. The effective dose of BS is estimated to be 3 mSv^[8]. It is not to be neglected, as it is added to the initial SS radiation exposure. What is also to be taken into account, is that sometimes a head CT or follow-up radiographs are needed. That makes the total dose radiation grows as well.

However, there are some drawbacks to WB-MRI. First of all, it requires a sedation to acquire sharp images because of the duration of the exam and its sensitivity to patient movements. It also requires compatible monitoring equipment. Nevertheless, in many cases, children admitted for non-accidental trauma also suffer head trauma. When head trauma is suspected, guidelines advise the realization of head CT to detect acute hemorrhage. It is also currently advised to realize a brain MRI^[43]. When head CT scan is positive, it permits the evaluation of lesions' extent. When head CT scan is negative, brain MRI performed within 5-7 days permits to detect intra-parenchymal or ischemic lesions, sometimes not seen on CT. Furthermore, it is now admitted that brain MRI should be performed in all children with extra-cranial manifestations of abuse^[44]. When there are no neurological signs, brain MRI should be preferred to CT because of its higher sensitivity to detect parenchymal injuries or lesions of different ages. When a subdural hematoma is present, it is recommended to add a medullar exploration^[45]. Regarding to these assessments, sedation needed to realize this brain imaging can be used to perform the whole-body MRI at the same time.

Another drawback of MRI is its low precision in lesions localization. Even with better and better spatial resolution, it is still difficult to localize bone lesions, especially on forearms (radius, ulna) and lower legs (tibia, fibula), but also on ribs. Besides, the same problem occurs with BS.

A common criteria used in the diagnosis of non-accidental trauma is the presence of fractures of different ages^[46]. An accurate dating of injuries is often crucial to determine potential perpetrators in child protection proceedings as well as criminal investigations and prosecutions. WB-MRI provides little direct information regarding fracture age, even if soft tissues swelling around fractures may be more important in acute lesions. This is an interesting finding as acute fractures may sometimes be more difficult to diagnose on SS. For older fractures, even if there is no bone edema or tissues swelling left (especially for CML and ribs fractures), SS do have a stronger sensitivity. In this way, WB-MRI and SS may be complementary imaging modalities to detect but also to approximately date fractures^[47-50]. On the other hand, we know that BS can remain abnormal for years after a trauma. It cannot accurately estimate stages of bone healing or determine the age of fractures^[8]. In cases in which dating by SS is indeterminate, clarification of fracture age is possible with the use of a follow-up examination.

Another setting that is to mention is that abnormalities seen on BS and WB-MRI are not specific of child abuse^[10,23,51]. Any bone lesion, due to infection or tumor for example, may result in BS or MRI modifications. That is why any imaging abnormality must be correlated with the clinical and radiographic findings.

The radiologist must be aware of potential artefacts that may occur with WB-MRI (even though this argument applies to every imaging modality). It is all the more true since WB-MRI is not a technique routinely used in this particular context of child abuse. What we noticed most commonly to create false images were soft tissues abnormalities due to a nearby injection site. This can be a similar problem with BS. Other false positive lesions in WB-MRI were due to the presence of normal lymph nodes, especially in sus-clavicular and axillar regions. These could mimic clavicular or ribs lesions. So could do the presence of pleural effusion of little abundance. The position into the machine is another important thing. Indeed, a bit asymmetric position can create false signal abnormalities. The child's sedation may facilitate the positioning to avoid these artefacts.

Another potential image the radiologist must know is the presence of vessels along bones which can mimic periosteal appositions. If there is no bone signal abnormality and no soft tissues swelling, a confrontation with radiographs can help not to diagnose unreal lesion.

Last but not least, recent vaccinations can appear as soft tissues high-intensity signal. These are not to be confused with non-accidental lesion. In this case, the localization and clinical history give the answer.

As WB-MRI is not commonly used in the context of child abuse for the moment, it required a learning curve to lead to an optimal interpretation. We realized that experts were more likely to diagnose lesions and avoid artefact traps at the end of collegial reviews than at the beginning. This implies the necessity of a pictorial review to image this and explain some learning points (*Annex*).

One of the limitations of our study is that there was no FUSS systematically realized. The realization of a complete FUSS in each child in addition to BS and initial SS would have made the effective radiation dose too high.

The other limitation is that even if imaging complements have been performed in some children, their results were not used in the consensus review. This could have added more confidence in the experts' decisions concerning some lesions. However, it was not planned in the initial protocol and it was difficult to secondly gather images since it was a multicenter and prospective study.

A study published in 2010 by Drubach and al^[52] evaluated the sensitivity of 18-labeled sodium Fluoride (18F-NaF) Positron emission Tomography (PET) in the detection of skeletal lesions in pediatric patients suspected of abuse. Among the 22 patients who underwent SS and 18F-NaF-PET, 14 also underwent a FUSS. A total of 156 fractures were detected with initial SS and 200 were detected at PET. PET and SS sensitivities were respectively of 85% and 72% for the detection of all fractures, 92% and 68% for the detection of thoracic fractures (ribs, sternum, clavicle and scapula), 93% and 73% for the detection of posterior rib fractures and 67% and 80% for the detection of CML. Even if 18F-NaF-PET had greater sensitivity in the overall detection of fractures related to child abuse than did the SS, it had a lower sensitivity for the detection of CML. These ones are characteristic of child abuse so initial radiographic evaluation remains necessary. Furthermore, PET is a radiating imaging modality. The radiation dose is 3.2 mSv for 18F-NaF-PET compared to 3.1 mSV for BS for a 10 kgs infant.

A last question remains about low-dose chest CT (LDCCT). Indeed, we know that LDCCT is very sensitive to diagnose non-displaced anterior or posterior rib fractures, especially in the acute stage, contrary to SS^[53]. A study published by Sanchez and al^[54] performed on 16 patients younger than 12 months showed that out of a total 105 rib fractures, 84% (87/105) were detected on the initial SS. Seventeen percent (18/105) were seen only after follow-up imaging and more than half of which (11/18) were detected on a subsequent CT. Majority of the fractures were posterior (43%) and anterior (30%) in location. An overwhelming majority (96%) of the fractures were non-displaced. In this study, the estimated dose of the LDCCT was around 0.48 mSv. A second study published by Wooton-Gorges and al^[53] involved 12 abused children with 131 ribs fractures visualized on CT and 79 on SS. One patient had a fracture only seen by CT. There were significantly ($p < 0,05$) more early subacute (24 vs 4), subacute (47 vs 26) and old fractures (4 vs 0) seen by CT than by SS. Bilateral fractures were detected more often by CT than by SS.

LDCCT can also help diagnose scapula fractures and lungs injuries (such as pneumothorax), but also dorsal fractures which are often difficult to diagnose on SS. Supposing a LDCCT would be realized instead of 3 views of the chest (antero-posterior and oblique views) and lateral and frontal views of the dorsal spine, the radiation dose would not be so much higher. This could be justified in this difficult context of child abuse but requires more investigations.

Conclusion

This study can make us wonder about a new imaging patient care concerning children suspected of non-accidental trauma. Skeletal survey appears to be essential in this evaluation since it is the most sensitive imaging modality, especially to detect metaphyseal and ribs lesions. To diagnose as many lesions as possible in this difficult context, a combination of exams seems to be essential. The combinations SS+BS or SS+WB-MRI show similar results concerning sensitivity, specificity, PPV and NPV in diagnosing bone lesions. However, we must remember that unlike WB-MRI which is a free-radiation technique, SS and BS are ionizing imaging modalities. WB-MRI can also help diagnose soft tissues injuries. The realization of WB-MRI, while performing brain MRI under sedation, is justified in association with SS.

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Liste des abréviations

PHRC: Programme Hospitalier de Recherche Clinique

SS: Skeletal Survey

WB-MRI: Whole-Body Magnetic Resonance Imaging

BS: Bone Scintigraphy

STIR: Short Tau Inversion Recovery

HAS: Haute Autorité de Santé

ACR: American College of Radiology

WHO: World Health Organization

FUSS: Follow-Up Skeletal Survey

SFIPP: Société Francophone d'Imagerie Pédiatrique et Périnatale

CT: Computed Tomography

ALARA: As Low And Reasonably Achievable

LDCCT: Low Dose Chest Computed Tomography

PET: Positron Emission Tomography

¹⁸F-NaF-PET: ¹⁸-labeled sodium Fluoride Positron Emission Tomography

CML: Classic Metaphyseal Lesion

Annexe

Whole Body Magnetic Resonance Imaging (STIR) in suspected child abuse: a pictorial review from the PEDIMA study

Préambule

La maltraitance physique de l'enfant est un problème de Santé Publique majeur. Le diagnostic de maltraitance sous-tend un abord pluridisciplinaire. La fréquence, l'urgence de la prise en charge, les difficultés du diagnostic radiologique et de la datation des lésions placent le radiopédiatre au centre du diagnostic. Ils justifient la mise en œuvre de moyens permettant un diagnostic de certitude en raison des implications thérapeutiques et judiciaires qui en découlent.

Jusqu'à ce jour, le bilan lésionnel repose majoritairement sur les radiographies du squelette entier. Ces radiographies sont réalisées selon les protocoles de l'HAS (Haute Autorité de Santé) et de l'ACR (American College of Radiology). Des clichés de suivi réalisés à J10-14 à la recherche de lésions occultes non diagnostiquées sur les radiographies initiales sont également indiqués. L'ACR recommande aussi la réalisation d'une imagerie cérébrale dans de larges indications. Par ailleurs, la scintigraphie osseuse peut être réalisée lorsque les radiographies sont normales mais qu'une forte suspicion clinique d'abus demeure.

L'IRM (Imagerie par Résonance Magnétique) corps entier avec des séquences STIR (Short Tau Inversion Recovery) est actuellement largement utilisée pour l'évaluation des lésions osseuses et extra-squelettiques chez des enfants atteints de pathologies infectieuses ou tumorales. Il existe peu de données dans la littérature concernant son évaluation dans le bilan lésionnel d'enfants suspects de maltraitance. Cependant, quelques articles démontrent que l'IRM corps entier peut aider à identifier des lésions des parties molles (œdème musculaire, épanchements articulaires ou des séreuses) mais également des fractures additionnelles.

