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Avaliação do padrão e tendência de uso de exames de diagnóstico por imagem no Brasil com ênfase em tomografia computadorizada pediátrica

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Avaliação do padrão e tendência de uso de exames de diagnóstico por imagem no Brasil com ênfase em tomografia computadorizada pediátrica

Tese apresentada ao Programa de Pós-Graduação em Radioproteção e Dosimetria do Instituto de Radioproteção e Dosimetria, como parte dos requisitos para obtenção do título de Doutor em Radioproteção e Dosimetria

Área de Concentração: Física Médica

Orientadora: Dra. Lene Holanda Sadler Veiga
Co-orientador: Dr. Luiz Antonio Ribeiro da Rosa

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A ciência será sempre uma busca, jamais uma descoberta.

É uma viagem, nunca uma chegada.

Karl Popper

RESUMO

Em países em desenvolvimento há pouca informação sobre o uso de procedimentos de diagnóstico por imagem e as doses associadas aos exames que envolvem exposição à radiação ionizante. Nesse trabalho se avaliou o padrão e a tendência de uso de procedimentos de diagnóstico por imagem em pacientes ambulatoriais do Sistema Único de Saúde (SUS) por modalidade e parte do corpo examinada. Foi dada ênfase a exames de tomografia computadorizada (TC), para os quais a análise se estendeu ao setor privado de saúde e incluiu a avaliação da distribuição dos exames por idade do paciente e a estimativa das doses em crianças e adultos jovens. Informações sobre o uso de procedimentos de diagnóstico por imagem em pacientes ambulatoriais do SUS foram obtidas do Sistema de Informações Ambulatoriais (SIA) do Departamento de Informática do SUS (DATASUS). Dados sobre o uso de TC no setor privado foram extraídos dos Sistemas de Informações Radiológicas (RIS) de 25 serviços privados de radiologia em 8 cidades no Brasil. As doses efetivas e as doses absorvidas em órgãos de interesse foram estimadas individualmente para 4.497 pacientes com menos de 20 anos de idade usando parâmetros técnicos dos exames de TC e simulações por Monte Carlo do transporte da radiação. Observou-se que entre 2002 e 2012 a radiologia convencional foi a modalidade mais frequente de diagnóstico por imagem em pacientes ambulatoriais do SUS, mas modalidades mais sofisticadas, como TC e ressonância magnética nuclear, apresentaram o maior crescimento ao longo do período de estudo. O exame de TC mais frequente em pacientes ambulatoriais do SUS entre 2001 e 2011 foi o de cabeça/pescoço, mas os exames de abdome/pelve foram os que mais cresceram. Pacientes com até 20 anos de idade fizeram cerca de 13% e 9% dos exames de TC realizados entre 2008 e 2014 nos sistemas público e privado de saúde, respectivamente. Cerca de um terço dos pacientes do setor privado fez mais de um exame de TC nesse período. Observou-se grande variação nas doses, inclusive para o mesmo tipo de procedimento em pacientes da mesma faixa etária. A maior dose efetiva média estimada foi de 13,5 mSv para TC de abdomen/pelve em crianças com menos de um ano de idade. As doses absorvidas mais altas foram estimadas para o cérebro após TC da cabeça/pescoço (23,8 a 29,0 mGy), que foi o tipo de TC mais comum em crianças e adultos jovens no período estudado. O intenso crescimento, a magnitude das doses estimadas e a grande proporção de exames de TC pediátricos no Brasil apontam para a necessidade de iniciativas para promover a adequada justificação e otimização desses exames no Brasil.

Palavras chave: radiação ionizante, dose efetiva, dose absorvida, proteção radiológica

ABSTRACT

There is little information on developing countries about the use of diagnostic imaging procedures and the doses associated with radiological examinations. This study assessed the pattern and trend of diagnostic imaging usage in outpatients of the Brazilian Unified Health System (SUS) by modality and examined body part. Emphasis was given to computed tomography (CT) scans for which the analysis was extended to the private healthcare sector and included the evaluation of age at examination distribution, and dose estimation for children and young adults. Information on the use of diagnostic imaging procedures among SUS outpatients was obtained from the Outpatient Information System (SIA) of the Department of Information Technology of SUS (DATASUS). Data on the use of CT in the private healthcare sector were extracted from the Radiological Information Systems (RIS) of 25 private radiology services in 8 Brazilian cities. Effective doses and absorbed doses on organs of interest were estimated individually for 4,497 patients younger than 20 years of age using CT scan technical parameters and Monte Carlo simulations of radiation transport. Between 2002 and 2012 it was observed that conventional radiology was the most frequent modality of diagnostic imaging in SUS outpatients, but more sophisticated modalities, such as CT and magnetic resonance imaging, had the highest growth rates over the study period. The most frequent CT scan in SUS outpatients between 2001 and 2011 was the head/neck exam, but abdomen/pelvis examinations were the ones that grew the most. Patients up to 20 years of age made approximately 13% and 9% of the CT examinations between 2008 and 2014 in the public and private healthcare systems, respectively. About one-third of the private-sector patients had more than one CT scan in this period. There was great variation in doses, even for the same type of procedure in patients of the same age group. The highest mean effective dose was 13.5 mSv estimated for abdomen/pelvis CT in children younger than one year of age. The highest absorbed doses were estimated for the brain after head/neck CT (23.8 to 29.0 mGy), which was the most common type of CT in children and young adults in the study period. The intense increase, the magnitude of the estimated doses and the large proportion of pediatric CT scans in Brazil point out to the need for initiatives to promote appropriate justification and optimization of these examinations in Brazil.

Key words: ionizing radiation, effective dose, absorbed dose, radiological protection

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SUMÁRIO

1. INTRODUÇÃO

A exposição da população à radiação ionizante cresceu muito nas últimas décadas em todo o mundo. A maior parte desse crescimento está relacionada ao aumento da frequência de procedimentos que utilizam radiação ionizante para fins diagnósticos, como radiografia convencional, fluoroscopia, tomografia computadorizada (TC) e medicina nuclear (METTLER et al., 2009; UNSCEAR, 2010). O uso de procedimentos diagnósticos que não envolvem o uso da radiação ionizante, como ressonância magnética nuclear (RMN) e ultrassonografia também cresceu intensamente nos últimos anos (LANG et al., 2013; NHS, 2014; SMITH-BINDMAN et al., 2008; SMITH-BINDMAN et al., 2012).

A disseminação da utilização de procedimentos de diagnóstico por imagem aumentou a precisão e rapidez da detecção, diagnóstico e acompanhamento de uma série de condições médicas, resultando em melhores condições de saúde para a população (IGLEHART, 2006; RUBIN, 2014). Entretanto, existe uma crescente preocupação com os potenciais riscos à saúde associados à exposição à radiação ionizante, um conhecido agente carcinogênico (BERRINGTON DE GONZALEZ&DARBY, 2004; EL GHISSASSI et al., 2009; HALL&BRENNER, 2008; LINET et al., 2012; SMITH-BINDMAN et al., 2012) e com o impacto do custo desses exames nos sistemas de saúde (HENDEE et al., 2010; IGLEHART, 2009; LANG et al., 2013; SMITH-BINDMAN et al., 2008).

Em particular, muita atenção tem sido dada aos exames de TC, que estão associados a doses de radiação relativamente altas para o paciente e estão entre os procedimentos cujo uso mais cresceu nos últimos anos (BERRINGTON DE GONZALEZ et al., 2009; BRENNER&HALL, 2007). A preocupação é ainda maior em relação à exposição de crianças e jovens, que frequentemente recebem doses de radiação mais elevadas, têm maior radiosensibilidade intrínseca e ainda, maior expectativa de vida, possibilitando o surgimento de um câncer radio-induzido após um longo período de latência (BRENNER et al., 2001; MIGLIORETTI et al., 2013). Estudos epidemiológicos recentes usando dados empíricos obtiveram evidência direta do aumento do risco de câncer após exposições à radiação em exames de TC na infância e juventude (BERRINGTON DE GONZALEZ et al., 2016; HUANG et al., 2014; MATHEWS et al., 2013; PEARCE et al., 2012b).

O risco de câncer em decorrência da exposição à radiação ionizante em procedimentos para fins de diagnóstico depende do sexo e idade do indivíduo irradiado e da dose absorvida nos órgãos e tecidos de interesse (ICRP, 2007). O risco individual é geralmente baixo, mas o grande número de indivíduos expostos pode ter importância sob o ponto de vista de saúde pública.

Assim, é importante avaliar a frequência e distribuição dos procedimentos que usam radiação ionizante para fins diagnósticos numa população, assim como as doses de radiação a eles associadas. A maior parte dos estudos sobre esse assunto é realizada em países desenvolvidos. Em contraste, há pouca informação sobre o padrão e tendência de uso de exames de diagnóstico por imagem em países em desenvolvimento, onde vivem dois terços da população mundial (KRILLE et al., 2012; METTLER et al., 2009; PEARCE, 2011; REHANI, 2014; THOMAS, 2011; UNSCEAR, 2010).

Tendo em vista a inexistência de uma avaliação sistemática da frequência e distribuição dos exames de diagnósticos por imagem no Brasil, principalmente dos exames de TC e suas doses associadas, este trabalho teve como objetivo avaliar o padrão e tendência de uso de exames de diagnóstico por imagem no Brasil, com ênfase nos exames de TC em crianças e adultos jovens nos sistemas públicos e privados de saúde do país.

2. OBJETIVO

Avaliar o padrão e a tendência de uso de exames de diagnóstico por imagem no Brasil nos últimos anos, particularmente em pacientes ambulatoriais do Sistema Público de Saúde (SUS). Foi dado destaque aos exames de tomografia computadorizada (TC), especialmente àqueles realizados em crianças e jovens, para os quais a análise se estendeu ao setor privado de saúde e incluiu uma estimativa das doses decorrentes deste procedimento.

2.1. OBJETIVOS ESPECÍFICOS

- Determinar, ao longo do tempo, o número de procedimentos de diagnóstico por imagem em pacientes ambulatoriais do SUS, para as diferentes modalidades de imagem e parte do corpo examinada;
- Determinar, ao longo do tempo, o número de equipamentos de diagnóstico por imagem existentes no país e o número de equipamentos disponíveis ao SUS;
- Determinar, ao longo do tempo, a distribuição por idade dos exames de TC em pacientes dos setores público e privado de saúde;
- Determinar a frequência de exames múltiplos de TC em crianças e jovens;
- Estimar as doses efetivas e as doses absorvidas em órgãos e tecidos nos exames de TC em crianças e jovens.

3. FUNDAMENTAÇÃO TEÓRICA

3.1. USO DE PROCEDIMENTOS DE DIAGNÓSTICO POR IMAGEM NO MUNDO

A frequência e tendência de uso de procedimentos de diagnóstico por imagem variam significativamente entre países e, ainda, para diferentes sistemas de saúde em um mesmo país. O mesmo ocorre em relação à distribuição desses procedimentos por modalidade, região anatômica examinada, e sexo e idade dos pacientes (DEMETER et al., 2005; HAMRA et al., 2014; LANG et al., 2013; METTLER et al., 2009; NHS, 2014; SMITH-BINDMAN et al., 2008; SMITH-BINDMAN et al., 2012; UNSCEAR, 2010).

Vários estudos têm mostrado um intenso aumento no uso de procedimentos de diagnóstico por imagem nas últimas décadas, em todo o mundo (LANG et al., 2013; METTLER et al., 2009; NHS, 2014; SMITH-BINDMAN et al., 2008; SMITH-BINDMAN et al., 2012; UNSCEAR, 2010). O Comitê Científico das Nações Unidas sobre os Efeitos da Radiação Atômica (UNSCEAR) estimou que, no período de 1997-2007, foram realizados anualmente mais de 3,6 bilhões de procedimentos utilizando radiação ionizante para fins diagnósticos, incluindo radiografias médicas e odontológicas convencionais, fluoroscopias, varreduras por tomografia computadorizada (TC) e estudos por medicina nuclear, totalizando o dobro do número de exames realizados no período de 1980-1984 e mais de 10 vezes o total de procedimentos que fora estimado para 1950 (METTLER et al., 2009; UNSCEAR, 2010). Apenas nos Estados Unidos, em 2006, foram realizados cerca de 400 milhões de procedimentos radiodiagnósticos (METTLER et al., 2009).

Smith-Bindman e colaboradores (SMITH-BINDMAN et al., 2012) estimaram uma frequência de 783 radiografias convencionais, 149 exames de TC e 21 procedimentos de medicina nuclear por 1.000 participantes de um grande sistema de saúde nos Estados Unidos, em 2010. Na Inglaterra, as frequências de exames de radiografia, TC e medicina nuclear foram estimadas em 423, 88 e 11 por 1.000 habitantes, respectivamente, em 2012/2013 (NHS, 2014; ONS, 2014). Em países de nível II de assistência à saúde (1.000 a 2.999 habitantes por médico), entre os quais o Brasil está incluído, a frequência de procedimentos que utilizam radiação para fins de diagnóstico é cerca de 4-6 vezes menor, mas também tem aumentado muito, tendo mais que dobrado entre 1997 e 2007 (METTLER et al., 2009; UNSCEAR, 2010).

Dentre os procedimentos que usam radiação ionizante para fins diagnósticos, a TC é o exame cujo uso mais cresceu nas últimas décadas (METTLER et al., 2009; UNSCEAR, 2010). A frequência desses procedimentos na população mundial aumentou de 1-3 exames por 1.000 habitantes em 1977-1980 para 35 exames por 1.000 habitantes em 1997-2007 (METTLER et al., 2009; UNSCEAR, 2010). Na Inglaterra, o uso de procedimentos de TC aumentou cerca de 10% ao ano entre 2000-2001 e 2012-2013, passando de 1,5 milhões para 4,7 milhões de procedimentos anuais, respectivamente (NHS, 2014). Também houve intenso crescimento no uso de TC em Israel (CHODICK et al., 2007), na Suíça (AROUA et al., 2013) e Austrália (BRADY et al., 2011). Nos Estados Unidos, o número de procedimentos TC passou de aproximadamente 3,3 milhões entre 1980 e 1982 para 67 milhões em 2006, atingindo a taxa de 223 exames/1.000 habitantes/ano. Vale ressaltar que isso representa um aumento anual de mais de 10%, enquanto no mesmo período a população norte-americana cresceu menos de 1% ao ano (METTLER et al., 2009; NCRP, 2009). Entretanto, mais recentemente, houve uma redução do crescimento ou mesmo uma redução no uso de exames de TC, principalmente em crianças, em alguns países desenvolvidos (LEVIN et al., 2012; NHS, 2014; SMITH-BINDMAN et al., 2012).

Houve também um grande aumento no uso de procedimentos de diagnóstico por imagem que não envolvem o uso de radiação ionizante. Nos Estados Unidos, os exames de ressonância magnética nuclear (RMN) em pacientes de um grande sistema de assistência a saúde aumentaram cerca de 10% ao ano entre 1996 e 2010, atingindo uma frequência de 65 exames por 1.000 habitantes ao final do período. O mesmo estudo mostrou um aumento anual de 3,9% para exames de ultrassonografia, que atingiram a frequência de 230 exames por 1.000 habitantes em 2010 (SMITH-BINDMAN et al., 2012). Na Inglaterra, entre 2000-2001 e 2012-2013, os aumentos anuais no uso de procedimentos de RMN e ultrassonografia foram de 11,9% e 4,7%, respectivamente, atingindo uma frequência de 46 e 174 exames por 1.000 habitantes, respectivamente, ao final do período (NHS, 2014).

3.2. DOSES EM PROCEDIMENTOS QUE USAM RADIAÇÃO IONIZANTE PARA FINS DE DIAGNÓSTICO POR IMAGEM

As grandezas de proteção radiológica mais frequentemente usadas para quantificar as exposições em procedimentos de diagnóstico por imagem são a dose absorvida e a dose efetiva.

A dose absorvida é uma grandeza dosimétrica básica em proteção radiológica e representa a quantidade de energia absorvida (Joule) por unidade de massa (kg), sendo sua unidade no Sistema Internacional de Unidades o Gray (Gy) (ICRP, 2007). A dose absorvida leva em consideração as variações na composição corporal e no tamanho dos pacientes, sendo a grandeza apropriada para a avaliação do risco individual de indução de câncer após uma exposição não uniforme à radiação, como exposições para fins de diagnóstico (ICRP, 2007).

A dose efetiva é uma grandeza derivada, calculada pelo somatório dos produtos das doses absorvidas em cada órgão ou tecido pelos respectivos fatores de ponderação para cada órgão e tipo de radiação incidente. Os fatores de ponderação para cada órgão ou tecido e para a radiação incidente são derivados de evidências epidemiológicas e indicam o maior ou menor risco de indução de câncer pela radiação naquele órgão ou tecido em um indivíduo de referência. A dose efetiva representa valores médios para humanos, ponderados para os dois sexos e todas as idades, sendo expressa em J/kg, com o nome especial de Sievert (Sv) (ICRP, 2007). Essa grandeza não considera a idade ou sexo do indivíduo exposto à radiação ionizante e tampouco que órgãos específicos foram irradiados, e assim não pode ser usada para a avaliação dos riscos associados aos exames que usam radiação para fins de diagnóstico (HARRISON et al., 2016). Entretanto, a dose efetiva é um bom indicador da quantidade de radiação recebida por um paciente, podendo ser usada para a comparação das doses em um determinado procedimento com aquelas associadas a outras modalidades diagnósticas, sendo muito útil para os procedimentos de otimização das doses.

A dose efetiva média anual global *per capita* proveniente do uso da radiação ionizante para fins diagnósticos quase duplicou entre 1997 e 2007, subindo de cerca 0,35 mSv para 0,62 mSv, o que representa 20% da dose efetiva média anual global *per capita*, que é 3,0 mSv (METTLER et al., 2009; UNSCEAR, 2010). Nos Estados Unidos, em 2006, a dose efetiva média *per capita* resultante de procedimentos que utilizam radiação ionizante para fins diagnósticos foi de 3,01 mSv, representando mais de 50% da dose efetiva média anual *per capita* norte-americana, estimada em 5,6 mSv. Tal valor representa um aumento de cerca de seis vezes em relação àquele de 1980, quando essa dose foi de 0,53 mSv, representando 15% da dose média *per capita*, 3,0 mSv (METTLER et al., 2009; NCRP, 2009). Em outros países com nível I de assistência à saúde (alto nível de assistência, com menos de 1.000 habitantes por médico) a dose efetiva média anual *per capita* decorrente desses procedimentos para o período 1997-2007 foi de

2,0 mSv, bem menor que a observada nos Estados Unidos, mas superior àquela estimada para o mundo como um todo (METTLER et al., 2009; UNSCEAR, 2010).

Apesar das doses em procedimentos radiológicos variarem muito de acordo com o tipo de exame e as características do equipamento e do paciente, exames de TC geralmente produzem doses mais elevadas do que aquelas resultantes de exames radiodiagnósticos convencionais. Por exemplo, enquanto um exame radiológico típico de tórax em adultos (projeções póstero-anterior e lateral) resulta em uma dose efetiva média de aproximadamente 0,1 mSv (com variação entre 0,05 e 0,24 mSv), um exame dessa região por TC resulta em doses entre 4,0 e 18,0 mSv, com dose efetiva média de 7 mSv. As doses absorvidas nos órgãos que estão no caminho do feixe primário podem variar entre 10 e 100 mGy, apresentando valores normalmente na faixa de 15 a 30 mGy (METTLER et al., 2008).

A dose efetiva média anual global *per capita* proveniente de procedimentos de TC aumentou cerca de cinco vezes entre 1985-1990 e 1997-2007, indo de 0,05 mSv para 0,24 mSv, o que representa cerca de 40% da dose efetiva média *per capita* decorrente de exames de radiodiagnóstico. Assim, atualmente a TC representa cerca de 7% dos procedimentos radiológicos de diagnóstico, mas aproximadamente 40% da dose efetiva coletiva mundial (METTLER et al., 2009; UNSCEAR, 2010). Nos Estados Unidos, a dose efetiva média *per capita* em decorrência desses exames em 2006 foi estimada em 1,47 mSv, um aumento de quase 100 vezes em relação ao período de 1980-1982, quando esta foi 0,016 mSv. De fato, quase todo o incremento da dose efetiva média *per capita* entre 1980-1982 e 2006 nos Estados Unidos é decorrente do aumento da dose proveniente de TC, que representa atualmente metade da dose efetiva média *per capita* resultante de aplicações da radiação em diagnóstico (METTLER et al., 2009; NCRP, 2009).

3.3. USO DE TOMOGRAFIA PEDIÁTRICA EM CRIANÇAS E JOVENS

A maior preocupação com os possíveis riscos de indução de câncer após a exposição à radiação ionizante para fins de diagnóstico é com o uso de exames de TC em crianças e jovens.

As crianças, em geral, apresentam maior radiossensibilidade intrínseca e maior expectativa de vida, o que possibilita o potencial desenvolvimento de um câncer radio-induzido mesmo após um longo período de latência (BRENNER et al., 2001; UNSCEAR, 2013). Além disso, crianças e jovens frequentemente recebem doses de radiação mais elevadas que adultos, devido ao uso de técnicas não adaptadas e à menor atenuação da radiação em indivíduos com menor massa corporal (HOLLINGSWORTH et al., 2003; HUDA&VANCE, 2007; PATERSON et al., 2001).

Vários estudos estimaram as doses absorvidas em diferentes órgãos em pacientes pediátricos submetidos à TC, seja por medições diretas utilizando dosímetros posicionados em simuladores antropomórficos físicos (BRISSE et al., 2009; MAZONAKIS et al., 2007) ou através de simulações usando modelos computacionais baseados no método de Monte Carlo para transporte da radiação (BERNIER et al., 2012; HUDA&VANCE, 2007; MAZONAKIS et al., 2007; STATON et al., 2006). Entretanto, esses dados são válidos apenas para as condições de irradiação consideradas em cada estudo e assim não podem ser diretamente extrapolados para os diferentes protocolos de varredura usados em cada grupo de pacientes e/ou serviço de TC. Alguns poucos estudos foram feitos usando simuladores com os tamanhos e as composições corporais adequadas para representar a população de pacientes pediátricos (BAHADORI et al., 2015; BRISSE et al., 2009; LEE et al., 2007; MIGLIORETTI et al., 2013). Esses autores mostraram que as doses absorvidas resultantes de TC em crianças e jovens variam muito e podem ser bastante altas em alguns procedimentos. Por exemplo, doses absorvidas no cérebro iguais ou acima de 50 mGy foram estimadas para 7%, 8% e 14% das varreduras de cabeça em crianças com idades nas faixas de <5, 5-9 e 10-14 anos, respectivamente. Esses resultados são preocupantes considerando que a cabeça é a região mais frequentemente examinada por TC em crianças e jovens e ainda, que crianças que receberam dose cumulativa de ao menos 50 mGy no cérebro tiveram um risco 2,8 vezes maior de desenvolver câncer de cérebro do que crianças que receberam doses inferiores a 5 mGy (PEARCE et al., 2012b).

O uso de TC em crianças e jovens tem crescido intensamente em muitos países (BRADY et al., 2011; CHODICK et al., 2006; MIGLIORETTI et al., 2013; MUHOGORA et al., 2010; PEARCE et al., 2012a; VASSILEVA et al., 2012). Além da maior disponibilidade de tomógrafos, parte desse crescimento é devida aos avanços tecnológicos, incluindo a introdução de equipamentos helicoidais e de múltiplos detectores, que ampliaram as aplicações de TC em pediatria. Esses tomógrafos tem tempo de varredura muito curto e permitem que a qualidade de imagem não seja prejudicada pela movimentação do paciente, reduzindo ou evitando a necessidade de sedação (MAHESH, 2011; WHITE, 1996; YEKELER, 2004). Além disso, esses equipamentos melhoraram a avaliação de regiões anatômicas com movimento intrínseco, como tórax e abdômen, e estenderam o uso da TC a estudos cardíacos e vasculares. A proporção de crianças e jovens adultos submetidos a exames de TC varia de 1% na Alemanha (GALANSKI et al., 2007) a 7-11 % nos Estados Unidos (BERRINGTON DE GONZALEZ et al., 2009; METTLER et al., 2000), sendo estimado que 7% dos exames de crânio e 3% dos exames corporais tomográficos realizados no mundo sejam feitos em crianças de até 15 anos de idade (UNSCEAR, 2010).

3.4. RISCO DE INDUÇÃO DE CÂNCER EM DECORRÊNCIA DA EXPOSIÇÃO À RADIAÇÃO EM EXAMES DE DIAGNÓSTICO POR IMAGEM

Vários autores relacionaram o aumento no número de casos de câncer ao uso crescente da radiação ionizante para fins de diagnóstico (HALL&BRENNER, 2008; LINET et al., 2012; SCHONFELD et al., 2011). Evidências epidemiológicas diretas da associação entre o desenvolvimento de câncer em decorrência da exposição à radiação em exames de diagnóstico por imagem são de difícil obtenção, principalmente devido às dificuldades metodológicas associadas às baixas doses envolvidas, que demandam estudos abrangentes e com longos períodos de seguimento (LAND, 1980).

