OULU 2021
D 1632

ACTA UNIVERSITATIS OULUENSIS

D
MEDICA

Pirita Tahvonen

APPROPRIATENESS OF RADIOLOGICAL EXAMINATIONS EXPOSING TO IONIZING RADIATION: THE EFFECT OF ACTIVE REFERRAL GUIDELINE IMPLEMENTATION

UNIVERSITY OF OULU GRADUATE SCHOOL;
UNIVERSITY OF OULU,
FACULTY OF MEDICINE;
MEDICAL RESEARCH CENTER OULU

ACTA UNIVERSITATIS OULUENSIS
D Medica 1632

PIRITA TAHVONEN

APPROPRIATENESS OF RADIOLOGICAL EXAMINATIONS EXPOSING TO IONIZING RADIATION: THE EFFECT OF ACTIVE REFERRAL GUIDELINE IMPLEMENTATION

Academic dissertation to be presented with the assent of the Doctoral Training Committee of Health and Biosciences of the University of Oulu for public defence in Auditorium 7 of Oulu University Hospital, on 10 September 2021, at 12 noon

UNIVERSITY OF OULU, OULU 2021

Acta Univ. Oul. D 1632, 2021

Supervised by
Professor Osmo Tervonen
Docent Heljä Oikarinen

Reviewed by
Docent Erkki Svedström
Docent Martti Kiuru

Opponent
Professor Ritva Vanninen

ISBN 978-952-62-3021-4 (Paperback)
ISBN 978-952-62-3022-1 (PDF)

ISSN 0355-3221 (Printed)
ISSN 1796-2234 (Online)

Cover Design
Raimo Ahonen

PUNAMUSTA
TAMPERE 2021

Tahvonen, Pirita , Appropriateness of radiological examinations exposing to ionizing radiation: the effect of active referral guideline implementation.
University of Oulu Graduate School; University of Oulu, Faculty of Medicine; Medical Research Center Oulu
Acta Univ. Oul. D 1632, 2021
University of Oulu, P.O. Box 8000, FI-90014 University of Oulu, Finland

Abstract

When using ionizing radiation, justification must always be considered due to the possibility of radiation-promoted carcinogenesis. The radiation-induced lifetime risk of cancer mortality is higher in young age. A radiological examination is justified when the benefit to the patient is greater than the expected harm. Although the risk to an individual is small, the concern is attributed to the rapid increase in collective radiation doses, especially related to increased use of CT. Radiographies are still the most frequent examinations using ionizing radiation. The radiation dose of lumbar spine radiography is among the highest, and the radiation is delivered to radiation-sensitive organs. Imaging referral guidelines have been developed to support referrers in selecting and justifying radiological procedures.

The purpose of this study was to follow up the effects of active guideline implementation, including education, on the volume and appropriateness of CTs and lumbar spine radiographs on young people in Oulu University Hospital and of spine radiographs in adults in primary care. Furthermore, the aim was to evaluate whether inappropriate lumbar spine radiographs in Oulu University Hospital had relevant findings.

A statistically significant reduction in the number of CTs in young people was seen in lumbar spine (-80%), cervical spine (-48%) and head (-21%). The number of all spine radiographs decreased significantly; that of lumbar spine radiographs in university hospital by 37% and spine radiographs in primary care by 51%. The justification of performed examinations improved or remained unchanged in all categories. A significant change was seen in overall appropriateness of CTs, from 71% to 87%. The appropriateness of lumbar spine examinations in Oulu University Hospital and of lumbar spine radiographs in primary care improved significantly. However, the level of appropriateness of different spine radiographs in primary care remained low even after the interventions. The proportion of notable findings in lumbar spine was significantly higher in radiographs that were in accordance with the guidelines than in radiographs that were not.

In conclusion, guideline implementation and education can significantly decrease the number of radiological examinations and result in more appropriate examinations. However, persistent follow-up and education seem to be necessary.

Keywords: appropriateness, back pain, CT, education, guidelines, imaging, ionizing radiation, justification, radiography, spine

Tahvonen, Pirita , Oikeutus ionisoivalle säteilylle altistavissa kuvantamistutkimuksissa: lähettämissuositusten ja koulutuksen vaikutukset.
Oulun yliopiston tutkijakoulu; Oulun yliopisto, Lääketieteellinen tiedekunta; Oulun yliopisto, Medical Research Center Oulu
Acta Univ. Oul. D 1632, 2021
Oulun yliopisto, PL 8000, 90014 Oulun yliopisto

Tiivistelmä

Ionisoivasta säteilystä aiheutuvien haittavaikutusten, erityisesti syöpäriskin, vuoksi ionisoivalle säteilylle altistavilla kuvantamistutkimuksilla tulee olla oikeutus. Säteilystä aiheutuvan elinikäisen syöpäkuoleman riski on suurempi nuorilla. Tutkimus on oikeutettu, kun siitä potilaalle odotettavissa oleva hyöty on suurempi kuin säteilyaltistukseen liittyvä haitta. Vaikka yksilön riski on pieni, väestön nopeasti lisääntyvä kollektiivinen säteilyannos aiheuttaa huolta erityisesti tietokonetomografiatutkimusten (TT) lisääntymiseen liittyen. Tavanomaisia röntgentutkimuksia tehdään kuitenkin edelleen määrällisesti eniten. Lannerangan röntgentutkimus on yksi korkeaannoksisimmista ja siinä säteily kohdistuu säteilyherkille alueille. Kuvantamistutkimusten lähettämissuositukset on kehitetty tukemaan lähettäviä lääkäreitä sopivan ja oikeutetun tutkimuksen valitsemisessa.

Tämän tutkimuksen tarkoitus oli seurata lähettämissuositusten ja koulutuksen vaikutusta kuvantamismääriin ja oikeutukseen nuorten TT-tutkimusten ja lannerangan röntgentutkimusten suhteen Oulun yliopistollisessa sairaalassa ja aikuisten rangan röntgentutkimusten suhteen perusterveydenhuollossa. Lisäksi tarkoitus oli selvittää, onko lähettämissuositusten vastaisissa lannerangan röntgentutkimuksissa merkittäviä kuvantamislöydöksiä.

Nuorten TT-tutkimusten määrä aleni tilastollisesti merkitsevästi lannerangan (-80 %), kaularangan (-48 %) ja pään (-21 %) TT-tutkimuksissa. Myös rangan röntgentutkimusten määrä laski merkitsevästi: lannerangan röntgentutkimukset vähenivät yliopistosairaalassa 37 % ja rangan röntgentutkimukset perusterveydenhuollossa 51 %. Oikeutettujen tutkimusten osuus lisääntyi tai pysyi ennallaan. Nuorten oikeutettujen TT-tutkimusten osuus kasvoi merkitsevästi, 71 %:sta 87 %:iin. Myös lannerangan TT-tutkimusten oikeutus yliopistosairaalassa ja lannerangan röntgentutkimusten oikeutus sekä yliopistosairaalassa että perusterveydenhuollossa parantui merkitsevästi. Oikeutettujen rangan röntgentutkimusten osuus oli kuitenkin yllättävän alhainen perusterveydenhuollossa vielä toimenpiteiden jälkeenkin. Merkittäviä löydöksiä oli merkitsevästi enemmän niissä lannerangan röntgentutkimuksissa, jotka olivat lähettämissuositusten mukaisia.

Lähettämissuositukset ja koulutus voivat vähentää säteilylle altistavien tutkimusten määrää ja parantaa tutkimusten oikeutusta merkitsevästi. Jatkuva seuranta ja kouluttaminen ovat kuitenkin tarpeen.

Asiasanat: ionisoiva säteily, koulutus, kuvantaminen, kuvantamissuositukset, natiiviröntgentutkimus, oikeutus, selkäkipu, selkäranka, säteilytutkimus, TT

To my family

Acknowledgements

This study was conducted in the Department of Diagnostic Radiology, Oulu University Hospital.

I wish to express my deepest gratitude to my supervisors, Professor Osmo Tervonen, M.D., and Docent Heljä Oikarinen, M.D. Professor Tervonen created an encouraging atmosphere and facilities in which to carry out this research and allowed me to do it in my own pace. Docent Heljä Oikarinen's experience and admirable knowledge on all aspects of this research has been indispensable. During these years, she has carefully guided and tirelessly supported me at the different stages of this project. She also helped me cope during some disappointing moments along this journey, never letting me give up. This thesis would not have been accomplished without her.

I am grateful to Docent Erkki Svedström, M.D., and Docent Martti Kiuru, M.D., for their efficient review and clear, constructive feedback to improve this work. I am thankful to Marianne Haapea, Ph.D., for help with statistical analysis. I wish to warmly to thank authorized translator Anna Vuolteenaho for the careful revision of the language of thesis and Teuvo Ryynänen, M.Sc. for his help editing this thesis to its final form.

I wish to express my gratitude to all my co-authors, Jaakko Niinimäki, Seija Mattila, Esa Liukkonen, Eija Pääkkö and Ari Karttunen. Your help has been essential. I wish to thank Docent Tarja Rissanen, M.D. and Terhi Nevala M.D. Ph.D, for forming such an efficient and easygoing follow-up group for my thesis.

I owe my thanks to my superior Juhani Törmänen, M.D., who never denied any of my requests for leave of absence for scientific work even though it sometimes meant more work burden to others. I owe numerous thanks to all my colleagues, with whom I have been fortunate to work with during my career particularly in Lapland Central Hospital, Oulu University Hospital and Turku University Hospital. I am especially grateful to my closest colleague and friend Matti Vähäkari, M.D., for the refreshing and entertaining but also supportive discussions both in and out of workplaces. Without your epic sighs and grunts my life would have been so much gloomier.

Furthermore, I want to thank the cornerstones of my life: my friends and family. All of you are so dear to me and because of you my life is brighter. I own my deepest thanks to my parents Merja and Eero: your love and support have led me here. My warmest thanks to my sister Milla, whose will power and persistency has taught me a great deal. Finally, I want to thank my dearest, Roope, You are my home.

The study was financially supported by the Radiological Society of Finland, University of Oulu and Oulu University Hospital. I acknowledge all of these funding sources with appreciation.

Karuna, July 2021 *Pirita Tahvonen*

Abbreviations

ACR	American College of Radiology
BEIR	Committee on the Biological Effects of Ionizing Radiations
CDS	Clinical decision support
CT	Computed tomography
DALY	Disability-adjusted life-years
ED	Emergency department
ESR	European Society of Radiology
IAEA	The International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
LBP	Low back pain
LNT	Linear-no-threshold
MRI	Magnetic resonance imaging
OECD	The Organization for Economic Co-operation and Development
RCR	Royal College of Radiologists
STUK	Radiation and Nuclear Safety Authority of Finland/Säteilyturvakeskus
Sv	Sievert
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation

List of original publications

This thesis is based on the following publications, referred to in the text by their Roman numerals.

I Tahvonen, P., Oikarinen, H., Pääkkö, E., Karttunen, A., Blanco Sequeiros, R., & Tervonen, O. (2013). Justification of CT examinations in young adults and children can be improved by education, guideline implementation and increased MRI capacity. *The British Journal of Radiology, 86*(1029), 20130337. https://doi.org/10.1259/bjr.20130337

II Tahvonen, P., Oikarinen, H., & Tervonen, O. (2020). The effect of interventions on appropriate use of lumbar spine radiograph and CT examinations in young adults and children: a three-year follow-up. *Acta Radiologica, 61*(8), 1042–1049. https://doi.org/10.1177/0284185119893091

III Tahvonen, P., Oikarinen, H., Niinimäki, J., Liukkonen, E., Mattila, S., & Tervonen, O. (2017). Justification and active guideline implementation for spine radiography referrals in primary care. *Acta Radiologica (Stockholm, Sweden : 1987), 58*(5), 586–592. https://doi.org/10.1177/0284185116661879

Table of contents

1 Introduction

Ionizing radiation is used in medical diagnostics, especially in conventional radiography (including fluoroscopy) and computed tomography (CT) examinations. This ionizing radiation can damage living cells by the interaction of X-ray photons with cell components, and one of these adverse health effects is the possibility of carcinogenesis (Hall & Giaccia, 2012). Although the risk to a single individual is small, increased use of imaging and therefore cumulative radiation doses may result in long-term public health problems. In particular, radiation-induced lifetime risk of cancer mortality is higher at younger age until approximately the age of 35 years and highest in children. That is because of the developmental and physiological status of the adolescent body and longer life expectancy, with increased expected exposure rate leading to higher radiation-dose accumulation and longer time period to develop the disease (Brenner, Elliston, Hall, & Berdon, 2001; Mathews et al., 2013; Pearce et al., 2012).

A radiological examination using ionizing radiation is justified if the expected benefit is greater than its potential harm. This justification process is one of the cornerstones of radiation protection. The right to use ionizing radiation in imaging is defined by international and national recommendations and laws. According to the legislation, the referrer requesting the examination is responsible for the rightful reason and conduction of referral containing detailed clinical information of the patient. It is the responsibility of the practitioner (i.e. radiologist) to make the final decision on a requested examination considering its benefit versus the radiation dose, choosing the suitable examination protocols and techniques. The purpose of this procedure is to prevent unnecessary radiation dose and its adverse health effects for the population (Finnish Radiation Act, 859/2018, 2018; ICRP, 1991; ICRP, 2007).

When used appropriately, diagnostic imaging is an essential part of modern medicine. Nevertheless, authoritative sources have estimated that about 20–50% of all radiological examinations are inappropriate (Malone et al., 2011). It is known that knowledge of radiation dose and related risks is poor among both physicians and radiologists, and risks are often underestimated (Krille, Hammer, Merzenich, & Zeeb, 2010). Furthermore, there is increasing international concern regarding the rising global radiation exposure, especially due to increased use of CT. It is likely that the use of advanced diagnostic imaging will continue to increase. Radiographs still make up most of the examinations using ionizing radiation. Among those, examinations of the spine, and especially those of the lumbar spine, have one of the highest radiation doses, and the radiation is also delivered to the area of radiation-sensitive organs. The number of these examinations is high because back pain is one of the leading causes of disability worldwide (UNSCEAR, 2010; European commission, 2008; GBD 2015 DALYs and HALE Collaborators, 2016).

There are international and national evidence-based imaging referral guidelines. The purpose of these guidelines is to support the referrer and radiologist to choose the right imaging examination at the right time for the right patients, and therefore improve justification (European Commission, 2008). To achieve this, these guidelines should be actively used (Remedios, Hierath et al., 2014). There are various interventions designed to improve guideline implementation and enhance the justification and appropriate use of radiological examinations. Change is thought to be possible when well-focused, combined interventions are used (Grimshaw et al., 2004).

In Oulu University Hospital, a previous survey demonstrated unjustified use of CT examinations in young patients, where 77% of CT examinations of the lumbar spine, 37% of the abdomen and 36% of the head were unjustified (Oikarinen et al., 2009). The hospital's internal audit also revealed inadequate justification of lumbar spine radiographs. After these results, various interventions to improve justification were introduced, namely interventions involving provision of education, distribution of guidelines and increased MRI capacity. Inadequate justification of lumbar spine radiographs in Oulu University Hospital raised concern of the justification in primary care. Specific guidelines for spine examinations with education were also introduced in primary care.

The aim of this study was to determine whether the interventions implemented would reduce the number of clinicians' requests for CT examinations and lumbar spine radiographs in Oulu University Hospital and spine radiographs in primary care and whether the examinations performed would be in better accordance with the guidelines after these interventions. Furthermore, the aim was to evaluate the referral indications of inappropriate examinations and to find out if inappropriate lumbar spine radiographs in Oulu University Hospital had relevant findings.

2 Review of the literature

2.1 Ionizing radiation in medical examinations

2.1.1 Basics of ionizing radiation

Ionizing radiation is radiation with sufficient energy which, through an interaction with material, liberates electrons from atom or molecule, causing them to become charged or ionized (Barrett & Swindell, 1981). Cosmic rays and environmental radioactivity (i.e. naturally radioactive materials such as radon and radium) are the primary sources of natural ionizing radiation on Earth referred to as background radiation. Globally, exposure to natural radiation is the largest component of total radiation exposure, contributing about 80% of the total exposure (UNSCEAR, 2000a). In radiological imaging, the ionizing radiation is generated artificially by accelerating electrons through a potential difference, using X-ray tubes, and directing them to a target material. X-rays can pass through material, including the human body, but while transversing it, also absorb into tissues according to tissues' chemical elements and density. Radiograph and computed tomography machines form images of X-rays that have passed through the tissues. (Barrett & Swindell, 1981)

2.1.2 Radiation biology and adverse effects of ionizing radiation

Ionizing radiation can damage living cells by the interaction of X-ray photons with cell components. Of the biological components, the damage is most destructive to the hereditary component of the cell, i.e. DNA: damage to nucleotide bases, cross-linking, and single- and double-strand breaks (Goodhead, 1994). The radiation-induced injury can occur via direct interaction of X-ray photons with DNA or, in most cases, through radiolysis of water molecules developing free unstable radicals that in the course of time can injure the DNA (UNSCEAR, 2000b; Takeshita, Fujii, Anzai, & Ozawa, 2004). Usually, radiation-induced damage to the DNA is repaired by various mechanisms within the cell, but especially the DNA double-strand breaks occasionally remain unrepaired, leading to possible induction of point mutation, gene mutation and chromosomal abnormalities, all of which are linked to the induction of cancer (Hall & Giaccia, 2012; Little, 2000). Any radiation, natural (i.e. from background radiation) or artificial (e.g. from radiological examinations), is detrimental to the cell. However, the amount of the radiation and the time period in which the radiation dose is received are significant, as are the characteristics of the radiation-exposed cell (Little, 2000).

The effects of ionizing radiation can be divided in two types: non-stochastic and stochastic effects. Non-stochastic effects, i.e. direct effects, are definite adverse effects leading to tissue damage occurring above a certain level of radiation dose. In other words, the non-stochastic effects have a threshold below which the effect does not occur. However, above the threshold, the injury severity, including tissue recovery impairment, increases with dose and dose rate. These injuries are usually related to massive single radiation dose (e.g. nuclear and radiation accidents, radiation therapy or long-lasting interventional angiology procedures). Examples of non-stochastic effects include skin damage, cataract, hair loss, sterility, radiation sickness, and fetal abnormality or ultimately, death (Hall & Giaccia, 2012; ICRP, 2007).

Stochastic effects probably have no threshold and can in principle occur with any dose of ionizing radiation. The chance of obtaining a radiation-injury is thus not dependent of the radiation dose but the probability of injury increases with higher doses and the risk is dependent of lifetime cumulative radiation dose. Epidemiological evidence points strongly towards radiation-induced carcinogenesis occurring in a stochastic manner also at low doses of ionizing radiations (Brenner et al., 2003; Cardis et al., 2007; Muirhead et al., 2009; Ozasa et al., 2012; Pierce, Shimizu, Preston, Vaeth, & Mabuchi, 1996). This is known as the linear-no-threshold (LNT) theory proposing that there is no absolutely safe level of radiation exposure, and that there is an increasing risk of cancer with increasing dose (Little, 2000; Shah, Sachs, & Wilson, 2012). There are some controversies regarding the theory of carcinogenesis in small-dose exposures. The LNT theory faces two competing theories: the threshold model and the radiation hormesis model. The first assumes that very small exposures are safe while the latter is the hypothesis that low doses of ionizing radiation are beneficial, stimulating the activation of repair mechanisms that protect against disease which are not activated in absence of radiation (Calabrese & Baldwin, 2000; Feinendegen, 2005; Wolff, 1998). The International Commission on Radiological Protection (ICRP) has stated that uncertainty with regard to the role of these processes remains until their relevance to the cancer development *in vivo* is demonstrated and there is knowledge of the dose dependence of the cellular mechanisms involved. As a result, the LNT theory is the current model used in official radiation protection. (ICRP, 2007).

The harmful effects of ionizing radiation have been well documented after the atomic bomb explosions in Hiroshima and Nagasaki, Japan, which caused high incidence of radiation-induced health issues, including diverse types of cancer (Ozasa et al., 2012; Preston et al., 2007; Thompson et al., 1994). Also in a study on low dose radiation risks of atomic bomb survivors who received 5–100 mSv radiation, a small but statistically significant excess of cancer from 1958 to 1998 was reported (81 radiation-related excess solid cancers out of 27 789 study population) (Preston et al., 2007).

In epidemiological studies, it has been stated that the lifetime risk of potential radiation damage to a single small dose of radiation at a certain age is higher in children (National Research Council, 2006; ICRP, 1991; Ozasa et al., 2012). This is due to longer life expectancy with the possibility of increased number of repeated exposures with higher radiation-dose accumulation and longer time period to develop the disease. Developing organs with a high rate of division and mitotic activity are also more sensitive to radiation than those that are fully mature (Brenner et al., 2001; Mathews et al., 2013; Pearce et al., 2012; Sodickson et al., 2009). The risk decreases with age, particularly after the age of 35 years (Brenner et al., 2001).