Notre récente étude PEDIMA réalisée de manière prospective en cours de publication a permis d'étudier le rôle de l'IRM corps entier sur une importante cohorte d'enfants de moins de 3 ans suspects de maltraitance. Les résultats de cette étude ont permis de démontrer l'intérêt majeur des radiographies osseuses dans le bilan lésionnel de ces enfants. Ils ont également prouvé la valeur ajoutée de la réalisation d'une IRM corps entier ou d'une

scintigraphie osseuse combinées aux radiographies corps entier. Il n'a pas été montré de différence significative entre l'utilisation de la combinaison radiographies + IRM ou radiographies + scintigraphie. L'IRM présente cependant l'intérêt d'être une modalité d'imagerie non irradiante.

Cette présente étude réalisée sous forme de revue iconographique vise à réunir l'ensemble des éléments clés permettant l'interprétation de l'IRM corps entier dans le cadre de la suspicion de maltraitance chez l'enfant. La première partie du document résume les principaux résultats de l'étude PEDIMA.

Abstract

The objective of the multicentric and prospective study PEDIMA (PHRC PEDIMA 2011) was to determine the role of WB-MRI in the detection of traumatic lesions in children suspected of abuse.

One hundred and seventy children under 3 years old were included. They all underwent a skeletal survey (SS), a bone scintigraphy (BS) and a whole-body MRI (WB-MRI). Sixty-four children had at least one lesion with a total of 146 lesions. Sensitivity and specificity of each exam were respectively 88.4% and 99.7% for the SS, 69.9% and 99.5% for WB-MRI and 54.8% and 99.7% for BS. Sensitivity and specificity were respectively 95.9% and 99.2% for the combination SS+WB-MRI and 95.2% and 99.4% for the combination SS+BS, without significant difference.

In conclusion, SS was the most sensitive exam for the detection of non-accidental lesions. Its sensitivity became better when combined with another imaging modality, either BS or WB-MRI.

Contrary to BS and SS, WB-MRI is a radiation-free imaging modality. For now, WB-MRI is not currently used in the context of child abuse. As it may become a part of the evaluation of non-accidental lesions, this pictorial review aims at gathering key frames essential to its interpretation.

Conflicts of interest

None.

Whole body Magnetic Resonance Imaging in suspected child abuse: a pictorial review from the PEDIMA study.

1. Introduction

Child abuse is a huge public health issue which requires a reliable and early diagnosis. This diagnosis involves therapeutic and judicial measures. Skeletal survey is essential in the evaluation of child abuse since it is the most sensitive imaging modality and has high-resolution for bones examination^[1]. To diagnose as many lesions as possible in this difficult context, a combination of exams seems necessary. For now, either bone scintigraphy or follow-up SS are usually performed in addition to initial SS^[2-5]. As magnetic resonance imaging (MRI) becomes more and more accessible and performant, we previously studied its potential role in child abuse imaging. Our precedent study (PHRC PEDIMA 2011) involved 170 children under 3 years old and compared skeletal survey (SS), bone scintigraphy (BS) and whole-body MRI (WB-MRI). Final results showed that SS was the most sensitive exam for the detection of traumatic bone lesions. However, combining SS with another imaging modality (BS or WB-MRI) permitted the best lesion statement. There was no significant difference when combining SS+WB-MRI or SS+BS. As WB-MRI is a radiation-free technique, it leads us to wonder about using it in a routine way in these young children suspected of abuse.

Nevertheless, WB-MRI is not a widespread technique used in this indication. The objective of this article is to describe specific lesions of abuse as it appears on MRI. Indeed, we noticed that WB-MRI interpretation involves a learning curve and that there were some traps easy to avoid. We finally found interesting to show some pictures of discrepant cases coming from our study (comparing SS, BS and WB-MRI). In fact, some lesions can be easier to diagnose on one imaging modality or another. It depends on its localization, its acuteness and other criteria. A global and comparative interpretation can lead to a precise and exhaustive lesions statement.

This pictorial review aims at gathering key frames essential to the WB-MRI interpretation in the case of suspected child abuse.

2. PEDIMA study

2a. Material and methods

Study population

The PEDIMA study was a prospective and multicentric study led from August 2011 to February 2015 in 10 French University Hospitals. It involved 170 children aged less than 3 years old and presenting lesions suspected of non-accidental origin (subdural hematoma, bone injuries highly associated with child abuse, cutaneous or abdominal lesions suspected from non-accidental origin). These children underwent three imaging modalities: a skeletal survey (SS), a bone scintigraphy (BS) and a whole-body MRI (WB-MRI). The study was done in accordance with the principles of the Declaration of Helsinki. Local ethics committees approved the protocol. All parents of patients included provided written informed consent at enrolment.

WB-MRI

The WB-MRI examination was realized under sedation, according to the age, the clinical settings and recommendations^[6]. The body was imaged from the vertex to the toes. MR examinations included at least coronal STIR (Short Tau Inversion Recovery) sequences and as often as possible sagittal STIR sequences on the spine. The technical STIR parameters were as follows : TR (Repetition Time)= 3761-7520 ms; effective TE (Echo Time)= 30.3-101 ms; inversion time= 145-160 ms; echo-train length= 8-33; signal averages= 1-3; BW (Bandwidth)= 122-315 Hz/Px; field of view= between 317x350 mm² and 530x530 mm²; matrix= between 169x288 and 512x292; section thickness= 4-6 mm; image acquisition time= 1,5/3 min per station.

There was no gadolinium injection and the average duration of the exam was 15 minutes.

Skeletal survey

The skeletal survey was performed according to the protocols of the American College of Radiology^[7], the British Society of Paediatric Radiology^[8] and the SFIPP (French Society of Pediatric Radiology). There were between 16 and 20 radiographs realized for each skeletal survey. This included frontal, lateral and Worms views for the head; antero-posterior and oblique views for the chest; frontal and lateral views for the limbs and pelvis; frontal and lateral views of the entire spine; frontal views of the hands and dorsoplantar views of the feet.

Head's radiographs were not realized if a head computed tomography had already been performed, especially in case of subdural hematoma, to limit ionizing radiation exposure.

The average ionizing dose lied between 0.03 and 0.35 mSv depending on the age and the number of radiographs.

Bone scintigraphy

There was an injection of 7.4 to 11.1 MBq/kg (mean activity 8 MBq/kg) of HMDP-99mTc (or equivalent) with a minimum activity of 37 MBq. The early phase (soft tissue uptake) was performed less than 5 minutes after the tracer injection, with static anterior and posterior views (matrix 128x128, time 180s), optional lateral views, the patient staying in a symmetric position.

A delayed acquisition (bone uptake) was performed 2 to 3 hours after the tracer injection with static images (matrix 256x256, time 180s), to obtain a whole-body scintigraphy. Multiple overlapping images were performed, in anterior and posterior views, right and left lateral and oblique anterior or posterior views of the head and the chest. There was a contention of children, without any sedation. Injection sites were noticed for each exam.

Imaging interpretation

The interpretation of exams was realized by a group of experts (at least 5 pediatric radiologists and 3 nuclear doctors) in a randomized, blinded and collegial manner. An ultimate review confronting the 3 imaging modalities permitted to settle discrepant cases and determine "real lesions". The results of experts consensus was considered as the gold standard.

2b. Results

There were a total of 4250 body part units analyzed for 170 children. Among them, the 3 imaging modalities were in agreement for 4114 body part units. They were discrepant for 136 body part units (concerning 58 children). These 136 examinations have been reviewed by experts to agree on a consensus. A consensus could not be obtained for 11 body part units that were removed from the final statistical analysis. At the end, statistical analysis concerned 4239 body part units.

After consensus, 64 (37.6%) children had at least one lesion with a total of 146 lesions. SS had the best sensitivity with a significant difference, comparing to other imaging

modalities (*Table 1*). Combining a second imaging modality with the SS, either BS or WB-MRI, adds confidence at the non-accidental trauma diagnosis even if this difference is non significant. There is no significant difference of sensitivity, specificity, PPV (predictive positive value) or NPV (negative predictive value) when comparing SS+MRI and SS+BS.

	Sensitivity [IC95%]	Specificity [IC95%]	PPV [IC95%]	NPV [IC95%]
SS	88,4 [82,0 - 93,1]	99,7 [99,5 - 99,8]	90,8 [84,9 - 95,0]	99,6 [99,3 - 99,8]
WB-MRI	69,9 [61,7 - 77,2]	99,5 [99,2 - 99,7]	82,3 [74,4 - 88,5]	98,9 [98,6 - 99,2]
BS	54,8 [46,4 - 63,0]	99,7 [99,5 - 99,9]	87,9 [79,4 - 93,8]	98,4 [98,0 - 98,8]
SS+WB-MRI	95,9 [91,3 - 98,5]	99,2 [98,9 - 99,4]	80,9 [74,3 - 86,5]	99,9 [99,7 - 99,9]
SS+BS	95,2 [90,4 - 98,1]	99,4 [99,2 - 99,6]	85,8 [79,5 - 90,8]	99,8 [99,6 - 99,9]

Table 1: Sensitivity, specificity and predictive values of each imaging modality and combinations of SS with BS or MRI (n=170) in child abuse diagnosis

Concerning WB-MRI findings, among 44 false negative body part units on WB-MRI, 9 were spine lesions including 6 lesions that appeared as shape abnormality without signal abnormality, so unnoticed; 7 were ribs fractures; 3 were feet lesions; 5 were clavicle lesions, 10 were periosteal appositions of long bones and 10 others were metaphyseal fractures.

Among 22 body part units that were FP on WB-MRI, 2 lesions of ulna and fibula were a mistake regarding the bone involved (ulna instead of radius and fibula instead of tibia). One lesion of the tibia was in fact soft tissues high-intensity signal due to perfusion. Some suspected bone lesions (3 humeral, 1 clavicle and 2 ribs) were in fact only soft tissues signal abnormalities. Some suspected lesions (2 humeral, 1 rib and one femoral) were due to positional artefacts. Seven suspected rib lesions were due to thin pleural effusion or adjacent lymph nodes and one was mistaken with an anterior cartilage. Finally, one suspected femoral lesion was vascular artefacts along the diaphysis.

WB-MRI identified soft tissues abnormalities in 85 children (50%), including muscular edema in 60 children (35.3%), sub-cutaneous edema in 47 (27.6%), peritoneal effusion in 8 (4.7%), articular effusion in 7 (4.1%), pleural effusion in 6 (3.5%) and spine ligament injury in 2 (1.2%). Among the 60 children that had a muscular edema, 7 did not have any associated bone lesion. There was no visceral lesion diagnosed.

3. Specific lesions in child abuse on WB-MRI

3a. *According to the type of bone lesions*

Diaphyseal lesions

One of the most easy-to-detect lesions is the diaphyseal long bone lesion (*Fig 1*). It associates STIR signal abnormalities of both bone marrow and surrounding soft tissues. Indeed, the edema is sometimes really important, especially in acute lesions.