Desta forma, modelos de projeção de risco - que estimam os riscos potenciais após exposições a baixas doses com base nas informações disponíveis após exposição a doses mais elevadas - têm sido usados para estimar o risco de indução de câncer após a exposição a baixas doses de radiação. Berrington de Gonzalez e colegas estimaram que aproximadamente 0,2% dos casos incidentes de câncer em geral poderiam ser atribuídos a varreduras tomográficas feitas no início dos anos 90 (BERRINGTON DE GONZALEZ&DARBY, 2004). Outros autores, considerando que nessa época o uso de TC nos Estados Unidos era 10 vezes maior que no Reino Unido, sugeriram que 1,5 a 2,0% dos casos incidentes de câncer nos Estados Unidos poderiam ser atribuídos ao uso de TC (BRENNER&HALL, 2007). Projeções de risco atualizadas mais recentemente, usando novas estimativas detalhadas da frequência de exposições diagnósticas nos Estados Unidos e modelos atualizados de projeção de risco para a população norte-americana (BEIR VII) (BEIR, 2006), sugeriram que as cerca de 70 milhões de varreduras por TC realizadas nos EUA em 2007 podem resultar em aproximadamente 29.000 casos futuros de câncer, que representam aproximadamente 2% dos casos diagnosticados anualmente nos Estados Unidos

(BERRINGTON DE GONZALEZ et al., 2009). Miglioretti e colegas estimaram em 4.870 os casos futuros de câncer que poderiam ocorrer anualmente nos Estados Unidos em consequência dos exames de TC pediátrica feitos no país (MIGLIORETTI et al., 2013).

Uma avaliação das doses absorvidas e dos riscos de indução de câncer de tireoide em pacientes pediátricos submetidos a exames de TC típicos na região da cabeça e pescoço, em equipamentos com detectores múltiplos, sugeriu que a exposição da tireoide pela irradiação direta do pescoço resulta em um risco relativamente alto de indução de câncer nessa glândula, enquanto o risco associado à radiação espalhada decorrente de varreduras na cabeça é menor, embora não negligenciável (MAZONAKIS et al., 2007). Estudos com base nos modelos atualizados de projeção de risco para a população americana (BEIR, 2006) também avaliaram o risco de câncer de tireoide após exames de TC na infância (SCHONFELD et al., 2011). Foram estimados riscos em excesso para toda a vida de 35 e 6 casos por 10.000 exames de TC de tórax em pacientes com menos de um ano de idade para os sexos feminino e masculino, respectivamente. Para todos os exames avaliados, o risco diminui com o aumento da idade na época da exposição, sendo menor no sexo masculino do que feminino, como esperado, considerando que as taxas basais de incidência de câncer de tireoide são maiores em mulheres (SCHONFELD et al., 2011).

Evidências diretas de um aumento significativo do risco de câncer de tireoide em crianças expostas a doses de 100-200 mGy na tireoide foram obtidas recentemente (VEIGA et al., 2016). Considerando que exames de TC pediátricos podem resultar em doses de radiação na tireoide superiores a 50 mGy (HUDA et al., 2013), e que exames múltiplos no mesmo paciente não são raros (PEARCE et al., 2012a), existe um grande potencial de que pacientes pediátricos recebam doses na tireoide na faixa para qual existe risco aumentado de desenvolvimento de câncer de tireoide (SCHNEIDER et al., 2016).

Estudos epidemiológicos usando dados empíricos também mostraram aumento do risco subsequente de outros tipos de câncer após exposição à radiação em exames de TC na infância e juventude, principalmente câncer de cérebro e leucemia, que são os tipos de câncer mais comuns na infância (BERRINGTON DE GONZALEZ et al., 2016; HUANG et al., 2014; MATHEWS et al., 2013; PEARCE et al., 2012b). Crianças que receberam dose cumulativa de ao menos 50 mGy no cérebro tiveram um risco 2,8 vezes maior de desenvolver câncer nesse órgão (PEARCE et al., 2012b).

3.5. PROTEÇÃO RADIOLÓGICA EM MEDICINA

Embora os riscos individuais de indução de câncer após exposições médicas à radiação ionizante sejam pequenos, o grande e crescente número de indivíduos expostos, especialmente em exames de TC, traz preocupações sob o ponto de vista de saúde pública e demanda a implementação de medidas de proteção radiológica. Isso é particularmente importante quando se sabe que cerca de um terço dos pacientes fazem múltiplos exames (PEARCE et al., 2012a), o que pode resultar em doses cumulativas na faixa para a qual há considerável evidência epidemiológica direta de risco em excesso (PEARCE et al., 2012b; PRESTON et al., 2012; VEIGA et al., 2016).

Além disso, muitas exposições para fins diagnósticos não estão adequadamente justificadas (OIKARINEN et al., 2009; TAHVONEN et al., 2013). A justificação é um dos princípios básicos de proteção radiológica em medicina e estabelece que um exame que usa radiação ionizante para fins de diagnóstico só deve ser realizado quando seu benefício clínico for superior ao potencial risco associado. Para isso, deve ser avaliado se o exame é necessário e ainda, se não poderia ser substituído com igual eficácia por modalidades alternativas que não fazem uso de radiação ionizante (ICRP, 2007). A implementação de critérios de adequação para os exames de TC e o treinamento dos profissionais que indicam exames pode ser apontada como uma das estratégias estabelecidas para melhorar a justificação de exames que usam a radiação ionizante para fins de diagnóstico (MALONE et al., 2012). Isso é particularmente importante considerando o grande desconhecimento sobre as doses e riscos associados a exames que usam radiação ionizante para fins diagnósticos por parte dos profissionais que prescrevem esses exames, inclusive no Brasil (BORÉM et al., 2013; MADRIGANO et al., 2014).

Outro importante princípio de proteção radiológica é o da otimização, que estabelece que as doses em um procedimento devem ser tão baixas quanto razoavelmente exequível (*As Low As Reasonable Achievable* – ALARA)(ICRP, 2007). A falta de otimização em procedimentos de diagnóstico por imagem é indicada pela grande variação nas doses entregues aos pacientes em exames de TC, inclusive para um mesmo tipo de procedimento em pacientes da mesma idade (BERNIER et al., 2012; MIGLIORETTI et al., 2013; REHANI, 2014; TAKEI et al., 2016; TSUSHIMA et al., 2010; VERDUN et al., 2008). Isso sugere que enquanto em alguns exames a exposição pode não ser suficiente para produzir uma imagem adequada, em outros a dose pode ser muito maior do que a necessária. Para fins de otimização, é fundamental a implementação de protocolos apropriados para pacientes pediátricos. Entre os parâmetros técnicos que influenciam a dose, destacam-se a tensão do tubo (kVp), o produto tempo corrente (mAs), a colimação do feixe e o fator de passo (*pitch*) (KALRA et al., 2004). Ainda, é importante comparar as doses de um determinado procedimento com as doses do mesmo procedimento em outros serviços ou, preferencialmente, com níveis de referência locais ou nacionais (IAEA, 2004).

3.6. ASSISTÊNCIA À SAÚDE NO BRASIL

O Brasil é um país de dimensões continentais, com uma população de mais de 200 milhões de habitantes e grande variações regionais. Nos últimos anos houve grandes avanços na assistência à saúde no país, principalmente no Sistema Ùnico de Saúde (SUS) (PAIM et al., 2011; VICTORA et al., 2011).

A assistência à saúde no Brasil conta com um setor público e um setor privado. O setor público é SUS, um dos maiores sistemas provedores de saúde do mundo, fornecendo assistência integral, universal e gratuita à saúde a qualquer pessoa no país (PAIM et al., 2011). O setor privado é caracterizado pelo pagamento de serviços por planos e seguros de saúde, diretamente ou por reembolso (sistema de saúde suplementar) e, em escala bem menor, pelo pagamento direto de serviços ao prestador (PORTO et al., 2011). Apenas cerca de 25% da população brasileira possui cobertura por planos ou seguradoras de saúde (PAIM et al., 2011). Assim, a maioria absoluta dos atendimentos médicos, em todas as regiões do país, é feita pelo SUS (PORTO et al., 2011). Entretanto, existem desigualdades na oferta e utilização de serviços de saúde, sendo o gasto *per capita* com saúde maior no setor privado, onde há maior disponibilidade de recursos finaceiros e humanos (BRASIL, 2012; SANTOS et al., 2008; SZWARCWALD et al., 2010). Ainda, há grandes diferenças regionais no atendimento à saúde no país, com a região sudeste apresentando a maior oferta de serviços e a maior taxa de cobertura por planos de saúde no Brasil (PAIM et al., 2011; TRAVASSOS et al., 2000).

Alguns trabalhos avaliaram o acesso a procedimentos de diagnóstico por imagem (LIMA et al., 2014) e a disponibilidade de equipamentos para diagnóstico por imagem no Brasil (SANTOS et al., 2014). Entretanto, não há nenhum estudo avaliando a distribuição desses procedimentos por modalidade, parte do corpo examinada ou idade dos pacientes. Alguns trabalhos também estimaram doses em exames de tomografia no Brasil usando simuladores antropomórficos representando pacientes adultos (ANDRADE et al., 2012; GONZAGA et al., 2014; MECCA et al., 2012). Mais recentemente, um estudo avaliou indíces de dose em exames de TC pediátrica na cidade do Rio de Janeiro, mas foi usado um simulador pediátrico padrão, impossibilitando que variações no tamanho dos pacientes fossem coinsideradas (DE JESUS et al., 2016).

O SUS, através de seu Departamento de Informática (DATASUS), disponibiliza na rede mundial de computadores (Internet) uma série de informações sobre assistência à saúde, incluindo a quantidade de procedimentos de diagnóstico por imagem aprovados pelo SUS por modalidade, tipo de exame, sexo, idade e local de residência do paciente. Também estão disponíveis informações sobre recursos humanos e físicos na área de saúde, incluindo dados sobre os equipamentos de diagnótico por imagem existentes no país e disponíveis ao SUS. O DATASUS ainda fornece estatísticas vitais, epidemiológicas e de morbidade e informações demográficas e socio-econômicas do Brasil (BRASIL). Essas informações não estão disponíveis de forma sistematizada para o setor privado de saúde.

4. ESTRUTURA DA TESE

Esta tese está estruturada na forma de três artigos científicos. Os dois primeiros artigos abordam o padrão e tendência de uso de exames de diagnóstico por imagem e de exames de tomografia computadoriza (TC) em pacientes ambulatoriais do Sistema Único de Saúde (SUS). O terceiro artigo avalia o padrão e doses nos exames de TC em crianças e adultos jovens nos sistemas público e privado de saúde no Brasil.

Artigo 1: "**Patterns and trends in outpatient diagnostic imaging studies of the Brazilian public healthcare system, 2002-2012"**

Autores: Ana C M Dovales, Richard W Harbron, Andressa A de Souza, Luiz A R da Rosa, Amy Berrington de González, Mark S Pearce and Lene H S Veiga

Submetido: Radiation Protection Dosimetry

Esse artigo apresenta dados sobre o padrão e tendência de uso de procedimentos de diagnóstico por imagem em pacientes ambulatoriais do SUS no período de 2002 a 2012. Analisou-se a frequência de uso das diferentes modalidades e a distribuição dos procedimentos de acordo com a parte do corpo examinada para cada uma delas. O número de equipamentos de cada modalidade existentes no país e disponíveis para uso no SUS também foi avaliado. Mostrou-se que houve um intenso crescimento no uso da maioria das modalidades durante o período estudado, principalmente daquelas associadas a um alto custo e/ou que resultam em exposição elevada do paciente à radiação ionizante, como TC e ressonância magnética nuclear. Embora esse aumento possa estar associado a melhores condições de saúde da população, o uso excessivo dessas modalidades não pode ser descartado. Em particular, o crescente uso de varreduras por TC gera preocupação sobre os potenciais riscos de indução de câncer associado a esses exames, principalmente em crianças e jovens.

Artigo 2: "Patterns and trends of computed tomography usage in outpatients of the Brazilian public healthcare system, 2001-2011"

Autores: Ana C M Dovales, Luiz A R da Rosa, Ausrele Kesminiene, Mark S Pearce and Lene H S Veiga

Publicado: Journal of Radiological Protection 36:547-560, 2016

Esse artigo apresenta dados sobre o padrão e tendência de uso de exames de TC em pacientes ambulatoriais do SUS no período de 2001 a 2011. Analisou-se a frequência e distribuição dos procedimentos de acordo com a parte do corpo examinada e idade do paciente e o número de equipamentos de TC existentes no país e disponíveis para uso no SUS, nas diferentes regiões geográficas do Brasil. Mostrou-se que há grande variação regional no uso da TC no país. Durante o período estudado, a frequência dos exames mais que triplicou, e continua crescendo. Os exames mais comuns foram os de cabeça/pescoço, mas varreduras do abdome e pelve foram as que apresentaram maiores taxas de crescimento no período estudado. Aproximadamente 13% dos exames foram feitos em pacientes com até 20 anos de idade, uma proporção alta quando comparada com a de outros países. Esses resultados indicam a necessidade de iniciativas para quantificar o risco-benefício associado a esses procedimentos, incluindo a determinação das doses recebidas pelos pacientes.

Artigo 3: "Pediatric and young adult CT scans in Brazil: Pattern of use and patient doses, 2008-2014"

Autores: Ana C M Dovales, Tainá Olivieri, Paulo Roberto Valle Bahia, Marcela Brisighelli Schaefer, Bruna Boaventura Failla, Lisa Susuki, Marcelo Valente, Vinicíus de Araújo Gomes, Luiz A R da Rosa, Andreas Jahnen, Choonsik Lee, Amy Berrington de Gonzalez, Ausrele Kesminiene, Mark S Pearce and Lene H S Veiga

A ser submetido a publicação

Esse artigo apresenta dados sobre o padrão e tendência de uso de exames de TC em pacientes com até 20 anos de idade no Brasil, no período entre 2008 e 2014. A frequência e a distribuição dos exames por idade e parte do corpo examinada foram avaliadas no SUS e no setor privado de saúde. O uso de procedimentos de TC em crianças e adultos jovens aumentou consideravelmente nos dois sistemas de assistência à saúde ao longo do período de estudo, sendo o crescimento maior no SUS do que no setor privado. Cerca de um terço dos pacientes do setor privado foi submetido a mais de um exame ao longo do período de estudo. As doses efetivas e absorvidas nos órgãos de interesse foram individualmente estimadas para um grande número de pacientes. Observamos grande variação nas doses estimadas para pacientes da mesma faixa etária, realizando o mesmo tipo de procedimento, o que indica a necessidade de otimização dos protocolos. As doses absorvidas mais altas foram no cérebro como resultado de exames da cabeça/pescoço, que é o tipo de exame mais comum em pacientes pediátricos e adultos jovens. Esses resultados sugerem a necessidade de esforços para aprimorar a proteção radiológica em TC no Brasil, incluindo a disseminação de critérios de adequação para exames e a otimização de protocolos pediátricos, incluindo o estabelecimento de níveis de referência e programas de garantia de qualidade. Ainda, é fundamental a educação e treinamento dos profissionais que indicam e realizam exames radiológicos.

5. ARTIGO 1

Patterns and trends in outpatient diagnostic imaging studies of the Brazilian public healthcare system, 2002-2012

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Abstract

The increasing growth of diagnostic imaging use is usually associated with improved healthcare. However, the rising costs of imaging technologies and radiation concerns associated with some diagnostic imaging practices, such as computed tomography, have slowed down the growth in advanced imaging utilization in some developed countries in recent years. The patterns and trends of diagnostic imaging use are relatively well documented in developed countries, but relatively little is known for developing countries, including Brazil. We evaluated the use of diagnostic imaging procedures among outpatients of the public healthcare system in Brazil (SUS), which is the unique healthcare provider to about 75% of the Brazilian population. We collected the annual number of procedures and the number of machines in use and available to SUS for each diagnostic imaging modality: radiography, fluoroscopy, dental radiology, mammography, bone densitometry, computed tomography, nuclear medicine, magnetic resonance imaging, and ultrasound, for the period 2002-2012. The use of most diagnostic imaging practices increased in Brazil over the study period. Radiographic examinations accounted for around two-thirds of all imaging procedures performed in the Brazilian public health system, but did not present a substantial increase over the study period (1.5- fold). Advanced diagnostic imaging methods, such as CT and MRI represented a relatively small proportion of the examinations (3.4% and 0.8%, respectively), but greatly increased over the study period (3- and 6- fold, respectively). The increasing number of diagnostic imaging machines available to SUS for most modalities might have had a great contribution to the overall increase in imaging diagnostic procedures over time. The use of diagnostic imaging in the public health care system in Brazil was still much lower than in developed countries, but it steeply increased over the last decade, which raises concern regarding pediatric CT use and its potential radiation-related risk.

Running title: Diagnostic imaging patterns and trends in Brazil

Key words: Diagnostic imaging, patterns, trends, Brazil

Submitted to:

1. Introduction

The use of diagnostic imaging has increased, worldwide, over the last two decades (1-5). This has contributed to improved health care, allowing for earlier and more accurate diagnosis and follow up of a variety of diseases. However, there are concerns with the rising costs of imaging technologies (3, 6, 7). Furthermore, increasing use of diagnostic imaging techniques using relatively high doses of ionizing radiation, such as computed tomography (CT), raises concerns about the associated subsequent risk of cancer induction, mainly among children (8-11).

The trends and patterns of distribution of examinations by imaging modality and imaged anatomical region differs significantly among countries, even for different healthcare systems within the same country (1, 2, 4, 5). Most information comes from developed countries, and very little is known about the patterns and trends of diagnostic imaging procedures in developing countries (1, 2).

Brazil is one of the five largest countries in the world, with a population of around 200 million people. The Brazilian healthcare system is made up of both private and government funded subsystems. The public subsystem, the Unified Health System (Sistema Único de Saúde, SUS), is a free universal coverage system that is one of the largest healthcare providers in the world (12). SUS plays an important role in Brazil, as about 75% of the Brazilian population depends only on SUS to receive any healthcare (13), although this percentage varies geographically

The aim of this study was to evaluate the patterns and trends of diagnostic imaging among outpatients of the public healthcare system in Brazil for the period of 2002 to 2012.

2. Methods

Data were obtained from the System of Health Information (Sistema de Informações de Saúde, TABNET) of the Information Technology Department (DATASUS) of SUS (14), which provides online information regarding health assistance in SUS, availability of human and physical resources in health, and demographic and socio-economic data for Brazil. Data on diagnostic imaging examinations among outpatients using SUS were collected from the Outpatient Information System (Sistema de Informações Ambulatoriais do SUS, SIA/SUS) (15), which is part of the System of Health Information and contains information about outpatient medical procedures performed in public, charity and private medical services funded by SUS. We extracted annual numbers of diagnostic imaging procedures, by imaging modality and type of examination, for all of Brazil between 2002 and 2012.

Diagnostic procedures were grouped by imaging modality (general radiography, fluoroscopy, dental radiology, mammography, bone densitometry, CT, nuclear medicine, magnetic resonance imaging - MRI, and ultrasound). Data were also analysed by the imaged body region (head, abdomen/pelvis, spine, chest and extremities). When not stated otherwise, “Head” also includes neck and “Extremities” include joints. In a number of situations, grouping was done for other body parts (urinary tract, digestive tract, heart, thyroid, eyes and breast) or more specific type of examination (histerosalpingography, artrography, angiography, obstetric, gynaecological). Information on other imaging modalities, such as PET-CT, angio-CT, angio-MRI and others, were not listed in DATASUS databases and therefore were not included in this study. Imaging procedures for therapeutic purposes were not included.

We also extracted data on the total number of diagnostic imaging machines in use in the country (from private, public and philanthropic institutions), and the number of machines available to SUS patients for 2002 and 2012. This information comes from the National Register of Health Institutions (Cadastro Nacional de Estabelecimentos de Saúde, CNES) (16, 17), and is available from the System of Health Informations website (14). Diagnostic machines available to SUS include most of those located in the public hospitals and clinics, as well as machines located in private and philanthropic institutions providing SUS assistance. Machines for fluoroscopy include machines for hemodynamic examinations.

Demographic data from the Brazilian Vital Statistics System (Instituto Brasileiro de Geografia e Estatística, IBGE) (18) and the proportion of people with private health insurance coverage in Brazil from the National Agency of Supplementary Health (Agência Nacional de Saúde Suplementar, ANS) (13) were also retrieved from the System of Health Information website (14).

The SUS dependent population was estimated as the proportion of the uninsured Brazilian population (not covered by private health insurance) for each year of the study. The number of examinations per million dependent on SUS was calculated using the annual number of outpatient procedures in SUS and the respective SUS dependent population. For mammography and breast, gynaeological and obstetric examinations by ultrasound we considered only the female SUS dependent population.

The number of machines in use, per million people, and the number of machines available to SUS per million SUS dependent population, were calculated using the respective number of machines and population figures, for each year.

Average compound annual growth rates (CAGR) were calculated by using equation (1), below, where $\mathrm{N}_{\mathrm{t}_0}$ and $\mathrm{N}_{\mathrm{t}_1}$ represent the number of procedures in the first and in the last year of the time period, respectively, and t_0 and t_1 represent the first and the last years of the corresponding time period, respectively.

$$CAGR\ (t_0, t_1) = \left[\left(N_{t_1}/N_{t_0}\right)^{1/(t_1 - t_0)}\right] - 1 \qquad (1)$$

3. Results

The SUS dependent population underwent almost 700 million outpatient diagnostic imaging procedures between 2002 and 2012. General radiographs were the most frequently performed examination, followed by ultrasound, mammography, dental x-rays and CT (Table 1). Other modalities each represented less than 1.0% of procedures. During the study period, there was an upward trend in the overall use of most types of diagnostic imaging, except for fluoroscopy (Table 1, Figure 1). The greatest rise was for MRI, which increased almost six-fold (CAGR = 19.5%), followed by bone densitometry, CT and mammography. Table 2 shows the distribution of diagnostic procedures among SUS outpatients by body part in 2002 and 2012. A positive annual growth rate was seen for all forms of general radiography, although for head examinations this increase was relatively modest, at 0.6%. Positive growth rates were also observed for CT and MRI for all body parts, especially abdominal/pelvic scans. Head scans were the most frequent CT examination, although the relative increase throughout the study period was lower than for other body parts. The increasing use of nuclear medicine for diagnosis purposes (4.7% per year) was mainly driven by the increasing use of cardiac scintigraphy and musculoskeletal examinations (9.1 and 3.7% per year, respectively). While obstetric ultrasound use remained relatively stable between 2002 and 2012, a shift from gynaecological pelvic ultrasound (CAGR = -10.9%) to transvaginal gynaecological ultrasound (+11.2%) was seen. Large relative increases in rates of orbital and extremity ultrasound were observed (CAGR of 27.5 and 27.7%, respectively), although these examinations remained uncommon. There was a decrease in most fluoroscopy examinations, except for angiography.

The total number of all diagnostic imaging machines in use in Brazil in 2002 and 2012 were 259.2 and 545.6 machines per million population, respectively. Nevertheless, only about half of these machines were available to SUS with 137.9 and 225.8 machines per million SUS-dependent population in 2002 and 2012, respectively (Table 3). During the study period, dental x-ray and ultrasound machines replaced general radiography machines as the most common imaging equipment in Brazil as a whole, although availability of all equipment increased. When analysis was restricted to machines available to SUS, the availability of most machines increased approximately two-fold between 2002 and 2012, while the number of general radiography, fluroscopy and nuclear medicine units was stable or decreased slightly. The number of procedures per machine available to SUS also increased over the study period for conventional radiography (CAGR = +4.3%), nuclear medicine (+5.2%), CT (+4.3%), MRI (+4.2%) and bone densitometry (+2.9%), but decreased for fluoroscopic, dental and ultrasound examinations (CAGR = -3.5%, -5.1% and -3.4%, respectively).

4. Discussion

In this study, we have evaluated the patterns and trends of outpatient diagnostic imaging studies performed between 2002 and 2012 in the Brazilian public healthcare system (SUS). The number of examinations increased over this period, by a factor ranging from 1.5 to 6, for all modalities except fluoroscopy. Part of this increase can be explained by the greater availability of imaging equipment to SUS, along with an increase in the number of procedures per machine, for most modalities. The distribution of diagnostic imaging procedures by body imaged region varied according to imaging modality, with an accentuated annual growth of head CT, extremities X-rays, cardiac scintigraphy, abdomen/pelvis MRI and ultrasound of the eyes.

Growth rates for most diagnostic imaging modalities in SUS outpatients were similar to or even higher than those reported for developed countries during similar periods. Use of CT and MRI in outpatients in the United States increased by around 15% per year between 2000 and 2005, when there was a levelling in the use of these imaging modalities (3). In patients enrolled in large integrated health care systems in the United States CT and MRI examinations increased annually by 7.8% and 10%, respectively, between 1996 and 2010 (4). In the same period, the growth rates for radiography (including breast imaging) and ultrasound were 1.2% and 3.9%, respectively, while the use of nuclear medicine decreased (-3% per year) (4). Interestingly, while the growth in CT and MRI usage in the United States tended to level off or even decline around 2005-2010 (3, 4, 19, 20), the use of these imaging modalities seemed to remain on an upward trend in Brazil. The rise in the use of diagnostic imaging was also higher for SUS outpatients than in England, where between 2000-2001 and 2012-2013, the annual growth rates for MRI, CT, radiography, ultrasound and nuclear medicine were around 11.9%, 10.1%, 1.1%, 4.7% and 0.9%, respectively (5). In contrast, the drop in fluoroscopy use was steeper among SUS outpatients in Brazil (-3.6% per year) than in the United States (-1.3% per year) (4) and England, where the use of this imaging modality remained relatively stable over time (0.4% per year) (5). Mammography also increased more among SUS outpatients (8.5% per year) than in patients of a large integrated health system in the United States (5% per year, between 1997 and 2006) (7).

The use of diagnostic imaging varies significantly between countries, including between countries of the same health-care level or even for different healthcare systems within the same country (1-5). A comparison of the annual number of examination for selected diagnostic imaging procedures per thousand population in Brazil (this study), United States (4) and England (5, 21) is presented in table 4. Differences were more striking for CT, MRI, nuclear medicine and fluoroscopy, for which usage rates in the United States in 2008 were around 9-, 15-, 20- and 53-fold higher, respectively, than the corresponding figures in SUS oupatients in Brazil in 2012. In comparison with England, differences in usage rates were smaller than for the United States, but still high. Usage rates for CT, MRI, nuclear medicine and fluoroscopy in England in 2012 were 4.5-, 9.6-, 4.1- and 21-fold higher, respectively, than those observed in SUS outpatients for the same period. Therefore, despite the great increase in the usage of diagnostic medical imaging in the Brazilian public healthcare system over the last decade, the absolute number of diagnostic imaging procedures per thousand population was still low, compared to developed countries.