The radiosensitivity varies in different organs. Organs that have immature and undifferentiated cells and those with highly active metabolism and rapid cell division are more radiosensitive. The most sensitive cells are spermatogoniae and erythroblasts, epidermal stem cells and gastrointestinal stem cells. In the ICRP recommendation, organs categorized as organs with a specific risk for stochastic effects have been given their own tissue weighting factors. These organs are shown in Table 1 (Hall & Giaccia, 2012; ICRP, 2007).

Table 1. Organs with a specific risk for stochastic effects and their tissue weighting factors by ICRP.

Tissue	wT[2]
Bone-marrow (red), Colon, Lung, Stomach, Breast, Remainder Tissues[1] (Nominal applied to the average dose to 14 tissues)	0.12
Gonads	0.08
Bladder, Esophagus, Liver, Thyroid	0.04
Bone surface, Brain, Salivary glands, Skin	0.01

[1] 14 in total: Adrenals, Extrathoracic region, Gall bladder, Heart, Kidneys, Lymphatic nodes, Muscle, Oral mucosa, Pancreas, Prostate, Small intestine, Spleen, Thymus, Uterus/cervix, [2] tissue weighting factors

2.1.3 Examinations that use ionizing radiation

In radiological imaging, ionizing radiation is most commonly used in conventional radiography (also including fluoroscopy and angiography) and in CT, and these examinations are an essential part of current diagnostic radiology practice. About 3.6 billion radiological examinations are conducted worldwide every year. Globally, medical diagnostic exposure (including angiological procedures) contributes about 20% of all radiation exposure to population and in the 21th century, the radiation exposure from medical sources has risen about 20% (UNSCEAR, 2010; World Health Organization, 2015). In countries with high levels of health care, exposure to medical is even higher; for example, in the US, half of all exposure comes from medical sources (annual effective dose per person of 2.16 mSv) (The National Council on Radiation Protection and Measurements, (NCRP), 2019). In Finland, the annual effective radiation dose is about 5.9 mSv and medical diagnostic exposure contributes about 12% of this. This annual effective collective dose from medical examinations per person has risen from 0.45 mSv in 2008 to 0.72 mSv in 2018 (Siikonen, 2020) .

CT technology has had a revolutionary impact in modern medicine (Alfidi et al., 1975). However, the radiation exposure from CT for both the individual and the population is one of the highest in diagnostic radiology and there is general concern related to the current rapid increase of CT use. Although the risk presented from radiation to an individual is very small, when applied to a large number of individuals, it can result in a significant public health problem (National Research Council, 2006; Hall & Brenner, 2008). The relevant cumulative organ dose varies according to the examinations made, possible use of contrast agent, and number of scans. The effective dose from one CT examination is usually around 10 mSv or less (European commission, 2008). With repetitive examinations, to some group of patients the cumulative CT effective dose can rise above 100 mSv, a threshold figure above which Japanese atomic bomb survivors had a significant increase in malignancies (Preston et al., 2007; Rehani et al., 2020; Sodickson et al., 2009). According to the Committee on the Biological Effects of Ionizing Radiations (BEIR), a lifetime cancer risk unrelated to radiation is approximately 42 cancers in every 100 people. The BEIR VII report uses a lifetime risk model that predicts that an effective dose of 10 mSv may result in one person per 1 000 developing cancer. (National Research Council, 2006). The ICRP considers that the same dose may be associated with an increased chance of developing fatal cancer for approximately one person in 2 000 (ICRP, 2007).

A study of CT examinations on young people (aged less than 22 years) in the United Kingdom (UK) showed that cumulative ionizing radiation doses from 2–3 head CTs (i.e. absorbed brain dose of 60 mGy) could almost triple the risk of brain tumors and 5–10 head CTs (i.e. absorbed red marrow dose of 50 mGy) could triple the risk of leukemia (Pearce et al., 2012). In a population-based cohort study of youths aged under 20 years from South Korea, the overall cancer incidence was greater among the individuals who had a radiological examination using ionizing radiation than among those who did not have one after adjusted for age and sex. The cohort included about 12 million citizen and out of those, about 1.3 million had had an examination using ionizing radiation. There were 405 additional solid cancers and 159 additional lymphoid or hematopoietic cancers in individuals who had been exposed to diagnostic low-dose ionizing (Hong, Han, Jung, & Kim, 2019). In an Australian cohort study of youths aged 0–19 years (10.9 million people, 680 211 people exposed to a CT) the overall cancer incidence was 24% greater for exposed than for unexposed people. There were increased risks of several types of solid cancers and of leukemia, myelodysplasia, and other lymphoid cancers among individuals exposed to at least one CT examination (Mathews et al., 2013). The risk of ionizing radiation, as a promoter of cancer count, is also estimated after risk models based on earlier epidemiological studies. In a study that utilized the risk models based on the BEIR VII report, it was estimated that 29 000 cancers will develop as a direct result of CT performed in 2007 in the USA (Berrington de González et al., 2009).

According to The Organization for Economic Co-operation and Development (OECD) statistics, there are approximately 111 CT scanners per one million inhabitants in Japan, 67 in Australia, 49 in Iceland, 44 in the United States (US), 34 in Greece, 22 in Finland, 18 in France and 9 in the UK (OECD, 2019b). The number of CT examinations per thousand inhabitants is 271 in the US, 231 in Japan, 230 in Iceland, 190 in France, 150 in Greece, 134 in Australia, 44 in Finland and 6 in the UK (National Health Service, 2018; OECD, 2019a). In the US, the number of emergency department (ED) visits that included CT examination has increased substantially, from 2.7 million patients in 1995 to 16.2 million in 2007 (annual growth rate of 16%) (Larson, Johnson, Schnell, Salisbury, & Forman, 2011).

In 2008 the number of CT examinations contributed about 10% of all ionizing radiation-based imaging globally but provided approximately 43% of the total collective dose (UNSCEAR, 2010). In the US, the CT examinations made up 50% of the collective dose from medical imaging procedures in 2006 and 63% in 2016. While the number of CT scans increased by 20% over that decade, the overall dose per person for CT procedures was essentially unchanged due to optimization and modern CT scan technologies (The National Council on Radiation Protection and Measurements, (NCRP), 2019). In many European countries, the largest proportion of total medical diagnostic collective effective dose is from CT examinations: 68% in the UK, 59% in Norway and 60% in Germany (Borretzen, Lysdahl, & Olerud, 2007; Bundesamt fuer Strahlenschutz, 2012; Hart, Wall, Hillier, & Shrimpton, 2010). In Finland, the number of CT examination has risen by 43% from 2008 to 2018 and the proportional dose due to CT examinations of the total collective effective dose from all x-ray examinations increased from 58% in 2008 to 70% in 2018 (Bly, Järvinen, Kaijaluoto, & Ruonala, 2020).

Although the CT examinations deliver the major proportion of medical diagnostic ionizing radiation, numerically, the most voluminous radiological examinations are radiographs (UNSCEAR, 2010). For example, in most European countries, 90% of all radiological examinations are radiographs (European Commission, 2015). In 2018 in Finland, 88% of all radiological examinations were radiographs and 10% were CTs (Ruonala, 2019). Regarding the conventional radiographs' radiation doses, spine radiographs, especially those of the lumbar spine, are amongst the highest ones. The dose from lumbar spine radiography is equivalent to about 50 posterior anterior (pa) chest radiographs, producing most of the collective effective dose from conventional x-ray procedures in Europe. In these examinations, radiation is also delivered to the area of some of the most radiation-sensitive organs of the body (European commission, 2008; European Commission, 2015; Richards, George, Metelko, & Brown, 2010). In the UK, approximately 6% and in Finland, 3% of radiographs are spine x-rays, which annually sums to 1.76 million spine radiographs in the UK and 90.5 thousand in Finland (Hart et al., 2010; Ruonala, 2019).

In diagnostic radiology, ionizing radiation is also used in nuclear medicine. In nuclear medicine, radioactive materials are introduced into the body, usually intravenously, orally or by inhalation, and radiation emitted from the body is analyzed to produce diagnostic images that provide information on either organ structure or function. Often also CT or MRI scans are combined to these examinations to provide better images of body structures. Globally, the annual per caput effective dose (Sievert, mSv) from any ionizing radiation is 3.08 mSv; about 20% of that is from medical diagnostic use and 1% from nuclear medicine (0.031 mSv) (UNSCEAR, 2010).

2.2 Principles of radiation protection

2.2.1 Justification, optimization, dose limitation

The international Commission on Radiological Protection (ICRP) is the organization responsible for developing the principles of radiation protection. These principles include three fundamental components: justification, optimization and dose limitation (ICRP, 1991). Justification means that any exposure to medical radiation to an individual should have greater expected benefit than expected harm. Optimization means that medical radiation exposure is always kept as low as reasonably achievable (ALARA principle) while obtaining the required diagnostic information. In optimization, economic and social factors as well as doses of non-target volumes and tissues should also be considered (European commission, 1997; ICRP, 2007). The principle of dose limitation concerns radiation to an individual from regulated sources in situations other than medical exposure of patients. The ICRP has set recommendations of radiation dose limitations to the workers and the public which should not be exceeded. At the moment, the recommended dose limits for occupationally exposed workers are the following: an effective dose of 20 mSv in a year (averaged over defined periods of 5 years with no single year > 50 mSv) and for the lens of the eye, 20 mSv in a year or 100 mSv in any five consecutive years. The dose limit for public exposure is an effective dose of 1 mSv in a year and for the lens of the eye, 15 mSv (European commission, 2014; ICRP, 2007).

Although the risk of cancer induction in a single individual due to ionizing radiation exposure is small, the adverse effect to societies (i.e. to cancer mortality) can be significant. Thus, in radiation protection, the society's total collective radiation dose is crucial (National Research Council, 2006; ICRP, 1991).

2.2.2 International guidelines and recommendations

The ICRP is an independent, international and non-governmental organization which releases recommendations and guidelines on all aspects of radiation protection based on the best scientific evidence available. The main goal of the ICRP is to minimize all radiation-induced health effects. The ICRP regularly releases its own publications, Annals of the ICRP (http://www.icrp.org/publications.asp). These publications are recommendations that do not legally bind anyone, but the ICRP has achieved status as a global authority. National radiation protection legislations around the world as well as the European Directive are largely based on these recommendations. At the moment, the most recent recommendation was released in 2007 (ICRP Publication 103). Complementary publications are released on elaborate specific topics in radiation protection (European commission, 2014; ICRP, 2007).

Assessing the adverse effects of ionizing radiation, the ICRP relies mainly on two scientific commissions: UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation) and BEIR (Committee on the Biological Effects of Ionizing Radiations). UNSCEAR is a committee of the United Nations and BEIR a committee of the American National Research Council (NAS). Both of these committees release from time to time broad reports on ionizing radiation concentrating on the different aspects of the adverse effects of ionizing radiation. The latest reports from UNSCEAR are from 2013, 2016 and 2017 and those of BEIR from 2006 (BEIR VII). All of these reports are based on the same epidemiological research, most importantly on the research of Japanese atomic bomb survivors, so called LSS research (Life Span Study) (National Research Council, 2006; UNSCEAR, 2014a, 2014b, 2017, 2018; Pierce et al., 1996; Pierce, Shimizu, Preston, Vaeth, & Mabuchi, 2012).

2.2.3 National legislation

Legislation about radiation in Europe is based on ICRP recommendations (ICRP, 2007). The European Directive, set by Euratom, represents Basic Safety Standards (BSS) for protection against the dangers arising from exposure to ionizing radiation. All members of the European Union, including Finland, are obligated to set their own national legislation and regulations based on these directives. The Finnish radiation legislation and statute have been revised in recent years and new legislation came into effect in 2018 and is based on the Council Directive 2013/59/Euratom (Finnish radiation act, 859/2018, 2018; European commission, 2014). The legislation contains all aspects of radiation but also all the basic regulations for using ionizing radiation for medical use. As such, it contains the regulations of radiation protection including the justification principle.

In Finland, specific regulations about the use of ionizing radiation are presented in radiation decrees by government. These are reinforced by specific regulations by the Radiation and Nuclear Safety Authority of Finland (STUK). STUK is responsible for maintaining surveillance on the implementation of safety standards as designated in the legislation. STUK also releases serial publications and brochures on instructions for medical imaging, including safe use of radiation, instruction on optimization and justification and referral criteria. The guidelines as well as the national legislation, statutes and regulations are available online on the website of STUK (www.stuk.fi).

2.3 Appropriateness and justification of radiological examinations

2.3.1 Justification

In ICRP recommendations and in our national legislation for radiation protection, the process of justification is included and described in detail. In general, the appropriateness of medical procedures has been defined as when the health benefit to be expected exceeds the expected negative consequences. The emphasis on appropriateness of radiological examinations is focused on the justification process (Finnish radiation act, 859/2018, 2018; ICRP, 2007; Mendelson, 2020).

There are three levels of justification. Level one justification refers to general justification of the use of ionizing radiation in medicine. Level two justification refers to the use of ionizing radiation for a generic clinical condition (for example, CT examinations for suspicion of pulmonary embolism). Justification of a radiological procedure for an individual patient is the level three justification.

This means that the appropriateness of an examination based on the clinical condition of the patient has to be evaluated individually beforehand and the examination should only be performed to answer a certain clinical question and when the answer will influence the decision-making process and treatment of the patient (Mendelson, 2020).

Medico-legal requirements identify that justification is an advocated and obligatory practice and it has to be performed by both the referrer and the practitioner. The referrer has to be aware of the risks related to ionizing radiation and the spectrum of radiation dose associated with the examination in question have. The assessment of appropriateness also includes consideration of all alternative examinations available that require no or less exposure to ionizing radiation (i.e. no imaging performed, MRI or ultrasonography or a modality with less exposure) and making sure that the required information is not already available. Examinations that are in accordance with imaging referral guidelines are appropriate, i.e. justified. The referrer should also consult the radiologist in unclear situations. If the referrer evaluates that the radiological examination is justified it is his or her responsibility to make a clear referral through which the practitioner responsible for an individual medical exposure (i.e. radiologists or radiographers authorized by radiologist) may ensure the justification (Finnish radiation act, 859/2018, 2018; European commission, 2008; ICRP, 2007).

2.3.2 Diagnostic imaging referral guidelines

Imaging referral guidelines for clinical imaging have been developed to support the referring clinicians and also radiologists in selecting and justifying radiological procedures. Continued use of these recommendations can decrease the number of referrals and also lead to a reduction in medical radiation exposure. However, the primary goal of the guidelines is to improve clinical practice.

These evidence-based guidelines have been available in Europe since 1989 when the Royal College of Radiologists (RCR) first published "Making the best use of a department of clinical radiology" (Royal College of Radiologists, 2012). The present online version is known as iRefer (8. edition, www.irefer.org.uk). In the European Commission Directives for protection against the dangers arising from exposure to ionizing radiation, a document that is legally binding requirement for European Union (EU) Member States, it is stated that referral guidelines for medical imaging, considering the radiation doses, have to be available to the referrers (European commission, 1997; European commission, 2014) In the year 2000, Radiation Protection 118: Referral Guidelines for Imaging was published by the European Commission and these guidelines were updated in 2003 (European commission, 2008). In recent years, the European Society of Radiology (ESR) has developed, in cooperation with the American College of Radiology (ACR), the ESR iGuide, which is a clinical decision support system for European imaging referral guidelines containing about 1 600 clinical indications. Through this, the guidelines are available online, can be used everywhere in Europe, and are regulatory updated (www.myesr.org/esriguide).

The American College of Radiology developed their own Appropriateness Criteria during the 1990s and these guidelines are continuously updated by panels which include radiologists and a number of specialists from other medical fields. In 2019, these guidelines exist as a clinical decision support database ACR Select and contain 189 Diagnostic Imaging and Interventional Radiology themes, over 1 680 clinical situations and about 6 000 literature references (American College of Radiology, (ACR); Cascade, 1994, 2000). Many other countries have developed or adopted their own national imaging referral guidelines for clinical imaging (Remedios et al., 2014). Still, in Europe, only the UK and France have fully developed guidelines. For example, South America and many parts of Asia do not have official referral guidelines but the need for imaging referral guidelines is recognized (European Society of Radiology, (ESR), 2017; Remedios, Cavanagh et al., 2014).

In Finland, the referral guidelines by the European Commission were translated into Finnish in 2001 and are considered to be partly out of date. STUK has released guidelines regarding radiological examinations of children (Merimaa, 2012; Radiation and Nuclear Safety Authority, 2008). The national "Current Care Guidelines" (available at www.kaypahoito.fi) also include recommendations concerning the use of radiological examinations. Additionally, different medical units and hospitals have their own locally produced focused guidelines.

2.3.3 Inappropriate radiological examinations

When a radiological examination is justified and appropriate, the benefit-to-risk ratio on any individual will be significant. However, it is estimated that a considerable proportion of radiological examinations are inappropriate and in those cases the benefit-to-risk ratio is not sufficient. Even though the risk of an individual of having an adverse effect from radiation is still small, with a large amount of inappropriate examinations and thereby inappropriate radiation exposure to population, there is concern of potential to produce significant long-term public health effects (Malone et al., 2012).

It has been assessed that about 20–50% of all radiological examinations are inappropriate and even more in the case with certain CT examinations (Almén, Leitz, & Richter, 2009; Bianco, Zucco, Lotito, & Pavia, 2018; Bouette et al., 2019; Espeland, Albrektsen, & Larsen, 1999; Halpin, Yeoman, & Dundas, 1991; Isaacs, Marinac, & Sun, 2004; Jenkins et al., 2018; Oakeshott, Kerry, & Williams, 1994; Oikarinen et al., 2009). The degree of justification varies by organ. For example, regarding radiographs, 50% of radiographs of the knee (Morgan, Mullick, Harper, & Finlay, 1997), 52–65% of the spine (Espeland et al., 1999; Halpin et al., 1991; Oakeshott et al., 1994) and 58% of the abdomen (Bell & McLaughlin, 2001) have been estimated to be inappropriate. Of CT examinations, 17–62% of CTs of the head, 18–37% of the abdomen and 42–77% of the lumbar spine have been found to be inappropriate (Almén et al., 2009; Lehnert & Bree, 2010; Oikarinen et al., 2009; Ravindran, Sennik, & Hughes, 2007; Sodhi et al., 2015). A study from the UK stated that 47–73% of the 1 025 CT examinations performed in a district general hospital could have been replaced with MRI, and that 91% of the lumbar spine CT examinations were inappropriate (Clarke, Cranley, Kelly, Bell, & Smith, 2001).

2.3.4 *Reasons for inadequate justification and insufficient use of referral guidelines*

The international recommendations and also Finnish radiation legislation states that the referring doctor must assess the justification of the examination that uses ionizing radiation before making a referral (Finnish radiation act, 859/2018, 2018; ICRP, 2007). To do that rationally, the referring doctor should be aware of the different radiological examination indications and of the risks related to ionizing radiation and the spectrum of radiation dose that the examination in question has.

Through many studies, it is acknowledged that the knowledge of the radiation dose and the related risk is often underestimated. In a study from the UK, 130 doctors were interviewed and none of them knew the approximate dose of radiation received by a patient during a chest X-ray. When evaluating the radiation doses of frequently used radiological examinations the correctness of answers ranged from 0% to 59% and almost all the answers (97%) underestimated the actual dose (Shiralkar et al., 2003). Majority of studies show that only 20–40% of the clinicians' estimations of frequently used radiological examinations dose are accurate. There is also a lack of knowledge of examinations that utilize ionizing radiation. For instance, 5–10% and 8–13% of doctors do not know that ultrasonography and MRI do not expose patients to ionizing radiation (Bosanquet et al., 2011; Günalp et al., 2014; Keijzers & Britton, 2010; Lee, Haims, Monico, Brink, & Forman, 2004; Mubeen, Abbas, & Nisar, 2008; Zhou, Wong, Nguyen, & Mendelson, 2010). Knowledge of cancer risk related to ionizing radiation varies in different studies. According to literature, only 5% of Italian physicians properly identified the cancer risk rate associated with abdominal computed tomography whereas 50% of Italian ED doctors and 41% of Australian students and interns comprehended the cancer risk of ionizing radiation (Campanella et al., 2017; Günalp et al., 2014; Zhou et al., 2010). There is clearly a need for education regarding radiation dose and related cancer risk.

Although the referral guidelines are available in many countries there are still countries and hospitals that do not have or use these guidelines. In the IAEA survey on pediatric CT Practice, only 50% of the respondent countries stated that they had specific referral guidelines for imaging available; 48% in Europe, 56% in Asia, 42% in Africa and 30% in Latin America (Vassileva et al., 2012). In a survey prepared by ESR for the European Commission the results indicated that imaging referral guidelines are available in two thirds of the EU Member States with legal requirement for Guidelines and that in only one third of those European countries who do not have a legal requirement for Guidelines. In the report, it was clearly stated that additional measures were needed to reinforce the use of guidelines (Remedios et al., 2014).

