UiT The Arctic University of Norway

Faculty of Health Science, Department of Clinical medicine
University Hospital of North Norway, Department of Radiology

Trauma radiology in northern Norway

A description of the potentially severely injured patients met with trauma team activation at the trauma centre in northern Norway in 2015

Anna Bågenholm

A dissertation for the degree of Philosophiae Doctor – May? 2020

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Diagnostic division
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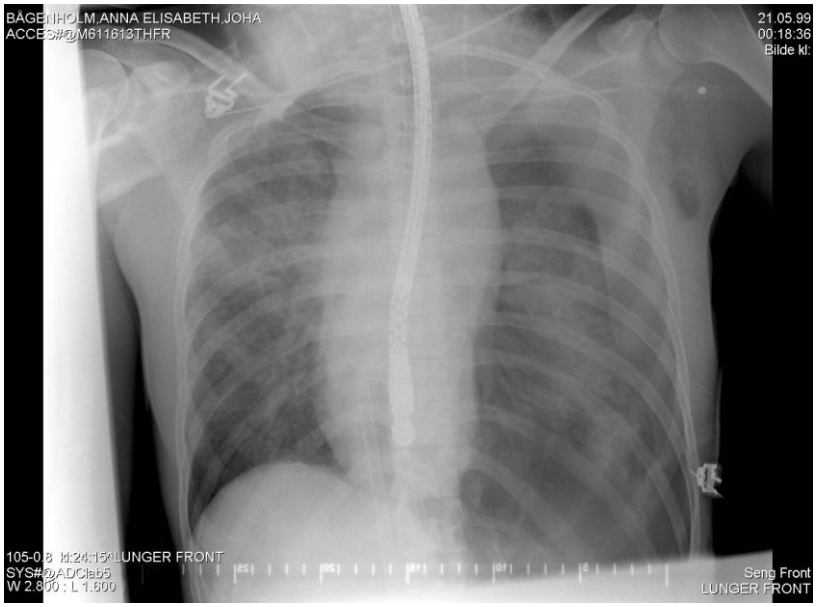
Foreword

My special interest for severe trauma, the main theme in this Ph.D. began on 20 May 1999. One year earlier in May 1998, I started as a speciality resident at the surgical department in Narvik.

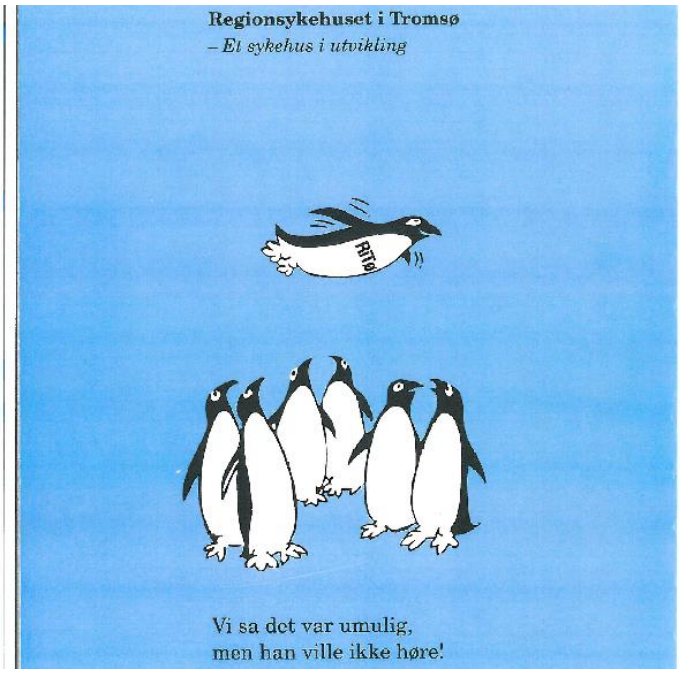
My research career began in December 1998. Without any knowledge of research ethics or rules, I asked patients admitted to the emergency bay, due to injuries sustained in the Narvik ski area, to fill out a questionnaire. At least the patients included all consented to take part when answering the questionnaire. I had no supervisor, only approval from the surgical department to make the quality study, and I published nothing. In July 2018, I looked for and found a summary note I had written on 5 December 2000 concerning the 45 patients. It explains why the quality study was never finished; “There are no multi trauma patients in the material that can be explained by the fact that the only severe trauma patient who was transported directly to Tromsø, happened to be myself”. The first diagnostic examination I underwent after arriving as a patient at the regional hospital in Tromsø was taken at 00:19 on 21 May 1999 and identified a pressure hemothorax. The image (see below) also shows that I was connected to a heart lung machine and had an ultrasound probe in my oesophagus. Even for me as radiologist, this image is astonishing.



After fantastic teamwork and persistent efforts by the persons at the accident scene, and the personnel both in the rescue Sea King helicopter and at the hospital in Tromsø, I survived a body core temperature of 13.7 degrees Celsius and a 2 hour and 45 minutes cardiac

arrest. All of this from a skiing accident close to Narvik ski area, which trapped me under ice in a frozen gully for 90 minutes (Lancet; Gilbert et al. Jan 29, 2000; 355,9201). My survival was a breakthrough in accidental hypothermia and nowadays the survival rate for deep hypothermic victims is around 40% (Resuscitation, Hilmo et al. 2014; 85: 1204-1211).

My rehabilitation started out with paralysis from the neck down (Clinical Neurophysiology; Løseth et al. 2013; 124: 1019-1024). I woke up in the second week after the accident unaware of what had happened, but even as a trained physician astonished by the work done. My family, friends and the personnel told me what happened piece by piece. I am now almost normal (assessed by myself) 21 years after my skiing accident. I believe that physiology combined with a strong belief in the possibility of achieving the impossible, not only among the first responders and the medical professionals, but also myself, explains the success. The picture below is from the 1995 annual report, from the regional hospital in Tromsø. The English translation is "We said it was impossible but he did not want to listen!". This is Tromsø hospital's slogan, which has helped not only me.



In 2002, I moved from Narvik to Tromsø and started my new career as a radiologist, as my manual fine motor skills were better suited to radiological work than surgical. I felt a need to give something back to the hospital in Tromsø. After working for some time, I decided that focusing on giving all trauma patients the same excellent treatment I received could be a fair goal.

1 Acknowledgement

I want to thank Eva Jacobsen, neuroradiologist, for inviting me into a research project about CT of the neck in 2003. While this project was never finished because Eva moved to Oslo, it introduced me to the research application jungle and the importance of systematic planning. In 2007, I invited myself into a trauma research project organized by two of my thesis supervisors Trond Dehli and Kristian Bartnes. This project ended as a publication in the Norwegian medical association journal in 2010 (Dehli et al. 2010; 130:1455-7).