Fig 1 A-B: Seven-months-old child painful at the right leg when diapered. Notion of falling from baby bouncer at the childminder. **A-** Coronal T2 STIR shows bone and soft tissues signal abnormalities (arrows) on the distal third of the right femoral diaphysis. **B:** Frontal and lateral views of the right femur show a hairline fracture (arrows) on the distal third of right femur. **C-D:** Functional impotence of the left leg in a 5 months-old little girl. **C-** Coronal T2 STIR shows bone and soft tissues signal abnormalities (arrows) on the left femur. **D-** Frontal view of the left femur shows buckle fracture (arrow) of the distal third of left femur.

Metaphyseal lesions

Metaphyseal lesions (*Fig 2*) are delicate lesions to detect, even on SS. It is important to diagnose them as they are highly specific of child abuse^[9,10]. Sometimes WB-MRI leads to diagnose unseen lesions on SS. Especially when the lesion appears as an evident bone marrow high-intensity signal or when it is associated with a joint effusion. Nevertheless, metaphyseal lesions often remain undiagnosed on WB-MRI. The acuteness of the fracture might be involved. Metaphyseal lesions are also hard to diagnose on BS because of the physiological uptake of tracer that occurs at the growth plate.

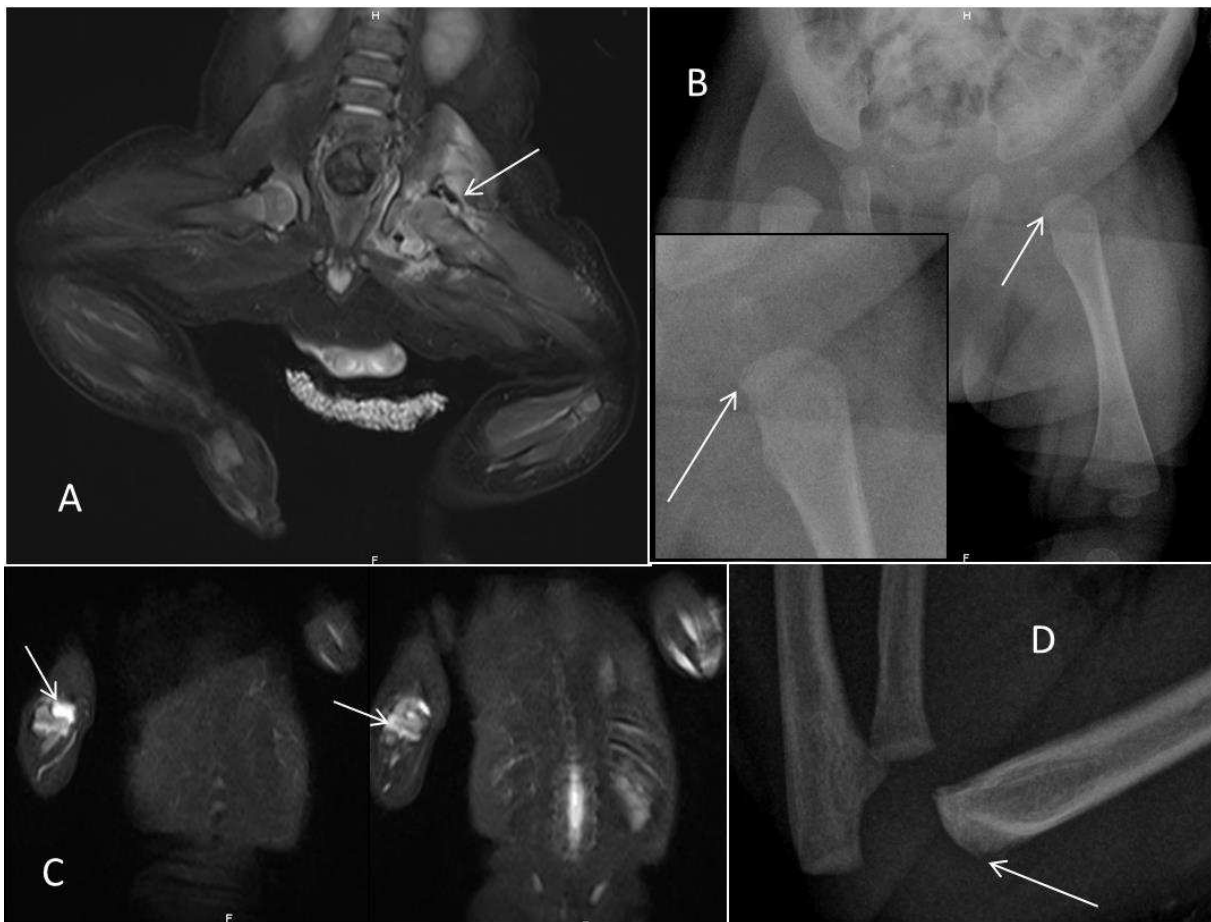


Fig 2 A-B: Two-months-old boy with asymmetric position while diapering with lack of mobility of the left leg **A-** Coronal STIR: soft tissues high-intensity signal surrounding coxo-femoral joint (arrow), associated with a joint effusion. **B-** Frontal view of left hip: subtle metaphyseal fracture of the left femoral upper extremity (arrow). This was secondary to post traumatic sub-luxation. **C-D:** One-month-old baby admitted for left humerus fracture without clear explanation. **C-** Coronal STIR: joint effusion on right elbow appearing as a high-intensity signal (arrows). **D-** Lateral view of right elbow: subtle metaphyseal fracture of the distal extremity of the right humerus (arrow).

Periosteal appositions

Periosteal appositions (*Fig 3*) need a little bit more attention as the radiologist is often not used to detect it on WB-MRI. It appears as thin and linear signal abnormalities along the periosteum. WB-MRI may detect bone lesions before the apparition of periosteal appositions on SS. In this case, we can see bone marrow signal abnormalities before the apparition of abnormalities on radiographs. This can be really useful to make an earlier diagnosis.

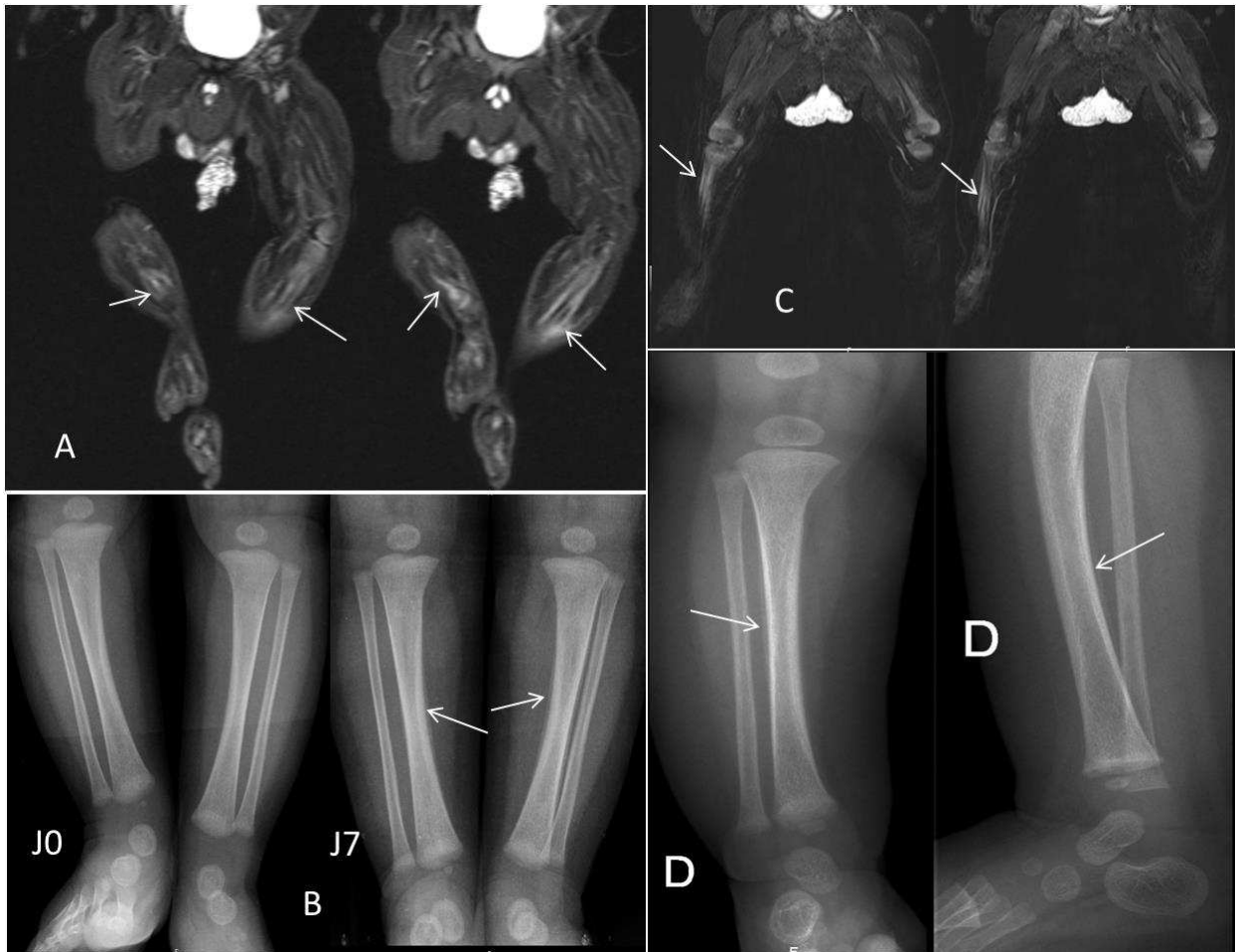


Fig 3 A-B: Two-months-old baby with left humeral fracture discovered because of a functional impotence lasting for 12-24h. **A-** Coronal T2 STIR: linear high-intensity signal along right and left tibiae's diaphysis (arrows) with subtle bone marrow signal abnormalities associated. **B –** Frontal views of both tibiae at first day showing no abnormality. At seventh day, thin periosteal appositions are appearing (arrows) on both tibiae's diaphysis.

C-D: Five-months-old child with functional impotence of left arm noticed by the parents after picking their child at the childminder. A fracture of both left forearm bones was diagnosed. **C:** Coronal STIR: linear high-intensity signal along the right tibia's diaphysis (arrows). **D:** Subtle periosteal appositions on the right tibia (arrows).