Many of the observed imaging diagnostic patterns can be explained by technological factors. These include the replacement of general radiography for head imaging by CT and MRI (22-24), the use of CT and ultrasound for imaging of kidney stones (24), the introduction of faster MRI scan times (25) allowing imaging of the chest and abdomen (26), the replacement of barium enemas with CT colonography, and the increased dopler ultrasound capabilities (27-29). Ultrasound has become the preferred modality for investigating thyroid nodules and for fine needle aspiration cytology guidance (24), which may explain the apparent shift from nuclear medicine to ultrasound for thyroid imaging. Indeed, the pattern of increasing thyroid cancer incidence in Brazil (30, 31) might be partially explained by these imaging trends. Obstetric ultrasound use remained relatively stable over the study period, which was unsurprising since birth rates decreased in Brazil between 2002 and 2012 (19.7 and 15.1 per 1,000, respectively) (32).

A number of other factors may have contributed to the changing patterns of diagnostic imaging use among SUS outpatients, including changing demographic and socio-economic status, access to health care, demand for examinations by patients and physicians and financial incentives for selected tests. The relatively low availability of machines to the Brazilian public health system may explain the relatively low use of diagnostic imaging in SUS. Yet the number of all CT scanners in use, per million, in Brazil in 2012 (15.8) was comparable to figures estimated by the OECD (33) for some developed countries in 2011 (15.4 for New Zealand, 15.7 for Ireland and 17.3 for Spain) and even higher than for others countries (8.9 for the United Kingdom, 12.5 for France and 14.6 for Canada). The scenario was similar for MRI, for which the number of all machines per million in Brazil in 2012 (6.9) was similar to the number in France (7.5), and higher than the number in the United Kingdom (5.9) and Australia (5.7) in 2011 (33). However, only about half of these machines were available to SUS in 2012 (62% and 50% of the CT and MRI scanners, respectively). Furthermore, some of the machines available to SUS were located in private hospitals, with limited access for SUS outpatients. A reduced number of SUS examinations performed using these shared machines might be expected, as compared to machines fully dedicated to SUS patients.

The increasing number of imaging procedures in the SUS dependent population was accompanied by increased availability of the respective machines and/or higher rates of examinations per machine. For CT, the number of scanners available to SUS per million dependent on SUS increased twofold between 2002 and 2012 and was accompanied by a 1.5-fold increase in the number of procedures per scanner. The availability to SUS and the rate of examinations per machine also greatly increased over the study period for MRI (3.9- and 1.5-fold, respectively). The number of procedures per CT or MRI scanner in SUS, was lower than many developed countries, however. This may be explained by the low non-public machine usage rate. While in the United Kingdom and the United States in 2011 there were 8,708 and 6,694 exams per CT scanner, respectively, and 7,017 and 3,260 examinations per MRI unit, respectively (33), the number of exams per machine available to SUS was only 1,974 and 1,374 exams per CT or MRI scanner, respectively, in 2012. Although we are unable to identify manufacturers and models of imaging machines or imaging protocols used in SUS, it is probable that more modern equipment and techniques were introduced later in Brazil. This may also have contributed to the relatively low number of CT and MRI examinations per machine, in SUS.

Conversely, the increase in the number of radiographic and nuclear medicine examinations in SUS outpatients over time cannot be accounted for by a rise in the number of machines available to SUS, since the number of both X-ray generators and gamma cameras for nuclear medicine was almost unchanged between 2002 and 2012. However, the number of examinations per machine increased over the study period by 1.5- and 1.7-fold, for radiography and nuclear medicine, respectively. Potential reasons for this include the introduction of digital detectors in general radiography, and dual-headed gamma cameras in nuclear medicine, both of which are associated with reduced imaging times (34).

For ultrasound, the number of machines available to SUS per million dependents more than doubled over the study period, whereas the number of ultrasound examinations per machine dropped by a factor of 0.7 between 2002 and 2012. As ultrasound examinations are highly operator dependent, it may be suggested that at least part of this decrease was a result of the increasing availability of ultrasound units without a corresponding growth in the number of machine operators.

Demographic changes over the study period may have also contributed to the increasing rates of diagnostic imaging use among SUS outpatients, as usage of diagnostic imaging tends to increase with age (4, 35). In Brazil, population aging has occurred rapidly as shown by the fall in birth rate from 19.7 to 15.3 births per 1,000 habitants in 2002 and 2012, respectively (32), and the increased life expectancy at birth, which increased from 70.7 to 74.5 years in the same period (36). Also, many economic and human development indicators have improved over recent decades in Brazil, including decreasing of the Gini coefficient for income concentration (37) and increasing gross domestic product per head and adult literacy. Importantly, access to healthcare has increased, but is still very unequal and lagged behind that in developed countries (37). These improvements were accompanied by a shift in the main health problems of the Brazilian population. While infectious diseases and injuries related to violence were still an important health problem, there were decreases in the rates in chronic non-communicable diseases, mainly cardiovascular and chronic respiratory diseases. Conversely, hypertension, obesity and diabetes have risen (37-40). All these changes may have affected the patterns and trends of diagnostic examinations in SUS.

The increasing use of diagnostic imaging, especially MRI and CT, raises some concerns regarding the increasing cost of healthcare services and, for CT, increased ionizing radiation exposure. There are reports of misuse and overuse of imaging procedures (41-43), and it is uncertain to what extent the rise in diagnostic imaging usage over the last decade contributed to improved health status (44). Advanced diagnostic imaging, such as MRI and CT were the most rapidly growing of all medical services in the North-American Medicare population between 2000 and 2006, and had a significative impact on the increasing cost of healthcare (3, 6, 7). Additionally, there is direct epidemiological evidence linking CT scans in childhood to subsequent increased cancer risk (10, 11). This is particularly important considering a recent publication which reported a relatively high proportion of CT procedures in children and young adults among SUS outpatients in Brazil (about 13%) (45).

In developed countries, radiation concerns have led to initiatives aiming to increase awareness about potential CT doses and risks, such as the Image Wisely (46) and Image Gently (47) campaigns of the American College of Radiologists. These campaigns concentrated efforts to avoid inappropriate use and to promote the most efficient and cost-effective use of diagnostic imaging services. This includes the development of guidelines and appropriateness criteria (24, 48), and the introduction of constraints to the payment of advanced imaging studies (19). As a result, there has been a reduction in the usage of advanced imaging in the United States (3, 4, 19, 20). To our knowledge, there have been no such campaigns in Brazil. The use of newer and more expensive technologies, such as CT and MRI, greatly increased in SUS, without a corresponding decrease in use of older and cheaper modalities. This is a typical pattern when new imaging technologies are introduced, as previously reported (7, 49).

Strengths of our study include using data from a public health care system, which covers about 75% of Brazilian population and is one of the largest public healthcare system in the world. Also, the DATASUS database, from which most of the information was extracted, is considered a complete and comprehensive automated information system of relatively good quality (50). Furthermore, this is the first study, to our knowledge, to document the patterns of diagnostic imaging over time and across different modalities in a developing country. Limitations of our study include the restriction of data to outpatients of the public healthcare system, which may be not representative of the patterns and trends for all Brazil. In particular, diagnostic imaging usage may greatly differ between outpatients from SUS and the private setting. Financial incentives and greater expenditures per capita might encourage increasing imaging in the private setting (7, 51).

5. Conclusion

In conclusion, this is the first study to present extensive data on the patterns and trends of diagnostic imaging usage in Brazil. The use of diagnostic imaging increased dramatically in Brazil over the study period, mainly for those modalities associated with high costs or high radiation doses (i.e. MRI and CT, respectively). Although several factors might have contributed to this increase, including wider availability of these modalities to the public health care system, the overuse of these imaging procedures can not be ruled out. The increasing use of CT in Brazil raises concerns regarding the potential radiation-related risks. A proper assessment of the corresponding benefits is required in order to develop imaging guidelines in Brazil. This is particularly important in developing countries where population ageing is taking place, increasing the demand for medical services in a set of limited healthcare resources.

Table 1. Number and proportion (%) of diagnostic imaging procedures among outpatients of the Brazilian public healthcare system per 1,000 SUS dependent population[a], by modality, by year, in 2002 and 2012.

Year		Imaging modality								
		Radiography	Fluoroscopy	Dental radiology	Mammography[b]	Bone densitometry	CT	Nuclear medicine	MRI	Ultrasound
2002	**N**	235.4	1.7	14.6	26.0	0.8	6.3	1.7	0.8	58.6
	(%)	(68.1)	(0.5)	(4.2)	(7.5)	(0.2)	(1.8)	(0.5)	(0.2)	(16.9)
2012	**N**	365.0	1.2	20.4	58.9	2.8	19.4	2.7	4.8	96.7
	(%)	(63.8)	(0.2)	(3.6)	(10.3)	(0.5)	(3.4)	(0.5)	(0.8)	(16.9)
CAGR[c]	**%**	**+4.5**	**- 3.6**	**+3.4**	**+8.5**	**+13.3**	**+11.9**	**+4.7**	**+19.5**	**+5.1**

Abreviattions: CT-computed tomography, MRI-magnetic resonance imaging.

[a]SUS dependent population is the proportion of the Brazilian population that depends exclusively on SUS to healthcare (82.0% in 2002 and 74.9% in 2012).

[b]Mammography rates were calculated among women.

[c]CAGR: Compound Annual Growth Rate was given by the equation $CAGR\ (t_0, t_1) = \left[\left(N_{t_1}/N_{t_0}\right)^{1/(t_1-t_0)}\right] - 1$, where N_{t0} and N_{t1} were respectively the number of procedures in the first and in the last year of the time period, and t_0 and t_1 were respectively the first and the last year of the corresponding time period. CAGR is given as a percentage of increase (+) or decrease (-).

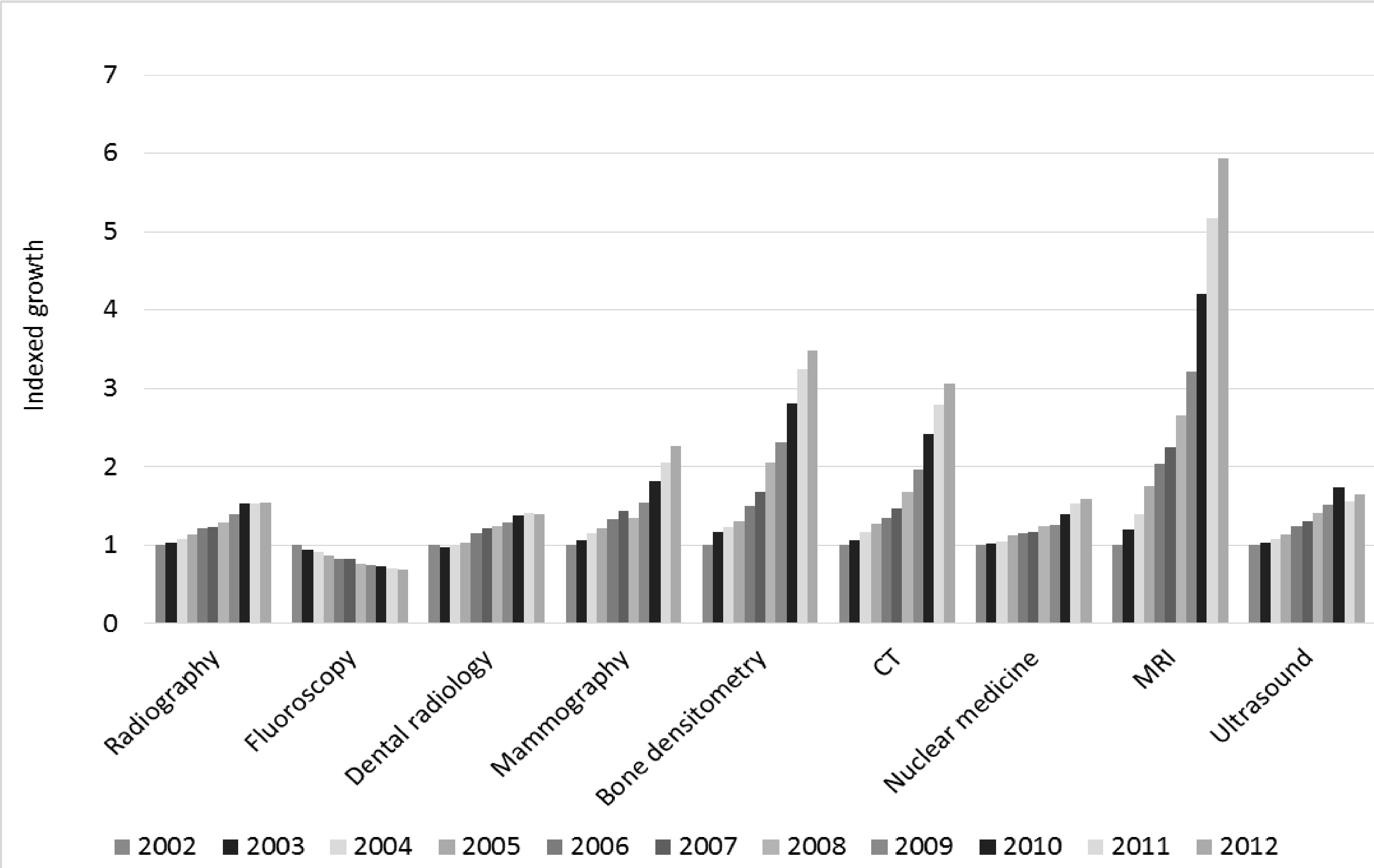

Figure 1. Indexed growth rate of diagnostic imaging procedures in outpatients of the Brazilian public healthcare system per 1,000 SUS dependent population, relative to the number of procedures in 2002, by modality, by year. SUS dependent population is the proportion of the Brazilian population that depends exclusively on SUS to healthcare (82.0% in 2002 and 74.9% in 2012). Mammography rates were calculated among women. CT: computed tomography, MRI: magnetic resonance imaging.

Table 2. Number and proportion (%) of diagnostic imaging procedures in outpatients of the Brazilian public healthcare system per 1,000 SUS dependent population[a], by imaged body region, by modality, by year, 2002 and 2012.

Examination	2002		2012		CAGR (%)
	N	(%)	N	(%)	
Radiography					
Chest	77.8	(33.0)	114.6	(31.4)	3.9%
Extremities	60.8	(25.8)	113.0	(30.9)	6.4%
Head	35.1	(14.9)	37.2	(10.2)	0.6%
Spine	26.2	(11.1)	42.6	(11.7)	5.0%
Abdomen/pelvis	15.7	(6.7)	24.3	(6.7)	4.4%
Other	19.8	(8.4)	33.5	(9.2)	5.4%
Fluoroscopy					
Digestive tract	0.7	(39.2)	0.3	(23.8)	-8.3%
Urinary tract	0.5	(26.6)	0.3	(28.0)	-3.1%
Histerosalpingography	0.2	(11.0)	0.1	(11.6)	-3.1%
Artrography	0.0	(2.8)	0.0	(2.4)	-5.3%
Angiography	0.3	(17.0)	0.4	(31.7)	2.6%
Other	0.1	(3.3)	0.0	(2.5)	-6.2%
CT					
Head	3.8	(59.7)	8.9	(45.8)	8.9%
Abdomen/pelvis	0.9	(14.2)	5.2	(27.1)	19.3%
Spine	0.9	(13.9)	2.4	(12.2)	10.4%
Chest	0.6	(9.9)	2.4	(12.4)	14.4%
Extremities	0.1	(2.3)	0.5	(2.6)	13.2%
Nuclear medicine					
Heart	0.6	(36.8)	1.5	(55.2)	9.1%
Musculoskeletal	0.5	(31.0)	0.8	(28.2)	3.7%
Urinary tract	0.2	(14.0)	0.2	(9.0)	0.2%
Thyroid	0.2	(9.6)	0.1	(3.5)	-5.4%
Other	0.1	(8.5)	0.1	(4.1)	-2.6%
MRI					
Head	0.3	(37.3)	1.3	(26.6)	15.5%
Spine	0.3	(34.6)	1.8	(37.2)	20.4%
Extremities	0.2	(20.6)	1.2	(25.6)	22.1%
Abdomen/pelvis	0.0	(6.1)	0.5	(9.5)	25.0%
Chest	0.0	(1.5)	0.1	(1.1)	16.4%
Ultrasound					
Obstetric[b]	26.8	(45.8)	27.7	(28.7)	0.3%
Gynaecological (pelvic)[b]	24.8	(42.4)	7.8	(8.1)	-10.9%
Gynaecological (transvaginal)[b]	13.4	(22.8)	38.5	(39.9)	11.2%
Abdomen/pelvis	13.2	(22.6)	21.9	(22.6)	5.1%
Eyes	0.4	(0.7)	4.6	(4.8)	27.5%
Extremities	0.9	(1.6)	10.9	(11.2)	27.7%
Heart	4.3	(7.4)	7.7	(7.9)	5.9%
Breast[e]	6.6	(11.3)	13.6	(14.0)	7.4%
Thyroid	0.8	(1.3)	2.7	(2.8)	13.1%
Other	2.5	(4.3)	4.3	(4.4)	5.4%

Abreviattions: CT-computed tomography, MRI-magnetic resonance imaging.

[a]SUS dependent population is the proportion of the Brazilian population that depends exclusively on SUS to healthcare (82.0% in 2002 and 74.9% in 2012).

[b]Obstetric, gynaecological and breast rates for ultrasound were calculated among women.

Table 3. Rates of in use diagnostic imaging machines per million Brazilian populations, of machines available to SUS per million dependent on SUS, and of procedures per each machine available to SUS, by modality, by year, 2002 and 2012.

Year		Imaging Modality								
		Radiography	Fluoroscopy	Dental radiology	Mammography	Bone densitometry	CT	Nuclear Medicine	MRI	Ultrasound
		Machines/million people[a]								
2002	**N**	94.2	9.2	38.7	28.2	5.3	9.3	3.9	2.5	67.9
2012	**N**	107.9	10.9	206.1	43.9	8.8	15.8	4.2	6.9	141.1
CAGR[c]	**(%)**	+1.4%	+1.7%	+18.2%	+4.5%	+5.1%	+5.5%	+0.9%	+10.8%	+7.6%
		Machines available to SUS/million SUS dependent population[b]								
2002	**N**	63.6	5.9	17.7	11.8	1.3	4.9	2.3	0.9	29.5
2012	**N**	64.5	5.8	41.8	25.6	3.5	9.8	2.2	3.5	69.1
CAGR[c]	**(%)**	+0.1%	-0.1%	+9.0%	+8.0%	+10.1%	+7.2%	-0.5%	+14.7%	+8.9%
		Procedures per machine available to SUS								
2002	**N**	3,702	293	827	2,193	612	1,292	714	911	1,984
2012	**N**	5,662	205	488	2,310	817	1,974	1,189	1,374	1,400
CAGR[c]	**%**	+4.3	-3.5	-5.1	+0.5	+2.9	+4.3	+5.2	+4.2	-3.4

Abreviattions: CT-computed tomography, MRI-magnetic resonance imaging.

[a]The rate of machines per million in Brazil was calculated considering the number of diagnostic machine in use for each imaging modality and the respective Brazilian population for each year.

[b]The rate of machines available to SUS per million dependent on SUS was calculated considering the number of diagnostic machines for each imaging modality available to SUS and the SUS dependent population in each year (82.0% in 2002 and 74.9% in 2012). For mammography only the female population was considered.

[c]CAGR: Compound Annual Growth Rate was given by the equation $CAGR\ (t_0, t_1) = \left[\left(N_{t_1}/N_{t_0}\right)^{1/(t_1-t_0)}\right] - 1$, where N_{t0} and N_{t1} were respectively the number of procedures in the first and in the last year of the time period, and t_0 and t_1 were respectively the first and the last year of the corresponding time period. CAGR is given as a percentage of increase (+) or decrease (-).

Table 4. Usage rates of diagnostic imaging examinations per thousand population in Brazil,the United States and England.

Procedures	Number of examinations/1,000		
	Brazil, 2012[a]	USA, 2008[b]	England, 2012[c]
Radiography	365	783	423
Ultrasound	97	271	174
Nuclear Medicine	3	53	11
Angiography/fluoroscopy	1	64	25
Computed Tomography	19	177	88
Magnetic Resonance Imaging	5	72	46

[a] This study – Rounded values for usage rates per thousand SUS-dependent population

[b] Data are from reference 4. Usage rates were standardized by sex and age. Radiography also includes mammography.

[c] Data are from references 5 and 21. Usage rates were estimated by dividing the annual number of examinations by the resident population for the same year.

References

1. UNSCEAR. Sources and Effects of Ionizing Radiation. Vol I, Annex A: Medical radiation exposures. New York, NY: United Nations Scientific Committee on the Effects of Atomic Radiation, 2010.

2. Mettler FA, Jr., Bhargavan M, Faulkner K, Gilley DB, Gray JE, Ibbott GS, et al. Radiologic and nuclear medicine studies in the United States and worldwide: frequency, radiation dose, and comparison with other radiation sources--1950-2007. Radiology. 2009;253(2):520-31.

3. Lang K, Huang H, Lee DW, Federico V, Menzin J. National trends in advanced outpatient diagnostic imaging utilization: an analysis of the medical expenditure panel survey, 2000-2009. BMC Medical Imaging. 2013;13:40.

4. Smith-Bindman R, Miglioretti DL, Johnson E, Lee C, Feigelson HS, Flynn M, et al. Use of diagnostic imaging studies and associated radiation exposure for patients enrolled in large integrated health care systems, 1996-2010. JAMA : The Journal of the American Medical Association. 2012;307(22):2400-9.

5. NHS. Total number of imaging and radiodiagnostic examinations or tests, by imaging modality, England, 1995-96 to 2012-13. England: National Health Services, 2013.

6. Iglehart JK. Health insurers and medical-imaging policy--a work in progress. The New England Journal of Medicine. 2009;360(10):1030-7.

7. Smith-Bindman R, Miglioretti DL, Larson EB. Rising use of diagnostic medical imaging in a large integrated health system. Health Affairs. 2008;27(6):1491-502.

8. Brenner DJ, Hall EJ. Computed tomography--an increasing source of radiation exposure. The New England Journal of Medicine. 2007;357(22):2277-84.

9. Miglioretti DL, Johnson E, Williams A, Greenlee RT, Weinmann S, Solberg LI, et al. The use of computed tomography in pediatrics and the associated radiation exposure and estimated cancer risk. JAMA Pediatrics. 2013;167(8):700-7.

10. Pearce MS, Salotti JA, Little MP, McHugh K, Lee C, Kim KP, et al. Radiation exposure from CT scans in childhood and subsequent risk of leukaemia and brain tumours: a retrospective cohort study. Lancet. 2012;380(9840):499-505.

11. Berrington de Gonzalez A, Salotti JA, McHugh K, Little MP, Harbron RW, Lee C, et al. Relationship between paediatric CT scans and subsequent risk of leukaemia and brain tumours: assessment of the impact of underlying conditions. British Journal of Cancer. 2016;114(4):388-94.

12. Paim J, Travassos C, Almeida C, Bahia L, Macinko J. The Brazilian health system: history, advances, and challenges. Lancet. 2011;377(9779):1778-97.

13. BRASIL. Informações de Saúde (TABNET). Indicadores de Saúde e Pactuações. Indicadores e Dados Básicos (IDB) - Brasil - 2012. IDB-2012. Indicadores de cobertura. Proporção da população coberta por planos privados de saúde - ANS:

DATASUS/SUS/Ministério da Saúde; [updated 22/10/2015]. Available from: http://tabnet.datasus.gov.br/cgi/deftohtm.exe?idb2012/f16.def.

14. BRASIL. Informações de Saúde (TABNET): DATASUS/SUS/Ministério da Saúde; [updated 22/10/2015]. Available from: http://datasus.saude.gov.br/informacoes-de-saude/tabnet.

15. BRASIL. Informações de Saúde (TABNET). Assistência à Saúde. Produção ambulatorial do SUS por local de residência, a partir de 2008: DATASUS/SUS/Ministério da Saúde [updated 22/10/2015]. Available from: http://tabnet.datasus.gov.br/cgi/deftohtm.exe?sia/cnv/qbuf.def.

16. BRASIL. Informações de Saúde (TABNET). Rede Assistencial. Pesquisa Assistência Médico Sanitária. AMS 2002. Equipamentos dos estabelecimentos, Brasil: DATASUS/SUS/Ministério da Saúde; [updated 22/10/2015]. Available from: http://tabnet.datasus.gov.br/cgi/tabcgi.exe?ams/cnv/namsebr.def.

17. BRASIL. Informações de Saúde (TABNET). Rede Assistencial. CNES - Recursos Físicos - Equipamentos, Brasil: DATASUS/SUS/Ministério da Saúde; [updated 22/10/2015]. Available from: http://tabnet.datasus.gov.br/cgi/deftohtm.exe?cnes/cnv/equipobr.def.

18. BRASIL. Informações de Saúde (TABNET). Demográficas e Socioeconômicas. População residente. Censos: DATASUS/SUS/Ministério da Saúde; [updated 22/10/215]. Available from: http://tabnet.datasus.gov.br/cgi/deftohtm.exe?ibge/cnv/popuf.def.

19. Levin DC, Rao VM, Parker L. The recent downturn in utilization of CT: the start of a new trend? Journal of the American College of Radiology : JACR. 2012;9(11):795-8.