In 2011, the same two supervisors started a trauma study, Hologram, including more patients than the study from 2007. I asked to participate in this Hologram study. In 2012, this participation developed into a protocol for describing the trauma radiology used among potentially severely injured patients over the course of one year supervised by Trond Dehli. The trauma radiology project application was submitted to the regional committee for medical and health research ethics (REK-Nord) in 2014. Meanwhile in 2013, Trond Dehli invited Nora Trasti, an interventional radiologist, and I to participate in a quality study of trauma to spleens. This study was published in in 2015 with Nora and I as second authors (SJTREM, Dehli et al 2015; 23:85).

In 2015, the quality assurance department at the university hospital in Tromsø advertised for a one year 20% employment position for clinicians with quality projects. I applied with the thought that this could be a good start for the protocol describing trauma radiology over the course of one year. I got the position and started on 1 August 2015. Whilst in this job, I began the work of achieving legal approval to collect patient information. In addition, I started up a programme for surgeons and anaesthetists at the local hospitals in northern Norway, educating them on the use of triage ultrasound on trauma patients.

In March 2016, I got the opportunity to start as a Ph.D. candidate in trauma radiology at the Arctic University of Norway. The initial work from my supervisor Trond Dehli and the 20 % employment at the quality assurance department at the university Hospital laid the foundation for this Ph.D. The support from the Diagnostic division at the University hospital of north Norway made it come true.

To finish the Ph.D. project I have to admit I have felt more dependent on others than I ever did when I was paralysed from neck down. I have to express my gratitude to Trond Dehli, Kristian Bartnes, Rune Sundset, Ina Lundberg, Bjørn Straume, Arne Erikson, Pål

Løvhaugen, Stig Hermansen and Tor Ingebrigtsen for all their help and support. I also want to say thank you to all of you knowing you have supported me in some way; this includes technical support, translating and many other things. In Appendix 1 I have tried to list all persons who have helped me during my Ph.D. years. Thank you so much to all of you. Without you, I would never have finished this project.

The Ph.D. life is like a walk in a tunnel and when you suddenly see daylight on the other side it feels fantastic. Trond, thank you for introducing me to the Ph.D. tunnel by guiding me comfortably through the jungle of applications, helping me with the protocol and paper I and III. I am so grateful for the time you invested in me, without you I would never have started a Ph.D. project. The first sensation of daylight existing on the other side came when Ina Lundberg invested so much time into my paper I. The second sensation came when Arne Erikson helped me with my ionizing data, supporting me with a dose estimating software programme in paper II. Arne also showed a true interest in things I wrote, and this interest was continued by Pål Løvhaugen when Arne finished his employment at UNN in 2018. The first time I saw daylight on the other side, was in my second last year as Ph.D. student working together with Stig Eggen Hermansen on paper III.

I came out in daylight again due to the time Tor Ingebrigtsen invested in my project. Tor your efforts to decrypt my long sentences, discuss the content with me and turn it into something solvable and explainable brought an end to the Ph.D. tunnel journey. Your help as my main supervisor has been so inspiring. Thank you so much for teaching me so many things, for helping me out and for all the time you spent together with me. I am so grateful to you for this.

Torvind, I am sorry for all the anaphylactic looking reactions my thesis gave you during the Ph.D. years and so thankful for all your help with technicalities during these years. I would have been totally lost without you. Being my best friend, debrief partner, rescuer in the frozen gully and the love of my life makes you the most important person in my life.

My hope is that all the work my helpers and I have put into this project, together with the inestimable support from the Diagnostic division at the university hospital in Tromsø, will bring the future trauma patients a better outcome. This thesis is my 21-year celebration and thank you to all and everyone contributing to my survival.

2 List of papers

1. Bågenholm A, Lundberg I, Straume B, Sundset R, Bartnes K, Ingebrigtsen T, Dehli T. *Injury coding in a national trauma registry: a one-year validation audit in a level 1 trauma centre*. *BMC Emergency Medicine* (2019) 19:61 https://doi.org/10.1186/s12873-019-0276-8

2. Bågenholm A, Løvhaugen P, Sundset R, Ingebrigtsen T. *Diagnostic imaging and radiation exposure in a Level 1 trauma centre population met with trauma team activation: A one-year patient record audit*. *Radiation protection dosimetry* (2020), pp. 1-13 doi/10.1093/rpd/ncaa010/5736355

3. Bågenholm A, Dehli T, Eggen Hermansen S, Bartnes K, Larsen M, Ingebrigtsen T. *Clinical guided computer tomography decisions are advocated in potentially severely injured trauma patients: a one-year audit in a level 1 trauma Centre with long pre-hospital times. Scandinavian journal of trauma, resuscitation and emergency medicine* (2020) 28:2 https://doi.org/10.1186/s13049-019-0692-5

3 Selected abbreviations

University Hospital of North Norway, Tromsø campus (UNN)

Computer tomography (CT)

Abbreviated injury scale (AIS)

Organ injury scale (OIS)

Injury Severity Score (ISS)

New ISS (NISS)

Emergency departments (ED)

Trauma team activation (TTA)

Photon radiation (X-rays)

Conventional radiographic ionizing radiation imaging (X-ray)

Milli Sievert (mSv)

Standardized whole-body CT (SWBCT)

United Nations environment programme (UNEP)

International commission on radiological protection (ICRP)

As low as reasonably achievable (ALARA)

Magnetic resonance imaging (MRI)

Dose Area Product (DAP)

Dose Length Product (DLP)

National Cancer Institute (NCI) CT dosimetry programme (NCICT)

Life span study (LSS)

Focused assessment with sonography for trauma (FAST)

Extended FAST (EFAST)

Revised Trauma Score (RTS)

Shock index HR/SBP (SI)

4 Introduction

This thesis focuses on the diagnostic imaging of potentially severely injured trauma patients in northern Norway in 2015. This region lacks a total analysis of the diagnostic imaging examinations used among trauma patients. A pervious small retrospective study for the years 2006 and 2007 was published in 2010. It described a population of severely injured patients who were transferred to the University Hospital of North Norway, Tromsø campus (UNN)[1]. The study summarized that the diagnostic imaging could be improved by introducing a more systematic use of imaging. The use of diagnostic imaging in trauma patients improves the patient short-term survival, but the examinations use ionizing radiation introducing a conflict as long-term survival can decrease due to cancer induction. This conflict between short and long-term survival in potentially severely injured trauma patients is the main theme in this thesis. The intention with the project is to contribute knowledge that can guide trauma teams at UNN in their decisions on how to examine trauma patients with justified ionizing radiation diagnostic examinations.