3b. According to the localization of bone lesions

Long bone fractures

Long bone fractures are more or less easy to detect depending on their location (diaphysis or metaphysis) as described before and depending on their acuteness. Acute fractures are easier to detect on WB-MRI because of the association with soft tissues edema. Older fractures are sometimes harder to diagnose with WB-MRI but frequently evident on radiographs (healing, periosteal appositions...).

Ribs fractures

Costal fractures (*Fig 4*) are one of the most difficult lesions to detect. Though, they are really important to diagnose as they are one of the most specific lesions of child abuse^[11]. Their detection requires a bit of experience. However, our study showed that there was no significant difference in rib fractures diagnosis using WB-MRI or BS. As other bone lesions, rib fractures appear as a bone marrow signal abnormality associated with more or less surrounding soft tissues edema depending on the acuteness of the fracture. WB-MRI can help diagnose acute fractures unseen on SS, when there is no healing yet. Sometimes this edema can persist while healing has already begun (*Fig 4-ABC*). However, most of the time, old fractures are difficult to see on WB-MRI (*Fig 4-DEF*) but they are then easier to diagnose on SS.

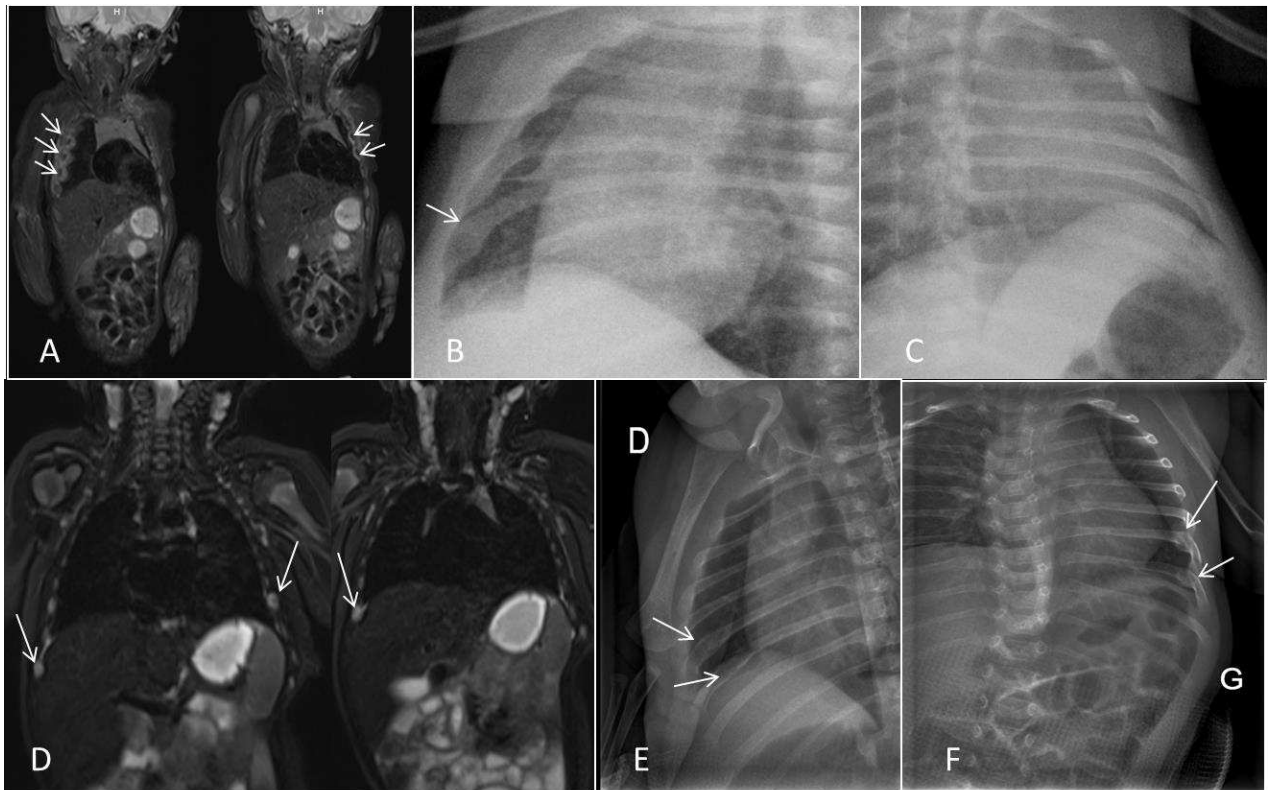


Fig 4 A-B-C: Two-months-old girl admitted for ecchymosis (twin pregnancy). **A-** Coronal STIR – signal abnormalities on medium right and left ribs arcs, especially on surrounding soft tissues (arrows). **B-** Right oblique view of ribs: healing fractures seen on right oblique view (arrow). **C-** Left oblique view of ribs: ribs fractures more difficult to see on radiographs.

D- E-F: Two-months-old baby admitted for unusual cries and functional impotence of right leg (diaphyseal fracture of right femur diagnosed). **D-** Coronal STIR. Discreet rounded signal abnormalities on medium costal arcs, on right and left sides (arrows) without surrounding soft tissues abnormality. **EF-** Right and left oblique views of ribs: bilateral ribs healing fractures (arrows).

Clavicle and scapula fractures

Clavicle and scapula fractures (*Fig 5*) present same particularities as described before. Some of them are difficult to diagnose on SS because of superpositions or when there is no displacement on acute lesions. These fractures may be easier to detect with WB-MRI when acute because of surrounding soft tissues signal abnormalities (*Fig 5-AB*).

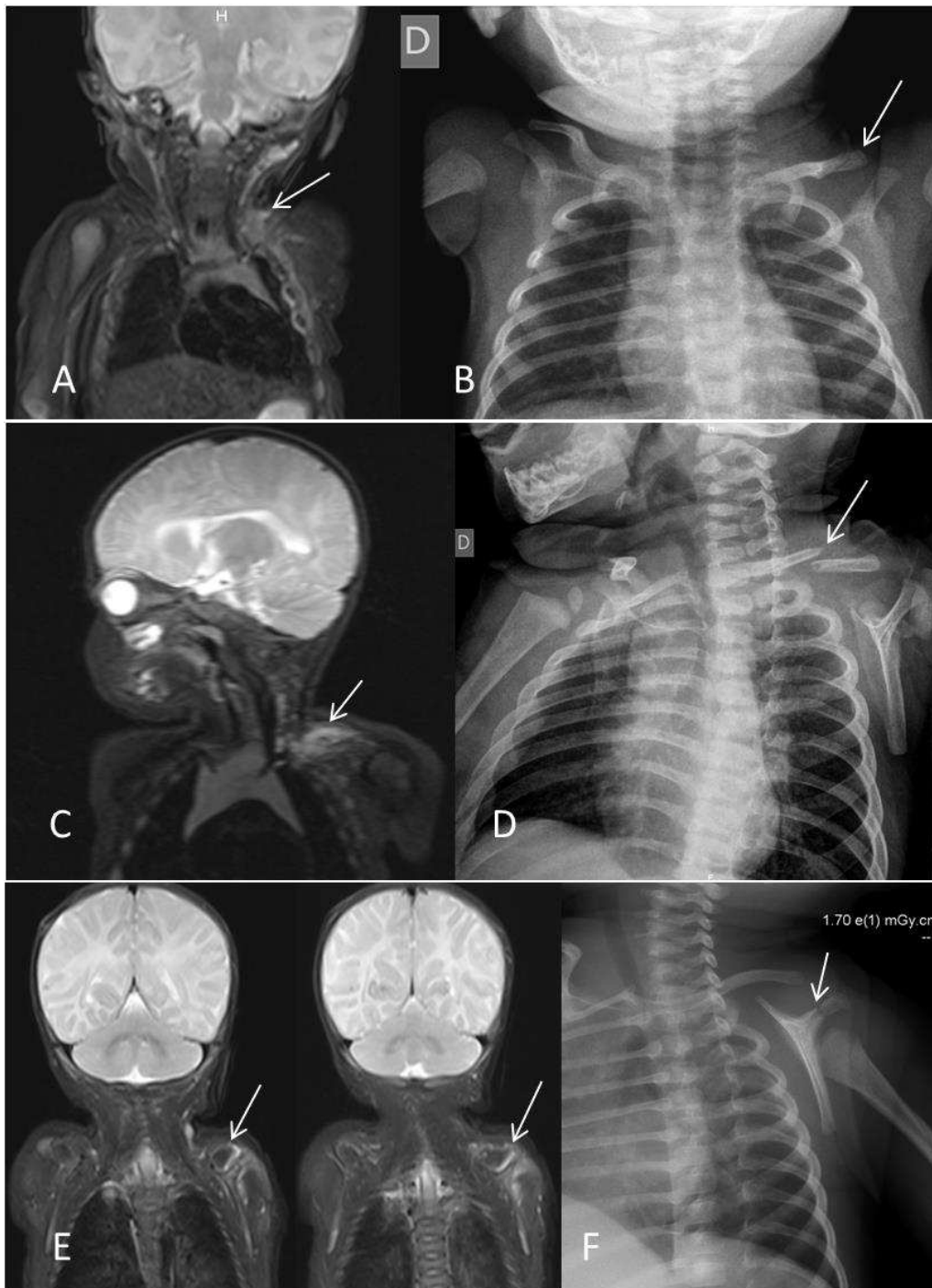


Fig 5 **A-B:** Two-months-old little girl admitted for cutaneous ecchymosis (twin pregnancy). **A-** Coronal STIR: Subtle high-intensity signal besides left clavicle, especially in soft tissues (arrow) **B –** Frontal view of the chest: left clavicle hairline fracture (arrow), not diagnosed initially. **C-D:** Functional impotence of the left arm in a four-months-old boy. **C-** Coronal STIR. Bone and soft tissues signal abnormalities on left clavicle (arrow). **D-** Frontal view of left clavicle: displaced fracture of the left clavicle (arrow). **E-F:** Cutaneous lesions on a one-month-old girl, discovered after judicial anonymous declaration. **E-** Coronal STIR: bone and soft tissues high-intensity signal on left scapula (arrows). **F-** Right oblique view of ribs: non displaced left scapula fracture (arrow).

Vertebral fractures

The case of vertebral fracture is particular. Sometimes these fractures can appear with vertebral body signal abnormality (*Fig 6-AB*). The presence of bone edema may be linked to the acuteness of the lesion. However, we noticed that vertebral fractures appear frequently as vertebral body shape abnormality on sagittal or coronal STIR sequences (*Fig 6-DH*), without signal abnormality. WB-MRI can be helpful to diagnose dorsal fractures especially because of superpositions with ribs on radiographs.