In addition to the lack of availability of imaging referral guidelines and not using them, there are also other reasons leading to inadequate justification: There can be poor access to alternative modalities (e.g. ultrasound, MRI); pressure on clinicians for performance (e.g. patient throughput) especially in ED; pressure or demand from patient or relatives; lack of dialog between referrers and radiologists, and also pressure from referring clinicians to radiologist or radiographer. Sometimes the reason is reliance on personal experience rather than evidence-based medicine. In some countries, health professionals have concerns about possible malpractice litigation. This so-called 'defensive-medicine' often leads to overuse of medical imaging and thereby to increased radiation exposure (Bettmann et al., 2015; Perez Mdel, 2015; Sierzenski et al., 2014).

2.4 Interventions to improve imaging appropriateness

2.4.1 Methods for guideline implementation

The need for the implementation of imaging referral guidelines in clinical routine and improvement of appropriateness is recognized worldwide (European Society of Radiology, (ESR), 2017). Procedures aiming to improve guideline implementation are considered to have controversial effects (Grol & Grimshaw, 2003; Oxman, Thomson, Davis, & Haynes, 1995). Distributing imaging referral guidelines without specific education does not seem to have an influence on practitioners' behavior (Dey et al., 2004; Freeborn, Shye, Mullooly, Eraker, & Romeo, 1997; Matowe et al., 2002). However, change is thought to be possible with interactive education aimed at small groups and a combination of different interventions (Davis et al., 1999; Grol & Grimshaw, 2003). In the European Commission report from 2014 it was stated that clinical audit should be used for monitoring of Guidelines' availability, their use and implementation (Remedios et al., 2014). Justification of radiological examinations can thus be facilitated by the "3 As": awareness, appropriateness and audit (Malone et al., 2012).

In a study based on Royal College of Radiologists' (RCR) guidelines it has been shown that targeted local interventions can change the practitioners' behavior. Starting to use these guidelines with local monitoring, and if needed, education, decreased the number of radiographs in general by 13% and those of the skull by 30%, spine by 18% and limbs and joints by 14% (Influence of the royal college of radiologists' guidelines on hospital practice: A multicentre study. royal college of radiologists working party, 1992; Influence of royal college of radiologists' guidelines on referral from general practice. royal college of radiologists working party, 1993). In some studies, guideline implementation with an educational message or lectures and feedback has reduced practitioners' spine radiography and knee referrals by 20–30% (de vos Meiring & Wells, 1990; Eccles et al., 2001; Kerry, Oakeshott, Dundas, & Williams, 2000; Oakeshott et al., 1994). Locally modified guidelines or request forms, with or without feedback, have been shown to reduce referrals for spinal radiography by 20% (Kerry, Dundas, Hilton, Rink, & Patel, 2000) and those for lumbar spine by 26% to 47% (Baker, Rabin, Lantos, & Gallagher, 1987; de vos Meiring & Wells, 1990). In a study setting where the referrals that were not in accordance with the guidelines were returned, the number of cervical spine, lumbar spine and knee radiographs decreased by 79% over a two-year period (Glaves, 2005). Focused guidelines have also decreased the number of CT examinations. A study about CTs on patients with suspicion of abdominal abscess the guideline implementation decreased the number of CTs by 10% and in another study about blunt trauma patients, about 30% (Baghdanian et al., 2017; Lal, Kazerooni, & Bree, 2000).

There are also some studies on the appropriateness of radiological examinations after the guideline implementation. Eccles et al. (2001) reported that specific lumbar spine and knee imaging guideline implementation with educational reminder messages reduced those particular radiograph referrals by 20%, which was more than in other intervention groups who received only guidelines or feedback. The referrals were also in better accordance with the guidelines after interventions, but the concordance between groups did not differ significantly (Eccles et al., 2001). In another study on RCR guidelines regarding general practitioners' referrals in London, practices which had received guidelines for the chest, limbs and joints and spine, requested significantly fewer examinations of the spine and made a significantly higher proportion of requests which were in accordance with the guidelines when compared with the practices that had not received the guidelines (84% versus 73%) (Oakeshott et al., 1994).

It has been showed that guideline implementation can change practitioners' behavior, but studies about possible changes in the appropriateness of performed examinations are scarce and studies with longer follow-up time are lacking.

2.4.2 Clinical decision support

Voluntary use of referral guidelines has shown relative success compared with the integration of the guidelines into order entry system with clinical decision support (CDS). With these systems, the referring doctors receive feedback on the degree of appropriateness of their choices relative to the referral guidelines (e.g. warnings and colored codes) and also on the references behind the guidelines. The system may also suggest an imaging modality based on the information about patients' symptoms. The importance of having such systems in place to assist referring physicians in making the best decisions has been widely acknowledged in recent years (European Society of Radiology, (ESR), 2017).

The legal environment in the USA (Protecting Access to Medicare Act, PAMA) requires that since 2020, physicians must consult government-approved, evidence-based appropriateness criteria through a CDS system, ACR Select, when ordering advanced diagnostic imaging exams. Because of the inadequate availability of imaging referral guidelines and the scarce guideline use in Europe, the ESR has develop a clinical decision support system for European imaging referral guidelines, iGuide. This was done in collaboration with ACR. Periodic content updates of ESR iGuide and ACR Select will be performed in cooperation between ESR and ACR (European Society of Radiology, (ESR), 2019). These clinical decision support systems are not yet in routine use in Finland.

According to earlier studies on clinical decision support, the number of CT and MRI examinations decreased and the use of guidelines in the test ordering process improved (Blackmore, Mecklenburg, & Kaplan, 2011; Ip et al., 2012; Raja et al., 2012; Sistrom et al., 2009; Vartanians, Sistrom, Weilburg, Rosenthal, & Thrall, 2010). In a study about the use of CT pulmonary angiography for the evaluation of acute pulmonary embolism, the implementation of evidence-based CDS significantly decreased the use of CT (about 20%) and was associated with a significant (69%) increase of the yield (Raja et al., 2012). Clinical decision support has also improved the appropriateness of radiological examinations (Appari, Johnson, & Anthony, 2018; Carton et al., 2002; Rosenthal et al., 2006; Tajmir et al., 2017). In a study on urban ED, introducing clinical decision support significantly decreased the proportion of low back pain patients receiving medical imaging (median from 22% to 17%) (Min et al., 2017).

2.5 Patient with back pain

2.5.1 Epidemiology of back pain

In general, low back pain (LBP) is a common disorder in developed countries. It seldom indicates a serious condition, as the clinical course in 95% of patients show functional recovery within six months of onset (Carey et al., 1995). Still, at 12 months of onset, about 30% of patients have recurrent pain episodes and about 80% of back pain patients have not completely recovered in terms of pain and disability (Croft, Macfarlane, Papageorgiou, Thomas, & Silman, 1998).

It is estimated that 10% to 20% of adults suffer from back pain during a single year (Freburger et al., 2009; Rubin, 2007). Globally, the lifetime prevalence of back pain ranges widely from 40 to 85% (Calvo-Muñoz, Gómez-Conesa, & Sánchez-Meca, 2013; Hoy et al., 2012; Murray & Lopez, 2013; van Tulder, Maurits, Koes, & Bombardier, 2002). These estimates of prevalence may vary because of national differences, age or gender of the population, and the method used. The prevalence rate for children and adolescents is lower than that seen in adults but is increasing (Hoy et al., 2012; Jones & Macfarlane, 2005). In the USA, the annual prevalence of low back pain is estimated at 15%, and it is estimated that over 100 million European citizens suffer from chronic musculoskeletal pain (Bevan et al., 2009; Martin et al., 2009). In a Finnish national survey, 41% of women and 35% of men reported having back pain in the last month, and from the year 2000 to 2011, the prevalence of back pain had been rising (from 30% to 35% in men and from 37% to 41% in women) (Koskinen, Lundqvist, & Ristiluoma, 2012). More than half of the visits attributed to low back pain are to primary care physicians; however, low back pain also constitutes the most common reason for visits to orthopedists and neurosurgeons (Cypress, 1983).

Low back pain is one of the leading causes of activity limitation and work absence. In the recent Global Burden of Disease Study, low back and neck pain was the fourth leading cause of disability-adjusted life-years (DALY); only ischemic heart diseases, cerebrovascular diseases and lower respiratory infections caused more DALYs. Low back and neck pain were responsible of 1 789 annual years of healthy life lost in 100 000 people in United States, 2 102 in the UK and 2 335 in

Finland (GBD 2015 DALYs and HALE Collaborators, 2016). In the United States, it is estimated that over 100 million work days are lost every year because of low back pain, with total costs of exceeding 100 billion (US$) per year (of which two-thirds is due to lost wages and lower productivity) (Back et al., 1999; Katz, 2006). According to Health and safety statistics in the UK, in 2016–2017 about 194 000 workers were suffering from work-related back disorders (new or long-standing) and about 3.2 million working days were lost due to these disorders (statistics from http://www.hse.gov.uk/statistics/). The annual total costs of back pain in UK have been estimated to be over 12 billion pounds (Maniadakis & Gray, 2000). Two million days' worth of sick allowance were paid due to back pain related symptoms in Finland in 2012 with the overall cost of 119.8 million euros. Moreover, 26 000 people were on disability pension for the same reasons; thus the total costs of diseases related to back were 346.6 million euros (Working group appointed by the Finnish Medical Society Duodecim and Societas Medicinae Physicalis et Rehabilitationis Fennia, 2014). As a whole, back pain has a significant impact on individuals but also on health care, societies and economics.

2.5.2 Imaging guidelines of back pain patients

International and national referral guidelines for radiological examinations provide evidence-based information on how and when to perform radiological examinations on back pain patients (American College of Radiology, (ACR); European Society of Radiology; Remedios et al., 2014). Additionally, national clinical guidelines on the management of low back pain have been published in several countries and those include also information about radiological testing (Koes, van Tulder, Ostelo, Kim Burton, & Waddell, 2001; O'Connell, Cook, Wand, & Ward, 2016; Working group appointed by the Finnish Medical Society Duodecim and Societas Medicinae Physicalis et Rehabilitationis Fennia, 2014). The contents of all these guidelines regarding the use of diagnostic examinations are rather similar. In acute back pain, radiological examinations are of limited value and do not improve the clinical outcome unless there are clinical "red flags" present suggesting serious pathology, such as cauda equina, fracture, infection or inflammatory disease or cancer (Chou, Fu, Carrino, & Deyo, 2009; Deyo, Rainville, & Kent, 1992; European commission, 2008; Koes et al., 2001). These serious pathologies are uncommon, representing less than 6% of all causes of back pain, and the prevalence of spinal malignant neoplasms among primary care patients with low back pain is less than 1% (Deyo & Diehl, 1988; Deyo & Weinstein, 2001).

The ESR iGuide states that in back pain with possible serious features such as: history of cancer, unexplained weight loss, immunosuppression, infection, intravenous drug use, prolonged use of corticosteroids, back pain not improved with conservative management, symptoms of cauda equina syndrome or severe neurologic complications, MRI is usually the best investigation (together with urgent specialist referral). In cases of trauma with neck or back pain, radiographs, CT and MRI are all indicated and the modality of choice depends on the injury and the availability of the modalities (European Society of Radiology). These recommendations are in line with the Finnish Current Care Guidelines for low back pain, which additionally states that in chronic (duration over 3 months) back pain the lumbar spine radiograph in standing position is the basic imaging examination, except in young fertile patients (Working group appointed by the Finnish Medical Society Duodecim and Societas Medicinae Physicalis et Rehabilitationis Fennia, 2014).

2.5.3 Imaging findings in spine and effect of imaging on outcomes

In most cases, up to 85%, low back pain is idiopathic with no pathoanatomical confirmation (Deyo & Weinstein, 2001). Furthermore, most findings in spine imaging (i.e. degeneration, spondylolysis and spondylolisthesis, congenital anomalies, disk calcification, Schmorl nodes, and mild-moderate scoliosis) are common in asymptomatic adults and are only weakly associated with back pain symptoms (van Tulder, Assendelft, Koes, & Bouter, 1997; White & Gordon, 1982).

Degenerative changes are the most common findings in spine radiographs and it has been shown that these changes and back pain do not correlate well (Brinjikji et al., 2015; Deyo & Weinstein, 2001). Post-mortem studies have shown degenerative changes present in the lumbar spine in 85% to 95% of all individuals over 55 years of age (Quinet & Hadler, 1979). In a study of asymptomatic volunteers, degenerative changes were present in 46% of lumbar spine MRI in people under the age 60 and in 93% of people over 60 years of age (Boden, Davis, Dina, Patronas, & Wiesel, 1990). In another similar study of pain-free volunteers (mean age of 42 years), only 36% had normal discs at all levels (Jensen et al., 1994). Spondylolisthesis (anterior displacement of one vertebra), which can be found in about 5% to 10% of normal adult subjects, can also been seen in radiographs, and whether it is more common in symptomatic patients is controversial (Beutler et al., 2003; Kalichman et al., 2009; Ko & Lee, 2011; Osterman, Schlenzka, Poussa, Seitsalo, & Virta, 1993).

CT and MRI are more sensitive than plain radiography for the detection of early spinal changes (for example, infection and cancer) and those examinations can also uncover herniated disks and spinal stenosis, which remain unseen in plain radiography. However, disk and other abnormalities are common among asymptomatic adults and can thus be misleading (Deyo & Weinstein, 2001). A bulging or herniated disk is found to be present in over 50% of asymptomatic peoples' MRI examinations (Boden et al., 1990; Jensen et al., 1994). The prevalence of these conditions increases with age as 30% of asymptomatic individuals 20 years of age and 84% of those 80 years of age seem to have a disk bulge (Brinjikji et al., 2015).

Overall, significant changes that alter the patients' care are scarce among back pain patients, especially in primary care. Halpin et al. (1991) reported that management of primary care patients with low back pain patient was altered by only 2 of the 100 radiographic requested, and 30 of the examinations still had distinctive findings of degeneration (Halpin et al., 1991). A study about general practitioners' referrals for lumbosacral radiographies found that examinations outside the advised criteria had few relevant findings and could probably have been cancelled (Espeland et al., 1999). Deyo et al. stated that in primary care, lumbar spine radiographs of LBP patients that were in accordance with the guidelines had over three times more explanatory findings compared to inappropriate ones (Deyo & Diehl, 1986). Some studies have shown that appropriate CT and MRI examinations are more likely to provide significant results compared to inappropriate ones (48–58% vs. 13–24%) (Lehnert & Bree, 2010; Rosenkrantz, Marie, & Doshi, 2015).

There is no evidence that early imaging in LBP patients is associated with better patient outcomes. In randomized trials of diagnostic tests, the use of imaging was not associated with any advantage in pain relief or functional recovery either in the short (< 3 months) or in the long term (6 months to a year) (Chou et al., 2009). Radiological examinations show findings that are also found in pain-free subjects. Studies suggest that such findings can lead to more surgery and more aggressive treatment, without improvements in patient outcomes (Jarvik et al., 2003; Kerry, Hilton, Dundas, Rink, & Oakeshott, 2002; Webster & Cifuentes, 2010). In the Pilot Project to Improve the Value of Emergency Care in the US, a "top-five" list of tests, treatments, and disposition decisions that are of little value to patient outcome was created. On that list, the 3rd recommendation was "Do not order magnetic resonance imaging of the lumbar spine for patients with lower back pain without high-risk features" (Schuur et al., 2014).

Knowing about imaging findings has been found to have controversial effects on patients. In some studies, patients report higher satisfaction with care for back pain if imaging is performed and even higher if advanced imaging (i.e. CT or MRI) is performed although the overall clinical outcome was not better (Jarvik et al., 2003; Kendrick et al., 2001). On the contrary, patients who underwent lumbar spine radiography reported more ongoing pain in follow-up (Kendrick et al., 2001). Also, in a trial of lumbar spine MRI, patients who did not receive the imaging results reported greater improvements in general health although overall clinical outcomes were the same for the two groups (Ash et al., 2008). Thus, the appropriateness of radiological examinations in back pain patients should always be thoughtfully considered as not imaging LBP patients, especially those with acute low back pain with no "red flags", will reduce harms and costs, without affecting clinical outcomes.

3 Purpose of the study

The purpose of this study was to assess the effect of active guideline implementation and education on the appropriateness of radiological examinations that use ionizing radiation. Particular aims were:

I To assess whether specific and targeted interventions – guideline distribution and education – had an effect on the number of CTs in young patients and if the examinations performed were more in accordance with the guidelines after the interventions.

II To find out and, in particular, follow up the effects of the specific interventions on the use and appropriateness of lumbar spine CTs and radiographs done on young adults and children in a university hospital. To assess whether the inappropriate lumbar spine radiographs contain notable findings that would affect patient care.

III To determine whether the interventions work also in primary care; to study the effect of the interventions on the number and appropriateness of different spine radiographs in adults.

4 Materials and methods

4.1 Study population (I, II, III)

This was a retrospective study. The radiation-induced lifetime risk of cancer mortality is higher at younger age until approximately the age of 35 years and highest in children (Brenner et al., 2001; Malone et al., 2012). Thus, the study population of the survey of CT examinations and lumbar spine radiographs done in the University hospital was selected to consist of patients under the age of 35 years (I, II). The University hospital is the only public hospital with CT in the Oulu area so all the CT examinations are performed in this hospital. The population base in that age group including all health care districts concerned was 319 730 in 2005 and 320 145 in 2009 (information from the national authority for collecting and compiling statistics on various fields of society and economy).

In the study concerning spine radiographs in primary care (III), the interventions were targeted at all patient groups (excluding children). It is supposed that patients in primary care are more unselected. In order to have a broad perception, all adult patients (older than 15 years) with spine radiographs were included in the analysis. Children were excluded from this analysis because they have different guidelines. The population base of adults was 114 161 in 2010, 116 166 in 2011, and 118 211 in 2012.

4.2 Interventions

4.2.1 In 2006 in Oulu University Hospital (I, II)

After the results demonstrating inadequate justification regarding CT studies on patients under the age of 35 years, various interventions were implemented in the hospital (Oikarinen et al., 2009). These interventions were introduced in 2006, and education was provided from 2006, continuing annually since then (I, II).

The referral criteria for imaging recommended by the European Commission, and also accepted in Finland and translated to Finnish, had been available online. The printed version of the guidelines was distributed to different areas of the Radiology Department. In addition, the following institutional recommendations were adopted to rationalize the use of CT by the referring practitioners and radiologists at our hospital: 1) MRI is the primary examination of the head. CT examination is indicated only in acute cases. 2) MRI is the preferred primary examination of the lumbar spine in young patients (except in trauma). 3) Clinicians are recommended to consult a radiologist before requesting an abdominal CT for a young patient. Because of the poor justification of lumbar spine radiographs discovered in the hospital's internal audit, separate indications for spine radiographies based on the European Commission criteria were also provided. These guidelines and recommendations were distributed by e-mail to the referring practitioners and to the staff of the Radiology Department and continue to be available on the hospital intranet.

Two-sided info pocket cards on radiation protection were established in 2006 and updated in 2008. They consist of information on radiation, justification, and doses of most frequently used X-ray, CT and nuclear medicine examinations, and the doses are compared to those of thorax posterioranterior X-ray and natural background radiation.

Furthermore, since 2006, four different 3-h educational lectures were provided each year for the staff of the Radiology Department and the referring practitioners. The sessions were also repeated; hence, altogether eight sessions were provided annually. The lectures were given by experts in radiology and they consisted of legislation on radiation protection, justification, the risks and doses of radiation, indications of different radiological examinations, and specific topics, e.g., orthopedic and pediatric imaging. Handout summaries were provided to participants. Attendance was voluntary but the sessions were also part of the official education on radiation protection, which is mandatory in Finland for both the personnel working with ionizing radiation and the referring practitioners.

The MRI capacity in the hospital was increased from two to three MRI systems in 2006.

4.2.2 In 2011 in primary care (III)

Since 2006, Oulu University Hospital has had guidelines in place for the use of spine radiographs based on the recommendations of the European Commission. These guidelines were also in use in Oulu health centers. More detailed guidelines based on the same source were established in 2011 (III). Guidelines for spine CT and MRI examinations were also provided. The guidelines and the study regarding spine radiographs in primary care were approved by the chief of the Health Center Services and the chief of the Physical Medicine and Rehabilitation Unit.