5 Background

5.1 Severely injured patients

5.1.1 Epidemiology

The most severe outcome for a patient involved in an accident is death. Injuries accounted for approximately 10% of the world global burden of disease in 2013, from whom as many as 4.8 million persons died mostly due to road injuries[2]. During the last four decades in Norway, the number of trauma deaths has been reduced by 44.2%. The death rate per 100.000 has decreased from 70.4 in 1975 to 39.3 in 2015. For female and male Norwegians aged 15 to 34 years, trauma related death was the leading cause of death in 2015[3]. The global world disability-adjusted life year due to injuries, an index summarizing premature mortality in years of life lost and non-fatal health outcomes in years lived with disability, is declined by 30.9% between 1990 and 2013, reported by Haagsma et al.[2] in 2015. Younger adults and especially men are still the ones most often involved in these accidents[2].

The decreased death rate is a result of several developments in emergency medicine, but also developments in other fields; such as safer cars, roads and improved health and safety at work. The developments in emergency medicine include improved knowledge and skills among first responders, better pre-hospital care, computer tomography (CT), improved

intensive care and surgical techniques. The introduction of the damage control surgery concept in 1993, interventional angiography around year 2000, and the damage control resuscitation concept in use from approximately year 2007 are important for the decreased death rate[4–8]. The latest contribution to improved trauma care in Norway is the introduction of the national Norwegian trauma system, initiated in 2005 and fully implemented in 2012[9]. The task for a trauma system is systematic organisation of trauma care from the accident until patient discharge from hospital, including rehabilitation.

5.1.2 AIS

The most used international system that standardises injuries is the Abbreviated Injury Scale (AIS). The Association for the advancement of automotive medicine (AAAM) manages the AIS manual[10]. The AIS system was introduced in 1969, sponsored by the American medical association[11]. AIS is a ranking scale for classifying injuries. AIS uses a six numeral anatomical description to locate the injury at the correct anatomical place in nine different body regions. These nine AIS body regions are head, face, neck, thorax, abdomen, spine, upper extremity, lower extremity and external. A post dot severity ranking score from 1 to 6 is added to the anatomical code and clarifies the injury severity. A minimal injury, such as a skin hematoma or abrasion, will have a severity score of 1 and a maximal injury, where death is mandatory, will have severity score of 6. Only certified AIS coders have access to the coding manual in order to keep coding uniform and correct.

5.1.3 AIS versus OIS

For medical personnel not certified in AIS coding there are other methods for grading injury severity. The organ injury scale (OIS) is popular and was established in 1987 by the Organ injury scaling committee of the American association for the surgery of trauma (AAST)[12]. The OIS system describes injury severity categories and uses Roman numerals I to VI. The injury scoring part in the AIS manual is in Arabic numerals 1 to 6. The AAAM started to adjust AIS severity scores to the OIS scores in their 1998 version and this continued in the 2005 version. For many injuries, the OIS grade will be the same as the AIS grade, but the AIS manual does not recommend AIS coders to adopt the OIS grade defined by the clinician in patient records. The AIS coders can only rely on an OIS code if no other information is found in the patient record note except the OIS grade recorded by the surgeon. On the AAST website and trauma.org, the OIS grades are published with corresponding AIS grades but using AIS version 90. This is a bit confusing as the AIS version that is in use today (in

publications) is the 2005 version update 2008, and a 2015 version exists. Many injuries coded as OIS grade I are graded AIS 2 according to the OIS tools found on the described websites. Among clinicians, there is inconsequent use of OIS and AIS grades, and few know that they are two separate scales from two separate organisations. As an example, the surgeons at UNN use AIS > 3 in their protocol for initiating angiography intervention in a patient with a spleen injury, but as they do not have access to the AIS tool, they use the above described OIS or AAST tools, which actually give them an AIS 90 manual grade. It would have been better to use the OIS grades at intervention decisions. In addition, in 2018 AAST published an upgrade of the OIS grades for liver, spleen and kidney injuries[13]. These scales now enable coding of active bleeding, a long-awaited improvement. The AIS code upgrading will probably follow, but not for many years, and until then the coders, certified in *AIS 2005 upgrade 2008*, have to code according to this AIS manual into the trauma registry.

5.1.4 ISS

In 1974, Baker et al[14] published a study associating the AIS severity ranking with mortality. They found that adding together the square of the highest AIS score in three of six different body regions showed a good correlation to survival. The body regions were defined as head and neck, face, thorax, abdomen incl. pelvic content and extremities with pelvic girdle. The sixth body region, the external, includes injuries to the external body such as skin wounds, burns and hypothermia. The publication introduced the Injury severity score (ISS) method, making it possible to stratify patients with several injuries with respect to mortality. Patients with no injuries have ISS 0, a minor injury ISS 1 and a maximal severity injury ISS 75. ISS 75 is achieved either after one injury severity score of 6, or by three AIS 5 injuries in three different ISS body regions. Baker et al. included ISS 0 in their paper from 1974, for classifying uninjured patients. The subsequent literature is inconsistent with regard to whether the range of the scale is 0-75 or 1-75. Including or excluding ISS 0 affects the median ISS for the reported population.

A complicating factor concerning ISS is that ISS is not a normal continuous variable or a normal ordinal categorical variable. ISS is something in between, and in most materials, it is positively skewed[15]. Correct use of statistical methods therefore requires this knowledge. ISS has a value from 0 to 75, but not all values exist. A total of 31 values are impossible to achieve, such as ISS 15. ISS > 15 is used by most as the definition of a severely

injured patient due to the research from Baker et al.[14], indicating that patients with ISS > 15 have a mortality above 10% (Figure 1).