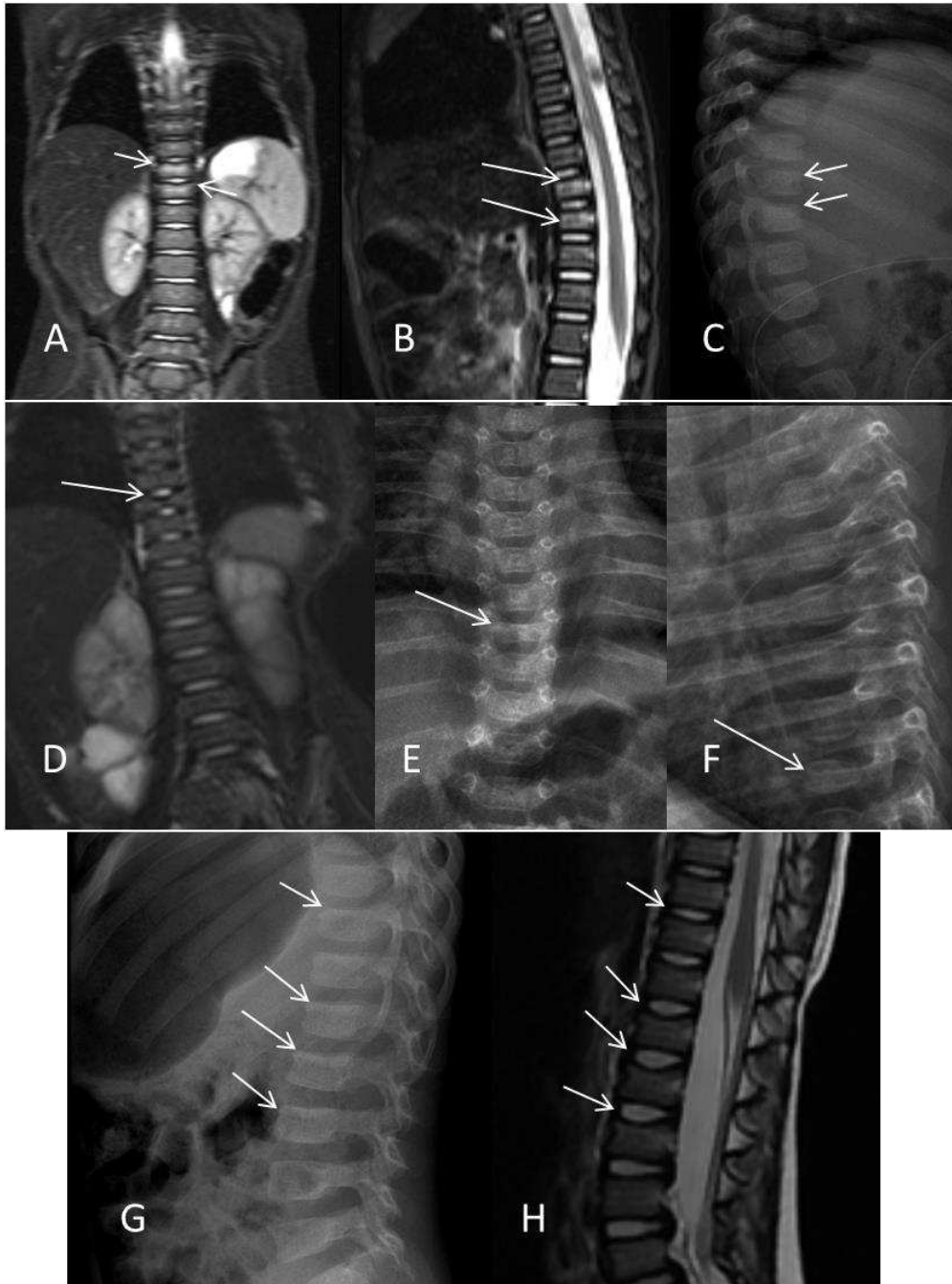


Fig 6 A-B-C: Nine-months-old child admitted for subdural hematoma discovered after hypotonia and emesis. **A-** Coronal STIR: high-intensity signal and shape abnormalities of T10 and T11 vertebral bodies (arrows). **B-** Sagittal STIR: Subtle loss of height and high-intensity signal of T10 and T11 vertebral bodies (arrows). **C-** Lateral view of dorsal spine: subtle loss of height of T10 and T11 vertebral bodies.

D-E-F: Two-months-old patient admitted for unusual cries and functional impotence of right leg (fracture of right femur diagnosed). **D-** Coronal STIR: shape abnormality of T9, without evident signal abnormality (arrow). **E-F:** Frontal and lateral views of dorsal spine. Loss of height of T9's vertebral body (arrows).

G-H: Three-years-old patient admitted for left femur fracture. **G-** Lateral view of dorso-lumbar spine. Loss of height of several vertebrae' upper shelves (arrows). **H-** Sagittal STIR: Shape abnormalities without high-intensity signal affecting the same vertebrae (arrows).

Extremities fractures

The higher and higher resolution of WB-MRI can help diagnose bone lesions on hands and feet (Fig 7), sometimes difficult to see on SS or BS. Signal abnormalities can then lead to identify additional fractures.

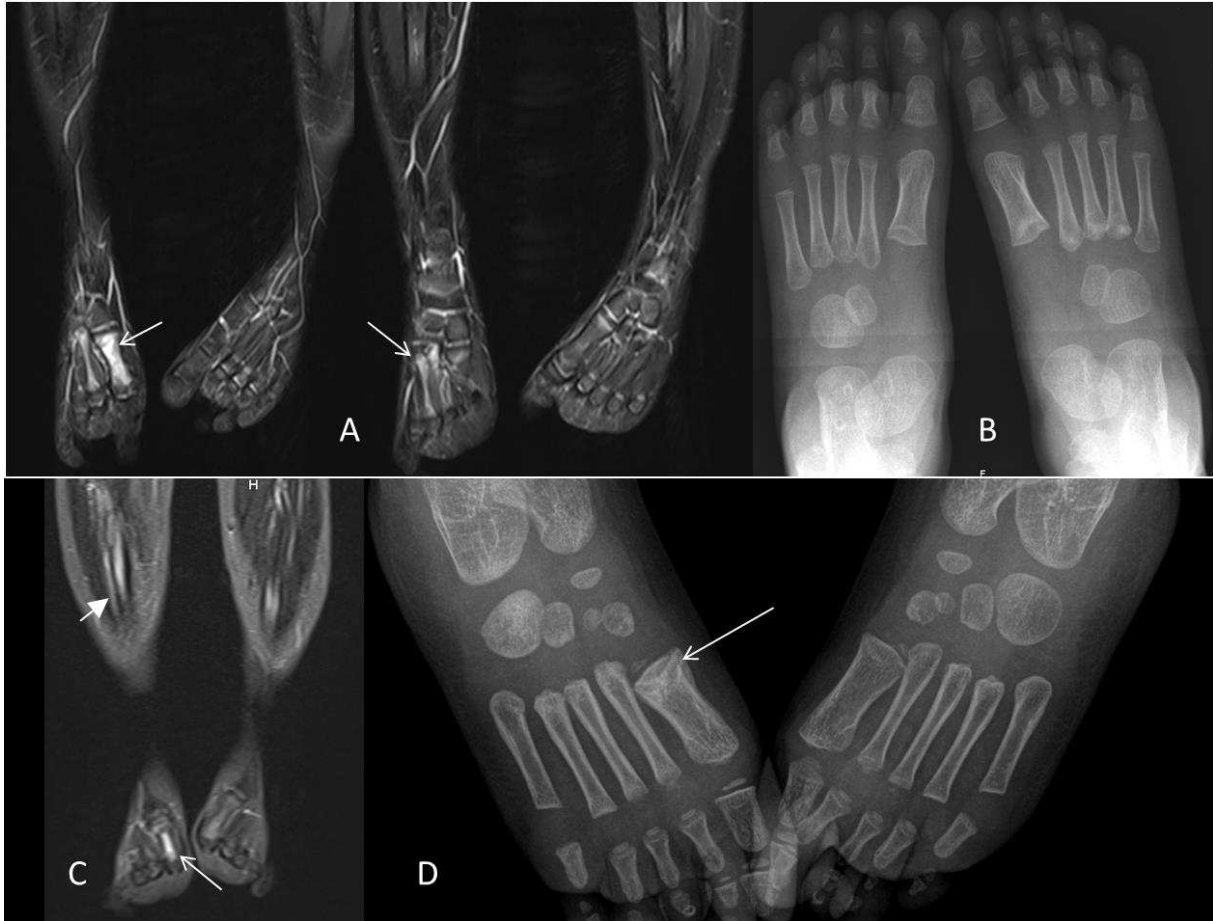


Fig 7 A-B: Two-years-old child admitted for multiple bruises on the face and lameness of the right leg. Notion of domestic violence. **A-** Coronal STIR WB-MRI shows high-intensity signal of the 1st, 2nd and 3rd metacarpus of the right foot (arrows). **B-** Radiographs, dorso-plantar view of the feet does not detect any abnormality.

C-D: Eighteen-months-old child admitted for functional impotence of the right arm and cries. Diagnosis of acute right arm fracture and several healing fractures. **C-** Coronal STIR: high-intensity signal of the first right metatarsus (arrow). Association with periosteal appositions on the right tibia (arrowhead). **D-** Frontal view of the right foot: condensation of the first right metatarsus base invoking a subacute fracture (arrow).

3c. Soft tissues injuries

Subcutaneous and muscular lesions

One of the best advantages of WB-MRI compared to SS or BS is its capacity to detect soft tissues injuries (*Fig 8-A*). These ones appear as signal abnormalities in muscles or subcutaneous tissues. Even when there are no evident bone lesions detected, we can suspect non accidental traumatism, as spanking for example. In our cohort, we also identified one Lavallée-Morel syndrome. This appeared as a linear high-intensity signal into right thigh lateral tissues, reflecting an abrupt and traumatic separation of subcutaneous fatty tissues with underlying fascia^[12-13] (*Fig 8-B*).

Effusions

WB-MRI can help detect joint effusions (*Fig 2*) which sometimes lead to diagnose additional lesions, especially metaphyseal fractures, highly specific of child abuse. It may also diagnose pleural or peritoneal effusions. In this case, when there is no favoring cause (systemic filling, reanimation), visceral lesions have to be suspected and searched.