20. Levin DC, Rao VM, Parker L, Frangos AJ, Sunshine JH. Bending the curve: the recent marked slowdown in growth of noninvasive diagnostic imaging. AJR Am J Roentgenol. 2011;196(1):W25-9.

21. ONS. UK Office for National Statistics. Population Estimates for UK, England and Wales, Scotland and Northern Ireland. (2014) Available at http://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates/datasets/populationestimatesforukenglandandwalesscotlandandnorthernireland.

22. Bodanapally UK, Sours C, Zhuo J, Shanmuganathan K. Imaging of Traumatic Brain Injury. Radiol Clin North Am. 2015;53(4):695-715, viii.

23. Lee B, Newberg A. Neuroimaging in traumatic brain imaging. NeuroRx. 2005;2(2):372-83.

24. RCR. iRefer: Making the best use of clinical radiology: The Royal College of Radiologists; 2015 [26/10/2015]. Available from: https://www.rcr.ac.uk/clinical-radiology/being-consultant/rcr-referral-guidelines/about-irefer.

25. Bushberg JT, Seibert JA, Jr. EML, Boone JM. The Essential Physics of Medical Imaging. 3rd ed. Philadelphia: Lippincott Williams and Wilkins; 2011.

26. Flohr TG, Schaller S, Stierstorfer K, Bruder H, Ohnesorge BM, Schoepf UJ. Multi-detector row CT systems and image-reconstruction techniques. Radiology. 2005;235(3):756-73.

27. Orge F, Harris A, Kagemann L, Kopecky K, Sheets CW, Rechtman E, et al. The first technique for non-invasive measurements of volumetric ophthalmic artery blood flow in humans. Br J Ophthalmol. 2002;86(11):1216-9.

28. Williamson TH, Harris A. Color Doppler ultrasound imaging of the eye and orbit. Surv Ophthalmol. 1996;40(4):255-67.

29. Sigel B. A Brief History of Doppler Ultrasound in the Diagnosis of Peripheral Vascular Disease. Ultrasound in Medicine & Biology. 1998;24(2):169-76.

30. Veiga LH, Neta G, Aschebrook-Kilfoy B, Ron E, Devesa SS. Thyroid cancer incidence patterns in Sao Paulo, Brazil, and the U.S. SEER program, 1997-2008. Thyroid : Official Journal of the American Thyroid Association. 2013;23(6):748-57.

31. Reis DSM, Morihisa IA, Medeiros KC, Fernades LM, Martins E, Curado MP, et al. Câncer da tireóide em Goiânia: estudo descritivo de base populacional no período de 1988 a 2003. Rev Bras Cir Cabeça Pescoço. 2008;37(2):62-6.

32. BRASIL. Brasil em Síntese. População. Taxas brutas de natalidade [22/10/215]. Available from: http://brasilemsintese.ibge.gov.br/populacao/taxas-brutas-de-natalidade.html.

33. OECD. Medical Technologies. In: OECD, editor. Health at a Glance 2013: OECD Indicators: OECD Publishing; 2013.

34. Allisy-Roberts P, Williams J. Farr`s Physics for Medical Imaging. 2nd edition: Saunders Elsevier; 2008.

35. Wang L, Nie JX, Tracy CS, Moineddin R, Upshur RE. Utilization patterns of diagnostic imaging across the late life course: a population-based study in Ontario, Canada. Int J Technol Assess Health Care. 2008;24(4):384-90.

36. BRASIL. Brasil em Síntese. População. Esperança de vida ao nascer [22/10/2012]. Available from: http://brasilemsintese.ibge.gov.br/populacao/esperancas-de-vida-ao-nascer.html.

37. Victora CG, Barreto ML, do Carmo Leal M, Monteiro CA, Schmidt MI, Paim J, et al. Health conditions and health-policy innovations in Brazil: the way forward. Lancet. 2011;377(9782):2042-53.

38. Schmidt MI, Duncan BB, Azevedo e Silva G, Menezes AM, Monteiro CA, Barreto SM, et al. Chronic non-communicable diseases in Brazil: burden and current challenges. Lancet. 2011;377(9781):1949-61.

39. Barreto ML, Teixeira MG, Bastos FI, Ximenes RA, Barata RB, Rodrigues LC. Successes and failures in the control of infectious diseases in Brazil: social and environmental context, policies, interventions, and research needs. Lancet. 2011;377(9780):1877-89.

40. Reichenheim ME, de Souza ER, Moraes CL, de Mello Jorge MH, da Silva CM, de Souza Minayo MC. Violence and injuries in Brazil: the effect, progress made, and challenges ahead. Lancet. 2011;377(9781):1962-75.

41. Lehnert BE, Bree RL. Analysis of appropriateness of outpatient CT and MRI referred from primary care clinics at an academic medical center: how critical is the need for improved decision support? J Am Coll Radiol. 2010;7(3):192-7.

42. Hendee WR, Becker GJ, Borgstede JP, Bosma J, Casarella WJ, Erickson BA, et al. Addressing overutilization in medical imaging. Radiology. 2010;257(1):240-5.

43. Lysdahl KB, Hofmann BM. What causes increasing and unnecessary use of radiological investigations? A survey of radiologists' perceptions. BMC Health Serv Res. 2009;9:155.

44. Baker LC, Atlas SW, Afendulis CC. Expanded use of imaging technology and the challenge of measuring value. Health Affairs. 2008;27(6):1467-78.

45. Dovales AC, da Rosa LA, Kesminiene A, Pearce MS, Veiga LH. Patterns and trends of computed tomography usage in outpatients of the Brazilian public healthcare system, 2001-2011. J Radiol Prot. 2016;36(3):547-60.

46. Brink JA, Amis ES, Jr. Image Wisely: a campaign to increase awareness about adult radiation protection. Radiology. 2010;257(3):601-2.

47. Goske MJ, Applegate KE, Bulas D, Butler PF, Callahan MJ, Coley BD, et al. Image Gently: progress and challenges in CT education and advocacy. Pediatric Radiology. 2011;41 Suppl 2:461-6.

48. ACR. Appropriateness Criteria: ACR. American College of Radiology; 2015 [26/10/2015]. Available from: https://acsearch.acr.org/list.

49. Baker L, Birnbaum H, Geppert J, Mishol D, Moyneur E. The relationship between technology availability and health care spending. Health Affairs. 2003;Suppl Web Exclusives:W3-537-51.

50. Brito C, Margareth C, Vasconcellos M. Avaliação da concordância de dados clínicos e demográficos entre Autorizações de Procedimento de Alta Complexidade Oncológica e prontuários de mulheres atendidas pelo Sistema Único de Saúde no Estado do Rio de Janeiro, Brasil. [Clinical and demographic data concordance comparing Authorizations for High-Complexity Oncological Procedures and patient records of women treated under the Unified National Health System in Rio de Janeiro, Brazil]. Cadernos de Saúde Pública 2005;21:1829-35.

51. BRASIL. Conta-Satélite de Saúde Brasil 2007-2009. Instituto Brasileiro de Geografia e Estatística - IBGE, 2012.

6. ARTIGO 2

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Patterns and trends of computed tomography usage in outpatients of the Brazilian public healthcare system, 2001-2011

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Abstract

While the patterns and trends of computed tomography (CT) are well documented in developed countries, relatively little is known about CT usage in developing countries, including Brazil. We evaluated CT usage among outpatients from the public healthcare system in Brazil (SUS), which is the unique healthcare provider to about 75% of the Brazilian population. We collected the annual number of CT procedures and type of CT examinations performed in SUS for the period 2001-2011. Age at examination was evaluated for 2008-2011. CT usage in Brazil has more than tripled during the study period, but the most striking annual increase (17.5%) was observed over the years 2008-2011. Head was the most frequently examined region for all age groups, but a decreasing trend of proportional contribution of head CT, with a simultaneous increase of abdomen/pelvis and chest CT over time was observed. CT examination for pediatric and young adult patients was about 13% of all CTs (9% if we considered age-standardized CT rates). CT usage has grown rapidly in Brazil and may still be increasing. Increased CT usage may certainly be associated with improved patient care. However, given the high frequency of pediatric and young adult CT procedures and the suggested associated cancer risk, efforts need to be undertaken to reduce unwarranted CT scans in Brazil.

Running title: Computed tomography trends in Brazil

Key words: Computed tomography, trends, Brazil, ionizing radiation

1. Introduction

During the last few decades, a rapid increase of computed tomography (CT) use has been observed in many countries [1-3]. As radiation doses from CT scans are among the highest in diagnostic radiology, the growing use of this procedure has raised concern about its potential risk of cancer induction, mainly among children who can be more radiosensitive and also have a longer life expectancy for cancer to develop [4-6]. Although concerns have been raised due to potential confounding by underlying conditions and reverse causation [7-10], recent epidemiological studies, using empirical data, reported that the radiation exposure from CT scans in childhood increases the subsequent risk of cancer [11-13].

The patterns and trends of CT procedures have been evaluated in a number of studies. The rate of CT use has increased about 7-15% annually over the last decade in the USA [14], Europe [15, 16] and Australia [17]. Pediatric CT has also increased in many countries [5, 17-19]. However, more recent data suggest that CT use may be declining in developed countries [14,15, 20]. The proportion of pediatric and young adult CT in developed countries ranges from 1% in Germany [21] to 7-11 % in the USA [22, 23]. Abdomen/pelvis is the most frequently imaged anatomical region in the whole population, whereas head scan is the most common type of CT in young people [3, 5, 18, 19, 24] . Conversely, relatively little is known about the trends and patterns of CT usage in developing countries, including Brazil [25-27].

Brazil has both public and privately funded healthcare systems. The public system is represented by the Unified Health System (SUS), a free universal coverage system that is one of the largest healthcare systems in the world [28]. SUS plays an important role in Brazil as about 75% of its 200 million population depends only on SUS to receive any healthcare [28, 29].

With so little known about the use of CT in developing countries, it is important to report such trends and patterns that could reflect differences in clinical practice between developed and developing part of the world. The aim of this study was to evaluate the patterns and trends of CT usage in Brazil, using information available from the Brazilian public healthcare system.

2. Methods

We collected data on CT examinations among outpatients using the public healthcare system in Brazil. The source was an online database of the Information Technology Department of SUS (DATASUS) [29], which contains information on outpatient medical procedures in public hospitals and some charity based and private medical services in Brazil. We extracted annual numbers of CT procedures by imaged anatomical region from 2001 to 2011 for the whole country and for the five different Brazilian geographical regions (North, Northeast, South, Southeast and Middle West). CT procedures listed in DATASUS were: 1) skull and sella turcica, 2) ears and mastoids, 3) face, sinus, and temporomandibular junction, 4) neck (soft tissue/larynx), 5) upper abdomen, 6) pelvis, 7) thorax, 8) cervical, thoracic or lumbar spine, 9) myelography, 10) appendicular segments (arms), 11) sternoclavicular joint, 12) shoulder joints, 13) elbow joints, 14) wrist joint, 15) sacroiliac joint, 16) coxofemural joint, 17) knees 18) upper limbs joints and 19) lower limbs joints. These CT procedures were grouped into five categories accordingly to body imaged region as suggested elsewhere [19]: head/neck (1 to 4), abdomen/pelvis (5 and 6), chest (7), spine (8 and 9), and extremities (10 to19). Each scanned region was included as a single CT procedure and there was no information about multiple examinations in the same patient.

Information on age at CT examination and gender was extracted only for the period 2008-2011, as this information was not available for the earlier periods. Pediatric and young adult patients were defined as patients bellow 20 years of age.

We calculated the compound annual growth rate (CAGR) for the whole study period and the three time periods 2001-2003, 2004-2007, 2008-2011 by using the equation (1), where N_{t_0} and N_{t_1} represent the number of procedures in the first and in the last year of the time period, respectively, and t_0 and t_1 represent the first and the last years of the corresponding time period, respectively.

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$$\mathrm{CAGR}\,(t_0, t_1) = \left[\left(N_{t_1}/N_{t_0}\right)^{1/(t_1 - t_0)}\right] - 1 \qquad (1)$$

Linear regression was used to test for time trends, with calendar year included as a linear predictor. Stata 13 software (Stata Corp, College Station, TX) was used for statistical analysis. P values are 2-tailed; $P < 0.05$ was considered statistically significant.

The total number of existing CT scanners (from private, public and philanthropic institutions) and number of CT scanners available to SUS were extracted from the DATASUS database, which also contains information about health resources and medical devices in Brazil collected from the National Register of Health Institutions [29]. The CT scanners available to SUS include most of those located in the public institutions, as well as machines located in those private and philanthropic institutions which provide SUS assistance. Using demographic data from the Brazilian Vital Statistical System [29] we estimated the number of existing CT scanners per million population in Brazil.

However, as the proportion of the Brazilian population that depends only on SUS for healthcare services varies by geographical region (90%, 89%, 83%, 76% and 63% for North, Northeast, Middle West, South and Southeast regions, respectively) [29] we used these proportions to estimate the number of CT scanners per million SUS-population for each geographical region of Brazil.

3. Results

About 15.8 million CT examinations were recorded in SUS outpatients between 2001 and 2011.The number of CT procedures more than tripled in the studied period, rising from 0.8 million examinations in 2001 to 2.6 million in 2011 [Table 1]. Head was the most frequently examined body region throughout the study period, followed by examinations of the abdomen/pelvis, spine, chest, and extremities [Table 1]. Nevertheless, the proportional contribution of head CT to the total number of CT examinations decreased over time (61% in 2001 to 47% in 2011) while proportional contribution of scans of the abdomen/pelvis tended to increase in the same period (13% to 26% in 2001 and 2011, respectively) [Table 1].

Table 2 shows the annual growth of CT usage by imaged anatomical region and time period among outpatients of the Brazilian public healthcare system. Between 2001 and 2011, the overall number of CT procedures in SUS outpatients increased by 12.1% per year, with a statistically significant linear trend ($p<0.01$). Head CT had the lowest annual growth rate (9.2 % per year), while abdomen/pelvis was the imaged anatomic region with the greatest annual increase (19.5%), followed by chest CT (14.7%). Although increasing trends were seen for the overall number of CTs throughout the three study periods, the most striking increase was observed in the years 2008-2011 (17.5% per year). Moreover, abdomen/pelvis and chest CTs had the greatest increase rates in this period (27.8% and 21.2% per year, respectively). Significant linear trends were also seen throughout the three study periods for all anatomical imaged regions, although marginally significant for head and chest CT in 2001-2003 ($p=0.08$).

Table 3 shows the age distribution of SUS outpatients who underwent CT examinations between 2008 and 2011 compared to the age structure of the Brazilian population in the same period. Most CT examinations (87%) were done in adult patients (≥ 20 years old), which represented about 66% of the Brazilian population. Patients older than 40 years received about two thirds of CT examinations, whereas this age group corresponded to only one third of the Brazilian population. CT examinations on pediatric and young adult patients (< 20 years old) contributed up to 13.4% of all CTs. It is noteworthy that children under 1 year old who represent 1.5% of the entire population received 1.1% of all CT examinations, in contrast to all other pediatric age groups, for whom proportion of CT examinations was far below the respective proportion in the population.

Table 4 shows the number of CT procedures by imaged anatomical region and age at examination during 2008-2011. Head was the most frequently examined region for all age groups, but the proportional contribution of this type of CT procedure to the total number of CT examinations tended to decrease with increasing age. Conversely, the contribution of scans of the abdomen/pelvis, chest and spine to the total number of CT procedures was generally higher among older patients.

From 2008 to 2011, the number of all SUS outpatient CT procedures increased among all age groups, with the greatest increase rate among patients aged 60 years or more (21% per year) (Table 4). In general, growth rates were lower in children than in adult patients. Scans of the abdomen/pelvis region showed the greatest increase rates for most age groups, except among children less than 1 year old, for whom the greatest increase rate was observed in the scans of head (12% per year), and, for children 1-4 and 5-9 years of age, for whom the greatest increase was in the scans of the spine (14 and 17% per year, respectively).

In 2011, there were 2,949 CT scanners in Brazil (public and private), corresponding to 15.3 CT scanners per million population (Table 5). The number of CT scanners available for SUS, which includes almost all public machines and a number of private units that are used for SUS patients by contract, was around half of the existing CT scanners. Considering the proportion of the Brazilian population that depends only on SUS to receive healthcare (76%), we estimated 9.3 CT scanners per million SUS-population and about 17,590 CT outpatient procedures per million population within the public health system.

There was a great inequality in the distribution of CT scanners in the different geographical regions of Brazil as can be seen in Table 5. About half of the existing CT scanners in Brazil was concentrated in the Southeast region, which is the most populated and developed region of the country. On the other hand, the North region of Brazil, the largest in extent with a quite low demographic index, is the less served with CT scanners. The North and Northeast regions of Brazil are those with the lowest numbers of CT scanners per million population (9.6 and 9.2, respectively), which are roughly half of that in the Southeast, South and Middle West (18.9, 18.6 and 18.2 CT scanners per million population, respectively). The South region of Brazil had the greatest rate of CT scanners per million population (14.7) that depends exclusively on SUS for medical assistance, whereas the lowest rates were observed for the North and Northeast region (6.1 and 5.6, respectively). The North and Northeast regions of Brazil had also the lowest rates regarding the number of CT procedures per SUS-population in 2011 (11,416 and 9,804 CT examinations per million, respectively). The highest usage was in the Southeast region, with 27,639 procedures per million SUS dependent population, followed by the South and Middle West regions (17,308 and 13,646 CT procedures per million SUS dependent population, respectively).

4. Discussion

In this study of outpatient data from the public healthcare system in Brazil, we have shown that the use of CT has more than tripled between 2001 and 2011, with the greatest increase observed in the years 2008-2011. Head was the most frequently examined anatomical region for all age groups, but the proportional contribution of head scans to the total number of CT has decreased in the study period, while the contribution of abdomen/pelvis CT has increased. About 13% of all CT procedures were performed in pediatric and young adult patients (below 20 years of age). CT use in the Brazilian population varied by geographical region, with most of CT procedures performed in the South and Southeast region, which are the most developed regions in the country.

Since its introduction in the 1970s, CT usage has become an essential tool for medical diagnosis, follow-up and intervention, with an increase trend over time reported in many studies worldwide [1-3, 16-18, 24, 30, 31]. From 2001 to 2011, the overall number of CT procedures among SUS outpatients in Brazil increased by 12.1% per annum, which represented an actual growth in the frequency of CT usage, since during the same period the Brazilian population growth was only 1.1% per year and the dependency on SUS for healthcare did not change significantly [28, 29]. The annual increase in CT practice in Brazil was greater than that estimated in developed countries at similar time periods (CAGR of 10.4%, 7.2% and 7.8% in England [15], Australia [32] and the United States [20], respectively). Moreover, while CT use among SUS outpatients in Brazil showed an increasing growth over the study period (CAGR of 9.2%, 9.0% and 17.5% in 2001-2003, 2004-2007 and 2008-2011, respectively), annual CT increase rate has been declining between 2004-2007 and 2008-2011 in England (CAGR of 12.4% and 9.3%, respectively [15] and Australia (CAGR of 8.4% and 5.6%, respectively) [32]. Also, in the United States, Medicare CT use flattened in 2008/2009 and then declined by 1.7% in 2010 [20]. The reduced annual CT rates in developed countries may be a consequence of the increasing awareness of the high doses and potential cancer risks associated with CT imaging, leading to efforts to avoid or reduce unnecessary CT exposure [20], as well as a shift to other imaging modalities [33]. Whether this is furthered by the findings of the recent empirical epidemiologic studies to date [11-13] remains to be seen. Conversely, the increasing use of CT among SUS outpatients may be viewed as an indicator of the recent improvements in healthcare assistance in Brazil [34]. Nevertheless, increase of unwarranted CT, as reported for developed countries [35-37], cannot be ruled out, especially as CT becomes more widely available.

The upward trend in CT utilization among SUS outpatients in Brazil may be attributed to several factors, including the increasing number of CT machines available to SUS, the increasing availability of faster scanners and the increasing demand of CT examinations by patients and physicians, among others [14, 38]. Indeed, the total number of CT machines available to SUS patients rose from 699 in 2002 to 1,357 in 2011, with a 7.6% annual increase (not shown). In addition to the increasing number of CT machines over the study period in Brazil, an improvement of the efficiency of CT machines usage was also observed (number of examinations per CT machine available to SUS increased from 1,292 in 2002 to 1,884 in 2011, not shown). The improved efficiency of CT machines may be a consequence of the introduction of helical and multislice CT (MSCT) which have very short acquisition times, allowing more examinations per machine per time period [39]. A pronounced increase of the number of CT examinations after 2000 was reported to coincide with the introduction of MSCT in the United States [40] and Denmark [41]. Although we do not have information about the trends on helical and MSCT scanners available to SUS, we can assume that these machines were introduced later in Brazil than in developed countries.

The introduction of MSCT scanners in Brazil may also be responsible for the observed changes in the pattern of CT procedures by imaged anatomical region, where a trend towards an increasing proportional contribution of abdomen/pelvis and chest CT with a simultaneous decreasing of head CT over time was observed. A similar change in the pattern of CT procedures by imaged anatomical region was also reported in France [24, 42] and in the United States [3, 22]. Although differences in living conditions and population distributions may result in different CT patterns, the increasing proportions of abdomen/pelvis and chest CT examinations, both in developed and developing countries, may have resulted from introduction of the faster scanners [39]. Noteworthy, when comparing the most and less developed geographical regions of Brazil, we observed not only the same CT pattern by body imaged region, but also the same change in CT pattern over time (results not shown). While in 2006/2007 abdomen/pelvis CT was already the most frequent examination in the United States [3], France [24] and Canada [30] (31.7%, 29.9% and 47.4%, respectively), the head was still the most frequently imaged anatomical region in Brazil in 2011 (47.4% of all CT examinations). This different pattern of CT use by anatomical region in Brazil might be only reflecting the later introduction of faster scanners in the country. It can be anticipated that as soon as the old model CT scanners are replaced in SUS across the country, abdomen/pelvis and chest CT will become the most frequent examination type, similarly to developed countries. Indeed, annual growth rates for abdomen/pelvis and chest CT in SUS outpatients in Brazil were more pronounced in the more recent time of the study period (CAGR of 15.6% for abdomen/pelvis CT in 2001-2003 and 27.8% in 2008-2011 and a CGAR of 9.8% and 21.2% for chest CT in the same time period).

Faster scanners have also broadened the applications of CT in pediatric patients by reducing the requirement of sedation to prevent children movement during examination. Furthermore, these scanners are associated with less need for oral contrast administration, reduced amount of intravenous contrast medium, and improved image quality. All these factors might have contributed to the raising numbers of pediatric CT examinations [43].

Patients under 20 years of age underwent 13.4% of all CT procedures performed in SUS between 2008 and 2011. Similarly, a high proportion of pediatric CT was observed in Africa and Asia, where the overall frequency of CT in patients, even younger than in our study (less than 15 years), was 8-20% and 12-16%, respectively [31, 44]. In contrast, pediatric and young adult CT examinations in developed countries were reported to be 1% in Germany [21] and France [42], 2.0% in Switzerland [45], 3.0% in Israel [18], but somewhat more frequent (7.0-11.0%) in the United States [22, 23]. As medical imaging tends to increase with age, when chronic diseases become more prevalent [14, 47], part of these differences may be a result of the higher proportions of older people in developed countries [46]. Nevertheless, when we estimate the proportion of pediatric CT examinations in SUS outpatients in Brazil applying age-standardized CT rates using the U.S. population as a standard population, we found a proportion of 9% of pediatric CT examinations (under 20 years old), which was still a high proportion compared to developed countries. Furthermore, it has been suggested that high frequencies of pediatric and young adult CT examinations in developing countries might be due to the lack of appropriateness criteria for CT examinations in children, as well as the non-availability of alternative imaging modalities such as magnetic resonance imaging and high resolution ultrasound [44].

In our study, infants in their first year of life underwent a high proportion of CT procedures in comparison with the corresponding proportion of this age group in the Brazilian population (see table 3). A high proportion of CT in young children has been also reported in Israel [18] and the United Kingdom [19] and may reflect a great frequency of health problems in this age group, including trauma as well congenital abnormalities that may require CT. Also, clinical evaluation of this patient group may be especially difficult, encouraging indication of complementary diagnostic procedures. In this case, CT may be preferably chosen for younger patients, since it can be performed without anesthesia, which is not the case for magnetic resonance imaging.

Head CT was by far the most frequent CT examination in patients under 20 years old, corresponding to nearly 75% of all pediatric and young adult CT in SUS outpatients in Brazil. This frequency of head CT in children and young adults is similar to the pattern reported in both developed and developing countries [5, 18, 19, 31, 48, 49]. Although head injury in children and young adults is a significant public health problem, and CT examination is the reference standard for head injury investigation, there is still a great concern regarding appropriateness criteria for referral for head CT examinations in young children [50].

While a leveling of, or even a reduction in, the number of pediatric and young adult CT examinations has been reported in recent years in developed countries such as Israel [18], the U.S. [5, 51] and Australia [17], an increasing trend of pediatric and young adult CT has been observed in developing countries. A survey conducted by the IAEA in 28 less resourced countries reported an average increase of 6.8% in the number of pediatric and young adult CT examinations between 2007 and 2009 [31]. Pediatric and young adult CT use was also on the rise among SUS outpatients in Brazil, increasing 42.7% between 2008 and 2011. The great increase in CT procedures among pediatric and young adult SUS outpatients in Brazil during the study period might be attributable to several factors, such as: the increasing number of CT machines available to SUS over time, lower availability of other sophisticated imaging techniques in SUS facilities and the lack of knowledge about radiation risks associated to CT examinations in childhood [52, 53]. Little understanding about CT doses and risks has also been reported in developed countries [54, 55]. Nevertheless, efforts to increase awareness about potential CT doses and risks as well as establishment of appropriateness criteria [56] were raised in developed countries, while, to our knowledge, no attempt in this sense has been made in Brazil.