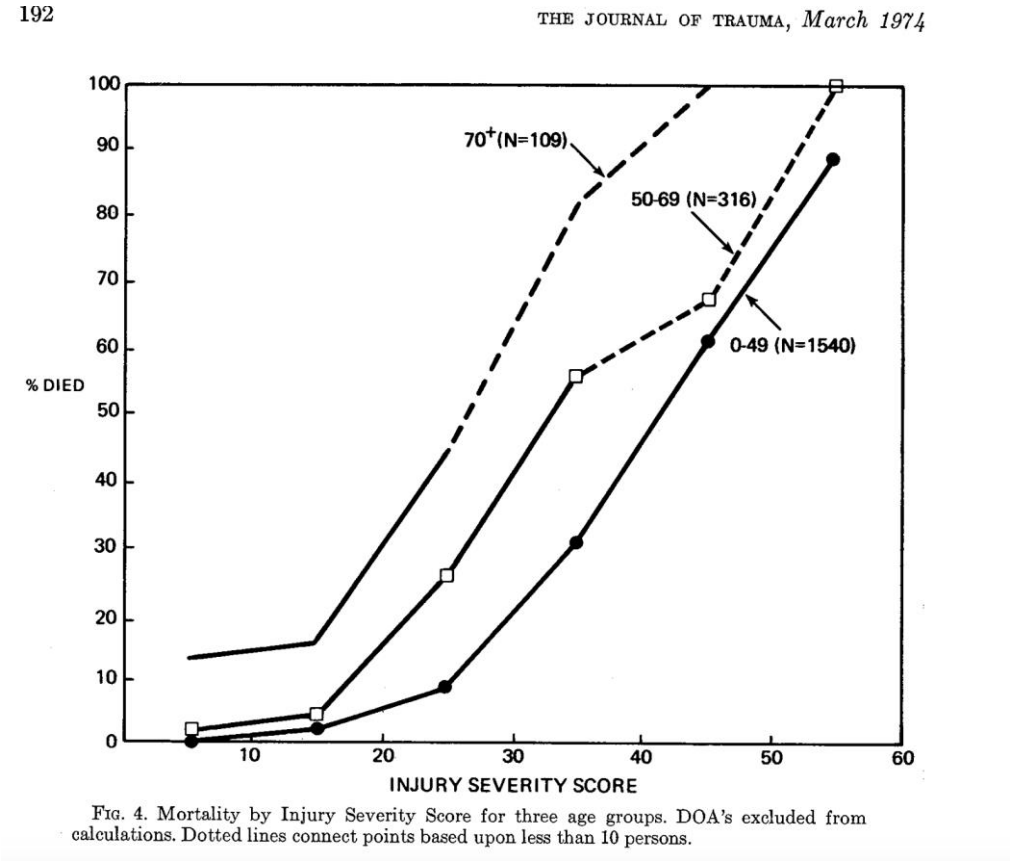


Figure 1 *Figure from the article The injury severity score: a method for describing patients with multiple injuries and evaluation emergency care; Journal of Trauma (1974), Vol.14, No.3.* DOA *Dead on arrival. Permission to reuse by Wolters Kluwer Health Inc.*

5.1.5 NISS

In 1997, the same research group that invented ISS introduced the New ISS (NISS)[16]. The NISS adds together the squares of the three highest AIS injury scores regardless of body regions. NISS predicts survival better then ISS and the method is easier to use. Osler et al.[16] proposed that "NISS should replace ISS as the standard measure of human trauma". Experience shows that it is difficult to substitute ISS with NISS[17–20]. Many publications therefore report both ISS and NISS.

5.1.6 2 x AIS > 2

The search for the most optimal system for survival prediction in severely injured trauma patients is ongoing. After a systematic review, Butcher et al.[21] proposed a new system in 2009 that was tested in a prospective observational study published in 2012 [22]. The system uses AIS as the foundation, but builds on assessing how many body areas have an AIS injury

of > 2 to evaluate polytrauma (2 x AIS > 2). This approach excludes monotrauma. The system works well for defining polytrauma and has the advantage of being usable for triage in the emergency department (ED). In 2014, Butcher et al.[23] validated the system and stated that the system is superior in use for defining polytrauma. The 2 x AIS > 2 method is not in use in Norway, but similar systems assessing injuries in more than two body areas have been proposed by others as useful tools for defining who needs a CT after trauma and which body parts need to be scanned[24,25]. The 2 x AIS > 2 definition was updated between 2010 and 2014 to also include physiological criteria[26]. The new scoring system is entitled the Berlin definition[27]. The Berlin definition has been validated in two different populations. Pothmann et al.[28] identified it to be superior to ISS and Rau et al.[29] validated that the method better identifies patients with higher morbidity and mortality.

5.1.7 Trauma systems

The American college of surgeons committee on trauma (ASC – COT) introduced a book in 1976 describing a system for organising hospital trauma care in the United States. The book is updated regularly, and it now describes the trauma care for all care levels. The latest published version is called *Resources for optimal care of the injured patient* dated 2014[30]. In Norway, the development of a trauma system began in 2005, initiated by the Norwegian Ministry of health and care service. The Ministry organised a working group with members from all four regional Norwegian health authorities. The mandate was to evaluate the need for a national Norwegian trauma system, based on the principles described in the ASC – COT manual. The group delivered their report on 09.10.2007 called the *Report on organisation of treatment of severely injured patients – Trauma system 2007*[31]. The report advocated the implementation of a trauma system in Norway. In northern Norway, the regional health authority initiated a working group which delivered a proposal for the first regional trauma plan on 23.04.10[32]. The plan was approved on 14.12.10[33], but not implemented before 01.01.12. The first revision of the Norwegian *Trauma system 2007* was completed in 2016, and it was approved for implementation in northern Norway on 29.03.17[34].

5.1.8 The national trauma registry in Norway

The national Norwegian trauma registry belongs to the Norwegian trauma system[35]. In order to improve and compare health care for trauma patients, clinical health registers which describe injuries, grade the injury severity and compare survival or mortality for different treatments are mandatory[36,37]. A true description of the injuries and uniform reporting in

trauma registries, are necessary for valid comparisons between patients, hospitals and countries[38]. The *Trauma system 2007* report demanded that all hospitals providing trauma care establish a trauma registry, with certified coders, and report to a national trauma registry within three months after patient discharge from hospital. The 2007 report even stated that physicians should help coders in order to make reported data valid and complete. The first 19 Norwegian coders were educated and certified in 2006[35]. In northern Norway, the first coders were educated and certified in 2012. Thereafter, all the hospitals started making entries in local trauma registries. The national Norwegian trauma registry database was established in 2007. The registry collected data from all of Norway for the first time in 2015.

Inclusion criteria for registering patients into the national Norwegian trauma registry are as follows; admitted with trauma team activation (TTA), NISS > 12, a single head injury with AIS ≥ 3, or a penetrating injury to the head, neck, torso or extremities proximal from elbow or knee. Patients reaching a hospital under treatment from medical personnel, who are declared dead after arrival are included in the trauma registry. The registry advises that patients with fatal injuries who do not reach a hospital after an accident are registered, if pre-hospital medical personnel were present at the accident scene. For patients admitted without TTA, exclusion criteria exist, such as chronic subdural hematoma, drowning, inhalation or asphyxia[39].