The new guidelines, together with an educational cover letter, were distributed by e-mail in the beginning of the year 2011 to all clinicians working in Oulu health centers and to radiologists and radiographers working in the Radiology Department of Oulu University Hospital where the examinations were performed. The educational cover letter included concise information about the project, the harmful effects of ionizing radiation, the purpose of the guidelines, and the principles of the justification process. It also emphasized that unjustified spine radiograph requests would be cancelled. It was also distributed to the nurses and receptionists at the health centers to enable informing patients. The guidelines were posted on the health centers' and the hospital's intranet. The new practice was implemented on the 1st of March, 2011. Reminders concerning the guidelines and the project were distributed by e-mail at the end of February 2011 and in June 2011. The guidelines were distributed again via e-mail in October 2011 and in June 2012.

One-hour information and educational lectures to referrers and staff working in the radiology department were provided by two radiologists from February to March 2011. The lectures comprised information on the project and the new guidelines, the risks and doses of radiation, indications for different spine examinations (including "red flags"), appropriate referrals, the process of justification, and legislation on radiation protection. The educational sessions were held during the health centers' weekly meetings and during the meetings of the Radiology Department. Two-sided laminated info pocket cards about radiation doses and justification procedure were also provided for the referring clinicians.

In March 2011, a brief article about radiation protection and this project was published in the local newspaper. It was drawn up to inform the public about this project and the harmful effects of ionizing radiation, the overutilization of radiological examinations, and the benefits of radiation protection.

In this project, as in general, the referrers made the primary justification assessment of spine radiographs. The radiographer evaluated the referral and made the final justification. Radiographers were advised to consult radiologists in unclear cases. Referrers were contacted by phone when additional information for justification was needed. Unjustified referrals were cancelled and radiologists made the note "cancelled based on justification" in the patient file. The referrers were thus able to receive feedback through the patient files.

4.3 Analysis

4.3.1 Number of examinations (I, II, III)

In the Oulu University Hospital, the number of CTs and lumbar spine radiograph was assessed before and after the interventions that took place in 2006.

The number of different CTs done on patients under age 35 and all age groups was analyzed in 2005 and 2009 (I). Furthermore, the number of lumbar spine CTs and lumbar spine radiographs on patients < 35 years were assessed in 2005, 2007, 2008 and 2009 (II). The radiographs were performed in three different radiological units (units 1–3). The number of lumbar spine radiographs performed on young adults each year in each unit was analyzed. It was known that referring clinics differed between the units. Hence, we wanted to find out whether the impact of the interventions differed between the units. The proportions of the referring clinics in each unit were also analyzed. Furthermore, the number of lumbar spine examinations of children (0–15 years) was analyzed separately. For reference, the volume of the same examinations in 2003, 2004, and, for long-term follow-up, in 2018 was also evaluated.

The number of all radiographs and spine radiographs (excluding flexion and extension x-rays) in Oulu primary care was analyzed over six-month periods before and after interventions that took place in 2011 (III). These study periods were from May 1st to October 31st before the interventions in 2010 and after them in 2011 and 2012. The study period was chosen to begin on the first of May to allow the health centers sufficient time to adapt to the new guidelines.

Due to the possibility of increasing demand for MRIs because of the interventions, the number of MRI examinations was also analyzed. The number of different MRIs in Oulu University Hospital in 2005 and 2009 was assessed (I). The number of spine MRIs performed on Oulu inhabitants at Oulu University Hospital during the primary care study periods in 2010, 2011 and 2012 was analyzed (III). This is the only public hospital performing MRI examinations in the Oulu area.

4.3.2 Appropriateness of examinations (I, II, III)

The retrospective analysis performed in the Oulu University Hospital of the appropriateness of CT examinations of patients under the age 35 in 2005 before the interventions took place has been published previously (Oikarinen et al., 2009). The appropriateness of the same CT examinations done after the interventions as the follow-up in 2009 was analyzed in this study (I). The analysis method of this study was similar to the previous one. The analysis was performed for CT of the lumbar spine, head, abdomen or upper abdomen, nasal sinuses, cervical spine and trauma. Trauma CT examination included CT of the head, neck, thorax, abdomen and pelvis. CT examinations of the thorax, lungs or body (including thorax and abdomen) were excluded from the study because there is no good alternative imaging modality for thorax CT examination for most of the indications and the number of thorax or mediastinal MRI examinations is generally rather low. The examinations were extracted from the electronic patient files of the hospital consecutively from the beginning of the year. The number of analyzed examinations in the CT cohort was 30 in all categories except for lumbar spine CTs in 2009, as only 27 examinations of the lumbar spine were performed on that age group.

Patient files, clinicians' referrals and indications of the examinations were analyzed by two radiologists. Using that information and the referral criteria for imaging recommended by the European Commission (European commission, 2008), it was decided whether the examinations had been in accordance with the guidelines, and if not, whether there would have been some other, more justifiable imaging modalities available.

In the evaluation of CT examinations, the following main categories were used:

1. Lumbar spine: CT is justified in trauma and control of fixation of the lumbar spine.
2. Head: CT is justified in trauma or in some other acute cases.
3. Abdomen or upper abdomen: The cases had to be considered case by case because they were so variable.
4. Nasal sinuses: Each patient expected to have functional endoscopic sinus surgery (FESS) should have CT of the sinuses.
5. Cervical spine: CT may be justified in the case of trauma.
6. Trauma CT is indicated in high-energy traumas.

Cases not falling into these categories were analyzed individually using the same principles as in the previous study. After that, radiologists trained in neuroradiology or abdominal radiology went through all the data collected and evaluated justification. If necessary, consensus of the first and second reviewers was used. The results of the survey were compared to the results of the previous study.

Because of the poor justification of lumbar spine CTs in the primary study (Oikarinen et al., 2009) and of the lumbar spine radiographs in the hospital's internal audit, the analysis of these examinations was made more extensively (II). The analysis of lumbar spine CTs and radiographs performed on patients under the age of 35 in the Oulu University Hospital was made in the years 2005, 2007, 2008 and 2009 (II). The examinations were extracted from the electronic patient files of the hospital consecutively from the beginning of the year. The radiographs from units 1–3 were analyzed separately, as were the radiographs of children (aged 0–15 years). The number of analyzed CT examinations was 30 in each year (except for lumbar spine CT in 2009) and in radiographs 20 per unit each year (except 13 in unit 2 in 2009 as there were no more examinations available). The analysis of appropriateness included 313 radiographs and 117 CT scans of the lumbar spine.

In the cohort of spine radiographs of primary care, the appropriateness of cervical, thoracic and lumbar spine radiographs was examined separately in the years 2010, 2011 and 2012 (III). The examinations were extracted from the electronic patient files consecutively from the first of May excluding occupational health care patients. The number of examinations analyzed was 50 in all categories except for thoracic spine in 2012, as only 48 examinations of the thoracic spine were performed during the six-month period in that year. The appropriateness survey thus included altogether 448 examinations.

In both appropriateness cohorts of spine (II, III), clinicians' referrals and corresponding patient files were analyzed by a radiologist. Using that information and related guidelines, the appropriateness was assessed. Subsequently, another radiologist went through the gathered information. In case of discrepancy, a consensus decision was made.

4.3.3 Indications and findings of examinations (I, II, III)

The referral indications for inappropriate and appropriate examinations were assessed in the cohort of CT examinations from 2009 (I). The indications for lumbar spine CTs and spine radiographs were also analyzed in both University Hospital and primary care studies (II, III).

In the cohort of lumbar spine radiographs of patients under the age of 35 in Oulu University Hospital, the findings of the radiographs obtained before the interventions and during three years of follow-up were assessed (II). The analysis of the findings was based on the radiological reports. Altogether 24 radiographies had no reports. In all, 18 of them were follow-up examinations of a fracture or an operation. Therefore, they had automatically significant findings. Six radiographies were analyzed afterwards by a radiologist. The findings were categorized as significant (i.e., findings that usually affect patient care) or non-significant. Mild degeneration or mild scoliosis was not considered a significant finding.

4.4 Statistical methods

Population proportions (n/100 000) were calculated for the numbers of different CT examinations and radiographs. The difference between total number of CTs and radiographs and the number of appropriate examinations was calculated separately.

The chi square goodness of fit test was used to compare the numbers of different CT examinations performed on patients aged < 35 years between 2005 and 2009 (I), and the z-test was used to compare the numbers of lumbar spine CT examinations and radiographs performed on patients aged < 35 years and children separately between 2005 and 2007 and 2005 and 2009 (II). The chi square goodness of fit test was used to compare the numbers of all radiographs and spine radiographs performed on patients aged > 15 years in primary care separately between 2010 and 2011 and 2010 and 2012 (III).

The proportions of justified CTs (in 2005 and 2009) and lumbar spine CTs and radiographs (in 2005, 2007, 2008 and 2009) in Oulu University Hospital and spine radiographs (in 2010, 2011 and 2012) in primary care were compared using Pearson’s chi square test or Fisher’s exact test (I, II, III).

$P < 0.05$ was considered significant in all analyses. IBM SPSS Statistics (versions 22–25; IBM Corp., Armonk, NY, USA) was used to conduct the statistical analyses.

5 Results

5.1 Number of examinations

5.1.1 CT (I, II)

The total number of CT examinations in Oulu University Hospital increased by 11% from 2005 to 2009 and the number of CTs performed on patients aged < 35 years decreased by 7% (Table 2) (I). The number of lumbar spine CTs decreased the most; in all age groups, by 75%, and in patients aged < 35 years, by 80% (II).

Table 2. The number (n/100 000 inhabitants) and changes in numbers of different CT examinations performed on patients under the age 35 of years and in all age groups in 2005 and in 2009 at the Oulu University Hospital.

CT examination	Under 35 years				All age groups		
	2005 n/10^5	2009 n/10^5	Change from 2005 to 2009		2005 n/10^5	2009 n/10^5	Change from 2005 to 2009
			%	p[1]			%
Head	332.5	263.3	-21	< 0.001	1132.3	1154.8	2
Thorax	75.4	77.2	2	ns[2]	249	277.1	11
Abdomen or upper abdomen	38.5	44.7	16	ns	228.2	300.1	32
Trauma	36.6	39.4	8	ns	30.4	34.2	13
Cervical spine	34.4	17.8	-48	< 0.001	49.8	26.5	-47
Lumbar spine	41.3	8.4	-80	< 0.001	172.0	43.1	-75
Nasal sinuses	31.3	24.7	-21	ns	50.8	36.1	-29
Body (thorax and abdomen)	25	31.9	28	ns	126.8	224.3	77
Other	126	179	42	< 0.001	297	500.9	69
Total	740.3	686.3	-7	ns	2336.2	2597.1	11

[1] Chi square goodness of fit -test, [2] no significant difference

Regarding the lumbar spine CTs of patients under the age of 35, the study consisted of information about the number of examinations from the years 2005, 2007, 2008 and 2009 (II, Table 3). The change in the number was already significant from 2005 to 2007. The changes in the years preceding the interventions were not significant. Altogether 234 lumbar spine CTs were performed in that age group during the study period and 6% of the patients were children. The total number of lumbar spine CTs on children was very low and the changes were not statistically significant (Table 3).

Table 3. The number (n/100 000 inhabitants) and changes in numbers of lumbar spine CT examinations performed on patients under the age 35 years and on children at the Oulu University Hospital.

Group	2003 n/10^5	2004 n/10^5	2005 n/10^5	2007 n/10^5	2008 n/10^5	2009 n/10^5	2018 n/10^5	Change 2005–2007		Change 2005–2009	
								%	p	%	p
< 35 y	59.59	68.43	41.28	11.60	11.89	8.43	8.83	-72	< 0.001	-80	< 0.001
Children	2.00	3.35	1.35	2.05	1.37	4.81	0.71	52	0.645	256	0.090

5.1.2 Lumbar spine radiographs in Oulu University Hospital (II)

In patients under the age of 35, altogether 1,342 lumbar spine radiographies were performed during the study period (years 2005, 2007, 2008 and 2009) (II). In that group, 52% were male and 48% were female. The average age of the patients was 21 years and 27% of the patients were children. The number of lumbar spine radiographies decreased significantly after the interventions (from 2005 to 2007) and the result persisted during the follow-up and also until 2018 (Table 4). The change in radiographies of children was not statistically significant. The changes in the number of lumbar spine examinations in the years preceding the interventions were not significant.

Radiographies of young adults (aged from 16 to 34) were performed in three different radiological units with different types of referring clinics. In unit 1, most of the referrals were made by the emergency department (49%) and surgery and neurosurgery department (49%). In that unit, the number of lumbar spine radiographies decreased from 2005 to 2007 by 21% and from 2005 to 2009 by 32%. In unit 2, most of the referrals were made by the department of physical medicine (47%), internal medicine (37%) and other non-trauma clinics: gynecology, neurology and oncology (7%). In that unit, the number of lumbar spine radiographies decreased from 2005 to 2007 by 63% and from 2005 to 2009 by 82%. In unit 3, most of the referrals were made by student health care (54%), occupational health care (18%), primary health care (13%) and non-acute surgery clinics (11%). In that unit, the number of lumbar spine radiographies o from 2005 to 2007 by 79% and from 2005 to 2009 by 45%.

Table 4. The number (n/100 000 inhabitants) and changes in the numbers of lumbar spine radiographs performed on patients under the age of 35 years and on children at the Oulu University Hospital.

Group	2003	2004	2005	2007	2008	2009	2018	Change 2005–2007		Change 2005–2009	
	n/10^5	n/10^5	n/10^5	n/10^5	n/10^5	n/10^5	n/10^5	%	p	%	p
< 35 y	143.83	134.67	141.68	94.97	94.47	88.71	75.88	-32.97	< 0.001	-37.39	< 0.001
Children	70.02	71.75	66.75	65.54	55.61	58.46	46.79	-1.81	0.898	-12.42	0.369

5.1.3 Spine radiographs in primary care (III)

The number of different spine radiographs on patients over the age of 15 decreased significantly in the 6-month period after the interventions in 2011 compared with 2010 (Table 5) (III). The results persisted after the follow-up in 2012. The total number of spine examinations decreased by 51% during the study period. During the study period, 65% of the examinations were done on women and 35% on men. The average age of the patients was 62 years.

Table 5. The number (n/100 000 adult inhabitants) and changes in numbers of different spine radiographs performed on patients over the age of 15 years in 6-month periods in primary care.

Radiograph	Before guidelines 2010 n/10^5	After guidelines 2011 n/10^5	After one-year follow-up 2012 n/10^5	Change from 2010 to 2011 %	p	Change from 2010 to 2012 %	p
All radiographs	9 463	9 401	8 646	-0.7	0.652	-9	< 0.001
Spine radiographs	953	498	469	-48	< 0.001	-51	< 0.001
Cervical spine	229	123	139	-46	< 0.001	-39	< 0.001
Thoracic spine	122	58	45	-53	< 0.001	-63	< 0.001
Lumbar spine	603	318	285	-47	< 0.001	-53	< 0.001

5.1.4 Changes in the number of MRI examinations during the study period (I, III)

From 2005 to 2009, the number of almost all MRI examinations increased (Table 6) (I). Only the number cervical spine MRIs decreased slightly in all age groups.

The number of MRI examinations of the abdomen increased the most, by 129%, in patients aged < 35 years. The second largest increase was seen in the number of lumbar spine MRIs (103% in patients aged < 35 years and 62% in all age groups).

From 2010 to 2012, the number of spine MRI examinations performed on Oulu citizens aged over 15 years decreased by 8% (Table 7) (III). C cervical spine MRIs were the only spine MRI examination that increased in number (by 8%).

Table 6. The number and changes in numbers of different MRI examinations performed in Oulu University Hospital.

MRI	Under 35 years			All age groups		
	2005	2009	Change from 2005 to 2009	2005	2009	Change from 2005 to 2009
	n	n	%	n	n	%
Head	1 023	1 414	38	2 357	2 991	27
Lumbar spine	200	406	103	1 206	1 951	62
Cervical spine	90	92	2	642	637	-0.80
Abdomen or upper abdomen	76	174	129	320	692	116
Other	1 231	1 908	55	4 078	5 387	32
Total	2 620	3 994	52	8 603	11 658	36

Table 7. The number and changes in numbers of spine MRI examinations performed on Oulu citizens aged over 15.

MRI	2010	2011	2012	Change from 2010 to 2012
	$n/10^5$	$n/10^5$	$n/10^5$	%
Cervical spine	127	117	137	+7.9
Thoracic spine	33	25	23	-30.3
Lumbar spine	477	389	423	-11.3
Total	638	531	584	-8.4

5.2 Appropriateness of examinations

5.2.1 CT (I, II)

Regarding different CT examinations done on young patients, there were statistically significantly more examinations in accordance with the guidelines after the interventions in 2009 compared to 2005 (87% versus 71%, $p < 0.001$, Table 8) (I). The level of appropriateness improved or remained unchanged in all categories.

The number of CT examinations evaluated was 177 and 15% of the examinations were performed on children (aged < 16 years). The level of appropriateness in children remained nearly constant from 2005 to 2009, being 86% and 92%, respectively.

Before the interventions, justification was poorest in lumbar spine CTs as only 23% of the examinations were in accordance with the guidelines. Regarding lumbar spine CTs, the appropriateness was assessed also in 2007 and in 2008 (II). The level of appropriateness improved significantly already in 2007 after the interventions and the result persisted during the follow-up (Table 8). This cohort of 117 CT examinations of the lumbar spine done on patients aged < 35 years included 11 CTs done on children. All of them were in accordance with the guidelines.

Table 8. The number (n) and proportion (%) of justified CT examinations out of the total number of the cases analyzed (patients aged < 35 years) and the difference between the proportions of justified CTs.

CT	2005 n (%)	2007 n (%)	2008 n (%)	2009 n (%)	Change from 2005 to 2009	
					%	p[3]
Lumbar spine	7 (23.3)	19 (63.3)	23 (76.7)	22 (81.5)[1]	58	< 0.001
Head	32 (64.0)[2]			22 (73.3)	9	0.464
Abdomen or upper abdomen	19 (63.3)			24 (80.0)	17	0.252
Nasal sinuses	24 (80.0)			27 (90.0)	10	0.472[4]
Cervical spine	29 (96.7)			29 (96.7)	0	1.000[4]
Trauma	30 (100.0)			30 (100.0)	0	-
Total	141 (70.5)			154 (87.0)	17	< 0.001

Total number of the cases is 30 in all categories except [1] 27 in 2009 and [2] 50 in 2005, [3] Pearson's chi square test, [4] Fisher's test

5.2.2 Lumbar spine radiographs in Oulu University Hospital (II)

The appropriateness level of lumbar spine radiographies done on young adults varied significantly between units 1–3, especially in 2005 ($p < 0.001$) and 2007 ($p < 0.001$) (II). The level of appropriateness improved or remained unchanged in all categories from 2005 to 2009 (Table 9). Before the interventions, 65% of the examinations were in accordance with the guidelines, compared to 85% after the follow-up ($p = 0.005$). In 2005, the level of appropriateness was highest in unit 1 which received referrals from ED and surgical clinics. There was no significant change of appropriateness in that unit during the follow-up. The proportion of appropriate examinations was poorer in unit 2 (referring clinics were mostly the departments of physical and internal medicine), and although there was some improvement during the follow-up, it was not statistically significant. The level of appropriateness was lowest in unit 3 (most of the referrals were made by student, occupational and primary health care), but appropriateness improved significantly during the follow-up ($p = 0.001$). Of lumbar spine radiographs of children, 85% were in accordance with the guidelines already before the interventions, and this did not change significantly during the follow-up.

Table 9. The proportion of appropriate lumbar spine radiographs in patients aged < 35 years and separately in children (aged 0–15 years) in different years.

Year	unit 1[1,2]		unit 2[1]		unit 3[1]		children	
	n/total	%	n/total	%	n/total	%	n/total	%
2005	19/20	95	13/20	65	7/20	35	17/20	85
2007	16/20	80	11/20	55	8/20	40	20/20	100
2008	19/20	95	17/20	85	15/20	75	20/20	100
2009	19/20	95	10/13	77	16/20	80	20/20	100

[1] Main referring clinics in unit 1: ED, clinics of surgery and neurosurgery; unit 2: clinics of physical and internal medicine; unit 3: student, occupational and primary health care, [2] includes three children

5.2.3 Spine radiographs in primary care (III)

The proportion of spine radiographs (patients aged over 15 years) that were in accordance with the guidelines improved slightly during the study period, from 34% in 2010 to 48% in 2012 (III). Before the interventions, in 2010, 24% of cervical spine, 46% of thoracic spine and 32% of lumbar spine radiographs were appropriate (Table 10). The improvement of the level of appropriateness was statistically significant only in lumbar spine radiographs, from 32% in 2010 to 64% in 2012 ($p = 0.005$).

Table 10. The number (n) and proportion (%) of justified spine radiography out of the total number of cases analyzed.