Brazil is a continent-sized country with the fifth largest population in the world and huge social and economic inequalities [28]. The inequalities in health care access are well recognized, both at individual and geographical levels. In general, people with private health insurance have easier access to medical services and sophisticated diagnostic examinations [28].

In 2011, we estimated an overall rate of 15.3 existing CT machines per million Brazilian population, which includes all public and private CT scanners. Nevertheless, only about half of the existing CT scanners in Brazil were available to SUS patients, resulting in a rate of 9.3 CT scanners per million SUS-population. This estimated rate was close to the reported rate for Israel and the UK (9.0 and 8.9 CT machines per million population, respectively), but lower than the reported rate for the US, Canada and France (40.9, 14.6 and 12.5 CT machines per million population, respectively) [2]. On the other hand, if we consider that half of existing CT machines in Brazil were used by only 24% of the Brazilian population with access to private healthcare, a rate of 33.9 scanners per million population can be estimated, which is similar to the greatest rates reported to Italy, Switzerland, Greece and South Korea (32.1, 33.6, 34.3 and 35.9 scanners per million persons, respectively) [2].

The association between diagnostic imaging utilization rate and socioeconomic status has been investigated by some authors [57-59]. It has been suggested a high rate of CT usage in socio-economically deprived area likely due to a higher burden of diseases in these areas [57]. Conversely, we observed a high rate of CT usage in the most developed regions of Brazil (South and Southeast). It can be suggested that differences in CT usage rates among regions of Brazil were related to the quality and access of public services in the most developed regions, as seen by the differences in number of CT scanners among regions. Moreover, a high proportion of faster scanners would result also in a higher rate of CT usage. Indeed, Southeast region had more CT procedures per million SUS-population than the South region (27,639 and 17,308 CT procedures per million SUS-population, respectively), despite of a lower number of CT scanners per million SUS-population (11.6 and 14.7 CT scanners per million in the Southeast and South regions, respectively).

Strengths of this study include availability of the relatively good quality DATASUS online database [60], and the fact that this is the first study to present data on the patterns and trends of CT usage in Brazil. This is particularly important considering the shortage of information in health care level II countries, where about half of the world’s population lives [1, 3]. Certain limitations should be considered, mainly regarding to the representativeness of the observed CT pattern and trend among outpatients of the public healthcare system to all Brazilian population. Since the public healthcare system in Brazil is the only health provider to 76% of the Brazilian population and outpatient data usually corresponds to the great majority of examinations performed in SUS [29], this study can be seen as representative of the public health system in Brazil, but not for the private settings. Further studies will include evaluating CT usage in the private healthcare system in Brazil, where it is expected higher CT rates than in the public healthcare, mainly due to greater number of scanners, financial and human resources. Differences in CT patterns may also be expected, mainly due to the greater availability of faster scanners in private settings. A further limitation is that neither the proportion of patients that receive multiple examinations, nor the average number of CTs performed per patient, was assessed in this study, due to a lack of available, relevant, data. Therefore it was not possible to evaluate if the observed increase in number of CT examinations was influenced by the increasing number of multiple scans per patient over the study period.

5. Conclusion

While a leveling or even a decline in CT usage has been observed more recently in some developed countries, CT trend seems still to be on the rise in Brazil. An increasing CT trend among SUS patients in Brazil might be due to improvement in healthcare assistance or due to unwarranted CT use. Although head CT remains the most frequent examination in all age groups, the percentage of head CT decreased in the study period while frequency of abdomen/pelvis CT has increased over the study period. About 13% of all scans in outpatients of the public healthcare system, or about 9% if we considered age-standardized CT rates were performed in those with less than 20 years of age, which is among the highest frequencies of pediatric and young adult CT worldwide [22, 23]. There was a large variation in CT usage among the geographical regions in Brazil, with a greatest CT use in the most developed regions.

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Table 1. Numbers (in millions) and proportions (%) of CT procedures by type of examination in outpatients of the Brazilian public healthcare system, 2001-2011.

Type of examination		**Year**										
		2001	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
Head[a]	N	0.50	0.54	0.56	0.61	0.67	0.68	0.72	0.82	0.94	1.09	1.21
	(%)	(61.2)	(59.7)	(57.9)	(56.8)	(56.0)	(53.6)	(52.0)	(51.9)	(50.9)	(49.3)	(47.4)
Abdomen/pelvis	N	0.11	0.13	0.15	0.17	0.19	0.22	0.25	0.31	0.40	0.53	0.65
	(%)	(13.5)	(14.2)	(15.1)	(15.5)	(15.8)	(17.1)	(18.4)	(19.9)	(21.8)	(23.9)	(25.6)
Spine	N	0.11	0.13	0.15	0.17	0.19	0.21	0.23	0.23	0.25	0.29	0.32
	(%)	(13.4)	(13.9)	(14.9)	(15.7)	(16.2)	(16.8)	(16.6)	(14.6)	(13.5)	(12.9)	(12.5)
Chest	N	0.08	0.09	0.10	0.10	0.12	0.13	0.15	0.18	0.21	0.26	0.31
	(%)	(9.7)	(9.9)	(9.8)	(9.7)	(9.8)	(10.2)	(10.8)	(11.1)	(11.6)	(11.7)	(12.2)
Extremities	N	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.04	0.04	0.05	0.06
	(%)	(2.2)	(2.3)	(2.3)	(2.3)	(2.2)	(2.2)	(2.3)	(2.4)	(2.2)	(2.2)	(2.4)
All CTs	**N**	**0.82**	**0.90**	**0.97**	**1.07**	**1.20**	**1.27**	**1.39**	**1.58**	**1.85**	**2.21**	**2.56**
	(%)	**(100)**	**(100)**	**(100)**	**(100)**	**(100)**	**(100)**	**(100)**	**(100)**	**(100)**	**(100)**	**(100)**

[a] Head category also include neck.

Table 2. Changes in CT use by type of examination and time period in outpatients of the Brazilian public healthcare system, 2001-2011.

Type of examination	**Time period**							
	2001-2003		2004-2007		2008-2011		**2001-2011**	
	CAGR	P [a]	CAGR	P [a]	CAGR	P [a]	CAGR	P [a]
Head[b]	+6.2	0.08	+5.9	0.04	+13.9	<0.01	**+9.2**	**<0.01**
Abdomen/pelvis	+15.6	<0.01	+15.5	<0.01	+27.8	<0.01	**+19.5**	**<0.01**
Spine	+14.9	0.03	+11.0	<0.01	+ 11.4	<0.01	**+11.2**	**<0.01**
Chest	+9.8	0.08	+12.8	<0.01	+21.2	<0.01	**+14.7**	**<0.01**
Extremities	+10.9	0.03	+8.7	0.01	+17.0	0.04	**+12.9**	**<0.01**
All CTs	**+9.2**	**0.03**	**+9.0**	**<0.01**	**+17.5**	**<0.01**	**+12.1**	**<0.01**

Note: CAGR - Compound Annual Growth Rate was given by the equation $CAGR = \left[(N_{t1}/N_{t0})^{1/(t_1 - t_0)} \right] - 1$, where N_{t0} and N_{t1} were respectively the number of procedures in the first and in the last year of the time period, and t_0 and t_1 were respectively the first and the last year of the corresponding time period. CAGR is given in percentage of increase (+) or decrease (-).

[a] P value for linear trend.

[b] Head category also includes also neck.

Table 3. Numbers (in millions) and proportions (%) of CT procedures by age at examination in SUS outpatients and age distribution of the Brazilian population (2008-2011).

Age (years)	**CT procedures**[a]		**Brazilian population**[b]	
	N	%	N	%
<1	0.09	1.1	2.9	1.5
1-4	0.18	2.2	12.0	6.3
5-9	0.23	2.8	16.0	8.4
10-14	0.28	3.4	16.9	8.8
15-19	0.32	3.9	17.0	8.9
20-39	1.88	23.0	64.1	33.5
40-59	2.86	34.9	42.4	22.2
>60	2.36	28.8	19.9	10.4
All ages	**8.2**	**100**	**199.3**	**100**

[a] Overall number of CT procedures in 2008-2011 (in millions).
[b] Mean Brazilian population in 2008-2011 (in millions).

Table 4. Numbers (in millions) and proportions (%) of CT procedures and changes (CAGR) in CT use by type of examination and age at exposure in outpatients of the Brazilian public healthcare system, 2008-2011.

Type of examination		**Age at exposure**								
		< 1	**1-4**	**5-9**	**10-14**	**15-19**	**20-39**	**40-59**	**≥60**	**All ages**
Head[a]	N (%)	0.07 (77)	0.15 (82)	0.18 (80)	0.21 (75)	0.22 (69)	1.03 (55)	1.15 (40)	1.06 (45)	4.06 (50)
	CAGR	+12.3	+11.8	+ 8.3	+10.7	+14.3	+13.8	+13.7	+16.5	+13.9
Abdomen/pelvis	N (%)	0.01 (9)	0.01 (8)	0.02 (9)	0.03 (10)	0.05 (14)	0.39 (21)	0.71 (25)	0.68 (29)	1.90 (23)
	CAGR	+ 7.7	+12.7	+13.8	+22.6	+30.6	+29.4	+27.5	+28.4	+27.8
Spine	N (%)	0.01 (6)	0.00 (3)	0.01 (3)	0.01 (4)	0.02 (6)	0.26 (14)	0.58 (20)	0.20 (8)	1.08 (13)
	CAGR	-1.1	+13.5	+17.0	+18.6	+26.2	+14.3	+8.0	+16.3	+11.4
Chest	N (%)	0.01 (6)	0.01 (6)	0.01 (5)	0.02 (6)	0.02 (7)	0.15 (8)	0.35 (12)	0.39 (17)	0.96 (12)
	CAGR	+4.0	+7.0	+4.7	+10.1	+16.2	+19.2	+22.2	+23.3	+21.2
Extremities	N (%)	0.01 (1)	0.01 (1)	0.01 (2)	0.01 (4)	0.01 (3)	0.06 (3)	0.07 (2)	0.03 (1)	0.19 (2)
	CAGR	-2.5	-11.9	+6.5	+9.6	+13.4	+18.2	+17.3	+23.9	+17.0
All CTs	**N (%)**[b]	**0.09 (100)**	**0.18 (100)**	**0.23 (100)**	**0.28 (100)**	**0.32 (100)**	**1.88 (100)**	**2.86 (100)**	**2.36 (100)**	**8.19 (100)**
	CAGR	**+10.2**	**+11.2**	**+8.8**	**+12.1**	**+17.2**	**+17.4**	**+16.8**	**+21.0**	**+17.5**

Note: CAGR - Compound Annual Growth Rate was given by the equation $CAGR = \left[(N_{t1}/\ N_{t0})^{1/(t_1-t_0)}\right] - 1$, where N_{t0} and N_{t1} were respectively the number of procedures in the first and in the last year of the time period, and t_0 and t_1 were respectively the first and the last year of the corresponding time period (LARSON et al., 2011). CAGR is given in percentage of increase (+) or decrease (-).

[a] Includes also neck.

[b] Total percentage may not sum up 100% due to rounding process.

Table 5. Number of CT scanners and CT procedures by geographic region of Brazil (2011).

	Southeast	**South**	**Middle West**	**North**	**Northeast**	**Brazil**
Number of existing CT scanners[a]	1,533	512	259	154	492	**2,949**
Number of existing CT scanners per million population	18.9	18.6	18.2	9.6	9.2	**15.3**
Number of CT scanners available to SUS[b]	591	307	105	88	266	**1,357**
Number of CT scanners per million SUS-population[c]	11.6	14.7	8.9	6.1	5.6	**9.3**
Number of CT procedures per million SUS-population[c]	27,639	17,308	13,646	11,416	9,804	**17,590**

[a] Includes all CT scanners in Brazil (public and private).

[b] Includes also private CT scanners available to the Public Healthcare System(SUS).

[c] It takes into account the proportion of population that depends exclusively on the Public Healthcare System in each region of Brazil: Southeast (63%). South (76%). Middle West (83%). North (90%). Northeast (89%) and Brazil (76%).

References

1. UNSCEAR. UNSCEAR 2008 Report to the General Assembly with Scientific Annexes. Sources and Effects of Ionizing Radiation. Vol I, Annex A: Medical radiation exposures. New York, NY: United Nations, 2010.

2. OECD. Computed tomography (CT) exams, total. Health: Key Tables from OECD, No 49 2013. Available from: http://dx.doi.org/10.1787/ct-exams-tot-table-2013-2-en.

3. Mettler FA, Jr., Bhargavan M, Faulkner K, Gilley DB, Gray JE, Ibbott GS, et al. Radiologic and nuclear medicine studies in the United States and worldwide: frequency, radiation dose, and comparison with other radiation sources:1950-2007. Radiology. 2009;253(2):520-31.

4. Brenner DJ, Hall EJ. Computed tomography: an increasing source of radiation exposure. N Engl J Med. 2007;357(22):2277-84.

5. Miglioretti DL, Johnson E, Williams A, Greenlee RT, Weinmann S, Solberg LI, et al. The use of computed tomography in pediatrics and the associated radiation exposure and estimated cancer risk. JAMA Pediatr. 2013;167(8):700-7.

6. UNSCEAR. UNSCEAR 2013 Report to the General Assembly with Scientific Annexes. Sources, Effects and Risks of Ionizing Radiation. Vol II, Annex B: Effects of radiaton exposure of children. New York, NY: United Nations, 2013.

7. Journy N, Rehel J-L, Pointe HDL, Lee C, Brisse H, Chateil J-F, et al. Are the studies on cancer risk from CT scans biased by indication? Elements of answer from a large-scale cohort study in France. British Journal of Cancer. 2015;112:185-93.

8. Boice JD, Jr. Radiation epidemiology and recent paediatric computed tomography studies. Annals of the ICRP. 2015;44(1 Suppl):236-48.

9. Krille L, Dreger S, Schindel R, Albrecht T, Asmussen M, Barkhausen J, et al. Risk of cancer incidence before the age of 15 years after exposure to ionising radiation from computed tomography: results from a German cohort study. Radiation and Environmental Biophysics. 2015;54(1):1-12.

10. Walsh L, Shore R, Auvinen A, Jung T, Wakeford R. Risks from CT scans--what do recent studies tell us? Journal of Radiological Protection : Official Journal of the Society for Radiological Protection. 2014;34(1):E1-5.

11. Pearce MS, Salotti JA, Little MP, McHugh K, Lee C, Kim KP, et al. Radiation exposure from CT scans in childhood and subsequent risk of leukaemia and brain tumours: a retrospective cohort study. Lancet. 2012;380(9840):499-505.

12. Mathews JD, Forsythe AV, Brady Z, Butler MW, Goergen SK, Byrnes GB, et al. Cancer risk in 680,000 people exposed to computed tomography scans in childhood or adolescence: data linkage study of 11 million Australians. BMJ. 2013;346:f2360.

13. Huang W-Y, Muo C-H, Lin C-Y, Jen Y-M, Yang M-H, Lin J-C, et al. Paediatric head CT scan and subsequent risk of malignancy and benign brain tumour: a nation-wide population-based cohort study. British Journal of Cancer. 2014;110:2354-60.

14. Smith-Bindman R, Miglioretti DL, Johnson E, Lee C, Feigelson HS, Flynn M, et al. Use of diagnostic imaging studies and associated radiation exposure for patients enrolled in large integrated health care systems, 1996-2010. JAMA. 2012;307(22):2400-9.

15. NHS. National Health Services. Total number of imaging and radiodiagnostic examinations or tests, by imaging modality, England, 1995-96 to 2012-13 England, UK: NHS; 2013. Available from: http://www.england.nhs.uk/statistics/statistical-work-areas/diagnostic-waiting-times-and-activity/imaging-and-radiodiagnostics-annual-data.

16. Aroua A, Samara ET, Bochud FO, Meuli R, Verdun FR. Exposure of the Swiss population to computed tomography. BMC Medical Imaging. 2013;13:22.

17. Brady Z, Cain TM, Johnston PN. Paediatric CT imaging trends in Australia. J Med Imaging Radiat Oncol. 2011;55(2):132-42.

18. Chodick G, Ronckers C, Ron E, Shalev V. The utilization of pediatric computed tomography in a large Israeli Health Maintenance Organization. Pediatric Radiology. 2006;36(6):485-90.

19. Pearce MS, Salotti JA, Howe NL, McHugh K, Kim KP, Lee C, et al. CT Scans in Young People in Great Britain: Temporal and Descriptive Patterns, 1993-2002. Radiol Res Pract. 2012;2012:594278.

20. Levin DC, Rao VM, Parker L. The recent downturn in utilization of CT: the start of a new trend? J Am Coll Radiol. 2012;9(11):795-8.

21. Galanski M, Nagel HD, Stamm G. [Results of a federation inquiry 2005/2006: pediatric CT X-ray practice in Germany]. Rofo. 2007;179(11):1110-1.

22. Mettler FA, Jr., Wiest PW, Locken JA, Kelsey CA. CT scanning: patterns of use and dose. Journal of Radiological Protection : Official Journal of the Society for Radiological Protection. 2000;20(4):353-9.

23. Berrington de Gonzalez A, Mahesh M, Kim KP, Bhargavan M, Lewis R, Mettler F, et al. Projected cancer risks from computed tomographic scans performed in the United States in 2007. Arch Intern Med. 2009;169(22):2071-7.

24. Etard C, Sinno-Tellier S, Empereur-Bissonet P, Aubert B. French Population Exposure to Ionizing Radiation From Diagnostic Medical Procedures in 2007. Health Phys. 2012;102(6):670-9.

25. Thomas KE. CT utilization--trends and developments beyond the United States' borders. Pediatric Radiology. 2011;41 Suppl 2:562-6.

26. Muhogora WE, Ahmed NA, Beganovic A, Benider A, Ciraj-Bjelac O, Gershan V, et al. Patient doses in CT examinations in 18 countries: initial results from International Atomic Energy Agency projects. Radiation Protection Dosimetry. 2009;136(2):118-26.

27. Pearce MS. Patterns in paediatric CT use: an international and epidemiological perspective. J Med Imaging Radiat Oncol. 2011;55(2):107-9.

28. Paim J, Travassos C, Almeida C, Bahia L, Macinko J. The Brazilian health system: history, advances, and challenges. Lancet. 2011;377(9779):1778-97.

29. SUS Database [Internet]. Ministério da Saúde, Brasil. [cited 09/10/2012]. Available from: http://www2.datasus.gov.br.

30. Chen J, Moir D. An estimation of the annual effective dose to the Canadian population from medical CT examinations. Journal of Radiological Protection : Official Journal of the Society for Radiological Protection. 2010;30(2):131-7.

31. Vassileva J, Rehani MM, Al-Dhuhli H, Al-Naemi HM, Al-Suwaidi JS, Appelgate K, et al. IAEA survey of pediatric CT practice in 40 countries in Asia, Europe, Latin America, and Africa: Part 1, frequency and appropriateness. AJR American Journal of Roentgenology. 2012;198(5):1021-31.

32. Medicare Health Statistics [Internet]. Medicare Australia. 2013. Available from: https://www.medicareaustralia.gov.au/statistics/mbs_group.shtml.

33. Parker MW, Shah SS, Hall M, Fieldston ES, Coley BD, Morse RB. Computed tomography and shifts to alternate imaging modalities in hospitalized children. Pediatrics. 2015;136(3):e573-81.

34. Victora CG, Barreto ML, do Carmo Leal M, Monteiro CA, Schmidt MI, Paim J, et al. Health conditions and health-policy innovations in Brazil: the way forward. Lancet. 2011;377(9782):2042-53.

35. Lehnert BE, Bree RL. Analysis of appropriateness of outpatient CT and MRI referred from primary care clinics at an academic medical center: how critical is the need for improved decision support? J Am Coll Radiol 2010;7(3):192-7.

36. Hendee WR, Becker GJ, Borgstede JP, Bosma J, Casarella WJ, Erickson BA, et al. Addressing overutilization in medical imaging. Radiology. 2010;257(1):240-5.

37. Lysdahl KB, Hofmann BM. What causes increasing and unnecessary use of radiological investigations? A survey of radiologists' perceptions. BMC Health Serv Res. 2009;9:155.

38. Smith-Bindman R, Miglioretti DL, Larson EB. Rising use of diagnostic medical imaging in a large integrated health system. Health Aff (Millwood). 2008;27(6):1491-502.

39. Flohr TG, Schaller S, Stierstorfer K, Bruder H, Ohnesorge BM, Schoepf UJ. Multi-detector row CT systems and image-reconstruction techniques. Radiology. 2005;235(3):756-73.

40. Mettler FA, Jr., Thomadsen BR, Bhargavan M, Gilley DB, Gray JE, Lipoti JA, et al. Medical radiation exposure in the U.S. in 2006: preliminary results. Health Phys. 2008;95(5):502-7.

41. Hansen J, Jurik AG. Analysis of Current Practice of CT examinations. Acta Oncol. 2009;48(2):295-301.

42. Scanff P, Donadieu J, Pirard P, Aubert B. Population exposure to ionizing radiation from medical examinations in France. The British Journal of Radiology. 2008;81(963):204-13.

43. White KS. Invited article: helical/spiral CT scanning: a pediatric radiology perspective. Pediatric Radiology. 1996;26(1):5-14.

44. Muhogora WE, Ahmed NA, Alsuwaidi JS, Beganovic A, Ciraj-Bjelac O, Gershan V, et al. Paediatric CT examinations in 19 developing countries: frequency and radiation dose. Radiation Protection Dosimetry. 2010;140(1):49-58.

45. Aroua A, Bochud FO, Valley JF, Vader JP, Verdun FR. Number of X-ray examinations performed on paediatric and geriatric patients compared with adult patients. Radiation Protection Dosimetry. 2007;123(3):402-8.

46. UN. World Population Ageing 2013. ST/ESA/SER.A/348. New York: United Nations. Department of Economic and Social Affairs, Population Division, 2013.

47. Wang L, Nie J, Tracy C, Moineddin R, Upshur R. Utilization patterns of diagnostic imaging across the late life course: a population-based study in Ontario, Canada. Int J Technol Asess Health Care. 2008;24(4):384-90.

48. Ghotbi N, Ohtsuru A, Ogawa Y, Morishita M, Norimatsu N, Namba H, et al. Pediatric CT scan usage in Japan: results of a hospital survey. Radiat Med. 2006;24(8):560-7.

49. Verdun FR, Gutierrez D, Vader JP, Aroua A, Alamo-Maestre LT, Bochud F, et al. CT radiation dose in children: a survey to establish age-based diagnostic reference levels in Switzerland. European Radiology. 2008;18(9):1980-6.

50. Lyttle MD, Crowe L, Oakley E, Dunning J, Babl FE. Comparing CATCH, CHALICE and PECARN clinical decision rules for paediatric head injuries. Emergency Medicine Journal : EMJ. 2012;29(10):785-94.

51. Townsend BA, Callahan MJ, Zurakowski D, Taylor GA. Has pediatric CT at children's hospitals reached its peak? AJR American Journal of Roentgenology. 2010;194(5):1194-6.

52. Borém L, Figueiredo M, Silveira M, Neto JR. O conhecimento dos médicos da atenção primária à saúde e da urgência sobre os exames de imagem [The knowledge about diagnostic imaging methods among primary care and medical emergency physicians]. Radiologia Brasileira. 2013;46(6):341-5.

53. Madrigano R, Abrão K, Puchnick A, Regacini R. Avaliação do conhecimento de médicos não radiologistas sobre aspectos relacionados à radiação ionizante em exames de imagem. [Evaluation of non-radiologist physicians' knowledge on aspects related to ionizing radiation in imaging]. Radiologia Brasileira. 2014;47(4):210-6.

54. Krille L, Hammer GP, Merzenich H, Zeeb H. Systematic review on physician’s knowledge about radiation doses and radiation risks of computed tomography. European Journal of Radiology. 2010;76:36-41.

55. Merzenich H, Krille L, Hammer G, Kaiser M, Yamashita S, Zeeb H. Paediatric CT scan usage and referrals of children to computed tomography in Germany - a crosssectional survey of medical practice and awareness of radiation related health risks among physicians. BMC Health Services Research. 2012;12.

56. Goske MJ, Applegate KE, Bulas D, Butler PF, Callahan MJ, Don S, et al. Image Gently 5 years later: what goals remain to be accomplished in radiation protection for children? AJR American Journal of Roentgenology. 2012;199(3):477-9.

57. Pearce MS, Salotti JA, McHugh K, Kim KP, Craft AW, Lubin J, et al. Socio-economic variation in CT scanning in Northern England, 1990-2002. BMC Health Serv Res. 2012;12:24.

58. Demeter S, Reed M, Lix L, MacWilliam L, Leslie WD. Socioeconomic status and the utilization of diagnostic imaging in an urban setting. CMAJ. 2005;173(10):1173-7.

59. Strauchler D, Freeman K, Miller TS. The impact of socioeconomic status and comorbid medical conditions on ionizing radiation exposure from diagnostic medical imaging in adults. Journal of the American College of Radiology : JACR. 2012;9(1):58-63.

60. Brito C, Margareth C, Vasconcellos M. Avaliação da concordância de dados clínicos e demográficos entre Autorizações de Procedimento de Alta Complexidade Oncológica e prontuários de mulheres atendidas pelo Sistema Único de Saúde no Estado do Rio de Janeiro, Brasil. [Clinical and demographic data concordance comparing Authorizations for High-Complexity Oncological Procedures and patient recors of women treated under the Unified National Health System in Rio de Janeiro, Brazil]. Cadernos de Saúde Pública 2005;21:1829-35.