5.2 Ionizing radiation

5.2.1 The energy transfer

In simple terms, radiation is energy transfer. Man-made ionizing radiation, used in medical imaging, and of interest in this thesis, carries enough energy (measured in electron volts (eV)) to liberate electrons around an atom and turn it into a charged atom. Charged atoms are ions, and ionisation is thereby the process when an atom turns positively or negatively charged, by adding or losing a negatively charged electron. The energy spectrum emitted in medical imaging belongs to the group electromagnetic photon radiation. In 1895, Wilhelm Conrad Röntgen described the photon radiation (he called the radiation X-rays) at a meeting for the Würzburger Physikalisch-Medizinisches Gesellschaft. The Annalen der physik und chemie published his speech in 1898[40]. Modern people associate X-rays with conventional radiographic imaging (X-ray). In this thesis is X-ray defined as the radiographic imaging method. X-rays are defined as the photon radiation from diagnostic imaging. Other radiation waves, for example radio waves or light with longer wavelengths, do not have ionizing

energy capacity because of lower energy, but are electromagnetic radiation. In a vacuum tube, the photons are emitted when an electron beam from a cathode hits an anode. The maximum voltage potential (peak kilo electron volt (kVp)), the electron current from cathode to anode (milliampere seconds (mAs), the anode material and metal filters in the beam path are important contributors for the energy spectrum of the X-rays[41,42].

5.2.2 Radioactivity

Atoms may also spontaneously liberate energy. Such atoms are unstable and radioactive. Unstable atoms, radionuclides, are present in the nature, and over time turn into stable atoms. We normally think of these radionuclides when we talk about radioactivity. The energy liberated from radionuclides when they are becoming more stable, can interact with stable atoms and, thus, ionise them. To lose energy, the radionuclides either emit energy as alpha decay (two protons and two neutrons), or by beta decay, which happens when only electrons are emitted from the atom. If the radionuclide is very unstable, alpha and beta decay may not be enough energy transfer to stabilize the atom, and extra energy loss in the form of electromagnetic photon radiation can be necessary. Natural photon energy transfer (gamma rays), have the same characteristics as the man-made X-rays, but as gamma rays arise in the atom nucleus, they have a slightly different energy spectrum than X-rays. A stable atom is the result after several different atoms and ion levels, a process that can take a few minutes to hundreds of years, depending on the type of atom. This radioactive process is measured in Becquerel (Bq), as nucleus decays per second. Radionuclides can also be man-made, as the ones used in nuclear medicine imaging, but in this thesis, the radionuclides are only described because they make up the background ionizing radiation dose all humans receive every year[41,42].

5.2.3 The natural background radiation

The background radiation varies with soil material (terrestrial radiation) and height in the atmosphere (cosmic radiation). Pilots are exposed to higher background radiation[41]. Radon gas (in the air) in houses built on ground containing high quantities of the unstable atom Radon (Rn) is contributing to Norwegians natural background radiation dose of approximately 4.1 milli Sievert (mSv) per year[43]. The average global background radiation to humans is about 2.4 mSv, but it ranges from 1 to 10 mSv depending on where on the earth a person lives and works[41]. The natural background radiation is stable, but the total mean dose per person from ionizing radiation has increased in industrial countries during the last

100 years and significantly during the last 20 years, mainly due to the increased use of ionizing radiation in medical imaging. In Norway, man-made medical imaging adds 1.1 mSv (number from 2008) to the background radiation[43]. An average Norwegian person therefore receives a mean ionizing radiation dose of 5.2 mSv per year.

5.2.4 CT availability

In 1971, a new prototype imaging technique, showing tissues as "X-rays in a scanning mathematical computing combination" was constructed. The person who introduced this was electrical engineer Godfrey N Hounsfield employed at Electrical and Music Industries. He placed the machine at Atkinson's Morley Hospital in Wimbledon, London. Hounsfield collaborated with radiologist Jamie Ambrose at the hospital. They named the method CT. During 1973 and 1974, at conferences and in papers, the benefits that the CT method gave to medicine became known among neuroradiologists and neurologists around the world[44–48].

Due to physicians taking the initiative and a positive hospital management, the first CT in northern Norway was installed in Tromsø already in autumn 1977 and was in regular use from 26 October 1977 (Figure 2).

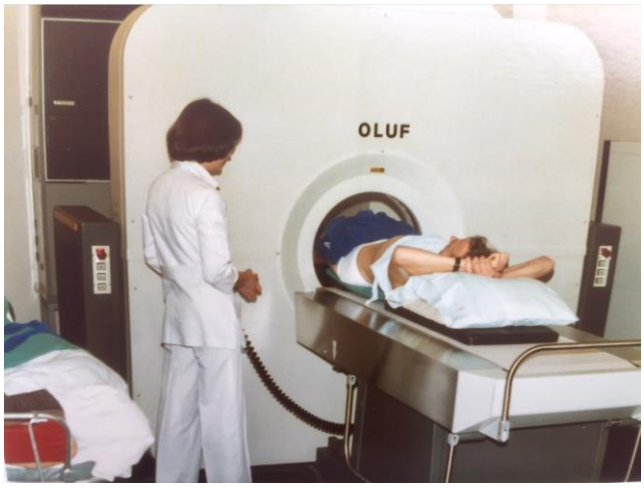


Figure 2 *The first CT in Tromsø installed in 1977, and named Oluf. The photo show CT radiographer Hjørdis Solstad and a patient undergoing a CT examination scan. Photo provided by and in courtesy of radiologist Johan Johansen.*

Thereafter, Bodø hospital installed a CT, five years after Tromsø, in 1982. The third installation in northern Norway came in Harstad in 1986. The hospitals in Gravdal and Mosjøen installed CT in 1987/1988 respectively. Except for the hospital in Sandnessjøen, which did not install CT until 1994, the other hospitals in northern Norway, (Stokmarknes, Narvik, Mo i Rana, Hammerfest and Kirkenes), all installed a CT in 1991. Summarized, it took almost 17 years from the first until the last hospital in northern Norway installed a CT.

The reason for this is the combination of the high cost for a CT and the low inhabitant numbers per hospital. After the installation of their first CT, all the eleven regular hospitals in northern Norway have invested in a new upgraded CT every ten years. Around year 2000, technical developments made it possible for the hospitals to install 4 and 16 multislice CT machines. Around year 2012, the manufactures made the 64 multislice CT machine available for installation, and some hospitals even invested in dual source CT machines. This corresponds to the normal technological CT machine development interval[49]. In 2015, all hospitals in northern Norway had at least one CT, except for the Spitsbergen archipelago hospital, which was still without. None of the hospitals have CT in the ED.

5.2.5 Multi trauma CT protocol recommendations

The use of whole-body CT (WBCT) in the trauma population has increased during the last 20 years, partly because of the increased availability and functionality of CT machines, as described above, and partly due to the literature advocating standardised WBCT (SWBCT) in the trauma population. The first time a standardised screening protocol with CT for trauma patients was described in medical literature was in 1994 by Leidner et al.[50] in the Swedish medical associations journal. In 1998, it was also published in English in European radiology[51]. Leidner et al. proposed a CT examination protocol of eight CT slices of one centimetre of the caput, and thereafter a CT slice of one centimetre separated by three centimetres spacing throughout the thorax and abdomen in hemodynamic stable trauma patients. This approach took 20 minutes in 1994 with their single slice machine. The examinations identified many findings that were not suspected by the surgeons, in spite of the non-continuous body examination. In 2001, Leidner et al.[52] published their standardised protocol in the Emergency radiology journal. The scanning time was still 20 minutes but now for continuous slices from head to pelvis, due to the introduction of the helical CT technology. In 2009, Huber-Wagner et al.[53] advocated immediate use of SWBCT for all stable trauma patients and in recent years it is also recommended in hemodynamic unstable patients due to a reduced scanning time of around 90 seconds[54,55].