Year	Cervical spine radiographs		Thoracic spine radiographs		Lumbar spine radiographs	
	n / total	%	n / total	%	n / total	%
2010	12 / 50	24	23 / 50	46	16 / 50	32
2011	5 / 50	10	26 / 50	52	20 / 50	40
2012	12 / 50	24	28 / 48	58	32 / 50	64

5.2.4 *Referral indications of inappropriate examinations and possibility of using other modalities (I, II, III)*

In the analysis of CT examinations' appropriateness in 2009 (I), the referral indications for inappropriate examinations were assessed. Regarding CTs of the head, 8 of the 30 examinations were inappropriate and all of those could have been made with MRI. The indications for inappropriate examinations were postoperative dizziness, control of trauma patients (ventricular size, hemorrhagia), control of hydrocephalus or shunt, migraine patient's transient aphasia and prolonged headache/suspicion of tumor. In the group of CT of the abdomen, 6 examinations were inappropriate and could have been examined with MRI (prolonged pain in lower abdomen, lesions of liver or spleen, evaluation of pancreatic pseudocyst) or US (abdominal pain over a few days). Three sinus CT examinations were inappropriate and could have been done with MRI if necessary (control of sinusitis) or required no examinations (control of incidental finding in head CT without any symptoms). One cervical CT examination was inappropriate and would have required no cervical imaging at all (trauma patient with aphasia, head CT was also performed).

Regarding the analysis of the lumbar spine CT examinations from the years 2005, 2007, 2008 and 2009, altogether 46 out of 117 CTs were inappropriate (I, II). In almost all inappropriate examinations, the referral indication for CT was symptoms of disk syndrome (97%) and could have been examined with MRI.

Regarding the analysis of appropriateness of lumbar spine radiographs performed in the Oulu University Hospital (years 2005, 2007, 2008 and 2009) altogether 62 of the 313 examinations were not in accordance with the guidelines (II). In the study of spine radiographs in primary care (years 2010, 2011 and 2012), altogether 274 of the 448 examinations were inappropriate (III).

The referral indications for inappropriate lumbar spine radiographs are shown in Table 11 (II, III). The indications for appropriate lumbar spine examinations are shown in Table 12 (II, III).

In the cohort of primary care patients, the most common referral indications for inappropriate cervical spine radiographs were neck pain, brachalgia or degenerative change (79%) and dizziness (12%). Regarding thoracic spine, the respective indications were chronic or worsened back pain (66%), neck pain and/or brachalgia (14%) and side/rib pain (14%) (III).

Table 11. The referral indications for inappropriate lumbar spine radiographs in primary care and in the Oulu University Hospital.

Indication	Primary care (> 16 years old)		University hospital (< 35 years old)	
	n	%	n	%
Acute or chronic back pain	51	62	42	68
Symptoms of disk syndrome	24	29	19	31
Degeneration	3	4		
Other	4	5	1	1

Table 12. The referral indications for appropriate lumbar spine radiographs in primary care and in University Hospital and lumbar spine CTs in the Oulu University Hospital.

Indication	Radiographs		CT
	Primary care (> 16 years old)	University hospital (< 35 years old)	University hospital (< 35 years old)
	%	%	%
Trauma / suspicion of fracture	53	38	59
Postoperative control	1	15	32
Suspicion of spondyloarthropathy	5	14	
Control of fracture	7	9	
Suspicion of bone anomalies		7	
Control of spondylolysis / listhesis		7	
Prolonged back pain (intention to send to special care)	16		
Known malignancy and pain	16		
Other	2	10	9

5.3 Significant findings in lumbar spine radiographs (II)

The total proportion of significant findings during the study period was statistically significantly higher in radiographies that were in accordance with the guidelines than in radiographies that were not; in young adults, 56% versus 21% ($p < 0.001$), and in children, 48% versus 0% (Table 13) (II). There were also statistically significantly more significant findings in the group of appropriate examinations in unit 3 that had the most inappropriate examinations ($p < 0.001$). Regarding the appropriate examinations in young adults, significant findings were a fracture in 23% of the cases, control of a fracture or an operation in 40%, spondylolysis and/or spondylolisthesis in 24%, and sacroiliitis in 11%. Regarding the inappropriate examinations, the significant findings were mainly spondylolysis and/or spondylolisthesis (83%). In children, the main significant findings related to the appropriate examinations were spondylolysis and/or spondylolisthesis (50%) and a fracture or control of a fracture or an operation (29%). The three inappropriate radiographies in children were normal.

Table 13. The proportion of significant findings in appropriate and inappropriate lumbar spine radiographs.

Year	Appropriate examinations				Inappropriate examinations			
	unit 1[1,2]	unit 2[1]	unit 3[1]	children	unit 1[1]	unit 2[1]	unit 3[1]	children
	n/total (%)	n/total (%)	n/total (%)	n/total (%)	n/total (%)	n/total (%)	n/total (%)	n/total (%)
2005	11/19 (58)	7/13 (54)	5/7 (71)	9/17 (53)	0/1	2/7 (29)	6/13 (46)	0/3
2007	10/16 (63)	6/11 (55)	5/8 (63)	11/20 (55)	0/4	1/9 (11)	1/12 (8)	0/0
2008	8/19 (42)	4/17 (24)	9/15 (60)	9/20 (45)	0/0	1/3 (33)	1/5 (20)	0/0
2009	10/19 (53)	5/10 (50)	16/16 (100)	8/20 (40)	0/1	0/3	1/ 4 (25)	0/0
Total	39/73 (53)	22/51 (43)	35/46 (76)	37/77 (48)	0/6	4/22 (18)	9/34 (26)	0/3

[1] Main referring clinics in unit 1: ED, clinics of surgery and neurosurgery; unit 2: clinics of physical and internal medicine; unit 3: student, occupational and primary health care, [2] includes three children

6 Discussion

6.1 Patient selection and methods used

The primary survey regarding the use of CT examinations on young patients in Oulu University Hospital and the internal audit regarding the use of lumbar spine radiographs revealed inadequate justification (Oikarinen et al., 2009). It has been assessed that about 20–50% of all radiological examinations are inappropriate, and even more in the case of certain CT examinations (Almén et al., 2009; Bianco, Aida, Zucco, Lotito, & Pavia, 2018; Bouette et al., 2019; Espeland et al., 1999).

In the present study, the aim was to find out whether it is possible to decrease the number of inappropriate radiological examinations that use ionizing radiation and to improve the justification of the performed examination. The methods used were evidence-based imaging referral guideline distribution, reminders and attached education. In previous studies, the combinations of these tactics have been shown to be functional (Baker et al., 1987; de vos Meiring & Wells, 1990; Eccles et al., 2001; Grol & Grimshaw, 2003; Kerry et al., 2000).

Despite the contradictory views, epidemiological studies have shown that also low dose radiation can be harmful and cause excess numbers of cancers (National Research Council, 2006; Cardis et al., 2005; ICRP, 1991; Mathews et al., 2013; Pearce et al., 2012; Pierce et al., 1996). There is increasing concern especially because of the rapid growth of the number of CT examinations used globally leading to larger cumulative radiation dose to populations (Hall & Brenner, 2008). The risk of potential radiation-induced adverse effect is higher in patients aged approximately 35 years or younger (Brenner et al., 2001). That is why the interventions in this study in the university hospital were targeted to examinations of patients under the age of 35.

Back complaints, especially low back pain, are a cause of major disability and costs to societies (GBD 2015 DALYs and HALE Collaborators, 2016). In examinations of the lumbar spine, the radiation is delivered to the area of radiation-sensitive organs. The radiation dose of lumbar spine radiography is also among the highest for conventional radiographies (European commission, 2008; Richards et al., 2010). In previous studies, is it acknowledged that lumbar spine examinations are often potentially inappropriate, especially in primary care (Almén et al., 2009; Espeland et al., 1999; Halpin et al., 1991; Oakeshott et al., 1994; Oikarinen et al., 2009). Thus, specific interventions were targeted to lumbar spine radiographies and

CT examinations performed in Oulu University Hospital and also to spine radiographies in primary care.

6.2 Effect of guideline implementation on the number of examinations

Although the number of CT examinations in Finland between 2005 and 2008 increased by about 23% (Tenkanen-Rautakoski, 2010) and also in Oulu University Hospital between 2005 and 2009 by about 11%, the number of CTs performed on young patients decreased by 7% after interventions targeted to that age group. The results varied according to body region as the CTs of lumbar spine decreased by 80%, those of cervical spine by 48%, and those of the head by 21%. On the contrary, the number of CTs of the abdomen increased by 16% and those of the body (thorax and abdomen) by 28%.

The number of lumbar spine CTs in all age groups in our hospital also decreased significantly, by 75%, from 2005 to 2009, while in Finland as a whole, there was a decrease of about 20% (from 2005 to 2008). At the same time, the number of lumbar spine MRIs increased in our hospital by 103% in young patients and also by 62% in all age groups. In Finland as a whole, this increase was about 15% (from 2005 to 2008). (Tenkanen-Rautakoski, 2010) The number of CTs of the head carried out on young patients decreased significantly during the study period and at the same time, the number of MRIs of the head increased even more (38%). The head CTs in all age groups increased by 3% in our hospital and by 10% in Finland, and the number of head MRI increased by 28% in Finland (Tenkanen-Rautakoski, 2006; Tenkanen-Rautakoski, 2010). The changes in both lumbar spine and head imaging in our hospital were greater than overall in Finland, reflecting a change in the clinical imaging request paradigm, probably because of the interventions implemented.

In the present study, the number of CTs of abdomen and body increased. The indications for these studies are multiple and variable, which makes the decision of appropriateness challenging. A majority of inappropriate examinations could have been replaced by MRI. In our practice, the CT referrals are preauthorized and protocols are planned one or two days prior or immediately prior to the examination, but in the case of questionable justification, there may not be any time slot available for an MRI scan. The change in numbers may reflect an overall pattern of increased use of all cross-sectional imaging in this patient group because the number of abdominal MRIs increased clearly (by 129% in young people) as well. Still, the number of abdominal CTs in all age groups increased even more in Finland from 2005 to 2008 than in our hospital from 2005 to 2009; 45% vs. 33%, respectively (Tenkanen-Rautakoski, 2006, 2010).

Because of the multiple indications for CT of the abdomen or body, the guideline implementation in these categories should probably be more targeted to achieve a positive outcome. In a study about incorporating the American College of Radiology appropriateness criteria on abdominal imaging with lectures to hospital practice there was a significant reduction in abdominal CT scans (Covington, Agan, Liu, Johnson, & Shaw, 2013). Also, studies that targeted guideline implementation solely to the use of triaging algorithm of CT for blunt abdominopelvic trauma, renal colic and patient with suspicion of abdominal abscess achieved a significant decrease in the number of abdominal CTs (by 32%, 38% and 10%, respectively) (Baghdanian et al., 2017; Lal et al., 2000; Raja et al., 2019). In these studies, the proportion of CT studies with positive findings also increased significantly.

There are only few earlier studies about guideline implementation that target the number of CTs. In a study about pediatric CT examinations where the referrals were prospectively reviewed and cancelled if not justified, about 8% of all CT referrals and 75% referrals of lumbar spine CT were cancelled (Sodhi et al., 2015). In earlier research about computer-based clinical decision support there was a significant decrease in CT volume growth after the system implementation (Sistrom et al., 2009) and in another study, the number of CT examinations on patients with suspicion of pulmonary embolism decreased by 20% (Raja et al., 2012).

The number of lumbar spine radiographs done in Oulu University Hospital on patients under age 35 decreased by 37% after the interventions from 2005 to 2009. Furthermore, the number of spine radiographs on adults in primary care in Oulu area decreased by 51% after interventions from 2010 to 2012. These findings are also supported by previous literature where different guideline implementation strategies have decreased the referrals of spine radiographies by about 20–30% and that of lumbar spine up to 47% (Influence of royal college of radiologists' guidelines on referral from general practice. royal college of radiologists working party, 1993; Baker et al., 1987; de vos Meiring & Wells, 1990; Eccles et al., 2001; Kerry et al., 2000; Oakeshott et al., 1994).

This study of spine radiographs contains information from one university hospital and primary care units of one city only. The numbers of two other university hospital cities' primary care spine radiographs (from 2010 and 2011) and statistics on radiological examinations in Finland (from 2005, 2008 and 2011, statistics are available for these years) were therefore evaluated (Table 14). The number of lumbar spine radiographies decreased in all age groups in our hospital by 32% from 2005 to 2009, but in Finland overall, it remained almost unchanged from 2005 to 2008. In the reference cities' primary care, the amount of spine radiography on adults decreased slightly from 2010 to 2011, but the changes are clearly smaller than in our study (48%). In Finland, the decrease was 15% from 2008 to 2011. In 2010, the number of spine radiography examinations in Oulu already seemed to be smaller compared to the other two cities. As presented in the present study, the guidelines for spine imaging have been in use in the Oulu area since 2006. Hence, clinicians in primary care may also have been more aware of the appropriate use of spine imaging than clinicians on average in Finland.

During the present study, our hospital's MRI capacity was increased by 30% in 2006. The total number of MRIs in young patients increased by 52% from 2005 to 2009. This probably reflects the universal trend of increased usage and access to MRI. When targeting the interventions to primary care spine radiographs in 2010, it was suspected that the amount of spine MRI would increase from 2010 to 2012. However, the number decreased slightly. With the interventions in this study, the guidelines for spine CT and MRI had also been provided. According to the guidelines, if a spine radiograph is not justified, the use of MRI is not necessarily indicated, so when the guidelines are used correctly, there should not be an excessive number of MRI examinations. However, this study focused on the appropriate use of radiographs; it is thus not known whether the spine MRI examinations performed were in accordance with the guidelines as they were not assessed.

We also recorded the number of cancelled requests for primary care spine radiographs, which was quite low (35 and 29 in 2011 and 2012, respectively). Regarding the radiographs, radiographers make the final justification based on referral and they were advised to consult radiologists in unclear cases. In this study, there were quite a lot of inappropriate examinations even after the interventions took place, implying that the justification decision is not easy or clear for the radiographers either, and more education is needed. The support of radiologists to radiographers in the justification process is also very important. Based on this information, it seems that the biggest change in this study was based on the change in the referral habits of the referrers.

Table 14. The numbers (per 100 000 inhabitants) and the change in the numbers (%) of spine radiography performed on citizens aged 16 years and older in three Finnish university hospital cities' primary care (from 1 May to 31 October) and in Finland (whole years).

Spine type	Tampere[1]			Kuopio[2]			Oulu			Finland[3]		
	2010	2011	Change	2010	2011	Change	2010	2011	Change	2010	2011	Change
	$n/10^5$	$n/10^5$	%	$n/10^5$	$n/10^5$	%	$n/10^5$	$n/10^5$	%	$n/10^5$	$n/10^5$	%
Spine radiographs	2 497	2 340	-6	2 962	2 850	-4	954	499	-48	4 957	4 192	-15
Cervical spine	601	496	-17	801	807	1	229	123	-46	1 417	1 124	-21
Thoracic spine	251	244	-3	300	223	-26	122	58	-53	603	497	-18
Lumbar spine	1 645	1 600	-3	1 863	1 820	-2	603	318	-47	2 937	2 571	-12

[1] Statistics from the radiology department of Tampere, [2] Statistics from the radiology department of Kuopio, [3] National reports are available from these years

6.3 Effect of guideline implementation on appropriateness of examinations

In the present study, the CT examinations of patients under the age of 35 were significantly more in accordance with the guidelines after the interventions in 2009 compared to 2005 (87% versus 71%, $p < 0.001$). The level of appropriateness improved or remained unchanged in all categories.

Earlier research (Almén et al., 2009; Bianco et al., 2018; Clarke et al., 2001; Lehnert & Bree, 2010; Oikarinen et al., 2009) points out that appropriateness of CT examinations varies according to body region. In this study, after the interventions in 2009, 73% of CTs of the head, 80% of the abdomen, 82% of the lumbar spine, and 97% of the cervical spine were appropriate. It was also concluded that a majority of inappropriate CT examinations could have been replaced by MRI (83%). This finding is also supported by previous literature as in the study by Clarke et al., 91% of lumbar spine CTs and 47–73 % of other CT examinations could have been investigated at least equally well by MRI (Clarke et al., 2001).

Studies on the effect of various interventions on the appropriateness of CT examinations are sparse. The use of computerized clinical decision support tools has improved the appropriateness of radiological examinations and some of these studies also include CT examinations (Appari et al., 2018; Carton et al., 2002; Rosenthal et al., 2006; Tajmir et al., 2017). In a study about the effect of computer-based referral guidelines for all radiological referrals the proportion of referrals that were not in accordance with guidelines decreased significantly from 33% to 27% (Carton et al., 2002). Another study concluded that CDS with decision-making pathways is associated with lower inappropriate utilization rates for abdominal CT ($p < 0.01$) (Appari et al., 2018). The present study evaluated more conventional interventions, but referral imaging guidelines are also the base of CDS.

The level of appropriateness of lumbar spine radiographies of young adults in Oulu University Hospital improved or remained unchanged from 2005 before the interventions to 2009 after the interventions and follow-up (65% versus 85%). In primary care, the proportion of spine radiographs (patients aged over 15 years) that were in accordance with the guidelines improved slightly during the study period, from 34% in 2010 to 49% in 2012. Still, even after the interventions, especially in primary care, there was an excess of inappropriate examinations.

In the cohort of young patients' lumbar spine imaging in Oulu University Hospital, the level of appropriateness was highest in the unit receiving referrals from quite selective patient groups, from ED and surgical clinics. In the two other units that received patients from the non-surgical specialities or, e.g., from student, occupational and primary health care, the level of appropriateness was unexpectedly low before the interventions (65% and 35%). This was also the case in primary care adult patients, as only 24% of cervical spine, 46% of thoracic spine and 32% of lumbar spine radiographies were appropriate in 2010, before the interventions. However, there was significant improvement of appropriateness regarding these patient groups; in lumbar spine radiographies in the University Hospital from 48% to 79% (2005–2009) and in primary care, from 32% to 64% (2010–2012). These patient groups are more unselected with symptoms related to the back without any trauma. Hence, the proportion of patients who should not have imaging is larger. It should also be noted that in the present study, the significant decrease in the numbers of spine radiography eliminated several inappropriate examinations. In any case, it seems to be important to analyze not only the change in the number of radiography examinations but also the appropriateness of performed imaging to get a complete picture of the current status of the imaging practice and the success in radiation protection.

In a study of targeted guideline implementation of limb and joint, chest and spine radiographs, the number of spine radiographs decreased by about 30% and the appropriateness of spine examinations improved from 40% to 45% and that of all targeted radiographs from 73% to 85% ($p < 0.01$) (Oakeshott et al., 1994). Introducing clinical decision support to an urban ED, the proportion of low back pain patients who received medical imaging order decreased significantly (median from 22% to 17%) (Min et al., 2017). Nevertheless, the strength of the present study is the 3-year follow-up that is missing from the other studies.

In literature, it has been shown that nonmedical aspects, such as capacity, expectation or demand for radiological examinations from patients or relatives as well as medico-legal considerations can be the reasons for unnecessary referrals (Lysdahl & Hofmann, 2009; Morgan et al., 1997; Sears et al., 2016; You, Levinson, & Laupacis, 2009). Lack of communication between clinicians and radiologists and gaps in the knowledge or education of the ordering physician also have an impact on the overutilization in medical imaging (Hendee et al., 2010; You et al., 2009). Radiologists may also contribute to overutilization because they do not routinely review orders for appropriateness before examinations are performed (Callahan, 2011; Hendee et al., 2010) In our hospital, as in Finland generally, the referrals for advanced imaging, e.g. CT and MRI examinations, are preauthorized by radiologist, but still there seems to be an excess of inappropriate examinations as presented in this study. Thus, radiologists should also be more aware of the harmful effects of ionizing radiation and the principles on radiation protection.

6.4 Effect of guideline implementation on the number and appropriateness in children

As children are most vulnerable to the harmful effects of ionizing radiation and have their own imaging guidelines, it is important to view their examinations separately. In the present study, the numbers of lumbar spine CT and radiography examinations done on children in the university hospital were low in the beginning and there were no significant changes during the study period. The level of justification of CT examinations and lumbar spine radiographs in the hospital remained nearly constant and high in children. It is likely that pediatricians pay more attention to justification and consult radiologists more often before requesting, especially considering CT examinations. However, the total number of pediatric examinations was small in both cohorts.

6.5 The importance of appropriate use of imaging referral guidelines

According to directives and legislation regarding radiation protection, the doctor requesting an examination where ionizing radiation is involved is also responsible for the appropriateness of indications, for obtaining previous diagnostic information, and for generation of detailed clinical information of the patient to be included in the referrals. It is the duty of the radiologist to make the final decision on a requested examination considering its benefit versus the radiation dose and choosing the suitable protocol. (Finnish radiation act, 859/2018, 2018; European commission, 2014; ICRP, 2007) The goal of this procedure is to prevent unnecessary radiation dose to population. Evidence-based imaging referral guidelines have been developed to help clinicians and radiologists to choose the right imaging modality at the right time. Despite the guidelines in place, the radiological examinations are overused. For example, a national survey about radiograph use in low back pain in the USA for the years 1998–2000 noted that in this patient group, over three million patients with "back symptoms" and no "red flags" 18% had a screening radiograph (Isaacs et al., 2004).