7. ARTIGO 3

Pediatric and young adult CT scans in Brazil: Pattern of use and patient doses, 2008-2014

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Abstract

Computed tomography (CT) is an indispensable imaging technique in many medical situations, but radiation exposure from CT scans may increase the subsequent risk of cancer, mainly in children. Our group recently showed that CT use has greatly increased over the last decade among outpatients using the Brazilian public health system (SUS). Further, CT examinations among patients younger than 20 years of age represented around 13.4% of all CT examinations in SUS between 2008 and 2011. In this paper we extended the evaluation of pediatric and young adult CT use in Brazil to the more recent period 2008-2014, and included examinations in the privately funded healthcare system. Information about CT use was obtained from an online database containing data on examinations in outpatients using SUS and from the Radiological Information Systems (RIS) of a sample of 25 private CT services. Effective and organ absorbed doses were estimated for 4,497 patients from 4 radiology services using scan technical parameters and age specific Monte Carlo simulations of radiation transport in the body. Patients younger than 20 years of age underwent around 8.9% of the overall number of CT procedures in the private healthcare systems, while in SUS this proportion was around 12.7%, which is slightly lower than in the period 2008-2011. Pediatric and young adult CT greatly increased in both healthcare systems over the study period, but annual growth rates were less pronounced in privately than in public funded healthcare system. Head/neck was the main type of CT examination in both settings and around one third of the patients in the private setting had more than one CT examination over the period investigated. Great variation on CT doses for the same type of procedure within an age group was observed, with the highest mean effective doses being delivered by abdomen/pelvis CT in children younger than 1 year of age (13.5 mSv). The highest median organ doses were estimated for the brain during head/neck CT, ranging from 23.8 to 29.0 mGy.

Running title: Pediatric computed tomography use and doses in Brazil

Key words: Computed tomography, pediatric, Brazil, ionizing radiation, doses

Submitted to:

1. Introduction

The benefits of computed tomography (CT) imaging to diagnosis and management of a number of diseases are well known [1]. However, there are concerns about the potential risk of developing cancer following radiation exposure during CT scans [2-5]. Actually, epidemiological studies using empirical data reported increased cancer risk following CT scans in childhood or adolescence [6-10].

Cancer risk following radiation exposure depends on the patient age, gender, and organ and tissue radiation absorbed doses [11, 12]. A number of studies have assessed pediatric CT patterns, trends and doses in many parts of the world [5, 13-22], but information is more limited in less resourced countries [23-26]. We have recently shown [27] that CT use has more than tripled between 2001 and 2011 in outpatients of SUS, the universal and free public healthcare system of Brazil, which is the only healthcare provider to around 75% of the Brazilian population [28]. Head was the most frequently examined body part for all age groups, but examinations of the abdomen/pelvis had the greatest growth rates over the study period. Importantly, between 2008 and 2011, around 13% of the examinations (9% if we consider age-standardized CT rates) were done in patients younger than 20 years of age [27]. This is higher than the proportion of pediatric and young adult CT examinations commonly reported in developed countries [3, 16, 18, 29-31], although similar rates have been showed for developing countries [32, 33].

However, CT use may be higher in the private setting in Brazil, where admission to medical services is usually easier than in SUS [28, 34, 35]. Although only about 25% of the Brazilian population has access to health plan or insurance coverage [28, 36], more than half of the CT scanners in the country are exclusive of the private setting [27, 37]. In addition, differences in CT patterns between private and public settings may also be awaited, mainly due to the expected greater availability of faster scanners in the former.

In the present work, we focused the analysis on CT pattern of use and patients doses among children and young adult from both Brazilian public and private healthcare system, for the period 2008-2014.

2. Methods

CT pattern of use

Data on CT use among outpatients using the public healthcare system in Brazil (SUS) were retrieved from an online database of the Information Technology Department of SUS (DATASUS) [36] for 2008-2014, as previously described [27]. Comparing to our previous study [27] that evaluated CT use among all ages for 2001 to 2011, we added 3 more years and focused on the use of pediatric CT during the most recent available period.

For evaluation of CT examinations on the Brazilian privately funded healthcare system, data were obtained from a sample of private CT services. Several radiology services around the country were contacted to determine the availability of electronic data on CT examinations and their willingness to participate in the study. A total of 25 private CT services meeting these requirements were included in the study ("private sample"): 15 general hospitals, 1 pediatric hospital and 9 outpatient diagnostic services. These CT services were located in 8 Brazilian cities: Rio de Janeiro (14), São Paulo (4), Duque de Caxias (2), Niterói (1), Volta Redonda (1), Brasília (1), Florianópolis (1), and Recife (1). Electronic information archived on Radiological Registration Systems (RIS), including patient numeric identification, dates of birth and of CT examination (or age at examination), gender, and type of CT procedure were extracted for all CTs underwent between 2008 and 2014 in each CT service included in the study.

Age at examination was categorized into groups <1, 1-4, 5-9, 10-14, 15-19, 20-39, 40-59 and >60. Body imaged region was sorted into five categories, as suggested elsewhere [19]: head/neck, abdomen/pelvis, chest, spine, and extremities. Examinations that did not fit in any of these categories were classified as "other" which included examinations of more than one part of the body and CT angiography.

Patient identification number was used to identify multiple CT procedures for the same patient in a given CT service over the study period.

CT trend

We evaluated temporal trend of CT use in the private setting using a restricted sample which included only CT services with regular number of CT examinations for all years of the study period. This "restricted" private sample included 8 CT services (4 general hospitals and 4 outpatient diagnostic units) from 3 Brazilian cities for the period 2008-2014. Compound annual growth rate (CAGR) was then calculated by using the equation (1), where N_{t_0} and N_{t_1} represent the number of procedures in the first and in the last year of the time period, respectively, and t_0 and t_1 represent the first and the last years of the corresponding time period, respectively

$$CAGR\ (t_0, t_1) = \left[\left(N_{t_1}/N_{t_0}\right)^{1/(t_1 - t_0)}\right] - 1 \qquad (1)$$

Dose estimation

Organ-absorbed doses and effective doses were estimated for 4,497 patients younger than 20 year of age that underwent CT in 2 private general hospitals and 2 outpatient diagnostic units (1 public and 1 private). We extracted patient data (id, age, gender and type of examination) and scan technical parameters (CT scanner make and model, tube potential, tube current time product, pitch and Volumetric Computed Tomography Dose Index - CTDIvol) from Digital Imaging and Communications in Medicine (DICOM) headers. This extraction was automatically performed using the Performance and Monitoring Server for Medical Data software (PerMoS) [38]. Patient doses were estimated individually using a batch calculation routine of the software NCICT [39]. This software calculates doses using individual exposure parameters and a library of organ doses coefficients, obtained from Monte Carlo simulations of radiation transport in the body using hybrid computational phantoms. These phantoms represent male or female patients from different age groups (newborn, 1, 5, 10 and 15 years old children, and adult), have realistic human anatomy details, and body composition and dimensions as established by ICRP [40, 41]. Calculations were preferentially based on machine displayed CTDIvol, but when these values were not available, doses were estimated from examination settings, as previously described [39]. Typical values for pediatric examinations in the UK [6, 39] were used for start and end positions of each type of CT scan.

Data treatment

All data treatment was done using the statistical software package Stata, version 10 (StataCorp, College Station, TX, USA).

3. Results

Table 1 shows the age distribution of CT examinations either on outpatients of the Brazilian public healthcare system (SUS) or among patients undergoing examinations on 25 privately funded CT services, between 2008 and 2014. About 17.8 and 1.5 million CT examinations were retrieved from SUS and the private setting, respectively. The proportion of CT examinations in children and young adults (less than 20 years of age) was 12.7% in SUS and 8.9% the private sample, with the youngest group of patients (infants aged less than 1 year) having 1.0% of the CT examinations in SUS, while patients of this age group underwent only 0.5% of the examinations in the private sample.

Table 2 shows the distribution of CT examinations by imaged body part and age at examination among SUS and the private sample patients, for the period 2008-2014. A total of around 2.2 million pediatric and young adult CT examinations were registered in SUS, while 133.238 CT scans were gathered from the private sample over the study period. Head/neck CT was the main type of examination for both SUS and the private sample for all pediatric and young adult age groups, with higher proportion of head/neck CT in SUS (72.6% of the procedures) than in the private sample (63.1%). In general, the proportion of head/neck CT procedures tended to decline with increasing age in both SUS outpatients and private sample patients, while proportions of abdomen/pelvis CT examinations tended to increase with increasing age at examination for both settings.

Temporal trends on pediatric and young adult CT examinations for SUS and the restricted private sample settings for 2008-2014 are shown in Table 3. The overall annual number of CT examinations increased in both SUS and the private funded healthcare system between 2008 and 2014, but the annual growth rate was greater in the public than in the private setting (10.8% and 6.8% per year, respectively). CT use increased for all age groups in SUS and privately funded CT services, with a greater growth rate in the public than in the private setting for most age groups, except for younger age groups (<1 and 1-4 years old) for which growth rates were greater in the private (13.1% and 10.3%, respectively) than in the public setting (7.6% and 8.9%, respectively).

Figure 1 shows the proportion of multiple CT examinations among pediatric and young adult patients in a sample of the private CT services. About 30% of the patients had more than one CT scan between 2008 and 2014 (20.2% having two examinations, 4.6% having 3 examinations, and 4.3% having 4 or more CT scans.) The number of CT examinations per patient increased with increasing age, from 16.2% of infants to 35.9% of the patients in the age group 15-19 years old receiving more than one CT examination in the period.

Table 4 shows effective and organ doses for 4,497 CT examinations in patients younger than 20 years of age from 4 CT services in Brazil. Mean effective doses greatly varied according to scanned body region and age group, with the lowest value estimated for head CT (1.2 mSv for patients aged 15-19 years) and the highest one estimated for abdomen/pelvis CT (13.5 mSv among children younger than 1 year of age). As expected, head CT delivered the highest organ doses to the brain (23.8 to 29.0 mGy, according to age group). Active bone marrow doses were highest for head CT among children younger than 10 years old (7.0 to 9.8 mGy) and for abdomen/pelvis CT among children younger than 1 year of age (7.1 mGy).

Figure 2 presents the dose distribution for the organ sites that were among the sites which received the highest dose for each scanned anatomic region, i.e, brain dose for head CT, thyroid dose for chest and spine CT, and colon dose for abdomen/pelvis CT. Even within the same age group and scanned body region, estimated organ dose varied substantially. The great variability in organ dose was observed for the brain due to head CT, for which interquartile range varied from 10.9 to 45.7 mGy per head scan.

4. Discussion

In the present study we evaluated CT pattern of use, trend and patient dose among children and young adults in Brazil for the period 2008-2014. We showed that pediatric and young adult patients represented around 13% of the 17.8 million CT procedures underwent by outpatients in SUS between 2008 and 2014, and about 9% of the procedures in a sample of around 1.5 million CT examinations in privately funded CT services. Pediatric and young adult CT greatly increased in both healthcare systems over the study period, but annual growth rates were less pronounced in privately than in public funded healthcare system. Head/neck was the most frequently examined body part for all pediatric and young adult age groups in both healthcare systems, but the relative proportion of head/neck CT was greater in SUS than in the private setting, while the relative proportion of abdomen/pelvis scans was much higher in the private setting than in SUS. The number of multiple examinations was evaluated for the private setting, where about one third of the patients younger than 20 years of age had more than one CT scan over the study period. Estimates of effective and organ specific absorbed doses for 4,497 examinations showed great variation for the same type of procedure within an age group, with the highest effective doses delivered by abdomen/pelvis CT for age groups < 1 and spine CT for age group 10-14. Highest median organ absorbed doses were estimated for the brain following examinations of the head/neck, ranging from 23.8 to 29.0 mGy.

The proportion of CT scans among patients younger than 20 years of age was higher in SUS than in the private setting. However, CT use in the private setting was evaluated in a sample that cannot be representative of CT use in the private setting in Brazil, in which the proportion of pediatric CT varied from % among CT services. Nevertheless, differences in age structure between populations depending on SUS for healthcare or using the private setting may have also contributed to the observed differences. A higher proportion of older people is expected in the private setting, which is accessed mainly through health insurance coverage, that increases with age [42]. Differences in age structures between developing and developed countries – with a higher proportion of older people in the latter [43] - may also result in higher proportions of CT scans among young patients both in SUS and in the private setting than in many developed countries. Nevertheless, pediatric CT among SUS outpatients was still high even when age-standardized CT proportion was considered [27].

CT use in children and young people in Brazil increased both in public and privately funded healthcare systems between 2008 and 2014. Growth rates for all pediatric and young adult CT were higher in SUS than in the private setting, but increases in both systems were higher than the average increase of 6.8% reported for less resourced countries between 2007 and 2009 [42]. However, a deceleration of the increasing rates of pediatric and young adult CT scans in SUS may be suggested since growth rates reported for the study period of 2008-2014 (10.8% per year) were lower than growth rates reported by Dovales and colleagues for the period 2008-2011 (17.5 %) for the same population [27]. Increasing CT trends in young people have also been reported in Great Britain [19], Australia [17], and the United States [5], but a more recent levelling or even reduction in CT use has been reported in some developing countries [5, 17, 18, 43]. It has been suggested that at least part of this decreasing trend may be a result of initiatives aiming to increase awareness about potential CT doses and risks, leading to efforts to reduce or avoid unnecessary CT exposure, mainly in children [44-46]. To our knowledge, no such attempts have been made in Brazil so far. Lack of data from previous periods impairs any conclusion about future trends of privately funded pediatric and young adult CT in Brazil. However, lower growth rates in this setting than in SUS over the study period might be reflecting lower unmet demand for CT in the former, where resources, including CT scanners, are more easily available [27, 37]. Interestingly, while pediatric CT use in young people in SUS increased more among those aged over 15 years, similar to what has been reported in Australia [17] and Great Britain [19], the greatest increase in pediatric CT use in the private setting was among infants.

As reported in other countries [13, 15, 19, 26], examinations of the head/neck represented the main type of CT procedure among children and young adults, both in SUS and the private sample, with the proportion of head examinations tending to decrease with increasing age. The proportion of head/neck CT was higher in SUS than among patients using the Brazilian private setting, while the opposite was observed for examinations of the abdomen/pelvis, which were much more frequent in the privately funded healthcare system than in SUS. CT scanning began as an imaging modality of the head only, with scanning of the body become possible following technological advances, as helical and multi-detector CT (MDCT scanners), which minimized motion artifacts due to reduced acquisition times [47]. More recently, nuclear magnetic resonance imaging (MRI) may be the procedure of choice for neuroimaging, frequently replacing head CT scans [48]. It can be hypothesized that lower availability of more modern imaging machines in the public setting, where financial resources are more limited [27, 28, 34, 35, 37], may difficult body scans, contributing to a higher proportion of head/neck scans. Accordingly, the proportion of pediatric head/neck CT in SUS (72.6%) was similar to the proportion in less resourced countries (72%) [26], but lower than those reported in developed countries (66% in Japan [13], 62% in Switzerland [15] and 60% in Great Britain [19]). Nevertheless, we can probably anticipate an increase in the proportion of body scans among SUS outpatients in the following years. Abdomen/pelvis CT increased more than head/neck examinations (21.9% and 8.5% per year, respectively) among pediatric and young adult patients using this healthcare system between 2008 and 2014 (results not shown), as reported previously for the period 2008-2011 [27].

CT is used not only for diagnostic purposes, but also to assess disease progress and/or the course of therapy [1]. Oncologic follow up, for instance, can account for around one third of all CT examinations in children [25]. Therefore, multiple examinations on the same patient over a time period are not uncommon. In this study almost one third of pediatric and young adult patients had more than one CT examination between 2008 and 2014, with around 4.3% having 4 or more CT scans. Similar proportions of multiple CT in young people were reported in Great Britain [19] and Israel [18], while a slightly lower proportion (22.9%) was observed in Japan [13]. However, the proportion of multiple CT examinations in this study may be an underestimation since only CT scans underwent in the CT services enrolled in this study were considered, excluding any examination done in other CT services. Although individual doses from CT scans are usually low, patients undergoing multiple CT scans can receive total radiation doses at levels for what increased risk for radiation-induced cataracts [49] and cancer [50] have been shown. The type of examination with higher proportion of more than one examination in the same patient over the study period was spine CT (60%, not shown), which delivers relatively high doses and has been reported as a frequently unjustified examination in young patients [51].

One of the most important principles of radiological protection in medicine is justification. A medical exposure is justified when the benefit to the patient exceeds potential radiation risk [11]. Unjustified CT use has been reported to occur in up to 30% of the examinations in young people, being represented mainly by procedures which could have been avoided or replaced by other imaging techniques that require no or less exposure to ionizing radiation [51, 52]. Inappropriate referrals may be reduced if the referring physician carefully considers using other imaging modalities, as MRI, ultrasound or examinations delivering lower radiation doses to the patient, such as x-rays [53]. We were not able to assess indications for pediatric CT in this study, but it is reasonable to suppose that unjustified CT occurs in Brazil. Appropriateness criteria for imaging, including guidelines for some pediatric conditions, have been published by the Brazilian College of Radiologists [54]. However, it has been shown that physicians which request imaging procedures in Brazil have little knowledge on aspects related to ionizing radiation in imaging and possible alternatives techniques [55, 56]. Further, alternative sophisticated techniques may not be available in many radiological services, mainly in the public setting [27, 28, 34, 35, 37]. Other reasons for unjustified CT scanning includes financially motivated referrals, using imaging instead of adequate clinical assessment due to time pressure, defensive medicine, increased patient demand for high-tech examinations, and difficult to identify previous examinations of the patient generating duplicate studies [53, 57, 58]. All these causes may be contributing to unjustified pediatric CT use both in private and public CT services in Brazil.

Another important principle in radiological protection is optimization, meaning that practices involving exposure to radiation must have the maximum benefit-risk ratio [11]. In CT imaging, an optimized protocol is one that produces the required image information with the lowest possible radiation exposure to the patient. We observed a great variation in effective and absorbed doses delivered to patients of the same age group undergoing the same type of CT examination, as previously reported for both developed [5, 14, 15, 59, 60] and developing countries [26]. This suggests that while some CT examinations used more radiation than would be necessary, in others the exposure might not be enough to provide proper image quality, showing the need for optimization of pediatric CT practice in Brazil. Large dose variation for the same type of CT examination has been previously reported in Brazil in studies using conventional adult anthropomorphic phantoms and scan technical parameters to assess doses [61-63]. A recent study focusing on pediatric CT reported wide variation in computed tomography dose index (CTDI) and dose length product (DLP) in examinations in the city of Rio de Janeiro, but a standard pediatric phantom was used, precluding variations in body size of patients to be taken into account [64]. This study also showed that inadequate tube potential and current-exposure time product was associated with higher doses in pediatric CT. The use of the same protocol for pediatric and adult CT is not uncommon [14, 33, 65, 66], but may be avoided because of the lower radiation attenuation in children smaller bodies [67]. Efforts for optimizing CT exposures have been done in many countries, and include the establishment of national surveys of CT protocols, quality assurance programs and diagnostic reference levels [44, 68, 69]. To our knowledge, quality assurance programs on CT are uncommon in Brazil, and although diagnostic reference levels have been published, they have not been updated and do not include pediatric examinations [70].

CT dose indexes and effective doses are good indicators of CT scanner performance and may be used for optimization purposes, since they can be compared for the same procedure across different hospitals or with established national dose reference levels. However, effective dose cannot be used to estimate radiation related risk, which is needed to justify a CT exposure. Instead, organ absorbed doses should be used for risk assessment purposes [12]. There are few studies reporting pediatric CT organ doses from MDCT scanners, most of them using water equivalent cylinder phantoms to represent the patient and Monte Carlo radiation transport methods [67]. Other data have been obtained using computational phantoms [59, 71, 72] or through direct measurements in anthropomorphic phantoms [72, 73]. However, evaluation of organ doses using pediatric anthropomorphic phantoms of various equivalent ages are scarce [73, 74] and only a few studies included a large number of patients [5, 75, 76]. Our estimates for mean brain doses following head CT among different age groups were lower than those by Lee and colleagues in Great Britain (31, 33, 38 and 33 mGy in age groups 0-4, 5-9, 10-14 and 15-19, respectively) [75]. Conversely, the median brain absorbed dose estimated for patients younger than 20 years of age undergoing head CT was slightly higher in our study (22.5 mGy, not shown) than in the United States (20 mGy) [76]. The proportion of pediatric patients receiving brain dose above 40 mGy following a single head CT in our study (22%, not shown) was higher than that estimated by Bahadori et al. (11%) and raises concerns about cancer risk in this population. Head is the main type of CT examination among children. Pearce and colleagues found that children who received a cumulative brain dose of at least 50-74 mGy were at 2.8 fold greater risk of brain cancer [6]. Miglioretti and colleagues reported absorbed doses to the brain of 50 mGy or higher in 7%, 8% and 14% of the head scans in children <5, 5-9 and 10-14 years old, respectively, and suggested that reducing the highest 25% of doses within age groups and anatomic regions to the median dose could prevent more than 40% of the estimated radiation induced cancers [5].

Pearce and colleagues [6] also presented direct evidence of increased risk of leukemia following pediatric CT examinations with a three-fold risk among patients who received cumulative dose of at least 30 mGy in the active bone marrow. In our study, the highest estimated mean bone marrow dose was about 10 mGy following a single head/neck CT. Another organ for which there is concern about increased cancer risk following CT exposure is the thyroid [77], for which there is direct evidence of significant increased cancer risk following doses around 100-200 mGy [78]. We found that 11.4% of pediatric and young adult patients doing a spine CT received thyroid doses above 40 mGy, with about 9% of patients having doses above 50 mGy (not shown). The fact that multiple CT examinations on the same patient are not uncommon suggests the potential for a great number of pediatric and young adult patients receiving doses for which there is a demonstrated increase cancer risk [6, 79].

This was the first comprehensive report on pediatric CT use in Brazil, which evaluated not only the patterns and trends of both public and privately funded pediatric CT, but also estimated effective and absorbed doses for different types of CT scans in a large number of patients. Although some papers have assessed CT patterns in less resourced countries [26], to our knowledge this is the first report on pediatric patient absorbed doses on a developing country. Further, absorbed doses were estimated using individual scan parameters rather than standard protocols, and realistic hybrid phantoms representing female and male patients of different ages were used for computational simulations of radiation. However, our study has some limitations. First, data on privately funded pediatric CT were obtained from a sample of CT services, most of which were reference CT services, localized at developed cities, where health resources, including CT scanners, are more easily available [27, 28]. Thus, data for the private setting in this study may not be representative of CT use in the whole country. This limitation was even sharper when we analyzed CT trends over time, since exclusion of CT services without data for the whole study period resulted in a more reduced sample. Other limitation is that analysis on CT use on SUS included only outpatients. However, CT scans underwent by inpatients in SUS were much less frequent and have a similar distribution pattern by type of examination [80]. An important drawback is that we were not able to evaluate indications for examination, precluding analysis of imaging appropriateness. Moreover, some of the parameters that impact organ dose were not properly considered for dose calculations. Patient age and not his/her actual height/weight were used, and scans start and scan end positions were from typical examinations. Considering the potential differences in height/weight between Brazilian and European patients and CT protocol variations, using individual parameters would help to reduce uncertainty in our dose estimations. Further, when scanner CTDIvol was not available, dose calculation relied on the normalized CTDIw library, which may have measurement errors, adding uncertainty in derived CTDIvol values used for dose calculation. Nevertheless, Lee et al. compared measured and estimated CTDIvol using scan parameter and found that differences were not greater than 20% [39]. Also, this methodology has been validated by previous studies [81, 82].

5. Conclusion

CT use in children and young adults had increased between 2008 and 2014 both in public and private healthcare systems in Brazil. Nevertheless, annual growth rates were less pronounced in privately than in public funded healthcare system. Head/neck was the main type of CT examination in both settings and around one third of the patients in the private setting had more than one CT examination over the period investigated. Although CT examinations may improve life quality, avoiding more invasive and costly procedures for the detection, diagnosis and treatment of a variety of diseases and injuries, CT overuse and/or misuse, which increase health costs and may harm patient's health, might also be driving this increase, mainly in the private setting. Also, the great variation in effective doses delivered from the same type of examination in the same age group, and the relatively high absorbed doses estimated for some examinations suggest the need for optimization of CT exposures in Brazil. Efforts to improve radiation protection in pediatric CT in Brazil should include dissemination and wider use of appropriateness criteria and education and training of referring physicians and radiologists, as well as patients and the public. Initiatives to optimize pediatric CT protocols, as the establishment of reference levels and quality assurance programs are also needed.