An overlap SWBCT protocol, scanning the thorax in the arterial contrast phase and the abdomen with pelvis in the venous contrast phase, both including the spleen, gives the patient a higher dose compared to a single scan protocol of thorax/abdomen/pelvis with dual contrast injections giving simultaneous arterial and venous scanning. In traumas, it is important that the spleen is scanned in both the arterial and venous phase, as a pseudoaneurysm is difficult to

detect in the venous phase[56,57]. It has been shown that a single scan CT protocol of the thorax/abdomen/pelvis with dual contrast phase reduces the amount of ionizing radiation for patients[58–61]. On the other hand, the dual intravenous contrast protocol also has limitations[62]. There are no guidelines on the most appropriate way to scan trauma patients according to the contrast phase, the scan length, or regarding the important question of when it appropriate to use a SWBCT[62–64]. One publication supports that SWBCT is appropriate in trauma patients with moderate to severe consciousness disturbances[65]. Some reviews of published literature point to supreme survival rates among patients receiving SWBCT[66,67], whereas other reviews do not conclude with this[68–70]. The publications mentioned above that support the SWBCT protocol for better survival rate draw their conclusions from for example retrospective register studies[53,54]. The first randomised prospective study of SWBCT immediately after admission compared to standard radiological workup, was published in 2016. There was no difference in survival between the study groups, but an increased radiation exposure was found in the immediate SWBCT group[71].

5.2.6 Doses from medical imaging

The average annual dose delivered to humans globally from medical ionizing radiation increased from 0.35 mSv in 1988, to 0.62 mSv in 2007[41,72]. The numbers are from industrial countries, and increase in CT examinations contribute most to this dose increase. In the United States, as much as 75% of the dose in medical imaging comes from CT examinations and nuclear medicine. These methods account for approximately 36% of the diagnostic imaging examinations. Medical imaging now adds an extra dose of 1.1 mSv in Europe and 3 mSv in the United States per person and year. In the United States therefore, the ionizing radiation dose from medical imaging is the same as the natural background radiation of 3 mSv. An average American therefore now receives a dose of 6 mSv per year [73–75].

The Figure 3 displays different dose estimates from ionizing radiation exposure as illustrated on the front page of the United Nations environment programme's (UNEP) 2016 book *Radiation Effects and Sources*[41]. This book offers a very informative and fundamental understanding of ionizing radiation.

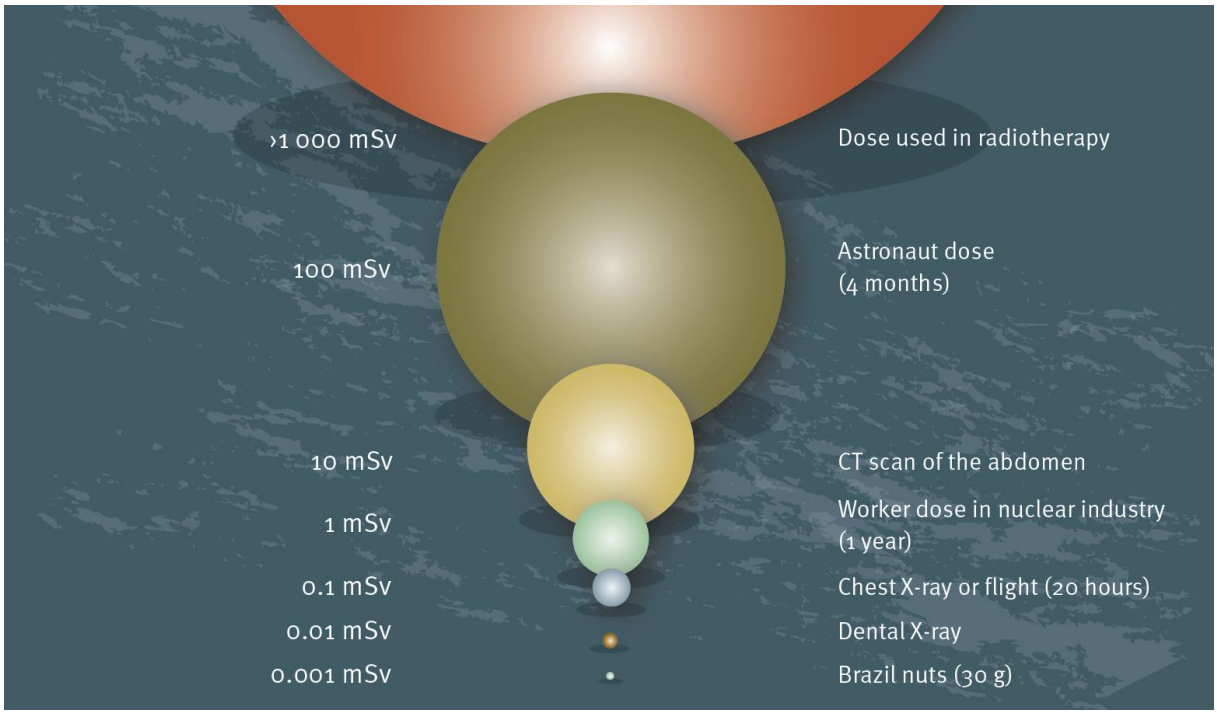


Figure 3 *Ionizing radiation doses as illustrated on the front page of the book Radiation Effects and Sources published by the United Nations environmental programme (UNEP) 2016. Permission to reuse from Dr Ferid Shannon, UNEP.*

5.2.7 Health effects

In his Nobel Prize lecture in June 1905, Pierre Curie, a pioneer in radioactivity research, talked about "the interesting positive biological effects of radium". He described that they knew "radium could be used to treat some conditions such as cancer and lupus". He also described that; "if one leaves a wooden or cardboard box containing a small glass ampulla with several centigrams of a radium salt in one's pocket for a few hours, one will fell absolutely nothing, but 15 days afterwards a redness will appear on the epidermis, and then a sore which will be very difficult to heal". He even described that "A more prolonged action could lead to paralyses and death". He stated in the lecture "Radium must be transported in a thick box of lead"[76]. What he described, just few years after the discovery of ionizing radiation materials, is the deterministic effect of ionizing radiation. The deterministic effect is a threshold dependent effect of ionizing radiation exposure leading to cell necrosis. Both Marie, (his wife and research partner), and Pierre had necrotic finger wounds, and Marie lost her vision due to the deterministic ionizing radiation cataract effect.