When using the imaging referral guidelines appropriately, there is a potential to decrease the number of radiological examinations and to improve the appropriateness of the examinations performed as shown in the present study. With the decrease in the number of examinations a notable dose reduction can be achieved. In the present study, the number of lumbar spine CT examinations on young people decreased by 79% from 2005 to 2009 and the computational dose reduction achieved after the interventions in the years 2007–2009 was about 2 650 mSv in this patient group (calculated with average doses of examinations at that time period). This equals approximately 88 200 chest radiographs, or 880 years of natural background radiation in Finland (based on the reports of that time period). The corresponding dose reduction regarding lumbar spine radiographs in the same study period was 940 mSv. It has been estimated that the risk ratio for inducing cancer with lumbar spine CT is about 1 in 3 200 (Richards, George, Metelko, & Brown, 2010). Fortunately, the absolute number of lumbar spine examinations exposing to ionizing radiation in young people in our hospital is small. If the majority of inappropriate imaging in our hospital, in Finland and even globally could be avoided in all age groups the consequences would be remarkably greater. In the US, about 2.2 million lumbar spine scans are performed annually and it is estimated that they result in an additional 1 200 future cases of cancer (Berrington de González et al., 2009). Physicians and radiologists need to be aware of this potential risk associated with imaging using ionizing radiation.

Inappropriate use of diagnostic imaging also puts an unnecessary strain on already overloaded hospital systems and is a financial burden to societies. In a study about imaging utilization patterns at a trauma center in the US, the application of the ACR criteria was found to have the potential to reduce imaging costs by 39% and the estimated radiation dose by 44% (Hadley, Agola, & Wong, 2006) In the present study regarding spine radiographs in primary care, the City of Oulu saved over 18 000 euros per 6 months from 2010 to 2012 thanks to reductions in the number of examinations. This also released resources for appropriate examinations. Should the result persist, the total economic relevance in the years to come would be significant.

It should be noted that it is always possible that some individual patients who do not have an indication for imaging would have benefited from it. However, imaging guidelines are evidence-based and developed by multi-disciplinary experts. Furthermore, in a review of 14 studies evaluating “red flags” in low back pain it is stated that many red flags in current guidelines provide virtually no change in the probability of detecting fracture or malignancy. In the case of fracture suspicion, the presence of older age, prolonged steroid use, severe trauma, and contusion or abrasion increased the probability of fracture to between 10% and

33%, and the presence of multiple red flags increased this between 42% and 90%. In the case of malignancy, the highest post-test probability for detection of spinal malignancy was history of malignancy which increased the probability between 7% and 33%, while older age, unexplained weight loss, and failure to improve after one month had post-test probabilities below 3%. Thus, it is suggested that there is a need for revision of many current guidelines (Downie et al., 2013). This means that even if guidelines are followed it can lead to excessive amount of imaging so it is important to at least ensure that the examinations done are in concordance with guidelines.

6.6 Back pain patients

6.6.1 Indications and radiological findings in spine examinations

When assessing the referral indications of lumbar spine radiographs on young patients in the university hospital and adults in primary care, the indications leading to inappropriate radiographs were almost solely acute or prolonged back pain, which is not a relevant indication in young patients, or symptoms of disk syndrome (97 % and 91%, respectively). The indication for most of the inappropriate lumbar spine CTs was symptoms of disk syndrome (97%). These indications are quite typical and this patient group is large. It has been shown in previous literature that lumbar spine imaging is not appropriate on acute non-trauma patients with no "red-flags" indicating serious conditions (Chou et al., 2009; Deyo et al., 1992; European commission, 2008; Koes et al., 2001). Nevertheless, overutilization of lumbar spine imaging still exists, e.g., the analysis of Medicare beneficiaries showed that almost 30% of patients underwent imaging within the first month of an episode of acute low back pain (Pham, Landon, Reschovsky, Wu, & Schrag, 2009). It seems that education and guideline implementation should focus on these patient groups in order to achieve better concordance with guidelines in future.

In the present study, the proportion of significant findings in lumbar spine radiographs was statistically significantly higher in examinations that were in accordance with the guidelines, i.e. justified; in young adults, 56% versus 21% ($p < 0.001$) and in children, 48% versus 0%. This was also the case in the radiological unit that had the most inappropriate examinations ($p < 0.001$). These results are in line with earlier research stating that examinations falling outside the indications of referral guidelines do not have a significant amount of relevant or explanatory findings (Deyo & Diehl, 1986; Espeland et al., 1999; Halpin et al., 1991). To our knowledge, there are only these few other studies that have assessed both appropriateness and findings regarding lumbar spine radiographies in patients with low back pain.

Regarding the appropriate lumbar spine radiographs in young adults and children, most of the significant findings were a fracture or follow-up imaging of a fracture or an operation (63% and 30%) and of spondylolysis and/or spondylolisthesis (24% and 51%). Regarding the inappropriate examinations of young adults, the significant findings were mainly spondylolysis and/or spondylolisthesis (83%). Earlier literature has shown that back pain and degeneration or mild scoliosis are only weakly associated, so in this study those findings were not interpreted as significant (Boden et al., 1990; Deyo & Weinstein, 2001; Jensen et al., 1994; White & Gordon, 1982). Furthermore, spondylolysis and/or spondylolisthesis is quite a common finding in lumbar spine radiographs as it can be found in about 5% to 10% of normal adult subjects, and the connection of this finding with back pain is controversial (Beutler et al., 2003; Ko & Lee, 2011; Osterman et al., 1993; van Tulder et al., 1997).

6.6.2 Impact of imaging on back pain patient outcome

In the present study on lumbar spine radiographies that were not in accordance with guidelines, almost all findings that were considered relevant were spondylolysis and/or spondylolisthesis. Although these are conditions that may require treatment, in our study group the treatment of these patients, if any, was physiotherapy, and none of these patients required any surgery. Hence, at least in our study, no findings that might have affected patient care would have been missed in the event of inappropriate radiographies not being performed. Earlier literature has implied this same conclusion as the use of imaging with acute or subacute low back pain was not associated with better pain relief, function recovery, quality of life, or overall outcome (Chou et al., 2009). It has also been shown that minor abnormal findings, e.g. degeneration or minor congenital abnormalities, on radiography on back pain patients made no difference to the outcome (Kendrick et al., 2001).

We did not assess the impact of significant findings on patient care in those cases where the radiographs were appropriate. Nor did we assessed the impact of not imaging patients who visited doctors for back pain, a study scenario which would be more difficult to carry out but would be an interesting topic of study. The real impact of imaging on patient care in all back pain patients was thus not assessed.

It has to be considered that, in some cases, negative or incidental findings can be significant. Nevertheless, one of the risks of routinely imaging uncomplicated acute low back pain is patient "labeling"; no evidence exists that labeling patients with a specific anatomic diagnosis improves outcomes. In a study about primary care, patients who underwent lumbar spine radiography reported more satisfaction with care but also worse pain and overall health during follow-up, and a higher proportion of participants consulted their doctor than those who had had no imaging (Kendrick et al., 2001). Literature suggest that verifying a patient's diagnosis, collecting all the information about the reason behind the patient requesting something, and providing information personalized to the patient's perspective may result in excellent patient satisfaction, despite rejecting the requests (Paterniti et al., 2010). Frequently discovered benign incidental findings and those of indeterminate clinical significance can cause uncertainty both for patients and their physicians (Orme et al., 2010). Furthermore, imaging studies have also indirect effects as increased amount of lumbar spine MRIs is associated with increased rates of spine surgery, without apparent differences in patient outcomes (Jarvik et al., 2003; Lurie, Birkmeyer, & Weinstein, 2003).

It is also suggested that patients obtain inadequate information regarding radiological examinations and dose and the risks of radiation, and a majority of the patients wished for more information on those topics (Ukkola, Oikarinen, Henner, Haapea, & Tervonen, 2017; Ukkola et al., 2016). The article about overutilization published in the local newspaper during our study was one of the tools to involve the public in the project and radiation protection.

6.7 Strength and Limitations

Several strengths of this study can be mentioned. We used a combination of interventions that have proven to be effective: guideline distribution, reminders, and active lectures to small groups. These interventions are also easy to implement in normal practice and might therefore be useful in other hospitals nationally or internationally. The study was mainly focused especially on young people who are more sensitive to the adverse effects of ionizing radiation. Our study differs from most of the earlier studies on imaging referral guideline implementation as we did not examine only the change in the number of examinations but also the justification of different imaging examinations. It was found that after the interventions and decrease in the number of examinations there is still quite a large amount of inappropriate studies. The assessment of justification is thus a valid part of the study, revealing that there is still need for a change. We also evaluated referral indications for inappropriate examinations and the findings of inappropriate lumbar spine radiographs. Previous studies including all these evaluations are scarce.

In assessing the justification of examinations, we not only evaluated the referrals but also all the corresponding patient files in order to have the same information as the referring physician had had while requesting the examination. As such, the evaluation was more accurate than if the assessment had only been made based on request forms. Furthermore, the strength of the present study is the longitudinal follow-up lasting several years; from 2005 to 2009 in CT examinations and lumbar spine radiographies in Oulu University Hospital and from 2010 to 2012 in spine radiographs in primary care. This long follow-up is lacking in most of other similar studies.

There are also several limitations to this study. A major limitation is that this study contains information from one institution and city only. The patient number selected for the justification evaluation is somewhat low. Inclusion of multiple institutions and a broader patient base might have provided more information. We did not measure the impact of various interventions separately. It is probable that certain interventions directed the referral practice more than others. Better access to MRI may have had some effect as well. In addition, we did not record referrers', radiographers', or radiologists' participation in the educational lectures. Monitoring the participations and participants might have offered an interesting perspective to the study. Furthermore, as the interventions described were targeted at all the referring clinicians and staff in radiology departments we did not have a control group. However, we used the change in the numbers of spine radiography examinations in the health centers of two other university hospital cities and statistics of Finland as a reference.

As a process, the evaluation of justification is also complicated. We realize that, in practice, many different aspects, such as capacity and financing, may have an effect on the choice of an examination and this data cannot be found in referrals or patient files. The expertise or the number of years at work, i.e. experience of referring clinicians was not analyzed. There have also been national and international changes in the utilization of imaging which have occurred over the same time period and may also have influenced the results of this study. However, suspicion of a notable proportion of inappropriate examinations still exists, and the interventions used in this study could also be used today.

6.8 Clinical implications and future perspectives

Inappropriate imaging increases the collective dose to populations and contributes to increased costs without improving the outcome. Even though in general, it is probably impossible to reach 100% justification, it is still essential to develop justification processes further. Referral guideline implementation and education on how to use them as well as monitoring their use can contribute to improved justification, help to reduce exposure to radiation, and release resources for appropriate examinations as shown in this study. Increasing patients' and public's awareness concerning issues related to radiation and relevant radiological examinations may also be a useful tool. Inappropriate use of spine radiography is a global problem which may be most prominent in primary care, where the patients are unselected and present with common symptoms but without any true indications for radiography. Efforts to improve justification should probably be directed, in addition to CT, to this area in particular. Furthermore, special attention should be paid to children and young adults who are more sensitive to radiation.

When an examination is not justified it should be cancelled or replaced with a more appropriate examination. Clinicians may take this as negative feedback and radiologists may be prone to approve examination regardless of their questionable referral indications. A referral should be perceived as a consultation, and co-operation between referrers and radiologist should be obvious.

The interventions used in this study could easily be implemented in other institutions worldwide. Active implementation of referral guidelines was supported by the results of our study. Recently, guidelines on the CDS platform have been an efficient tool to improve appropriateness. It is important to update referral guidelines regularly, audit their use, and monitor whether the clinicians are following them. While integrating guidelines with CDS to imaging order systems, these measures are possible. The use of CDS in advanced imaging is already mandatory in the USA. The European Society of Radiology has also generated European referral guidelines supported by CDS which are already accessible online. Hopefully, up-to-date guidelines with CDS will be in national use also in Finland in the near future.

7 Conclusion

1. Specific and targeted interventions – guideline distribution, education and increased MRI capacity – decreased the number of different CT examinations performed on young patients and significantly improved the justification of the performed examinations.
2. The interventions achieved a significant and sustained reduction in the number of lumbar spine radiographies and CTs in young patients. Appropriateness improved significantly as well. Regarding radiographs, the proportion of notable findings was higher in appropriate examinations than in inappropriate ones. Inappropriate lumbar spine radiographs taken on patients with low back pain do not seem to contain notable findings that would affect patient care.
3. The number of different spine radiographies in primary care was reduced significantly by active referral guideline implementation. However, the proportion of inappropriate radiographies was unexpectedly high even after the interventions. Thus, further education and surveys targeted to these examinations seem to be needed.

References

Alfidi, R. J., Haaga, J., Meaney, T. F., MacIntyre, W. J., Gonzalez, L., Tarar, R., … Jelden, G. (1975). Computed tomography of the thorax and abdomen; a preliminary report. *Radiology, 117*(2), 257–264. https://doi.org/10.1148/117.2.257

Almén, A., Leitz, W., & Richter, S. (2009). National survey on justification of CT-examinations in sweden. Swedish radiation safety authority. *SSM Report, 03*

American College of Radiology, (ACR). ACR approriateness criteria. Retrieved from https://www.acr.org/Clinical-Resources/ACR-Appropriateness-Criteria

Appari, A., Johnson, M. E., & Anthony, D. L. (2018). Health IT and inappropriate utilization of outpatient imaging: A cross-sectional study of U.S. hospitals. *International Journal of Medical Informatics, 109*, 87–95. https://doi.org/10.1016/j.ijmedinf.2017.10.020

Ash, L. M., Modic, M. T., Obuchowski, N. A., Ross, J. S., Brant-Zawadzki, M. N., & Grooff, P. N. (2008). Effects of diagnostic information, per se, on patient outcomes in acute radiculopathy and low back pain. *AJNR. American Journal of Neuroradiology, 29*(6), 1098–1103. https://doi.org/10.3174/ajnr.A0999

Baghdanian, A. H., Baghdanian, A. A., Armetta, A., Krastev, M., Dechert, T., Burke, P., … Soto, J. A. (2017). Effect of an institutional triaging algorithm on the use of multidetector CT for patients with blunt abdominopelvic trauma over an 8-year period. *Radiology, 282*(1), 84–91. https://doi.org/10.1148/radiol.2016152021

Baker, S. R., Rabin, A., Lantos, G., & Gallagher, E. J. (1987). The effect of restricting the indications for lumbosacral spine radiography in patients with acute back symptoms. *AJR. American Journal of Roentgenology, 149*(3), 535–538. https://doi.org/10.2214/ajr.149.3.535

Barrett, H., & Swindell, W. (1981). Radiological imaging. the theory of image formation, detection, and processing . In H. Barrett, & W. Swindell (Eds.), *Radiological imaging. The theory of image formation, detection, and processing* (pp. 706). San Diego: Academic Press. Retrieved from https://www.sciencedirect.com/science/article/pii/B9780080572307500019

Bell, R. E., & McLaughlin, R. E. (2001). Ionising radiation (medical exposure) regulations (northern ireland) 2000 and their implications for accident and emergency (A&E) doctors in training. *The Ulster Medical Journal, 70*(1), 19–21.

Berrington de González, A., Mahesh, M., Kim, K., Bhargavan, M., Lewis, R., Mettler, F., & Land, C. (2009). Projected cancer risks from computed tomographic scans performed in the united states in 2007. *Archives of Internal Medicine, 169*(22), 2071–2077. https://doi.org/10.1001/archinternmed.2009.440

Bettmann, M. A., Oikarinen, H., Rehani, M., Holmberg, O., del, R. P., Naidoo, A., … Ebdon-Jackson, S. (2015). Clinical imaging guidelines part 4: Challenges in identifying, engaging and collaborating with stakeholders†. *Journal of the American College of Radiology, 12*(4), 370–375. https://doi.org/10.1016/j.jacr.2014.07.020

Beutler, W. J., Fredrickson, B. E., Murtland, A., Sweeney, C. A., Grant, W. D., & Baker, D. (2003). The natural history of spondylolysis and spondylolisthesis: 45-year follow-up evaluation. *Spine, 28*(10), 1027–1035; discussion 1035. https://doi.org/10.1097/01.BRS.0000061992.98108.A0

Bevan, S., Quadrello, T., McGee, R., Mahdon, M., Vavrovsky, A., & Barham, L. (2009). Fit for work? musculoskeletal disorders in the european workforce. *The Work Foundation,* Retrieved from http://www.fitforworkeurope.eu/Website-Documents/Fit%20for%20Work%20pan-European%20report

Bianco, A., Zucco, R., Lotito, F., & Pavia, M. (2018). To what extent do hospitalised patients receive appropriate CT and MRI scans? results of a cross-sectional study in southern Italy. *BMJ Open, 8*(2), e018125-018125. https://doi.org/10.1136/bmjopen-2017-018125

Blackmore, C. C., Mecklenburg, R. S., & Kaplan, G. S. (2011). Effectiveness of clinical decision support in controlling inappropriate imaging. *Journal of the American College of Radiology: JACR, 8*(1), 19–25. https://doi.org/10.1016/j.jacr.2010.07.009

Bly, R., Järvinen, H., Kaijaluoto, S., & Ruonala, V. (2020). Contemporary collective effective dose to the population from X-ray and nuclear medicine examinations-changes over last 10 years in Finland. *Radiation Protection Dosimetry.* https://doi.org/10.1093/rpd/ncaa045

Boden, S. D., Davis, D. O., Dina, T. S., Patronas, N. J., & Wiesel, S. W. (1990). Abnormal magnetic-resonance scans of the lumbar spine in asymptomatic subjects. A prospective investigation. *The Journal of Bone and Joint Surgery. American Volume, 72*(3), 403–408.

Borretzen, I., Lysdahl, K. B., & Olerud, H. M. (2007). Diagnostic radiology in Norway trends in examination frequency and collective effective dose. *Radiation Protection Dosimetry, 124*(4), 339–347. https://doi.org/10.1093/rpd/ncm204

Bosanquet, D. C., Green, G., Bosanquet, A. J., Galland, R. B., Gower-Thomas, K., & Lewis, M. H. (2011). Doctors' knowledge of radiation -- a two-centre study and historical comparison. *Clinical Radiology, 66*(8), 748–751. https://doi.org/10.1016/j.crad.2011.03.009

Bouette, A., Karoussou-Schreiner, A., Ducou Le Pointe, H., Grieten, M., de Kerviler, E., Rausin, L., … Majerus, P. (2019). National audit on the appropriateness of CT and MRI examinations in Luxembourg. *Insights into Imaging, 10*(1), 54–59. https://doi.org/10.1186/s13244-019-0731-9

Brenner, D. J., Doll, R., Goodhead, D. T., Hall, E. J., Land, C. E., Little, J. B., … Zaider, M. (2003). Cancer risks attributable to low doses of ionizing radiation: Assessing what we really know. *Proceedings of the National Academy of Sciences of the United States of America, 100*(24), 13761–13766. https://doi.org/10.1073/pnas.2235592100

Brenner, D. J., Elliston, C. D., Hall, E. J., & Berdon, W. E. (2001). Estimated risks of radiation-induced fatal cancer from pediatric CT. *American Journal of Roentgenology, 176*(2), 289–296.