Other soft tissues lesions

In our cohort we also diagnosed one anterior epidural detachment on sagittal STIR sequence (*Fig 8-C*), sign of spine traumatism. Some children presented pulmonary parenchymal condensations (*Fig 8-D*).

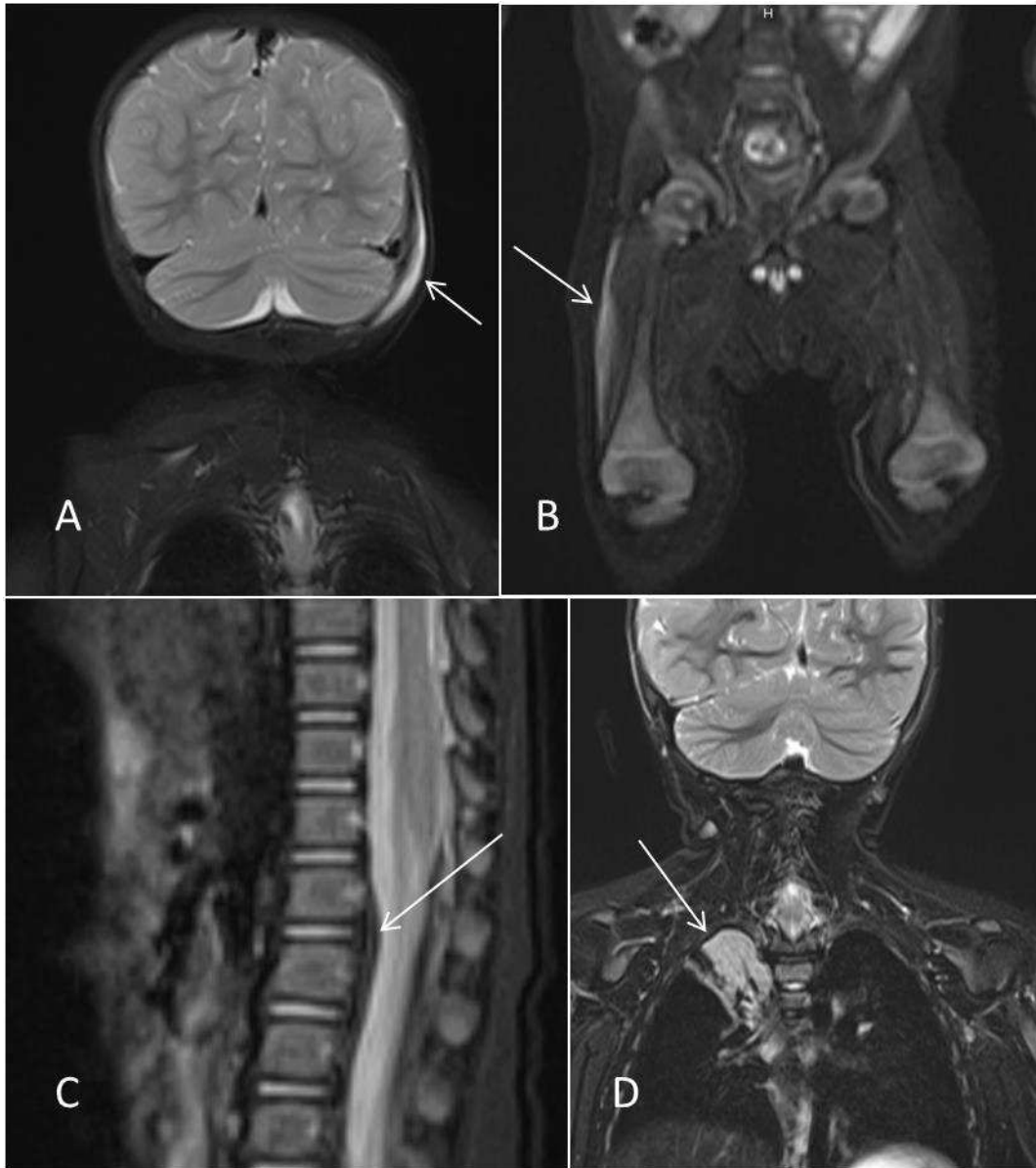


Fig 8 A- Ten-months-old little girl admitted for cutaneous injuries on the face after going to the childminder. Coronal STIR: sub-galeal hematoma appearing as parieto-occipital soft tissues signal abnormalities (arrow).

B- Two-months-old child admitted for convulsions. Coronal STIR: Linear high-intensity signal into right thigh lateral tissues, reflecting an abrupt and traumatic separation of subcutaneous fatty tissue with underlying fascia (arrow). Lavallée-Morel syndrome.

C- Five-months-old child admitted for brutal status epilepticus at the childminder. Sagittal STIR: anterior epidural hematoma (arrow).

D- Five-months-old child admitted for important erythema of the buttock, back hematoma and bruises on the face. Coronal STIR: right pulmonary parenchymal condensation (arrow).

4. Traps to avoid

4a. Artefacts

Positional artefacts

To avoid positional artefacts, the child must be correctly laid into the machine. There must be a perfect symmetry, especially in limbs positioning (*Fig 9-A*). This is possible as all young children undergo a short sedation to realize the MR imaging^[6]. Perfect symmetrical position avoids false positive results.

Movements' artefacts

WB-MRI is very sensitive to movements. If the child moves into the machine, it can create false images or on the contrary hide lesions. That is why an effective sedation is necessary to acquire interpretable sequences.

4b. Confusion images

Some images can be confusing and mimic lesions. This review aims at gathering them to avoid misinterpretation.

Perfusions

One of the most frequent sources of error is the presence of perfusions. Either it is a peripheral or central catheter, it can create soft tissues signal abnormalities due to liquid suffusion (*Fig 9-BC*). This must not be confused with a post-traumatic injury. It can be a good reflex to notice the localization of perfusions before the exam.

Lymph nodes

Normal lymph nodes frequently appear with high-intensity signal (*Fig 9-D*). That can be all the more confusing when they are located besides non accidental lesion specific sites. For example, sus-clavicular lymph nodes must not be confused with a clavicle fracture. Axillar lymph nodes may also be confused with ribs fractures. Recognizing these images can avoid misinterpretation.

Pleural effusion and ribs fractures

A pleural effusion of little abundance creates a high-intensity signal really close to ribs. It is not to be confused with a fracture. The image appears just besides the rib as a linear and thin fluid signal abnormality and not on the bone (*Fig 10-A*). Another image which can create confusion is the anterior rib cartilage that can imitate a healing fracture. The image's position is very important.

Vaccines

Vaccines injections create signal abnormalities in subcutaneous tissues when recent (*Fig 10-B*). This must be correlated with the clinical history of the patient to avoid misdiagnosing a post-traumatic lesion.

Blood vessels

On STIR sequences, blood vessels appear as linear signal abnormalities. They can be confusing when located just besides the periosteum (*Fig 10-C*). The continuity of this image must be searched not to misdiagnose a periosteal apposition.

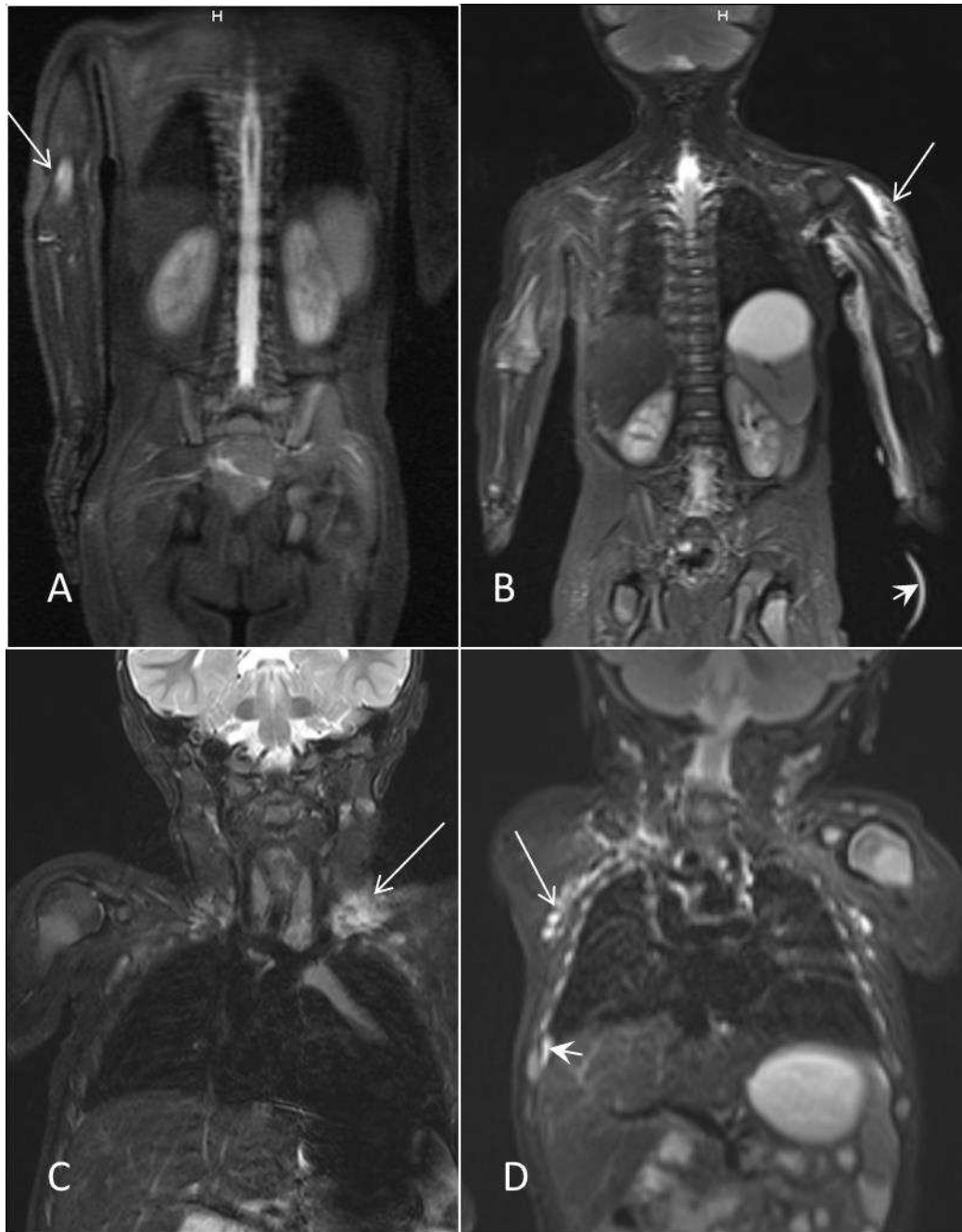


Fig 9 A- Coronal STIR: signal abnormality in bone marrow of right humerus (arrow) due to an asymmetric position. It is not to be confused with a fracture.