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Table 1. Age distribution of CT examinations among SUS outpatients or patients using a sample of private CT services in Brazil (2008-2014)

Age	Population			
	SUS		Private sample	
<1	178,828	(1.0)	6,775	(0.5)
1-4	348,833	(2.0)	27,414	(1.8)
5-9	439,526	(2.5)	25,014	(1.7)
10-14	548,054	(3.1)	26,091	(1.7)
15-19	724,579	(4.1)	47,944	(3.2)
20-39	4,093,871	(22.9)	392,524	(26.1)
40-59	6,127,319	(34.3)	438,644	(29.1)
>60	5,390,453	(30.2)	540,228	(35.9)
All ages[a]	17,852,434	(100.0)	1,504,792	(100.0)

a. There were 971 and 158 CT scans with missing age in SUS and the private sample, respectively

Table 2. Number (N) and proportion (%) of CT examinations among patients younger than 20 years of age in the Brazilian public healthcare system (SUS) or in a sample of privately funded CT services, by imaged body part and age at examination (2008-2014)

Imaged body part	Population	Age at examination											
		<1		1-4		5-9		10-14		15-19		All	
head/neck	SUS	136,975	(76.6)	284,585	(81.6)	342,606	(77.9)	396,343	(72.3)	465,499	(64.2)	1,626,008	(72.6)
	Private sample	5,850	(86.3)	22,228	(81.1)	17,996	(71.9)	15,667	(60.0)	22,397	(46.7)	84,138	(63.1)
abdomen/pelvis	SUS	17,955	(10.0)	28,849	(8.3)	47,432	(10.8)	69,138	(12.6)	129,457	(17.9)	292,831	(13.1)
	Private sample	293	(4.3)	2,196	(8.0)	4,054	(16.2)	5,906	(22.6)	17,991	(37.5)	30,440	(22.8)
Spine	SUS	10,230	(5.7)	10,018	(2.9)	15,287	(3.5)	25,346	(4.6)	53,722	(7.4)	114,603	(5.1)
	Private sample	149	(2.2)	961	(3.5)	1,203	(4.8)	1,637	(6.3)	2,473	(5.2)	6,423	(4.8)
Chest	SUS	11,560	(6.5)	20,628	(5.9)	23,300	(5.3)	32,638	(6.0)	50,721	(7.0)	138,847	(6.2)
	Private sample	382	(5.6)	1,717	(6.3)	1,013	(4.0)	1,118	(4.3)	3,013	(6.3)	7,243	(5.4)
extremities	SUS	2,108	(1.2)	4,753	(1.4)	10,901	(2.5)	24,589	(4.5)	25,180	(3.5)	67,531	(3.0)
	Private sample	16	(0.2)	203	(0.7)	646	(2.6)	1,588	(6.1)	1,543	(3.2)	3,996	(3.0)
Other	SUS	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)
	Private sample	85	(1.3)	109	(0.4)	100	(0.4)	173	(0.7)	524	(1.1)	991	(0.7)
All[a]	SUS	178,828	(100.0)	348,833	(100.0)	439,526	(100.0)	548,054	(100.0)	724,579	(100.0)	2,239,820	(100.0)
	Private sample	6,775	(100.0)	27,414	(100.0)	25,014	(100.0)	26,091	(100.0)	47,944	(100.0)	133,238	(100.0)

a. There were 7 pediatric and young adult CT scans with missing imaged body part in the private sample

Table 3. Annual growth rates (CAGR, %) of CT examinations among patients younger than 20 years of age in the Brazilian public healthcare system (SUS) or in a sample of privately funded CT services, by age at examination (2008-2014)

Age	Population	CAGR (%)
<1	SUS	7.6
	Private sample (restricted)	13.1
1-4	SUS	8.9
	Private sample (restricted)	10.3
5-9	SUS	7.3
	Private sample (restricted)	5.3
10-14	SUS	8.8
	Private sample (restricted)	3.8
15-19	SUS	16.4
	Private sample (restricted)	7.1
Total	SUS	10.8
	Private sample (restricted)	6.8

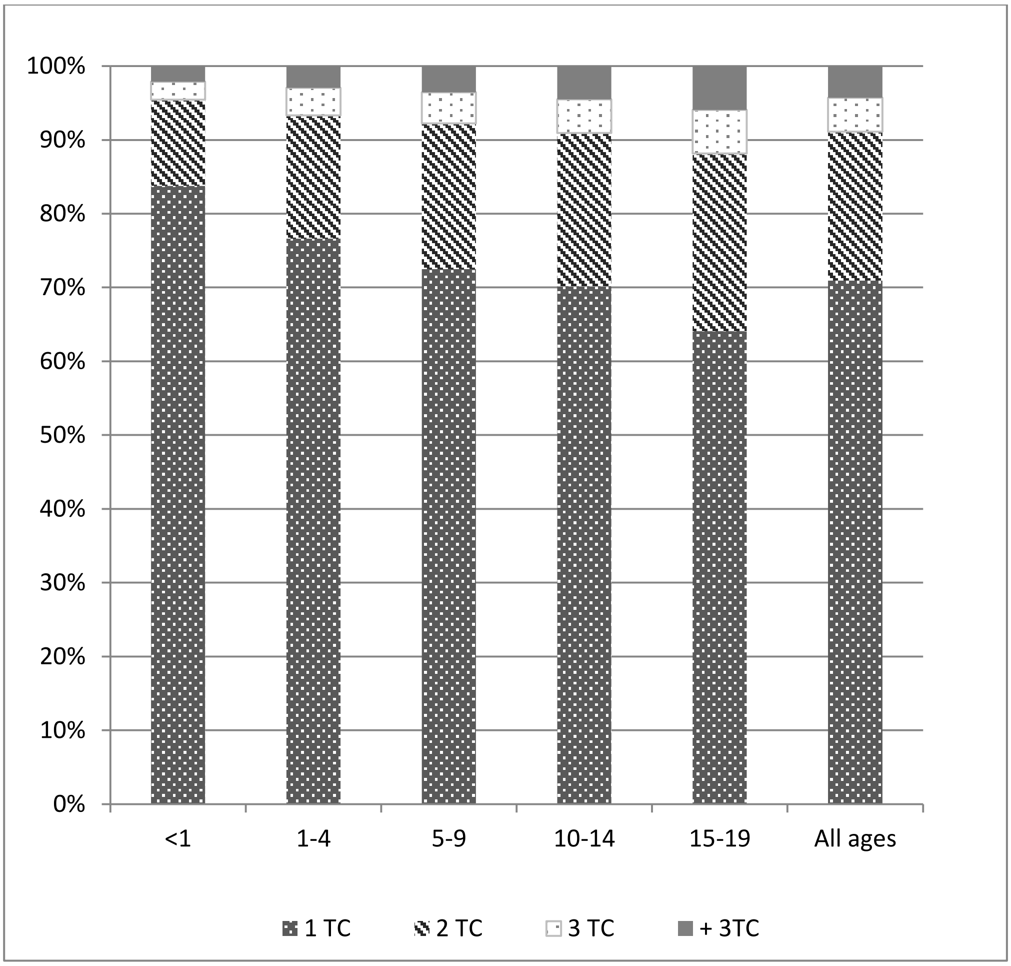

Figure 1. Proportion of multiple CT examinations per patient among patients younger than 20 years of age using a sample of private CT services in Brazil, by age group (2008-2014)

Table 4: Estimated effective and organ-absorbed doses from CT examinations by anatomic region and age at examination

	Head/neck CT					Chest CT					Abdomen/pelvis CT					Spine CT[a]		
	< 1	**1-4**	**5-9**	**10-14**	**15-19**	**< 1**	**1-4**	**5-9**	**10-14**	**15-19**	**< 1**	**1-4**	**5-9**	**10-14**	**15-19**	**5-9**	**10-14**	**15-19**
N exams	146	411	573	773	1,259	8	36	30	88	173	11	31	108	241	530	4	17	58
Effective dose (mSv)																		
Mean	1.6	2.1	2.1	1.4	1.2	2.1	2.9	2.4	3.0	4.4	13.5	4.8	5.3	7.5	7.4	5.9	9.3	7.3
Min	0.1	<0.1	<0.1	<0.1	<0.1	0.8	0.1	0.3	0.8	0.4	2.9	0.3	0.3	0.3	0.1	0.5	1.4	0.3
Max	3.8	5.1	6.1	7.2	6.6	4.2	4.7	8.9	12.0	24.2	36.0	19.2	24.8	37.1	31.9	14.7	22.3	54.2
Organ dose, mean (mGy)																		
Brain	25.2	27.5	29.0	27.2	23.8	0.5	0.1	0.1	0.2	0.1	0.3	0.1	0.0	0.0	0.0	1.8	1.8	0.3
Thyroid	2.3	2.4	2.9	2.1	2.7	7.6	7.5	6.4	10.2	11.3	6.9	0.7	0.4	0.4	0.2	18.6	23.5	8.9
Esophagus	0.9	1.5	1.2	0.7	0.8	4.8	5.2	4.1	5.6	6.8	11.7	3.3	3.0	4.1	2.7	5.7	10.1	4.1
Lungs	0.6	0.8	0.8	0.4	0.3	4.1	6.0	5.1	6.0	7.9	13.6	5.2	3.3	4.5	2.4	2.2	7.7	2.7
Breast	0.3	0.3	0.2	0.1	0.1	1.7	4.8	3.9	4.9	6.6	10.6	6.9	7.1	7.9	2.4	1.9	9.2	1.8
Stomach	0.2	0.2	0.1	0.1	0.0	1.6	3.4	2.9	3.4	6.5	23.2	8.4	9.3	13.2	14.6	7.6	13.1	13.6
Liver	0.2	0.2	0.1	0.1	0.1	1.7	3.8	3.2	4.0	6.7	23.4	8.3	8.8	12.3	13.2	7.2	12.8	11.9
Colon	0.1	0.1	0.0	0.0	0.0	0.7	0.5	0.3	0.4	1.3	20.4	7.1	10.2	14.7	16.6	9.0	12.9	16.9
Retosigmoid	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	16.4	2.6	5.5	7.7	9.6	6.0	4.7	6.9
Urinary bladder	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	14.9	2.0	3.8	5.8	9.5	6.0	2.4	5.0
Prostate	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.8	0.4	0.9	1.6	1.5	0.0	0.1	0.6
Ovaries	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	4.1	1.4	2.0	3.9	5.7	6.1	3.1	3.0
Active Bone Marrow	7.0	9.8	7.9	4.3	2.4	1.7	1.7	1.1	1.6	2.3	7.1	2.0	2.2	4.2	5.3	3.2	5.2	5.1

a. There was no registered spine CT for patients younger than 5 years old.

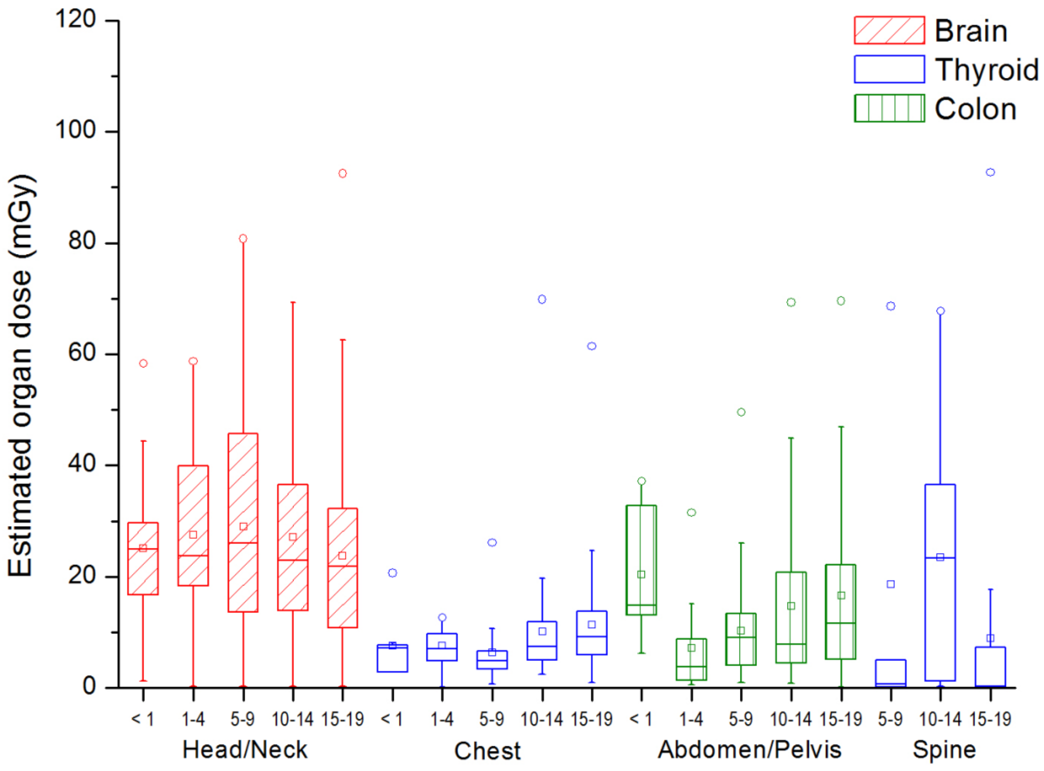

Figure 2. Variation in organ absorbed doses from pediatric and young adult CT scans among patients younger than 20 years of age in Brazil, by age group

References

1. Rubin, G.D., Computed tomography: revolutionizing the practice of medicine for 40 years. Radiology, 2014. 273(2 Suppl): p. S45-74.

2. Brenner, D., et al., Estimated risks of radiation-induced fatal cancer from pediatric CT. AJR Am J Roentgenol, 2001. 176(2): p. 289-96.

3. Berrington de Gonzalez, A., et al., Projected cancer risks from computed tomographic scans performed in the United States in 2007. Arch Intern Med, 2009. 169(22): p. 2071-7.

4. Sodickson, A., et al., Recurrent CT, cumulative radiation exposure, and associated radiation-induced cancer risks from CT of adults. Radiology, 2009. 251(1): p. 175-84.

5. Miglioretti, D.L., et al., The use of computed tomography in pediatrics and the associated radiation exposure and estimated cancer risk. JAMA Pediatr, 2013. 167(8): p. 700-7.

6. Pearce, M.S., et al., Radiation exposure from CT scans in childhood and subsequent risk of leukaemia and brain tumours: a retrospective cohort study. Lancet, 2012. 380(9840): p. 499-505.

7. Mathews, J.D., et al., Cancer risk in 680,000 people exposed to computed tomography scans in childhood or adolescence: data linkage study of 11 million Australians. BMJ, 2013. 346: p. f2360.

8. Huang, W.-Y., et al., Paediatric head CT scan and subsequent risk of malignancy and benign brain tumour: a nation-wide population-based cohort study. British Journal of Cancer, 2014. 110: p. 2354-2360.

9. Berrington de Gonzalez, A., et al., Relationship between paediatric CT scans and subsequent risk of leukaemia and brain tumours: assessment of the impact of underlying conditions. Br J Cancer, 2016. 114(4): p. 388-94.

10. Krille, L., et al., Risk of cancer incidence before the age of 15 years after exposure to ionising radiation from computed tomography: results from a German cohort study. Radiat Environ Biophys, 2015. 54(1): p. 1-12.

11. ICRP, The 2007 Recommendations of the International Commission on Radiological Protection. ICRP publication 103. Ann ICRP, 2007. 37(2-4): p. 1-332.

12. ICRP, Radiological Protection in Medicine. ICRP Publication 105. Ann ICRP 2007. 37(6): p. 1-64.

13. Ghotbi, N., et al., Pediatric CT scan usage in Japan: results of a hospital survey. Radiat Med, 2006. 24(8): p. 560-7.

14. Takei, Y., et al., Nationwide survey of radiation exposure during pediatric computed tomography examinations and proposal of age-based diagnostic reference levels for Japan. Pediatr Radiol, 2016. 46(2): p. 280-5.

15. Verdun, F.R., et al., CT radiation dose in children: a survey to establish age-based diagnostic reference levels in Switzerland. Eur Radiol, 2008. 18(9): p. 1980-6.

16. Galanski, M., H.D. Nagel, and G. Stamm, [Results of a federation inquiry 2005/2006: pediatric CT X-ray practice in Germany]. Rofo, 2007. 179(11): p. 1110-1.

17. Brady, Z., T.M. Cain, and P.N. Johnston, Paediatric CT imaging trends in Australia. J Med Imaging Radiat Oncol, 2011. 55(2): p. 132-42.

18. Chodick, G., et al., The utilization of pediatric computed tomography in a large Israeli Health Maintenance Organization. Pediatr Radiol, 2006. 36(6): p. 485-90.

19. Pearce, M.S., et al., CT Scans in Young People in Great Britain: Temporal and Descriptive Patterns, 1993-2002. Radiol Res Pract, 2012. 2012: p. 594278.

20. Neves, A., et al., Assessment of paediatric CT exposure in a Portuguese hospital. Radiat Prot Dosimetry, 2012. 151(3): p. 456-62.

21. Buls, N., K. Nieboer, and J. de Mey, Comment on article of K. Udayasankar, J. Li, D.A. Baumgarten, W.C. Small, M.K. Kalra: acute abdominal pain:value of non-contrast enhanced ultra-low-dose multi-detector row CT as a substitute for abdominal radiographs (2009). Emerg Radiol, 2010. 17(2): p. 165-6; author reply 167-8.

22. Brisse, H.J. and B. Aubert, [CT exposure from pediatric MDCT: results from the 2007-2008 SFIPP/ISRN survey]. J Radiol, 2009. 90(2): p. 207-15.

23. Thomas, K.E., CT utilization: trends and developments beyond the United States' borders. Pediatr Radiol, 2011. 41 Suppl 2: p. 562-566.

24. Pearce, M.S., Patterns in paediatric CT use: an international and epidemiological perspective. J Med Imaging Radiat Oncol, 2011. 55(2): p. 107-9.

25. Krille, L., et al., Computed tomographies and cancer risk in children: a literature overview of CT practices, risk estimations and an epidemiologic cohort study proposal. Radiat Environ Biophys, 2012. 51(2): p. 103-11.

26. Rehani, M.M., Multi-national findings on radiation protection of children. Pediatr Radiol, 2014. 44 Suppl 3: p. 475-8.

27. Dovales, A.C., et al., Patterns and trends of computed tomography usage in outpatients of the Brazilian public healthcare system, 2001-2011. J Radiol Prot, 2016. 36(3): p. 547-560.

28. Paim, J., et al., The Brazilian health system: history, advances, and challenges. Lancet, 2011. 377(9779): p. 1778-97.

29. Scanff, P., et al., Population exposure to ionizing radiation from medical examinations in France. Br J Radiol, 2008. 81(963): p. 204-13.

30. Aroua, A., et al., Number of X-ray examinations performed on paediatric and geriatric patients compared with adult patients. Radiat Prot Dosimetry, 2007. 123(3): p. 402-8.

31. Mettler, F.A., Jr., et al., CT scanning: patterns of use and dose. J Radiol Prot, 2000. 20(4): p. 353-9.

32. Vassileva, J., et al., IAEA survey of paediatric computed tomography practice in 40 countries in Asia, Europe, Latin America and Africa: procedures and protocols. Eur Radiol, 2013. 23(3): p. 623-31.

33. Muhogora, W.E., et al., Paediatric CT examinations in 19 developing countries: frequency and radiation dose. Radiat Prot Dosimetry, 2010. 140(1): p. 49-58.

34. Szwarcwald, C.L., P.R. Souza-Júnior, and G.N. Damacena, Socioeconomic inequalities in the use of outpatient services in Brazil according to health care need: evidence from the World Health Survey. BMC Health Services Research, 2010. 10: p. 217.

35. Viacava, F. and J.G. Bellido, Health, access to services and sources of payment, according to household surveys. Cien Saude Colet, 2016. 21(2): p. 351-70.

36. BRASIL. DATASUS. SUS Database. Ministério da Saúde, Brasil: Brasília, Brasil.

37. BRASIL. Escassez e fartura: distribuição da oferta de equipamentos de diagnóstico por imagem no Brasil in Indicadores sociodemográficos e de saúde no Brasil: 2009, Instituto Brasileiro de Geografia e Estatística (IBGE), Editor. 2009: Rio de Janeiro.

38. Jahnen, A., et al., Automatic computed tomography patient dose calculation using DICOM header metadata. Radiat Prot Dosimetry, 2011. 147(1-2): p. 317-20.

39. Lee, C., et al., NCICT: a computational solution to estimate organ doses for pediatric and adult patients undergoing CT scans. J Radiol Prot, 2015. 35(4): p. 891-909.

40. ICRP, Basic anatomical and physiological data for use in radiological protection: reference values. A report of age- and gender-related differences in the anatomical and physiological characteristics of reference individuals. ICRP Publication 89. Ann ICRP, 2002. 32(3-4): p. 5-265.

41. ICRP, Adult reference computational phantoms. ICRP Publication 110. Annals ICRP, 2009. 39: p. 1-166.

42. Vassileva, J., et al., IAEA survey of pediatric CT practice in 40 countries in Asia, Europe, Latin America, and Africa: Part 1, frequency and appropriateness. AJR Am J Roentgenol, 2012. 198(5): p. 1021-31.

43. Townsend, B.A., et al., Has pediatric CT at children's hospitals reached its peak? AJR Am J Roentgenol, 2010. 194(5): p. 1194-6.

44. Goske, M.J., et al., Image Gently 5 years later: what goals remain to be accomplished in radiation protection for children? AJR Am J Roentgenol, 2012. 199(3): p. 477-9.

45. Levin, D.C., V.M. Rao, and L. Parker, The recent downturn in utilization of CT: the start of a new trend? J Am Coll Radiol, 2012. 9(11): p. 795-8.

46. Parker, M.W., et al., Computed tomography and shifts to alternate imaging modalities in hospitalized children. Pediatrics, 2015. 136(3): p. e573-581.

47. Flohr, T.G., et al., Multi-detector row CT systems and image-reconstruction techniques. Radiology, 2005. 235(3): p. 756-73.

48. Irimia, P., et al., Use of imaging in cerebrovascular disease, in European Handbook of Neurological Management. 2011, Blackwell Publishing Ltd.

49. Michel, M., et al., Eye lens radiation exposure and repeated head CT scans: A problem to keep in mind. Eur J Radiol, 2012. 81(8): p. 1896-900.

50. Preston, D.L., et al., Studies of mortality of atomic bomb survivors. Report 13: solid cancer and noncancer disease mortality: 1950-1997. 2003. Radiat Res, 2012. 178(2): p. AV146-72.

51. Oikarinen, H., et al., Unjustified CT examinations in young patients. Eur Radiol, 2009. 19(5): p. 1161-5.

52. Tahvonen, P., et al., Justification of CT examinations in young adults and children can be improved by education, guideline implementation and increased MRI capacity. Br J Radiol, 2013. 86(1029): p. 20130337.

53. Hendee, W.R., et al., Addressing overutilization in medical imaging. Radiology, 2010. 257(1): p. 240-5.

54. CBR. Colégio Brasileiro de Radiologia e Diagnóstico por Imagem. Critérios de adequação de exames de imagem e radioterapia, 2005.

55. Borém, L., et al., O conhecimento dos médicos da atenção primária à saúde e da urgência sobre os exames de imagem [The knowledge about diagnostic imaging methods among primary care and medical emergency physicians]. Radiologia Brasileira, 2013. 46(6): p. 341-345.

56. Madrigano, R., et al., Avaliação do conhecimento de médicos não radiologistas sobre aspectos relacionados à radiação ionizante em exames de imagem. [Evaluation of non-radiologist physicians' knowledge on aspects related to ionizing radiation in imaging]. Radiologia Brasileira, 2014. 47(4): p. 210-216.

57. Lehnert, B.E. and R.L. Bree, Analysis of appropriateness of outpatient CT and MRI referred from primary care clinics at an academic medical center: how critical is the need for improved decision support? . J Am Coll Radiol, 2010. 7(3): p. 192-7.

58. Lysdahl, K.B. and B.M. Hofmann, What causes increasing and unnecessary use of radiological investigations? A survey of radiologists' perceptions. BMC Health Serv Res, 2009. 9: p. 155.

59. Bernier, M.O., et al., Radiation exposure from CT in early childhood: a French large-scale multicentre study. Br J Radiol, 2012. 85(1009): p. 53-60.

60. Tsushima, Y., et al., Radiation exposure from CT examinations in Japan. BMC Med Imaging, 2010. 10: p. 24.

61. Gonzaga, N.B., et al., Organ equivalent doses of patients undergoing chest computed tomography: measurements with TL dosimeters in an anthropomorphic phantom. Appl Radiat Isot, 2014. 83 Pt C: p. 242-4.

62. Andrade, M.E., et al., Organ doses and risks of computed tomography examinations in Recife, Brazil. J Radiol Prot, 2012. 32(3): p. 251-60.

63. Mecca, F.A., et al., Volume computed tomography air kerma index and image quality evaluation in Brazil. Radiat Prot Dosimetry, 2012. 148(4): p. 452-6.

64. de Jesus, F.M., L.A. Magalhaes, and S. Kodlulovich, Paediatric Ct Exposure Practice in the County of Rio De Janeiro: The Need to Establish Diagnostic Reference Levels. Radiat Prot Dosimetry, 2015. 171(3): p.389-397.

65. Paterson, A., D.P. Frush, and L.F. Donnelly, Helical CT of the body: are settings adjusted for pediatric patients? AJR Am J Roentgenol, 2001. 176(2): p. 297-301.

66. Hollingsworth, C., et al., Helical CT of the body: a survey of techniques used for pediatric patients. AJR Am J Roentgenol, 2003. 180(2): p. 401-6.

67. Huda, W. and A. Vance, Patient radiation doses from adult and pediatric CT. AJR Am J Roentgenol, 2007. 188(2): p. 540-6.

68. Shrimpton, P.C., et al., Doses from Computed Tomography (CT) Examinations - in the UK – 2011 Review, P.H. England, Editor. 2014: London.

69. Strauss, K.J., et al., Image gently: Ten steps you can take to optimize image quality and lower CT dose for pediatric patients. AJR Am J Roentgenol, 2010. 194(4): p. 868-73.

70. BRASIL, Diretrizes de Proteção Radiológica em Radiodiagnóstico Médico e Odontológico, in Portaria 453. 1998, Secretaria de Vigilância Sanitária. Ministério da Saúde: Brasil.

71. Staton, R.J., et al., Organ and effective doses in newborn patients during helical multislice computed tomography examination. Phys Med Biol, 2006. 51(20): p. 5151-66.

72. Mazonakis, M., et al., Thyroid dose from common head and neck CT examinations in children: is there an excess risk for thyroid cancer induction? Eur Radiol, 2007. 17(5): p. 1352-7.

73. Brisse, H.J., et al., Assessment of organ absorbed doses and estimation of effective doses from pediatric anthropomorphic phantom measurements for multi-detector row CT with and without automatic exposure control. Health Phys, 2009. 97(4): p. 303-14.

74. Lee, C., et al., Organ and effective doses in pediatric patients undergoing helical multislice computed tomography examination. Med Phys, 2007. 34(5): p. 1858-73.