Brinjikji, W., Luetmer, P. H., Comstock, B., Bresnahan, B. W., Chen, L. E., Deyo, R. A., … Jarvik, J. G. (2015). Systematic literature review of imaging features of spinal degeneration in asymptomatic populations. *American Journal of Neuroradiology, 36*(4), 811. https://doi.org/10.3174/ajnr.A4173

Bundesamt fuer Strahlenschutz. (2012). Umweltradioaktivität und strahlenbelastung im jahr 2010: Unterrichtung durch die bundesregierung. *Bundesministerium Für Umwelt, Naturschutz Und Reaktorsicherheit (BMU)*

Calabrese, E. J., & Baldwin, L. A. (2000). Chemical hormesis: Its historical foundations as a biological hypothesis. *Human & Experimental Toxicology, 19*(1), 2–31. https://doi.org/10.1191/096032700678815585

Callahan, M. J. (2011). CT dose reduction in practice. *Pediatric Radiology, 41 Suppl 2*, 488–492. https://doi.org/10.1007/s00247-011-2099-y

Calvo-Muñoz, I., Gómez-Conesa, A., & Sánchez-Meca, J. (2013). Prevalence of low back pain in children and adolescents: A meta-analysis. *BMC Pediatrics, 13*(1), 14. https://doi.org/10.1186/1471-2431-13-14

Campanella, F., Rossi, L., Giroletti, E., Micheletti, P., Buzzi, F., & Villani, S. (2017). Are physicians aware enough of patient radiation protection? results from a survey among physicians of Pavia District- Italy. *BMC Health Services Research, 17*(1), 406. https://doi.org/10.1186/s12913-017-2358-1

Cardis, E., Vrijheid, M., Blettner, M., Gilbert, E., Hakama, M., Hill, C., … Veress, K. (2007). The 15-country collaborative study of cancer risk among radiation workers in the nuclear industry: Estimates of radiation-related cancer risks. *Radiation Research, 167*(4), 396–416. https://doi.org/10.1667/RR0553.1

Cardis, E., Vrijheid, M., Blettner, M., Gilbert, E., Hakama, M., Hill, C., … Veress, K. (2005). Risk of cancer after low doses of ionising radiation: Retrospective cohort study in 15 countries. *BMJ (Clinical Research Ed.), 331*(7508), 77. https://doi.org/10.1136/bmj.38499.599861.E0

Carey, T. S., Garrett, J., Jackman, A., McLaughlin, C., Fryer, J., & Smucker, D. R. (1995). The outcomes and costs of care for acute low back pain among patients seen by primary care practitioners, chiropractors, and orthopedic surgeons. The North Carolina Back Pain Project. *The New England Journal of Medicine, 333*(14), 913–917. https://doi.org/10.1056/NEJM199510053331406

Carton, M., Auvert, B., Guerini, H., Boulard, J. C., Heautot, J. F., Landre, M. F., … Chagnon, S. (2002). Assessment of radiological referral practice and effect of computer-based guidelines on radiological requests in two emergency departments. *Clinical Radiology, 57*(2), 123–128. https://doi.org/10.1053/crad.2001.0827

Cascade, P. N. (1994). Setting appropriateness guidelines for radiology. *Radiology, 192*(1), 50A–54A.

Cascade, P. N. (2000). The American College of Radiology. ACR Appropriateness Criteria project. *Radiology, 214 Suppl*, 3–46. https://doi.org/10.1148/radiology.214.1.r00ja5510

Chou, R., Fu, R., Carrino, J. A., & Deyo, R. A. (2009). Imaging strategies for low-back pain: Systematic review and meta-analysis. *Lancet (London, England), 373*(9662), 463–472. https://doi.org/10.1016/S0140-6736(09)60172-0

Clarke, J. C., Cranley, K., Kelly, B. E., Bell, K., & Smith, P. H. (2001). Provision of MRI can significantly reduce CT collective dose. *The British Journal of Radiology, 74*(886), 926–931.

Covington, M. F., Agan, D. L., Liu, Y., Johnson, J. O., & Shaw, D. J. (2013). Teaching cost-conscious medicine: Impact of a simple educational intervention on appropriate abdominal imaging at a community-based teaching hospital. *Journal of Graduate Medical Education, 5*(2), 284–288. https://doi.org/10.4300/JGME-D-12-00117.1

Croft, P. R., Macfarlane, G. J., Papageorgiou, A. C., Thomas, E., & Silman, A. J. (1998). Outcome of low back pain in general practice: A prospective study. *BMJ (Clinical Research Ed.), 316*(7141), 1356–1359.

Cypress, B. K. (1983). Characteristics of physician visits for back symptoms: A national perspective. *American Journal of Public Health, 73*(4), 389–395. https://doi.org/10.2105/AJPH.73.4.389

Davis, D., O'Brien, M. A., Freemantle, N., Wolf, F. M., Mazmanian, P., & Taylor-Vaisey, A. (1999). Impact of formal continuing medical education: Do conferences, workshops, rounds, and other traditional continuing education activities change physician behavior or health care outcomes? *JAMA : The Journal of the American Medical Association, 282*(9), 867–874. https://doi.org/10.1001/jama.282.9.867

de vos Meiring, P., & Wells, I. P. (1990). The effect of radiology guidelines for general practitioners in Plymouth. *Clinical Radiology, 42*(5), 327–329. https://doi.org/10.1016/S0009-9260(05)82146-4

Dey, P., Simpson, C. W., Collins, S. I., Hodgson, G., Dowrick, C. F., Simison, A. J., & Rose, M. J. (2004). Implementation of RCGP guidelines for acute low back pain: A cluster randomised controlled trial. *The British Journal of General Practice : The Journal of the Royal College of General Practitioners, 54*(498), 33–37.

Deyo, R. A., & Diehl, A. K. (1986). Lumbar spine films in primary care: Current use and effects of selective ordering criteria. *Journal of General Internal Medicine, 1*(1), 20–25.

Deyo, R. A., & Diehl, A. K. (1988). Cancer as a cause of back pain: Frequency, clinical presentation, and diagnostic strategies. *Journal of General Internal Medicine, 3*(3), 230–238.

Deyo, R. A., & Weinstein, J. N. (2001). Low back pain. *The New England Journal of Medicine, 344*(5), 363–370. https://doi.org/10.1056/NEJM200102013440508

Deyo, R. A., Rainville, J., & Kent, D. L. (1992). What can the history and physical examination tell us about low back pain? *Jama, 268*(6), 760–765. https://doi.org/10.1001/jama.1992.03490060092030

Downie, A., Williams, C. M., Henschke, N., Hancock, M. J., Ostelo, Raymond W J G, de Vet, Henrica C W, … Maher, C. G. (2013). Red flags to screen for malignancy and fracture in patients with low back pain: Systematic review. *BMJ (Clinical Research Ed.), 347*, f7095.

Eccles, M., Steen, N., Grimshaw, J., Thomas, L., McNamee, P., Soutter, J., … Bond, S. (2001). Effect of audit and feedback, and reminder messages on primary-care radiology referrals: A randomised trial. *Lancet, 357*(9266), 1406–1409. https://doi.org/10.1016/S0140-6736(00)04564-5

Espeland, A., Albrektsen, G., & Larsen, J. L. (1999). Plain radiography of the lumbosacral spine. an audit of referrals from general practitioners. *Acta Radiologica (Stockholm, Sweden : 1987), 40*(1), 52–59.

European commission. (1997). Council directive 97/43/euratom of 30 june 1997 on health protection of individuals against the danger of ionizing radiation in relation to medical exposure, and reapealing directive 84/466/euratom. *Official Journal of the European Communities, 40*, 22–27. Retrieved from http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A31997L0043

European commission. (2008). Radiation protection 118, update mars 2008; Referral guidelines for imaging.

European commission. (2014). Council directive 2013/59/euratom of 5 december 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation, and repealing directives 89/618/euratom, 90/641/euratom, 96/29/euratom, 97/43/euratom and 2003/122/euratom. *Official Journal of the European Union, 57*

European Commission. (2015). *Radiation protection 180, medical radiation exposure of the european population.* Luxemburg: Retrieved from https://ec.europa.eu/energy/sites/ener/files/documents/RP180web.pdf

European Society of Radiology, (ESR). (2017). Summary of the proceedings of the international forum 2016: "Imaging referral guidelines and clinical decision support - how can radiologists implement imaging referral guidelines in clinical routine?". *Insights into Imaging, 8*(1), 1–9. https://doi.org/10.1007/s13244-016-0523-4

European Society of Radiology, (ESR). (2019). Methodology for ESR iGuide content. *Insights into Imaging, 10*(1), 32-z. https://doi.org/10.1186/s13244-019-0720-z

European Society of Radiology. ESR iGuide, clinical decision support using european imaging referral guidelines. Retrieved from https://www.myesr.org/esriguide

Feinendegen, L. E. (2005). Evidence for beneficial low level radiation effects and radiation hormesis. *The British Journal of Radiology, 78*(925), 3–7. https://doi.org/10.1259/bjr/63353075

Finnish radiation act, 859/2018, (2018). Retrieved from https://www.finlex.fi/fi/laki/alkup/2018/20180859

Freburger, J. K., Holmes, G. M., Agans, R. P., Jackman, A. M., Darter, J. D., Wallace, A. S., . . . Carey, T. S. (2009). The rising prevalence of chronic low back pain. *Archives of Internal Medicine, 169(*3), 251–258. https://doi.org/10.1001/archinternmed.2008.543

Freeborn, D. K., Shye, D., Mullooly, J. P., Eraker, S., & Romeo, J. (1997). Primary care physicians' use of lumbar spine imaging tests: Effects of guidelines and practice pattern feedback. *Journal of General Internal Medicine, 12*(10), 619–625.

GBD 2015 DALYs and HALE Collaborators. (2016). Global, regional, and national disability-adjusted life-years (DALYs) for 315 diseases and injuries and healthy life expectancy (HALE), 1990-2015: A systematic analysis for the global burden of disease study 2015. *Lancet (London, England), 388*(10053), 1603–1658. https://doi.org/S0140-6736(16)31460-X

Glaves, J. (2005). The use of radiological guidelines to achieve a sustained reduction in the number of radiographic examinations of the cervical spine, lumbar spine and knees performed for GPs. *Clinical Radiology, 60*(8), 914–920. https://doi.org/10.1016/j.crad.2005.02.013

Goodhead, D. T. (1994). Initial events in the cellular effects of ionizing radiations: Clustered damage in DNA. *International Journal of Radiation Biology, 65*(1), 7–17.

Grimshaw, J. M., Thomas, R. E., MacLennan, G., Fraser, C., Ramsay, C. R., Vale, L., … Donaldson, C. (2004). Effectiveness and efficiency of guideline dissemination and implementation strategies. *Health Technology Assessment (Winchester, England), 8*(6), iii-72. https://doi.org/10.3310/hta8060

Grol, R., & Grimshaw, J. (2003). From best evidence to best practice: Effective implementation of change in patients' care. *Lancet, 362*(9391), 1225–1230. https://doi.org/10.1016/S0140-6736(03)14546-1

Günalp, M., Gülünay, B., Polat, O., Demirkan, A., Gürler, S., Akkaş, M., & Aksu, N. M. (2014). Ionising radiation awareness among resident doctors, interns, and radiographers in a university hospital emergency department. *La Radiologia Medica, 119*(6), 440–447. https://doi.org/10.1007/s11547-013-0374-8

Guo, H. R., Tanaka, S., Halperin, W. E., & Cameron, L. L. (1999). Back pain prevalence in US industry and estimates of lost workdays. *American journal of public health, 89*(7), 1029–1035. https://doi.org/10.2105/ajph.89.7.1029

Hadley, J. L., Agola, J., & Wong, P. (2006). Potential impact of the American College of Radiology appropriateness criteria on CT for trauma. *American Journal of Roentgenology, 186*(4), 937–942. https://doi.org/10.2214/AJR.05.0041

Hall, E. J., & Brenner, D. J. (2008). Cancer risks from diagnostic radiology. *British Journal of Radiology, 81*(965), 362–378. https://doi.org/10.1259/bjr/01948454

Hall, E. J., & Giaccia, A. J. (2012). *Radiobiology for the radiologist* (7. ed ed.). Philadelphia: Wolters Kluwer [u.a.].

Halpin, S. F., Yeoman, L., & Dundas, D. D. (1991). Radiographic examination of the lumbar spine in a community hospital: An audit of current practice. *BMJ (Clinical Research Ed.), 303*(6806), 813–815.

Hart, D., Wall, B., Hillier, M., & Shrimpton, P. (2010). HPA-CRCE-012 - frequency and collective dose for medical and dental X-ray examinations in the UK, 2008. *Health Protection Agency Publications*

Hendee, W. R., Becker, G. J., Borgstede, J. P., Bosma, J., Casarella, W. J., Erickson, B. A., … Wallner, P. E. (2010). Addressing overutilization in medical imaging. *Radiology, 257*(1), 240–245. https://doi.org/10.1148/radiol.10100063

Hong, J., Han, K., Jung, J., & Kim, J. S. (2019). Association of exposure to diagnostic low-dose ionizing radiation with risk of cancer among youths in South Korea. *JAMA Network Open, 2*(9), e1910584. https://doi.org/10.1001/jamanetworkopen.2019.10584

Hoy, D., Bain, C., Williams, G., March, L., Brooks, P., Blyth, F., … Buchbinder, R. (2012). A systematic review of the global prevalence of low back pain. *Arthritis and Rheumatism, 64*(6), 2028–2037. https://doi.org/10.1002/art.34347

ICRP. (1991). 1990 recommendations of the international commission on radiological protection. ICRP publication 60. *Annals of the ICRP, 21*(1–3). Retrieved from http://www.icrp.org/publication.asp?id=icrp%20publication%2060

ICRP. (2007). The 2007 recommendations of the international commission on radiological protection. ICRP publication 103. *Ann. ICRP, 37*(2–4)

Influence of royal college of radiologists' guidelines on referral from general practice. royal college of radiologists working party. (1993). *BMJ (Clinical Research Ed.), 306*(6870), 110–111.

Influence of the royal college of radiologists' guidelines on hospital practice: A multicentre study. royal college of radiologists working party. (1992). *BMJ (Clinical Research Ed.), 304*(6829), 740–743.

Ip, I. K., Schneider, L. I., Hanson, R., Marchello, D., Hultman, P., Viera, M., … Khorasani, R. (2012). Adoption and meaningful use of computerized physician order entry with an integrated clinical decision support system for radiology: Ten-year analysis in an urban teaching hospital. *Journal of the American College of Radiology : JACR, 9*(2), 129–136. https://doi.org/10.1016/j.jacr.2011.10.010; 10.1016/j.jacr.2011.10.010

Isaacs, D. M., Marinac, J., & Sun, C. (2004). Radiograph use in low back pain: A united states emergency department database analysis. *The Journal of Emergency Medicine, 26*(1), 37–45.

Jarvik, J. G., Hollingworth, W., Martin, B., Emerson, S. S., Gray, D. T., Overman, S., … Deyo, R. A. (2003). Rapid magnetic resonance imaging vs radiographs for patients with low back pain: A randomized controlled trial. *Jama, 289*(21), 2810–2818. https://doi.org/10.1001/jama.289.21.2810

Jenkins, H. J., Downie, A. S., Maher, C. G., Moloney, N. A., Magnussen, J. S., & Hancock, M. J. (2018). Imaging for low back pain: Is clinical use consistent with guidelines? A systematic review and meta-analysis. *The Spine Journal : Official Journal of the North American Spine Society, 18*(12), 2266–2277. https://doi.org/S1529-9430(18)30203-1

Jensen, M. C., Brant-Zawadzki, M. N., Obuchowski, N., Modic, M. T., Malkasian, D., & Ross, J. S. (1994). Magnetic resonance imaging of the lumbar spine in people without back pain. *The New England Journal of Medicine, 331*(2), 69–73. https://doi.org/10.1056/NEJM199407143310201

Jones, G. T., & Macfarlane, G. J. (2005). Epidemiology of low back pain in children and adolescents. *Archives of Disease in Childhood, 90*(3), 312–316. https://doi.org/10.1136/adc.2004.056812

Kalichman, L., Kim, D. H., Li, L., Guermazi, A., Berkin, V., & Hunter, D. J. (2009). Spondylolysis and spondylolisthesis: Prevalence and association with low back pain in the adult community-based population. *Spine, 34*(2), 199–205. https://doi.org/10.1097/BRS.0b013e31818edcfd

Katz, J. N. (2006). Lumbar disc disorders and low-back pain: Socioeconomic factors and consequences. *The Journal of Bone and Joint Surgery. American Volume, 88 Suppl 2*, 21–24. https://doi.org/10.2106/JBJS.E.01273

Keijzers, G. B., & Britton, C. J. (2010). Doctors' knowledge of patient radiation exposure from diagnostic imaging requested in the emergency department. *The Medical Journal of Australia, 193*(8), 450–453.

Kendrick, D., Fielding, K., Bentley, E., Kerslake, R., Miller, P., & Pringle, M. (2001). Radiography of the lumbar spine in primary care patients with low back pain: Randomised controlled trial. *BMJ (Clinical Research Ed.), 322*(7283), 400–405.

Kerry, S., Dundas, D., Hilton, S., Rink, E., & Patel, S. (2000). Routine referral for radiography of patients presenting with low back pain: Is patients' outcome influenced by GPs' referral for plain radiography? *Health Technology Assessment, 4*(20) https://doi.org/10.3310/hta4200

Kerry, S., Hilton, S., Dundas, D., Rink, E., & Oakeshott, P. (2002). Radiography for low back pain: A randomised controlled trial and observational study in primary care. *The British Journal of General Practice : The Journal of the Royal College of General Practitioners, 52*(479), 469–474.

Kerry, S., Oakeshott, P., Dundas, D., & Williams, J. (2000). Influence of postal distribution of the royal college of radiologists' guidelines, together with feedback on radiological referral rates, on X-ray referrals from general practice: A randomized controlled trial. *Family Practice, 17*(1), 46–52.

Ko, S. B., & Lee, S. W. (2011). Prevalence of spondylolysis and its relationship with low back pain in selected population. *Clinics in Orthopedic Surgery, 3*(1), 34–38. https://doi.org/10.4055/cios.2011.3.1.34

Koes, B. W., van Tulder, M. W., Ostelo, R., Kim Burton, A., & Waddell, G. (2001). Clinical guidelines for the management of low back pain in primary care: An international comparison. *Spine, 26*(22), 2504–4.

Koskinen, S., Lundqvist, A., & Ristiluoma, N. (2012). Terveys, toimintakyky ja hyvinvointi suomessa 2011. *Raportti / Terveyden Ja Hyvinvoinnin Laitos 68/2012.*

Krille, L., Hammer, G. P., Merzenich, H., & Zeeb, H. (2010). Systematic review on physician's knowledge about radiation doses and radiation risks of computed tomography. *European Journal of Radiology, 76*(1), 36–41. https://doi.org/10.1016/j.ejrad.2010.08.025

Lal, N. R., Kazerooni, E. A., & Bree, R. L. (2000). Development and implementation of an appropriateness guideline for use of CT in cases of suspected intraabdominal abscess. *Academic Radiology, 7*(9), 711–716.

Larson, D. B., Johnson, L. W., Schnell, B. M., Salisbury, S. R., & Forman, H. P. (2011). National trends in CT use in the emergency department: 1995-2007. *Radiology, 258*(1), 164–173. https://doi.org/10.1148/radiol.10100640

Lee, C. I., Haims, A. H., Monico, E. P., Brink, J. A., & Forman, H. P. (2004). Diagnostic CT scans: Assessment of patient, physician, and radiologist awareness of radiation dose and possible risks. *Radiology, 231*(2), 393–398. https://doi.org/10.1148/radiol.2312030767

Lehnert, B. E., & Bree, R. L. (2010). 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? *Journal of the American College of Radiology : JACR, 7*(3), 192–197. https://doi.org/10.1016/j.jacr.2009.11.010; 10.1016/j.jacr.2009.11.010

Little, J. B. (2000). Radiation carcinogenesis. *Carcinogenesis, 21*(3), 397–404.

Lurie, J. D., Birkmeyer, N. J., & Weinstein, J. N. (2003). Rates of advanced spinal imaging and spine surgery. *Spine, 28*(6), 616–620. https://doi.org/10.1097/01.BRS.0000049927.37696.DC

Lysdahl, K. B., & Hofmann, B. M. (2009). What causes increasing and unnecessary use of radiological investigations? A survey of radiologists' perceptions. *BMC Health Services Research, 9*, 155. https://doi.org/10.1186/1472-6963-9-155

Malone, J., Guleria, R., Craven, C., Horton, P., Jarvinen, H., Mayo, J., … Czarwinski, R. (2012). Justification of diagnostic medical exposures: Some practical issues. report of an international atomic energy agency consultation. *The British Journal of Radiology, 85*(1013), 523–538. https://doi.org/10.1259/bjr/42893576

Maniadakis, N., & Gray, A. (2000). The economic burden of back pain in the UK. *Pain, 84*(1), 95–103.