B- Coronal STIR: soft tissues signal abnormalities in left arm (arrow) due to peripheral catheter suffusion (arrowhead). It is not to be confused with soft tissues post traumatic lesions.

C- Coronal STIR: left sus-clavicular soft tissues high-intensity signal due to central catheter suffusion (arrow). It is not to be confused with a clavicular fracture.

D- Coronal STIR: right axillar high-intensity signals along the ribs, due to axillar lymph nodes (arrow). Subtle high-intensity signal along ribs due to little pleural effusion (arrowhead). These are not to be confused with ribs fractures.

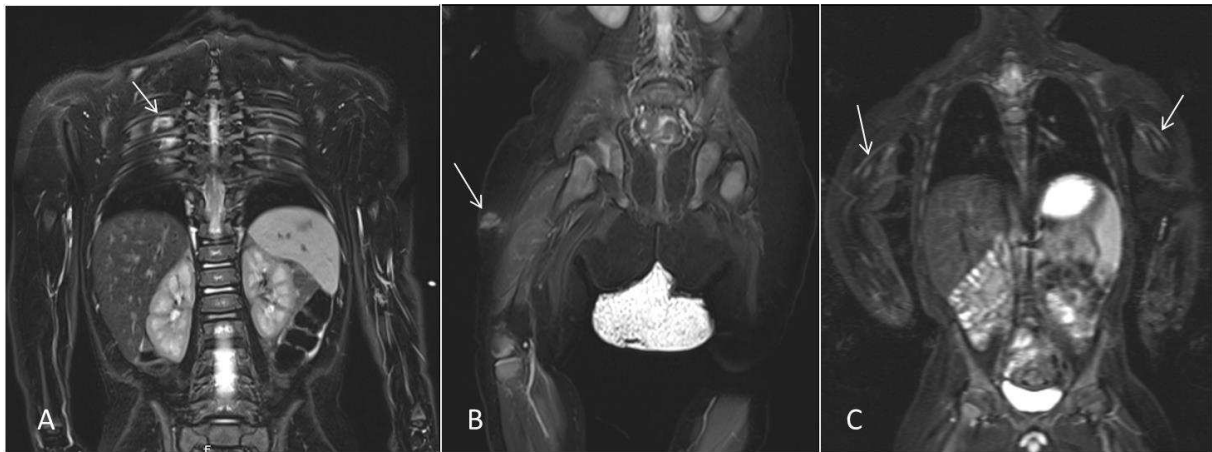


Fig 10 A- Coronal STIR: high-intensity signal besides the right ribs posterior arcs due to little pleural effusion (arrow). It is not to be confused with ribs fractures.
B- Coronal STIR: signal abnormality in fatty tissues of the right thigh (arrow) due to a recent vaccine. It is not to be confused with a soft tissues post-traumatic injury.
C- Coronal STIR: thin linear high-intensity signal along both humerus (arrows) due to the presence of vessels. It is not be confused with periosteal appositions.

5. Discrepant cases

As suspicion of child abuse requires a reliable diagnosis, we thought it would be interesting to gather some cases which had been problematic. Indeed, different imaging modalities are often discrepant, according to the sensibility of each exam, the acuteness and localization of lesions, etc.... These cases prove that a good interpretation must be based on a correlation of different imaging modalities and also clinical findings.

In the first case (*Fig 11*), subtle signal abnormalities on right posterior ribs were seen on WB-MRI. There were also suspected discreet healings on radiographs and discreet bone uptake on BS in the same area. A low dose CT chest has been performed and confirmed the 4 healing right posterior ribs fractures^[14-15].

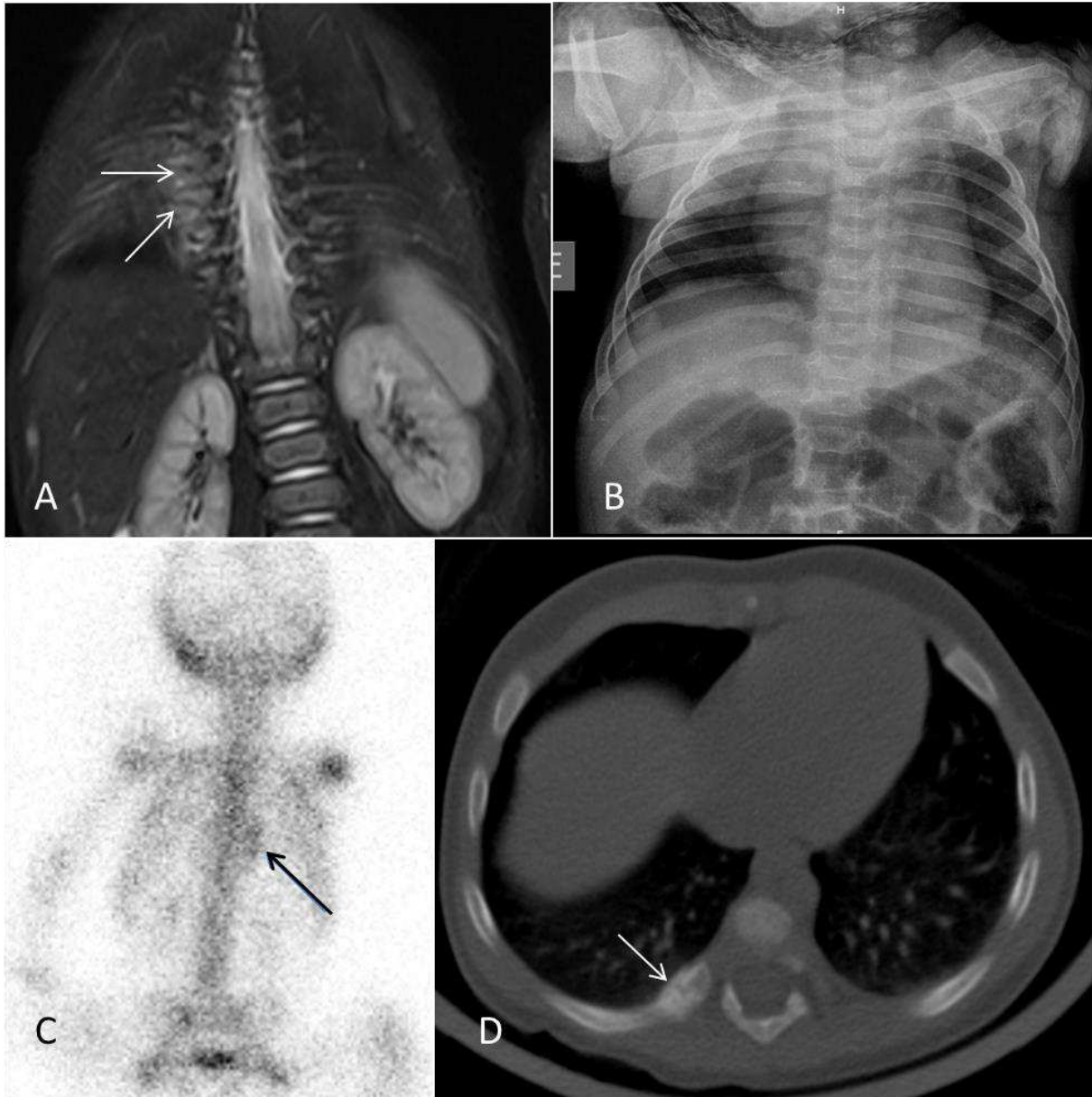


Fig 11: Six-months-old boy admitted for functional impotence of the right arm upon awakening. Diagnosis of right humerus diaphysal displaced fracture.

A- Coronal STIR: signal abnormalities of the right posterior ribs (arrows), asymmetric comparing to the other side.

B- Radiographs, frontal view of the chest. Doubt about subtle healing of right posterior ribs, not diagnosed initially.

C- Bone scintigraphy posterior view: discreet fixation on right posterior ribs (arrow).

D- Low dose chest CT: diagnosis of 4 healing fractures on right posterior ribs (arrow).

In the second case (*Fig 12*), we can see that sometimes BS can be faulted even for subacute lesions. This could be linked to the little asymmetric position of the child or to the localization next to the epiphysis of the radial lesion. Conversely, the fracture is quite easily diagnosed on WB-MRI.

Concerning the same child (*Fig 13*), we can see that sometimes metaphyseal lesions are paradoxically easier to see on WB-MRI or on BS than on radiographs. This may be linked to the acuteness of the fracture since soft tissues abnormalities are important on the WB-MRI. This is interesting because acute fractures are often more difficult to diagnose on radiographs. This complementarity of imaging modalities can lead to an earlier diagnosis.