75. Lee, C., et al., Reduction in radiation doses from paediatric CT scans in Great Britain. Br J Radiol, 2016. 89(1060): p. 20150305.

76. Bahadori, A., et al., Calculation of Organ Doses for a Large Number of Patients Undergoing CT Examinations. AJR Am J Roentgenol, 2015. 205(4): p. 827-33.

77 Schonfeld, S.J., C. Lee, and A. Berrington de Gonzalez, Medical exposure to radiation and thyroid cancer. Clin Oncol (R Coll Radiol), 2011. 23(4): p. 244-50.

78. Veiga, L.H., et al., Thyroid Cancer after Childhood Exposure to External Radiation: An Updated Pooled Analysis of 12 Studies. Radiat Res, 2016. 185(5): p. 473-84.

79. Schneider, A., L. Veiga, and J. Lubi, A Perspective on the New Pooled Analysis of Radiation-Associated Thyroid Cancer. Clinical Thyroidology, 2016. 28: p. 256-258.

80. Dovales, A.C.M., A.A. De Souza, and L.H. Veiga, Tomografia computadorizada no Brasil: frequência de uso em pacientes internados no Sistema Único de Saúde (SUS) [Computed tomography in Brazil: frequency and pattern of usage among inpatients of the Unified Health System (SUS)]. Revista Brasileira de Física Médica, 2015. 9(1): p. 11-14.

81. Dabin, J., et al., Validation of calculation algorithms for organ doses in CT by measurements on a 5 year old paediatric phantom. Phys Med Biol, 2016. 61(11): p. 4168-82.

82. Olerud, H.M., et al., Reconstruction of paediatric organ doses from axial CT scans performed in the 1990s - range of doses as input to uncertainty estimates. Eur Radiol, 2016. 26(9): p. 3026-33.

8. CONCLUSÕES E COMENTÁRIOS FINAIS

Este trabalho reporta um intenso crescimento no uso de procedimentos de diagnóstico por imagem no Brasil, que pode estar associado a melhores condições de assistência à saúde no país, possibilitando uma melhoria na detecção, diagnóstico e acompanhamento de uma variedade de condições médicas. Entretanto, não se pode descartar a possibilidade de uso excessivo ou inadequado desses exames, resultando em maiores custos na área de saúde e potenciais efeitos danosos à saúde dos pacientes.

O grande aumento no uso da tomografia computadorizada (TC), a proporção relativamente alta desses exames em crianças e jovens, e a magnitude das doses estimadas geram preocupação sobre os potenciais riscos de indução de câncer associados a essa modalidade de diagnóstico por imagem. Desta forma, ações de proteção radiológica em TC, particularmente nos exames de crianças e adultos jovens, devem ser promovidas no Brasil. Isso inclui a disseminação de critérios de adequação para exames radiológicos e a educação e treinamento de radiologistas e de profissionais que prescrevem exames sobre as doses e riscos associados a estes procedimentos, fundamentais para que os exames sejam justificados. Também é necessário que sejam tomadas iniciativas para otimizar os protocolos de exames, incluindo o estabelecimento de níveis de referência e de programas de garantia de qualidade.

Este trabalho possui pontos fortes e algumas limitações. Dentre os pontos fortes, podemos destacar o fato desse trabalho se constituir na primeira avaliação sistemática do padrão e tendência de uso de procedimentos de diagnóstico por imagem no Brasil, incluindo um detalhamento do uso da TC por crianças e adultos jovens. É também um dos poucos estudos que estimou doses em exames de TC para um grande número de pacientes pediátricos de diversas idades, sendo o primeiro em um país em desenvolvimento. Foi utilizada uma grande base de dados sobre exames em pacientes ambulatoriais do SUS, que é o principal provedor de assistência à saúde para aproximadamente 150 milhões de brasileiros (PAIM et al., 2011) e um dos maiores sistemas de assistência à saúde do mundo. Finalmente, as doses absorvidas foram estimadas usando parâmetros individuais e não protocolos padrão de exames, usando uma metodologia previamente validada (DABIN et al., 2016; LEE et al., 2015; OLERUD et al., 2016) e que está sendo usada para a dosimetria em exames de TC em um grande estudo epidemiológico sobre risco de câncer em decorrência desses exames (THIERRY-CHEF et al., 2013).

Dentre as limitações, podemos citar o fato da maior parte dos dados ser proveniente de pacientes ambulatoriais do SUS, não incluindo dados de pacientes internados nesse sistema de saúde. No entanto, os procedimentos de TC em pacientes ambulatoriais representam a maior parcela desses exames no SUS (cerca de 65% do total de procedimentos), apresentando tendência de uso e distribuição por tipo de exame similar a dos procedimentos hospitalares (BRASIL; DOVALES et al., 2015). Ainda, embora o SUS seja o principal provedor de assistência à saúde no Brasil, não é possível afirmar que os resultados aqui apresentados sejam representativos do padrão e tendência do uso de procedimentos de diagnóstico por imagem no Brasil como um todo. O setor privado só é acessível a uma menor proporção da população brasileira, mas tem maior disponibilidade de recursos finaceiros e humanos (BRASIL, 2012; SANTOS et al., 2008; SZWARCWALD et al., 2010), podendo apresentar padrão e tendência de uso de procedimentos de diagnóstico por imagem diferente do setor público. A avaliação do uso de TC por crianças e adultos jovens, incluindo a estimativa das doses, se estendeu ao setor privado, mas foi utilizada uma amostra, composta principalmente de serviços de radiologia de referência, localizados em grandes cidades do país. Essa amostra não é representativa da grande diversidade regional existente na assistência à saúde no Brasil (TRAVASSOS et al., 2000), mas pode ser vista como representativa do padrão de uso de TC em grandes centros urbanos. Adicionalmente, as incertezas associadas às estimativas de dose nesse estudo poderiam ser reduzidas pelo uso do peso e altura do paciente, ao invés de sua idade, e ainda, pela utilização de posições de início e fim de varredura obtidas do exame individual e não das posições extraídas de protocolos típicos. Finalmente, quando o valor de CTDIvol do tomógrafo computadorizado não está disponível, o cálculo das doses depende de uma biblioteca de CTDIw normalizada, que pode ter erros de medição, adicionando incerteza aos valores de CTDIvol calculados e usados para a estimativa das doses. Porém, essas diferenças foram estimadas como inferiores a 20% (LEE et al., 2015)

Como continuação desse trabalho, pretende-se:

a) Estender a avaliação do padrão e tendência de usos de exames de TC a diferentes tipos de serviços de radiologia (hospitais gerais e especializados, serviços ambulatoriais de diagnóstico por imagem, etc.) em diferentes regiões geográficas do Brasil;

b) Estender a avaliação das doses em exames de TC em crianças e adultos jovens a diferentes tipos de serviços de radiologia no Brasil;

c) Determinar os valores típicos das posições de início e fim de varredura para os principais exames de TC em crianças e adultos jovens no Brasil;

d) Calcular o risco de indução de câncer em decorrência de exames de TC em crianças e jovens no Brasil;

e) Avaliar as indicações clínicas para exames de TC em crianças e adultos jovens;

9. ASPECTOS ÉTICOS

De acordo com a resolução CNS 196/96, esta pesquisa é dispensada de apresentar termos de consentimento livre e esclarecido, uma vez que: i) É um estudo descritivo retrospectivo, que emprega apenas informações de sistemas de informação institucionais e/ou demais fontes de dados e informações disponíveis na instituição sem previsão de utilização de material biológico; ii) Todos os dados são manejados e analisados de forma anônima, sem identificação nominal dos participantes de pesquisa; iii) Os resultados decorrentes do estudo são apresentados de forma agregada, não permitindo a identificação individual dos participantes, e iv) Se trata de um estudo não intervencionista (sem intervenções clínicas) e sem alterações/influências na rotina/tratamento do participante de pesquisa, e consequentemente sem adição de riscos ou prejuízos ao bem-estar dos mesmos.

10. SUPORTE FINANCEIRO

Este projeto teve o apoio financeiro da CAPES, através do AUXP 138/2013, do Programa Pesquisador Visitante Especial.

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REFERÊNCIAS

ANDRADE, M.E., et al. Organ doses and risks of computed tomography examinations in Recife, Brazil. **J Radiol Prot**, v. 32, p. 251-260, 2012.

AROUA, A., et al. Exposure of the Swiss population to computed tomography. **BMC Med Imaging**, v. 13, p. 22, 2013.

BAHADORI, A., et al. Calculation of Organ Doses for a Large Number of Patients Undergoing CT Examinations. **AJR Am J Roentgenol**, v. 205, p. 827-833, 2015.

BEIR. Health risks from exposure to low levels of ionizing radiation: BEIR VII Phase 2. (Washington, DC: Biological Effects of Ionizing Radiation. National Research Council (U.S.). Committee to assess health risks from exposure to low level of ionizing radiation.), 2006

BERNIER, M.O., et al. Radiation exposure from CT in early childhood: a French large-scale multicentre study. **Br J Radiol**, v. 85, p. 53-60, 2012.

BERRINGTON DE GONZALEZ, A.; DARBY, S. Risk of cancer from diagnostic X-rays: estimates for the UK and 14 other countries. **Lancet**, v. 363, p. 345-351, 2004.

BERRINGTON DE GONZALEZ, A., et al. Projected cancer risks from computed tomographic scans performed in the United States in 2007. **Arch Intern Med**, v. 169, p. 2071-2077, 2009.

BERRINGTON DE GONZALEZ, A., et al. Relationship between paediatric CT scans and subsequent risk of leukaemia and brain tumours: assessment of the impact of underlying conditions. **Br J Cancer**, v. 114, p. 388-394, 2016.

BORÉM, L., et al. O conhecimento dos médicos da atenção primária à saúde e da urgência sobre os exames de imagem [The knowledge about diagnostic imaging methods among primary care and medical emergency physicians]. **Radiologia Brasileira**, v. 46, p. 341-345, 2013.

BRADY, Z.; CAIN, T.M.; JOHNSTON, P.N. Paediatric CT imaging trends in Australia. **J Med Imaging Radiat Oncol**, v. 55, p. 132-142, 2011.

BRASIL. DATASUS. SUS Database (Brasília, Brasil: Ministério da Saúde, Brasil),

BRASIL. Informações de Saúde (TABNET) (DATASUS/SUS/Ministério da Saúde),

BRASIL. Instituto Brasileiro de Geografia e Estatística - IBGE. Conta-Satélite de Saúde Brasil 2007-2009. Contas Nacionais, 2012

BRENNER, D., et al. Estimated risks of radiation-induced fatal cancer from pediatric CT. **AJR Am J Roentgenol**, v. 176, p. 289-296, 2001.

BRENNER, D.J.; HALL, E.J. Computed tomography: an increasing source of radiation exposure. **N Engl J Med**, v. 357, p. 2277-2284, 2007.

BRISSE, H.J., et al. Assessment of organ absorbed doses and estimation of effective doses from pediatric anthropomorphic phantom measurements for multi-detector row CT with and without automatic exposure control. **Health Phys**, v. 97, p. 303-314, 2009.

CHODICK, G., et al. The utilization of pediatric computed tomography in a large Israeli Health Maintenance Organization. **Pediatr Radiol**, v. 36, p. 485-490, 2006.

CHODICK, G., et al. Excess lifetime cancer mortality risk attributable to radiation exposure from computed tomography examinations in children. **Isr Med Assoc J**, v. 9, p. 584-587, 2007.

DABIN, J., et al. Validation of calculation algorithms for organ doses in CT by measurements on a 5 year old paediatric phantom. **Phys Med Biol**, v. 61, p. 4168-4182, 2016.

DE JESUS, F.M.; MAGALHAES, L.A.; KODLULOVICH, S. Paediatric CT Exposure Practice in the County of Rio De Janeiro: The Need to Establish Diagnostic Reference Levels. **Radiat Prot Dosimetry**, v. 171, p. 389-397, 2016.

DEMETER, S., et al. Socioeconomic status and the utilization of diagnostic imaging in an urban setting. **CMAJ**, v. 173, p. 1173-1177, 2005.

DOVALES, A.C.M.; DE SOUZA, A.A.; VEIGA, L.H. Tomografia computadorizada no Brasil: frequência de uso em pacientes internados no Sistema Único de Saúde (SUS) [Computed tomography in Brazil: frequency and pattern of usage among inpatients of the Unified Health System (SUS)]. **Revista Brasileira de Física Médica**, v. 9, p. 11-14, 2015.

EL GHISSASSI, F., et al. A review of human carcinogens--part D: radiation. **Lancet Oncol**, v. 10, p. 751-752, 2009.

GALANSKI, M.; NAGEL, H.D.; STAMM, G. [Results of a federation inquiry 2005/2006: pediatric CT X-ray practice in Germany]. **Rofo**, v. 179, p. 1110-1111, 2007.

GONZAGA, N.B., et al. Organ equivalent doses of patients undergoing chest computed tomography: measurements with TL dosimeters in an anthropomorphic phantom. **Appl Radiat Isot**, v. 83 Pt C, p. 242-244, 2014.

HALL, E.J.; BRENNER, D.J. Cancer risks from diagnostic radiology. **Br J Radiol**, v. 81, p. 362-378, 2008.

HAMRA, G.B., et al. Trends in diagnostic CT among fee-for-service enrollees, 2000-2011. **J Am Coll Radiol**, v. 11, p. 125-130, 2014.

HARRISON, J.D., et al. Use of effective dose. **Ann ICRP**, v. 45, p. 215-224, 2016.

HENDEE, W.R., et al. Addressing overutilization in medical imaging. **Radiology**, v. 257, p. 240-245, 2010.

HOLLINGSWORTH, C., et al. Helical CT of the body: a survey of techniques used for pediatric patients. **AJR Am J Roentgenol**, v. 180, p. 401-406, 2003.

HUANG, W.-Y., et al. Paediatric head CT scan and subsequent risk of malignancy and benign brain tumour: a nation-wide population-based cohort study. **British Journal of Cancer**, v. 110, p. 2354-2360, 2014.

HUDA, W.; VANCE, A. Patient radiation doses from adult and pediatric CT. **AJR Am J Roentgenol**, v. 188, p. 540-546, 2007.

HUDA, W., et al. Computation of thyroid doses and carcinogenic radiation risks to patients undergoing neck CT examinations. **Radiat Prot Dosimetry**, v. 156, p. 436-444, 2013.

IAEA. International Atomic Energy Agency. Optimisation of the radiological protection of patients undergoing radiography, fluoroscopy and computed tomography. Document no. IAEA-TECDOC-1423 (Vienna, Austria), 2004

ICRP. International Commission on Radiological Protection. Radiological Protection in Medicine. ICRP Publication 105. **Ann ICRP**, v. 37, p. 1-64, 2007.

IGLEHART, J.K. The new era of medical imaging--progress and pitfalls. **N Engl J Med**, v. 354, p. 2822-2828, 2006.

IGLEHART, J.K. Health insurers and medical-imaging policy--a work in progress. **N Engl J Med**, v. 360, p. 1030-1037, 2009.

KALRA, M.K., et al. Strategies for CT radiation dose optimization. **Radiology**, v. 230, p. 619-628, 2004.

KRILLE, L., et al. Computed tomographies and cancer risk in children: a literature overview of CT practices, risk estimations and an epidemiologic cohort study proposal. **Radiat Environ Biophys**, v. 51, p. 103-111, 2012.

LAND, C.E. Estimating cancer risks from low doses of ionizing radiation. **Science**, v. 209, p. 1197-1203, 1980.

LANG, K., et al. National trends in advanced outpatient diagnostic imaging utilization: an analysis of the medical expenditure panel survey, 2000-2009. **BMC Med Imaging**, v. 13, p. 40, 2013.

LARSON, D.B., et al. Rising use of CT in child visits to the emergency department in the United States, 1995-2008. **Radiology**, v. 259, p. 793-801, 2011.

LEE, C., et al. Organ and effective doses in pediatric patients undergoing helical multislice computed tomography examination. **Med Phys**, v. 34, p. 1858-1873, 2007.

LEE, C., et al. NCICT: a computational solution to estimate organ doses for pediatric and adult patients undergoing CT scans. **J Radiol Prot**, v. 35, p. 891-909, 2015.

LEVIN, D.C.; RAO, V.M.; PARKER, L. The recent downturn in utilization of CT: the start of a new trend? **J Am Coll Radiol**, v. 9, p. 795-798, 2012.

LIMA, D., et al. Access and equity in use of diagnostic imaging in Brazil: a longitudinal ecological study. **Lancet**, v. 384, S 17, p., 2014.

LINET, M.S., et al. Cancer risks associated with external radiation from diagnostic imaging procedures. **CA Cancer J Clin**, v. 62, p. 75-100, 2012.

MADRIGANO, R., et al. Avaliação do conhecimento de médicos não radiologistas sobre aspectos relacionados à radiação ionizante em exames de imagem. [Evaluation of non-radiologist physicians' knowledge on aspects related to ionizing radiation in imaging]. **Radiologia Brasileira**, v. 47, p. 210-216, 2014.

MAHESH, M. Advances in CT technology and application to pediatric imaging. **Pediatr Radiol**, v. 41 Suppl 2, p. 493-497, 2011.

MALONE, J., et al. Justification of diagnostic medical exposures: some practical issues. Report of an International Atomic Energy Agency Consultation. **Br J Radiol**, v. 85, p. 523-538, 2012.

MATHEWS, J.D., et al. Cancer risk in 680,000 people exposed to computed tomography scans in childhood or adolescence: data linkage study of 11 million Australians. **BMJ**, v. 346, p. f2360, 2013.

MAZONAKIS, M., et al. Thyroid dose from common head and neck CT examinations in children: is there an excess risk for thyroid cancer induction? **Eur Radiol**, v. 17, p. 1352-1357, 2007.

MECCA, F.A., et al. Volume computed tomography air kerma index and image quality evaluation in Brazil. **Radiat Prot Dosimetry**, v. 148, p. 452-456, 2012.

METTLER, F.A., JR., et al. CT scanning: patterns of use and dose. **J Radiol Prot**, v. 20, p. 353-359, 2000.

METTLER, F.A., JR., et al. Effective doses in radiology and diagnostic nuclear medicine: a catalog. **Radiology**, v. 248, p. 254-263, 2008.

METTLER, F.A., JR., et al. Radiologic and nuclear medicine studies in the United States and worldwide: frequency, radiation dose, and comparison with other radiation sources:1950-2007. **Radiology**, v. 253, p. 520-531, 2009.

MIGLIORETTI, D.L., et al. The use of computed tomography in pediatrics and the associated radiation exposure and estimated cancer risk. **JAMA Pediatr**, v. 167, p. 700-707, 2013.

MUHOGORA, W.E., et al. Paediatric CT examinations in 19 developing countries: frequency and radiation dose. **Radiat Prot Dosimetry**, v. 140, p. 49-58, 2010.

NCRP. National Council on Radiation Protection and Measurements. Report No. 160: Ionizing Radiation Exposure of the Population of the United States, 2009

NHS. National Health Services. Total number of imaging and radiodiagnostic examinations or tests, by imaging modality, England, 1995-96 to 2012-13 (England: NHS), 2014

OIKARINEN, H., et al. Unjustified CT examinations in young patients. **Eur Radiol**, v. 19, p. 1161-1165, 2009.

OLERUD, H.M., et al. Reconstruction of paediatric organ doses from axial CT scans performed in the 1990s - range of doses as input to uncertainty estimates. **Eur Radiol**, v. 26, p. 3026-3033, 2016.

ONS. UK Office for National Statistics. Population Estimates for UK, England and Wales, Scotland and Northern Ireland, 2014

PAIM, J., et al. The Brazilian health system: history, advances, and challenges. **Lancet**, v. 377, p. 1778-1797, 2011.

PATERSON, A.; FRUSH, D.P.; DONNELLY, L.F. Helical CT of the body: are settings adjusted for pediatric patients? **AJR Am J Roentgenol**, v. 176, p. 297-301, 2001.

PEARCE, M.S. Patterns in paediatric CT use: an international and epidemiological perspective. **J Med Imaging Radiat Oncol**, v. 55, p. 107-109, 2011.

PEARCE, M.S., et al. CT Scans in Young People in Great Britain: Temporal and Descriptive Patterns, 1993-2002. **Radiol Res Pract**, v. 2012, p. 594278, 2012a.

PEARCE, M.S., et al. Radiation exposure from CT scans in childhood and subsequent risk of leukaemia and brain tumours: a retrospective cohort study. **Lancet**, v. 380, p. 499-505, 2012b.

PORTO, S.M.; UGA, M.A.; MOREIRA RDA, S. [An analysis of use of the health services by financing system: Brazil 1998-2008]. **Cien Saude Colet**, v. 16, p. 3795-3806, 2011.

PRESTON, D.L., et al. Studies of mortality of atomic bomb survivors. Report 13: solid cancer and noncancer disease mortality: 1950-1997. 2003. **Radiat Res**, v. 178, p. AV146-172, 2012.

REHANI, M.M. Multi-national findings on radiation protection of children. **Pediatr Radiol**, v. 44 Suppl 3, p. 475-478, 2014.

RUBIN, G.D. Computed tomography: revolutionizing the practice of medicine for 40 years. **Radiology**, v. 273, p. S45-74, 2014.

SANTOS, D.L., et al. [CT scanners in the Brazilian Unified National Health System: installed capacity and utilization]. **Cad Saude Publica**, v. 30, p. 1293-1304, 2014.

SANTOS, I.S.; UGA, M.A.; PORTO, S.M. [The public-private mix in the Brazilian Health System: financing, delivery and utilization of health services]. **Cien Saude Colet**, v. 13, p. 1431-1440, 2008.

SCHNEIDER, A.; VEIGA, L.; LUBI, J. A Perspective on the New Pooled Analysis of Radiation-Associated Thyroid Cancer. **Clinical Thyroidology**, v. 28, p. 256-258, 2016.

SCHONFELD, S.J.; LEE, C.; BERRINGTON DE GONZALEZ, A. Medical exposure to radiation and thyroid cancer. **Clin Oncol (R Coll Radiol)**, v. 23, p. 244-250, 2011.

SMITH-BINDMAN, R.; MIGLIORETTI, D.L.; LARSON, E.B. Rising use of diagnostic medical imaging in a large integrated health system. **Health Aff (Millwood)**, v. 27, p. 1491-1502, 2008.

SMITH-BINDMAN, R., et al. Use of diagnostic imaging studies and associated radiation exposure for patients enrolled in large integrated health care systems, 1996-2010. **JAMA**, v. 307, p. 2400-2409, 2012.

STATON, R.J., et al. Organ and effective doses in newborn patients during helical multislice computed tomography examination. **Phys Med Biol**, v. 51, p. 5151-5166, 2006.

SZWARCWALD, C.L.; SOUZA-JÚNIOR, P.R.; DAMACENA, G.N. Socioeconomic inequalities in the use of outpatient services in Brazil according to health care need: evidence from the World Health Survey. **BMC Health Services Research**, v. 10, p. 217, 2010.

TAHVONEN, P., et al. Justification of CT examinations in young adults and children can be improved by education, guideline implementation and increased MRI capacity. **Br J Radiol**, v. 86, p. 20130337, 2013.

TAKEI, Y., et al. Nationwide survey of radiation exposure during pediatric computed tomography examinations and proposal of age-based diagnostic reference levels for Japan. **Pediatr Radiol**, v. 46, p. 280-285, 2016.

THIERRY-CHEF, I., et al. Assessing organ doses from paediatric CT scans--a novel approach for an epidemiology study (the EPI-CT study). **Int J Environ Res Public Health**, v. 10, p. 717-728, 2013.

THOMAS, K.E. CT utilization: trends and developments beyond the United States' borders. **Pediatr Radiol**, v. 41 Suppl 2, p. 562-566, 2011.

TRAVASSOS, C.M.R., et al. Desigualdades geográficas e sociais na utilização de serviços de saúde no Brasil. [Social and geographical inequalities in health services utilization in Brazil]. **Ciência & Saúde Coletiva**, v. 5, p. 133-149, 2000.

TSUSHIMA, Y., et al. Radiation exposure from CT examinations in Japan. **BMC Med Imaging**, v. 10, p. 24, 2010.

UNSCEAR. United Nations Scientific Committee on the Effects of Atomic Radiation. UNSCEAR 2008 Report to the General Assembly with Scientific Annexes. Sources and Effects of Ionizing Radiation. Vol I, Annex A: Medical radiation exposures (New York, NY), 2010

UNSCEAR. United Nations Scientific Committee on the Effects of Atomic Radiation. UNSCEAR 2013 Report to the General Assembly with Scientific Annexes. Sources, Effects and Risks of Ionizing Radiation. Vol II, Annex B: Effects of radiation exposure of children. (New York, NY: United Nations), 2013

VASSILEVA, J., et al. IAEA survey of pediatric CT practice in 40 countries in Asia, Europe, Latin America, and Africa: Part 1, frequency and appropriateness. **AJR Am J Roentgenol**, v. 198, p. 1021-1031, 2012.

VEIGA, L.H., et al. Thyroid Cancer after Childhood Exposure to External Radiation: An Updated Pooled Analysis of 12 Studies. **Radiat Res**, v. 185, p. 473-484, 2016.

VERDUN, F.R., et al. CT radiation dose in children: a survey to establish age-based diagnostic reference levels in Switzerland. **Eur Radiol**, v. 18, p. 1980-1986, 2008.

VICTORA, C.G., et al. Health conditions and health-policy innovations in Brazil: the way forward. **Lancet**, v. 377, p. 2042-2053, 2011.

WHITE, K.S. Invited article: helical/spiral CT scanning: a pediatric radiology perspective. **Pediatr Radiol**, v. 26, p. 5-14, 1996.

YEKELER, E. Pediatric abdominal applications of multidetector-row CT. **Eur J Radiol**, v. 52, p. 31-43, 2004.