Marie Curie died in 1934, from leukaemia-associated anaemia. Leukaemia belongs to the other known ionizing radiation exposure induced effect, called the stochastic effect or the non-threshold dependent effect. The stochastic effect of ionizing radiation makes small changes in the cell genome, which after years or decades can turn the cell into a cell with loss

of self-regulating growth capacity, also called a cancer cell. The pioneers suffered from both deterministic and stochastic effects due to their work with ionizing radiation and described the symptoms after first experiencing them. In his Nobel lecture, Pierre Curie questioned if humans were ready to benefit from this knowledge of radioactivity, or if the knowledge would instead be harmful. He summarized that he "believed mankind will derive more good than harm from new discoveries". In 2011, Sansare et al.[77] published a summary article describing the early victims of ionizing radiation with the deterministic effects cataract, skin ulcers, cell necrosis and the stochastic effects in form of induced cancers. The publication illustrates that the knowledge of ionizing harm came from learning by doing. The pioneers were unaware of the dangers of radiation. Some might have been partially aware, but ignorant. Deterministic symptoms were already described from 1896 and the first death from stochastic effect is thought to have happened in 1904. Ionizing radiation can also affect the cardiovascular system but exactly how is uncertain[78,79]. The immune system is affected because high ionizing radiation decreases the number of lymphocytes[41].

5.2.8 International commission on radiological protection

In 1928, the International commission on radiological protection (ICRP), an international independent non-profit organisation, was established[80]. The organisation produces and publishes recommendations after consensus conferences. In the beginning, the recommendations mainly concerned threshold doses for employees working with ionizing radiation, but after ionizing radiation became more widespread in medicine, the recommendations also included patients. Since their first recommendation published in 1928, they have published recommendations on a regular basis, with their latest in 2007[42]. The commission is an advisory board. Most international organisations and national authorities responsible for ionizing radiation protection use the recommendations from ICRP as basis for their own recommendations. Two populations with a known high incidence of ionizing radiation induced problems have highly influenced the recommendations: The X-ray pioneers and the atomic bomb victims from the Hiroshima and Nagasaki bombings in 1945[77,81–83].

In 1955, ICRP introduced the statement "Every effort should be made to reduce exposures to all types of ionizing radiation to the lowest possible level". In 1973, this was rephrased into the famous and still used "Ionizing radiation should be as low as reasonably achievable (ALARA), economic and social considerations being taken into account" [42].

The first quantified cancer risk model, the low dose linear-non-threshold (LNT) model was launched by ICRP in 1977. The LNT model has no threshold dose for cancer incidence risk, but as the dose increases, the risk increases[42]. Together with the LNT model, ICRP launched the principles of "justification, optimisation and individual dose limitation". The principles demonstrate three different levels of justification in medicine[42,84].

- "Level one: The use of ionizing radiation in medicine should give health benefits to the global population. The beneficial use of diagnostic medical exposures is not in doubt at this level."
- "Level two: The different procedures used in medical imaging should all be justified, and they should be under review continuously. The most optimized dose for the patient for a specific procedure should always be given." This level concerns protocol and machine optimisation.
- "Level three: The individual dose level for the patient is a medical professional decision matter. Ionizing radiation should do more benefit then harm to the individual patient. The decision-making process should have risk of radiation harm included, but in the decision, everything concerning the activity should be considered, such as other risks, costs and benefits of the activity."

In recent years, the LNT model for very low (X-ray) and the low (CT) ionizing radiation doses has been questioned. There is even some arguing that these low doses can protect against cancer[41,85–89]. A review done by experts in the field, from the United States council on Radiation protection and measurements, concluded in 2018 that the LNT model still is the best for radiological protection, but the current epidemiological data cannot exclude that for low doses another model could be better at explaining the risk after ionizing radiation[79].

5.2.9 United Nations scientific committee on the effects of atomic radiation

In 1955, the United Nations scientific committee on the effects of atomic radiation (UNSCEAR) was established[90]. UNSCEAR assesses and reports exposure levels and effects. Already in the first report from 1958, medical imaging exposures were shown to be a major part of the man-made exposures. The UNSCEAR reports are used by other organisations working to reduce the negative effects from ionizing radiation in the world. In 2008, UNSCEAR reviewed and reported all radiation accidents from 1947 to 2007. The report showed that the highest number of cases of acute injuries were due to radiation

accidents during medical imaging. They also concluded that there must be an under-reporting in the medical field. Since 1967, they found only 32 incidents with 46 deaths. Another 623 persons with early acute deterministic symptoms due to medical ionizing diagnostics were also identified[91].

The secretariat of UNSCEAR hosts the United Nations environment program (UNEP) who is the leading global environmental authority. In 2016, UNEP published the summary book for the public about radiation, its effects and sources, based on the reports from UNSCEAR[41].

5.2.10 International atomic energy agency

The International atomic energy agency (IAEA) is part of the United Nations. It was created in 1957 because of fears of nuclear technology. Atoms for Peace was the name given to the organisation in 1953 from the initiator of the project, the U.S. president Eisenhower. The organisation had 81 member nations at the start. In April 2018, the organisation had 170 members[92]. In 2001, IAEA organised the first international conference on radiological protection of patients in diagnostic and interventional radiology in Malaga[93]. At that time, 95% of man-made radiation came from medical imaging and accounted for approximately 12% of the total exposure to humans. The increasing use of interventional diagnostic procedures, helical CT and some patient incidents raised the need for patient adjusted guidelines in medical imaging. After the conference, the *Action plan for radiological protection of patients* was initiated. In 2007 and 2009, IAEA arranged a conference in Vienna and Brussels, respectively. These two conferences were initiated due to findings showing that justification in medical imaging was not as it should be, and tools that could improve the justification existed[94,95]. The conference in 2009 concluded that a campaign of *Awareness, appropriateness and audit* (*the triple A campaign)* was needed. In 2012, IAEA arranged a conference in Bonn, called *Radiation protection in medicine: setting the scene for the next decade*. The conference syllabus foreword states that several countries now experience population doses from medical imaging that exceed the natural background radiation[96]. *The Bonn call for action* was “to strengthen the radiation protection of patients and workers overall” and “to attain the highest benefit with the least possible risk to all patients by the appropriate use of ionizing radiation in medicine”. Other things of importance to work for were to “aid the full integration of radiation protection into health care systems”, “to help

improve benefit-risk dialogue with patients and the public", and "to enhance the safety of technical operations in medicine"[96].