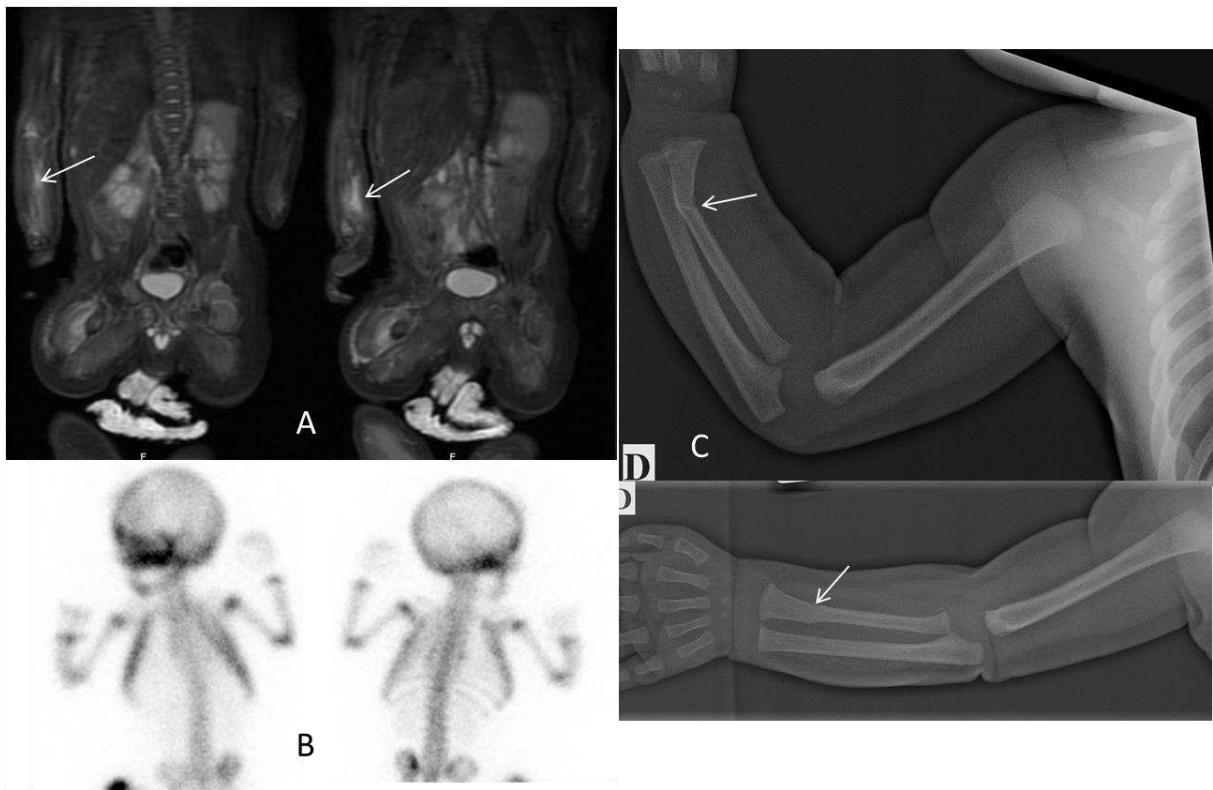


Fig 12: Two-months-old child admitted for cutaneous injuries. Diagnosis of both forearms fractures. No incident reported by parents unless unceasing cries since birth.

A- Coronal STIR: high-intensity signal of right radius bone marrow and surrounding soft tissues (arrows).

B- Bone scintigraphy: no evident fixation abnormality noticed.

C- Radiograph, lateral and frontal views of right forearm: non displaced fracture of the distal third of right radial diaphysis (arrows).

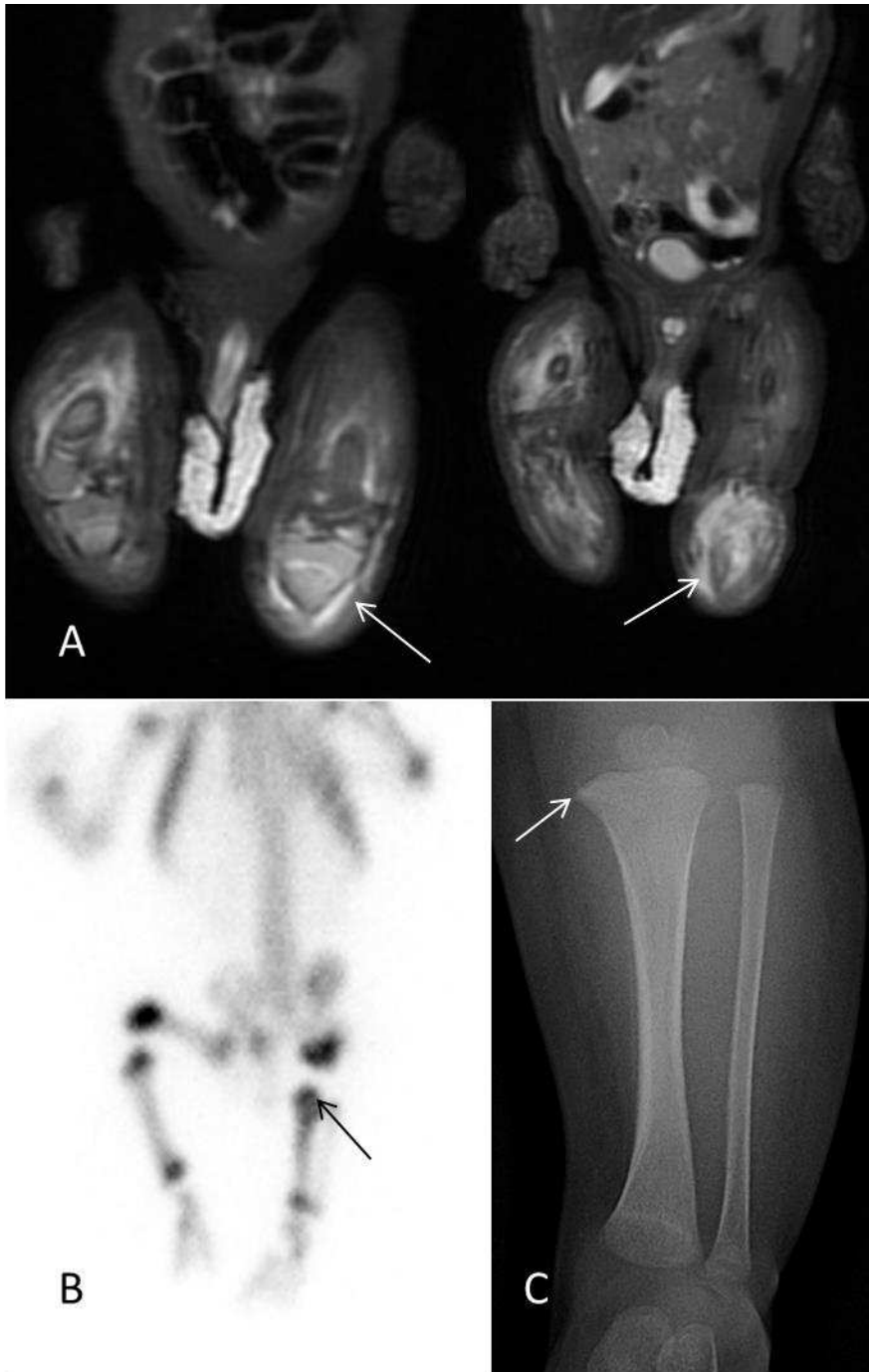


Fig 13: Other images concerning the previous child.

A- Coronal STIR: signal abnormalities of bone marrow and surrounding soft tissues of the upper extremity of left tibia and fibula (arrows).

B- Bone scintigraphy, anterior view: uptake of the upper extremity of left tibia (arrow).

C- Radiograph, frontal view of left lower leg: subtle metaphyseal fracture of the upper extremity of the left tibia (arrow), hard to see.

The third case (*Fig 14*) illustrates the importance of confronting different imaging modalities when abnormalities are really tenuous. In this case, the thin periosteal appositions on SS and the subtle uptake on right tibia on BS were secondly diagnosed after seeing signal abnormalities on right tibia on the WB-MRI.



Fig 14: Nineteen-months-old child admitted for left femur fracture without any recent traumatism reported by the parents.

A- Coronal STIR: high-intensity signal in right tibia bone marrow without soft tissues abnormality (arrows). There are also really thin linear signal abnormalities along the periosteum. We can see soft tissues signal abnormalities on left femur linked with the recent lesion (arrowheads).

B- Bone scintigraphy, anterior view: subtle uptake of the right tibia diaphysis, not diagnosed initially (arrow). We can see uptake of the left femur due to the acute fracture (arrowhead).

C- Radiograph, lateral views of both lower legs: subtle periosteal appositions of the right tibia (arrow), not diagnosed initially.

Finally, the fourth case (*Fig 15*) shows us how BS and WB-MRI can be helpful in diagnosing extremities lesions. In this case, radiographs did not find any abnormality whereas there was a clear uptake and a discreet signal abnormality of the right ankle respectively on BS and WB-MRI. Even if we cannot affirm the existence of a fracture, we can suspect at least a bone contusion. Of course, each radiological abnormality must be correlated to the clinical findings and the patient history, not to misdiagnose lesions.



Fig 15: Two-years-old child admitted for multiple cutaneous ecchymosis on the face.
A- Coronal STIR: subtle high-intensity signal of the right talus (arrow) without soft tissues abnormality.
B- Bone scintigraphy, anterior and posterior views: uptake of the right ankle (arrows).
C- Radiographs, frontal views of both feet: no abnormality diagnosed.

6. Conclusion

Whole-body MRI is a really informative imaging modality in the diagnosis of child abuse, especially for its capacity to detect soft tissues injuries. Furthermore, it is a radiation-free exam which could help reduce the radiation exposure in this context. Knowledge of lesions appearance and eventual traps to avoid is very important since WB-MRI is not commonly used in this indication for the moment.

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84 feuilles, 3 figures, 5 tableaux. , 30 cm.- Thèse : Médecine ; Rennes 1; 2018 ; N°

Résumé français

Objectif: Comparer la sensibilité et la spécificité de la radiographie de squelette corps entier (RX), de l'IRM corps entier et de la scintigraphie osseuse (SO) dans le dépistage des lésions traumatiques d'origine indéterminée chez l'enfant.

Matériel et méthode: Il s'agit d'une étude multicentrique prospective (PHRC PEDIMA 2011) ayant inclus des enfants de moins de 3 ans suspects de traumatisme non accidentel. Tous les enfants ont bénéficié des 3 modalités d'imagerie (RX+SO+IRM). Le gold standard était le consensus de l'interprétation collégiale des 3 examens en aveugle par les experts.

Résultats: Au final, 170 enfants ont été inclus. Le délai moyen de réalisation des examens d'imagerie était de 4.4 jours. Soixante-quatre enfants avaient au moins une lésion, avec un total de 146 lésions. La sensibilité et la spécificité de chaque examen étaient respectivement de 88.4% et 99.7% pour la RX, 69.9% et 99.5% pour l'IRM, 54.8% et 99.7% pour la SO. La sensibilité et la spécificité pour le couple RX + IRM étaient respectivement de 95.9% et 99.2% et pour le couple RX + SO de 95.2% et 99.4%.

Conclusion : La RX est l'examen le plus sensible pour détecter les lésions osseuses traumatiques d'origine indéterminée. Sa sensibilité est augmentée si associée à une SO et/ou une IRM corps entier.

Rubrique de classement : RADIOLOGIE

Mots-clés : Maltraitance, IRM corps entier, scintigraphie osseuse, radiographies squelette, traumatisme non accidentel, enfant, fractures métaphysaires, appositions périostées, fractures de côtes

Mots-clés anglais MeSH : Child abuse, whole-body MRI, bone scintigraphy, skeletal survey, non-accidental trauma, metaphyseal lesion, periosteal appositions, rib fracture

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