Martin, B. I., Turner, J. A., Mirza, S. K., Lee, M. J., Comstock, B. A., & Deyo, R. A. (2009). Trends in health care expenditures, utilization, and health status among US adults with spine problems, 1997-2006. *Spine, 34*(19), 2077–2084. https://doi.org/10.1097/BRS.0b013e3181b1fad1

Mathews, J. D., Forsythe, A. V., Brady, Z., Butler, M. W., Goergen, S. K., Byrnes, G. B., … Darby, S. C. (2013). Cancer risk in 680 000 people exposed to computed tomography scans in childhood or adolescence: Data linkage study of 11 million Australians. *BMJ (Clinical Research Ed.), 346*, f2360. https://doi.org/10.1136/bmj.f2360

Matowe, L., Ramsay, C. R., Grimshaw, J. M., Gilbert, F. J., Macleod, M. J., & Needham, G. (2002). Effects of mailed dissemination of the royal college of radiologists' guidelines on general practitioner referrals for radiography: A time series analysis. *Clinical Radiology, 57*(7), 575–578. https://doi.org/10.1053/crad.2001.0894

Mendelson, R. M. (2020). Diagnostic imaging: Doing the right thing. *Journal of Medical Imaging and Radiation Oncology,* https://doi.org/10.1111/1754-9485.13004

Merimaa, K. (2012). *Lasten TT-tutkimusohjeisto.*

Min, A., Chan, V. W. Y., Aristizabal, R., Peramaki, E. R., Agulnik, D. B., Strydom, N., … Forster, B. B. (2017). Clinical decision support decreases volume of imaging for low back pain in an urban emergency department. *Journal of the American College of Radiology : JACR, 14*(7), 889–899. https://doi.org/S1546-1440(17)30308-3

Morgan, B., Mullick, S., Harper, W. M., & Finlay, D. B. (1997). An audit of knee radiographs performed for general practitioners. *The British Journal of Radiology, 70*, 256–260. https://doi.org/10.1259/bjr.70.831.9166050

Mubeen, S. M., Abbas, Q., & Nisar, N. (2008). Knowledge about ionising and non-ionising radiation among medical students. *Journal of Ayub Medical College, Abbottabad: JAMC, 20*(1), 118–121.

Muirhead, C. R., O'Hagan, J. A., Haylock, R. G. E., Phillipson, M. A., Willcock, T., Berridge, G. L. C., & Zhang, W. (2009). Mortality and cancer incidence following occupational radiation exposure: Third analysis of the national registry for radiation workers. *British Journal of Cancer, 100*(1), 206–212. https://doi.org/10.1038/sj.bjc.6604825

Murray, C. J. L., & Lopez, A. D. (2013). Measuring the global burden of disease. *N Engl J Med, 369*(5), 448–457. https://doi.org/10.1056/NEJMra1201534

National Health Service, (2018). Diagnostic imaging dataset statistical release.

National Research Council. (2006). *Health Risks from Exposure to Low Levels of Ionizing Radiation: BEIR VII Phase 2*. Washington, DC: The National Academies Press. https://doi.org/10.17226/11340

Oakeshott, P., Kerry, S. M., & Williams, J. E. (1994). Randomized controlled trial of the effect of the royal college of radiologists' guidelines on general practitioners' referrals for radiographic examination. *The British Journal of General Practice : The Journal of the Royal College of General Practitioners, 44*(382), 197–200.

O'Connell, N. E., Cook, C. E., Wand, B. M., & Ward, S. P. (2016). Clinical guidelines for low back pain: A critical review of consensus and inconsistencies across three major guidelines. *Best Practice & Research. Clinical Rheumatology, 30*(6), 968–980. https://doi.org/10.1016/j.berh.2017.05.001

OECD. (2019a). Computed tomography (CT) exams (indicator). Retrieved from http://data.oecd.org/healthcare/computed-tomography-ct-exams.htm.

OECD. (2019b). Computed tomography (CT) scanners (indicator).

Oikarinen, H., Meriläinen, S., Pääkkö, E., Karttunen, A., Nieminen, M. T., & Tervonen, O. (2009). Unjustified CT examinations in young patients. *European Radiology, 19*(5), 1161–1165. https://doi.org/10.1007/s00330-008-1256-7

Orme, N. M., Fletcher, J. G., Siddiki, H. A., Harmsen, W. S., O'Byrne, M. M., Port, J. D., … Wolf, S. M. (2010). Incidental findings in imaging research: Evaluating incidence, benefit, and burden. *Archives of Internal Medicine, 170*(17), 1525–1532. https://doi.org/10.1001/archinternmed.2010.317

Osterman, K., Schlenzka, D., Poussa, M., Seitsalo, S., & Virta, L. (1993). Isthmic spondylolisthesis in symptomatic and asymptomatic subjects, epidemiology, and natural history with special reference to disk abnormality and mode of treatment. *Clinical Orthopaedics and Related Research,* (297), 65–70.

Oxman, A. D., Thomson, M. A., Davis, D. A., & Haynes, R. B. (1995). No magic bullets: A systematic review of 102 trials of interventions to improve professional practice. *CMAJ : Canadian Medical Association Journal = Journal De L'Association Medicale Canadienne, 153*(10), 1423–1431.

Ozasa, K., Shimizu, Y., Suyama, A., Kasagi, F., Soda, M., Grant, E. J., … Kodama, K. (2012). Studies of the mortality of atomic bomb survivors, report 14, 1950–2003: An overview of cancer and noncancer diseases. *Radiation Research, 177*(3), 229–243.

Paterniti, D. A., Fancher, T. L., Cipri, C. S., Timmermans, S., Heritage, J., & Kravitz, R. L. (2010). Getting to "no": Strategies primary care physicians use to deny patient requests. *Archives of Internal Medicine, 170*(4), 381–388. https://doi.org/10.1001/archinternmed.2009.533

Pearce, M. S., Salotti, J. A., Little, M. P., McHugh, K., Lee, C., Kim, K. P., … Berrington de Gonzalez, A. (2012). Radiation exposure from CT scans in childhood and subsequent risk of leukaemia and brain tumours: A retrospective cohort study. *Lancet, 380*(9840), 499–505. https://doi.org/10.1016/S0140-6736(12)60815-0

Perez Mdel, R. (2015). Referral criteria and clinical decision support: Radiological protection aspects for justification. *Annals of the ICRP, 44*(1 Suppl), 276–287. https://doi.org/10.1177/0146645314551673

Pham, H. H., Landon, B. E., Reschovsky, J. D., Wu, B., & Schrag, D. (2009). Rapidity and modality of imaging for acute low back pain in elderly patients. *Archives of Internal Medicine, 169*(10), 972–981. https://doi.org/10.1001/archinternmed.2009.78

Pierce, D. A., Shimizu, Y., Preston, D. L., Vaeth, M., & Mabuchi, K. (1996). Studies of the mortality of atomic bomb survivors. report 12, part I. cancer: 1950–1990. *Radiation Research, 146*(1), 1–27.

Pierce, D. A., Shimizu, Y., Preston, D. L., Vaeth, M., & Mabuchi, K. (2012). Studies of the mortality of atomic bomb survivors. report 12, part I. cancer: 1950–1990. 1996. *Radiation Research, 178*(2), AV61-87.

Preston, D. L., Ron, E., Tokuoka, S., Funamoto, S., Nishi, N., Soda, M., … Kodama, K. (2007). Solid cancer incidence in atomic bomb survivors: 1958–1998. *Radiation Research, 168*(1), 1–64. https://doi.org/10.1667/RR0763.1

Quinet, R. J., & Hadler, N. M. (1979). Diagnosis and treatment of backache. *Seminars in Arthritis and Rheumatism, 8*(4), 261–287.

Radiation and Nuclear Safety Authority. (2008). *Lasten röntgentutkimuskriteerit*.

Raja, A. S., Ip, I. K., Prevedello, L. M., Sodickson, A. D., Farkas, C., Zane, R. D., … Khorasani, R. (2012). Effect of computerized clinical decision support on the use and yield of CT pulmonary angiography in the emergency department. *Radiology, 262*(2), 468–474. https://doi.org/10.1148/radiol.11110951

Raja, A. S., Pourjabbar, S., Ip, I. K., Baugh, C. W., Sodickson, A. D., O'Leary, M., & Khorasani, R. (2019). Impact of a health information technology-enabled appropriate use criterion on utilization of emergency department CT for renal colic. *AJR. American Journal of Roentgenology, 212*(1), 142–145. https://doi.org/10.2214/AJR.18.19966

Ravindran, V., Sennik, D., & Hughes, R. A. (2007). Appropriateness of out-of-hours CT head scans. *Emergency Radiology, 13*(4), 181–185; discussion 187,189. https://doi.org/10.1007/s10140-006-0531-7

Rehani, M. M., Yang, K., Melick, E. R., Heil, J., Šalát, D., Sensakovic, W. F., & Liu, B. (2020). Patients undergoing recurrent CT scans: Assessing the magnitude. *European Radiology, 30*(4), 1828–1836. https://doi.org/10.1007/s00330-019-06523-y

Remedios, D., Cavanagh, P., Ashford, N., Grenier, P., Bezzi, M., & Chateil, J. (2014). *Radiation protection N° 178 referral guidelines for medical imaging availability and use in the european union.* Luxembourg: Publications Office of the European Union.

Remedios, D., Hierath, M., Ashford, N., Cavanagh, P., Grenier, P. A., Lloyd, C. M., … Vilgrain, V. (2014). European survey on imaging referral guidelines. *Insights into Imaging, 5*(1), 15–23. https://doi.org/10.1007/s13244-013-0300-6

Richards, P. J., George, J., Metelko, M., & Brown, M. (2010). Spine computed tomography doses and cancer induction. *Spine, 35*(4), 430–433. https://doi.org/10.1097/BRS.0b013e3181cdde47

Rosenkrantz, A. B., Marie, K., & Doshi, A. (2015). Assessing the appropriateness of outpatient abdominopelvic CT and MRI examinations using the American college of radiology appropriateness criteria. *Academic Radiology, 22*(2), 158–163. https://doi.org/10.1016/j.acra.2014.08.005

Rosenthal, D. I., Weilburg, J. B., Schultz, T., Miller, J. C., Nixon, V., Dreyer, K. J., & Thrall, J. H. (2006). Radiology order entry with decision support: Initial clinical experience. *Journal of the American College of Radiology: JACR, 3*(10), 799–806. https://doi.org/10.1016/j.jacr.2006.05.006

Royal College of Radiologists. (2012). Making the best use of clinical radiology, 7th edition. Retrieved from http://www.rcr.ac.uk/content.aspx?PageID=995

Rubin, D. I. (2007). Epidemiology and risk factors for spine pain. *Neurologic Clinics, 25*(2), 353–371. https://doi.org/10.1016/j.ncl.2007.01.004

Ruonala, V. (2019). *Number of radiological examinations in Finland in 2018.* Helsinki: Radiation and Nuclear Safety Authority. Retrieved from http://www.julkari.fi/handle/10024/138743

Schuur, J. D., Carney, D. P., Lyn, E. T., Raja, A. S., Michael, J. A., Ross, N. G., & Venkatesh, A. K. (2014). A top-five list for emergency medicine: A pilot project to improve the value of emergency care. *JAMA Internal Medicine, 174*(4), 509–515. https://doi.org/10.1001/jamainternmed.2013.12688

Sears, E. D., Caverly, T. J., Kullgren, J. T., Fagerlin, A., Zikmund-Fisher, B. J., Prenovost, K., & Kerr, E. A. (2016). Clinicians' perceptions of barriers to avoiding inappropriate imaging for low back pain-knowing is not enough. *JAMA Internal Medicine, 176*(12), 1866–1868. https://doi.org/10.1001/jamainternmed.2016.6364

Shah, D. J., Sachs, R. K., & Wilson, D. J. (2012). Radiation-induced cancer: A modern view. *The British Journal of Radiology, 85*(1020), 1166. https://doi.org/10.1259/bjr/25026140

Shiralkar, S., Rennie, A., Snow, M., Galland, R. B., Lewis, M. H., & Gower-Thomas, K. (2003). Doctors' knowledge of radiation exposure: Questionnaire study. *BMJ (Clinical Research Ed.), 327*(7411), 371–372. https://doi.org/10.1136/bmj.327.7411.371

Sierzenski, P. R., Linton, O. W., Amis, E. S., Jr, Courtney, D. M., Larson, P. A., Mahesh, M., … Schauer, D. A. (2014). Applications of justification and optimization in medical imaging: Examples of clinical guidance for computed tomography use in emergency medicine. *Journal of the American College of Radiology : JACR, 11*(1), 36–44. https://doi.org/10.1016/j.jacr.2013.09.023

Siikonen, T. (2020). *Suomalaisten keskimääräinen efektiivinen annos vuonna 2018*. STUK.

Sistrom, C. L., Dang, P. A., Weilburg, J. B., Dreyer, K. J., Rosenthal, D. I., & Thrall, J. H. (2009). Effect of computerized order entry with integrated decision support on the growth of outpatient procedure volumes: Seven-year time series analysis. *Radiology, 251*(1), 147–155. https://doi.org/10.1148/radiol.2511081174

Sodhi, K. S., Krishna, S., Saxena, A. K., Sinha, A., Khandelwal, N., & Lee, E. Y. (2015). Clinical application of 'justification' and 'optimization' principle of ALARA in pediatric CT imaging: "How many children can be protected from unnecessary radiation?". *European Journal of Radiology, 84*(9), 1752–1757. https://doi.org/10.1016/j.ejrad.2015.05.030

Sodickson, A., Baeyens, P. F., Andriole, K. P., Prevedello, L. M., Nawfel, R. D., Hanson, R., & Khorasani, R. (2009). Recurrent CT, cumulative radiation exposure, and associated radiation-induced cancer risks from CT of adults. *Radiology, 251*(1), 175–184. https://doi.org/10.1148/radiol.2511081296

Tajmir, S., Raja, A. S., Ip, I. K., Andruchow, J., Silveira, P., Smith, S., & Khorasani, R. (2017). Impact of clinical decision support on radiography for acute ankle injuries: A randomized trial. *The Western Journal of Emergency Medicine, 18*(3), 487–495. https://doi.org/10.5811/westjem.2017.1.33053

Takeshita, K., Fujii, K., Anzai, K., & Ozawa, T. (2004). In vivo monitoring of hydroxyl radical generation caused by x-ray irradiation of rats using the spin trapping/EPR technique. *Free Radical Biology & Medicine, 36*(9), 1134–1143. https://doi.org/10.1016/j.freeradbiomed.2004.02.016

Tenkanen-Rautakoski, P. (2006). Number of radiological examinations in Finland in 2005. *Stuk-B-Sto 62*

Tenkanen-Rautakoski, P. (2010). Number of radiological examinations in Finland in 2008. *Stuk-B 121*

The National Council on Radiation Protection and Measurements, (NCRP). (2019). *Report No. 184 – Medical Radiation Exposure of Patients in The United States (2019).* Bethesda, MD.

Thompson, D. E., Mabuchi, K., Ron, E., Soda, M., Tokunaga, M., Ochikubo, S., … Preston, D. L. (1994). Cancer incidence in atomic bomb survivors. part II: Solid tumors, 1958-1987. *Radiation Research, 137*(2), S17–S67. https://doi.org/10.2307/3578892

Ukkola, L., Oikarinen, H., Henner, A., Haapea, M., & Tervonen, O. (2017). Patient information regarding medical radiation exposure is inadequate: Patients' experience in a university hospital. *Radiography (London, England: 1995), 23*(4), e114–e119. https://doi.org/10.1016/j.radi.2017.04.001

Ukkola, L., Oikarinen, H., Henner, A., Honkanen, H., Haapea, M., & Tervonen, O. (2016). Information about radiation dose and risks in connection with radiological examinations: What patients would like to know. *European Radiology, 26*(2), 436–443. https://doi.org/10.1007/s00330-015-3838-5

UNSCEAR. (2000a). *Sources and Effects of Ionizing Radiation, United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 2000 Report, Volume I: Report to the General Assembly, with Scientific Annexes – Sources*. UN. New York. https://doi.org/10.18356/49c437f9-en

UNSCEAR. (2000b). *Sources and Effects of Ionizing Radiation, United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 2000 Report, Volume II: Report to the General Assembly, with Scientific Annexes – Effects*. UN, New York. https://doi.org/10.18356/47a75909-en

UNSCEAR. (2010). *Sources and Effects of Ionizing Radiation, United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 2008 Report, Volume I: Report to the General Assembly, with Scientific Annexes A and B - Sources*. UN, New York. https://doi.org/10.18356/cb7b6e26-en

UNSCEAR. (2014a). *Sources, Effects and Risks of Ionizing Radiation, United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 2013 Report, Volume I: Levels and effects of radiation exposure due to the nuclear accident after the 2011 great East-Japan earthquake and tsunami*. UN, New York. https://doi.org/10.18356/744848ef-en

UNSCEAR. (2014b). *Sources, Effects and Risks of Ionizing Radiation, United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 2013 Report, Volume II: Scientific Annex B - Effects of Radiation Exposure of Children*. UN, New York. https://doi.org/10.18356/fd14587c-en

UNSCEAR. (2017). *Sources, Effects and Risks of Ionizing Radiation, United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 2016 Report: Report to the General Assembly, with Scientific Annexes*. UN, New York. https://doi.org/10.18356/2055d684-en

UNSCEAR. (2018). *Sources, Effects and Risks of Ionizing Radiation, United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 2017 Report: Report to the General Assembly, with Scientific Annexes*. UN, New York. https://doi.org/10.18356/7e4f1c5a-en

van Tulder, M. W., Assendelft, W. J., Koes, B. W., & Bouter, L. M. (1997). Spinal radiographic findings and nonspecific low back pain. A systematic review of observational studies. *Spine, 22*(4), 427–434.

van Tulder, M., Koes, B., & Bombardier, C. (2002). *Low back pain.* https://doi.org/9443/10.1053/berh.2002.0267

Vartanians, V. M., Sistrom, C. L., Weilburg, J. B., Rosenthal, D. I., & Thrall, J. H. (2010). Increasing the appropriateness of outpatient imaging: Effects of a barrier to ordering low-yield examinations. *Radiology, 255*(3), 842–849. https://doi.org/10.1148/radiol.10091228

Vassileva, J., Rehani, M. M., Applegate, K., Ahmed, N. A., Al-Dhuhli, H., & Al-Naemi, H. M. (2012). IAEA survey of paediatric computed tomography practice in 40 countries in Asia, Europe, Latin America and Africa: Procedures and protocols. *European Radiology*. https://doi.org/10.1007/s00330-012-2639-3

Webster, B. S., & Cifuentes, M. (2010). Relationship of early magnetic resonance imaging for work-related acute low back pain with disability and medical utilization outcomes. *Journal of Occupational and Environmental Medicine, 52*(9), 900–907. https://doi.org/10.1097/JOM.0b013e3181ef7e53

White, A. A., 3rd, & Gordon, S. L. (1982). Synopsis: workshop on idiopathic low-back pain. *Spine, 7*(2), 141–149. https://doi.org/10.1097/00007632-198203000-00009

Wolff S. (1998). The adaptive response in radiobiology: evolving insights and implications. *Environmental health perspectives, 106 Suppl 1*(Suppl 1), 277–283. https://doi.org/10.1289/ehp.98106s1277

Working group appointed by the Finnish Medical Society Duodecim and Societas Medicinae Physicalis et Rehabilitationis Fennia. (2014). Low back pain. current care guidelines. Retrieved from www.kaypahoito.fi

World Health Organization, (2015). Ionizing radiation. environmental radiation.

You, J. J., Levinson, W., & Laupacis, A. (2009). Attitudes of family physicians, specialists and radiologists about the use of computed tomography and magnetic resonance imaging in Ontario. *Healthcare Policy = Politiques De Sante, 5*(1), 54–65.

Zhou, G. Z., Wong, D. D., Nguyen, L. K., & Mendelson, R. M. (2010). Student and intern awareness of ionising radiation exposure from common diagnostic imaging procedures. *Journal of Medical Imaging and Radiation Oncology, 54*(1), 17–23. https://doi.org/10.1111/j.1754-9485.2010.02132.x

Original publications

I Tahvonen, P., Oikarinen, H., Pääkkö, E., Karttunen, A., Blanco Sequeiros, R., & Tervonen, O. (2013). Justification of CT examinations in young adults and children can be improved by education, guideline implementation and increased MRI capacity. *The British Journal of Radiology, 86*(1029), 20130337. https://doi.org/10.1259/bjr.20130337

II Tahvonen, P., Oikarinen, H., & Tervonen, O. (2020). The effect of interventions on appropriate use of lumbar spine radiograph and CT examinations in young adults and children: a three-year follow-up. *Acta Radiologica, 61*(8), 1042–1049. https://doi.org/10.1177/0284185119893091

III Tahvonen, P., Oikarinen, H., Niinimäki, J., Liukkonen, E., Mattila, S., & Tervonen, O. (2017). Justification and active guideline implementation for spine radiography referrals in primary care. *Acta Radiologica (Stockholm, Sweden : 1987), 58*(5), 586–592. https://doi.org/10.1177/0284185116661879

Original publications are not included in the electronic version of the dissertation.

Book orders:
Virtual book store
http://verkkokauppa.juvenesprint.fi

UNIVERSITY OF OULU P.O. Box 8000 FI-90014 UNIVERSITY OF OULU FINLAND

ACTA UNIVERSITATIS OULUENSIS

UNIVERSITY OF OULU

ISBN 978-952-62-3021-4 (Paperback)
ISBN 978-952-62-3022-1 (PDF)
ISSN 0355-3221 (Print)
ISSN 1796-2234 (Online)