These conferences illustrate how the focus on justification in medicine concerning the use of ionizing radiation has been raised over the last 20 years. The conclusions from the conferences stress that radiation authorities are aware of the increasing use and the population health issue of benefit versus risk from ionizing diagnostics.

IAEA also produce safety standards, in the form of international consensus global references for protecting people and the environment from ionizing radiation. There are three levels of standards; fundamentals, requirements and safety guides. The last safety guide for medical radiation was published in 2018[97]. The guide contains information on justification in medical imaging following the three justification levels from ICRP. For the level three, the guide stresses shared responsibility between the referring clinician and the radiological medical practitioner: "A referral is a request for a specialist consultation not an instruction for a given examination to be performed. The patient should be informed about the radiological procedures benefits, risks and limitations before the examination. Appropriateness follows evidence for choosing an examination with maximum chance of solving the problem with minimum risk for the patient following referral guidelines. Pregnant females and children need extra attention in the individual justification process". The guide recommends that awareness, appropriateness and audition should be used for justification and encourage all radiological departments to use only equipment and protocols that meet international or national standards. Such a standard is for example The European society of radiology's (ESR) launched EuroSafe Imaging in 2014. Their goal is a global programme of medical dose reduction, achieved by implementation of dose tracking systems, development of referral clinical decision support and implementation of training programmes[98,99].

5.2.11 Norwegian radiation protecting agency

The Norwegian radiation protecting authority (NRPA) is the national authority and expert body in nuclear security, radiation use, natural radiation and radioactive contamination in the environment. NRPA changed its name on 1 January 2019 to the Norwegian radiation and nuclear safety authority (DSA)[100]. As all the references used in this thesis are from before 2019, I have kept the acronym NRPA in this thesis. NRPA follows the *Norwegian Regulation on radiation protection and the use of radiation* [Forskrift om strålevern og bruk av stråling], which builds on the *Act on radiation protection and the use of radiation* [Lov om strålevern

og bruk av stråling.] NRPA produce reports and national guidelines following international standards from ICRP and IAEA.

In 2012, NRPA published a statement on the increased use of CT together with the other radiation protection authorities in the Nordic countries[101]. The authorities highlight the importance of the *Triple A approach* introduced by IAEA in 2009. Figure 4 illustrates the trends for the Nordic countries in CT procedures per 1000 inhabitants, per year from 1993 until 2010. The examination rate in the Norwegian population was almost twice as high as in the other Nordic countries in 2010.

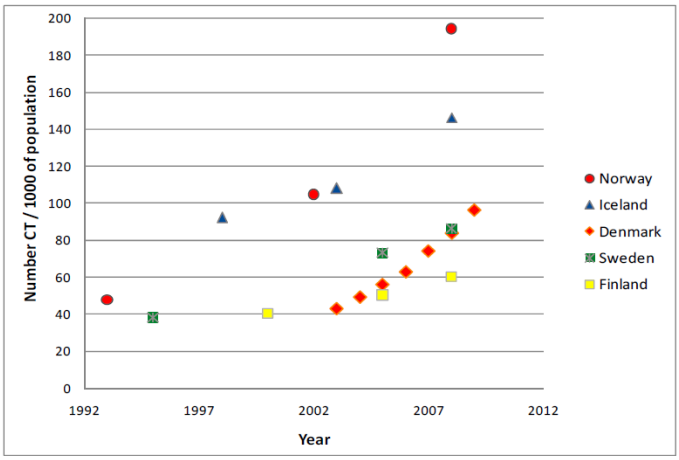


Figure 1. The trends in the number of computed tomography (CT) procedures, per 1000 inhabitants in the Nordic Countries during 1993 to 2010.

Figure 4 *Figure from the statement concerning the increased use of computer tomography in the Nordic countries published on 16.01.2012. Permission to reuse figure from Anders Widmark, NRPA*

Three NRPA publications are used in this thesis. First, the *Guidance to regulation for radiation protection and use of radiation, Guidance No. 5* [Veileder nr. 5], revised 2018[102]. *Guidance No. 5* provides information on how requirements in the radiation protection regulation and act may be fulfilled with regard to patient and personnel protection in medical radiation imaging. For example, it gives instructions for equipment approval, shielding and reporting doses from machines and personnel. Next, the NRPA radiation protection report *Radiation doses to the Norwegian population* [Stråledoser til befolkningen] published in 2015, provides information on the normal background radiation and doses from different areas including medical imaging[43].

Finally, the NRPA radiation protection Report on *Diagnostic reference levels in Norway 2017* [Representative doser i Norge 2017] 2018:3 is used[103]. The first time the NRPA requested radiological departments in Norway to report diagnostic reference doses was

in 2008/2009, and thereafter NRPA published the first report on diagnostic reference levels in 2014. In this thesis, the second report published in 2018 is used[103]. Body mass index influences the ionizing harm, as a higher dose has to be given to patients with high body mass index. Patient weight and height are infrequently reported variables in radiology departments except for in magnetic resonance imaging (MRI) examinations. The radiology departments therefore asked for the possibility to report the CT diagnostic reference doses without patient weight in 2017, as reporting on weight in 2008/2009 was troublesome. In order to compensate for the lack of patient weight, NRPA asked the departments to report between nine and twenty patient doses without knowledge of weight in median and fifty doses for patients with known weight 55-90 kilograms in mean. The overall result between reported reference levels in 2014 and 2018 was a reduction of the reference dose levels. After analysing the reported data in 2017, NRPA found that mean and median dose were approximately similar. NRPA retrieved statistic weight data for patients in different parts of Norway and these data illustrated that weight varies significantly with geography. Increasing average body mass index in the Norwegian populations can influence reference values.

The first time NRPA reported a reference level for a SWBCT was in the 2017 report. The reported local diagnostic reference dose is therefore a dose from a unique CT machine examined with that department's SWBCT protocol. The national reference level follows the upper quartile for the reported diagnostic reference doses. This means that a dose under the reference value is below the 25% highest reported reference doses. For laboratories with measurements below the lower quartile, the reference instruction manual recommends to focus on image quality control. Data for the first SWBCT reference value in Norway came from 23 departments reporting on the reference doses from 28 CT machines for 880 patient examinations. However, as the SWBCT protocol parameters are unique for most radiological departments (as no national or international protocol exists), awareness of this is important when analysing the reference level dose acquired for a specific CT machine.

5.2.12 Ionizing radiation doses and their units

Absorbed dose is the dose of radiation per kilogram tissue measured in gray (Gy) as joules per kilogram, or the mean energy imparted (given) to the exposed body mass. A very low dose is under 10 milli Gy (mGy) and corresponds to doses after X-ray plain imaging. A low dose is below 100 mGy and corresponds to doses after a single CT examination and a normal angiographic examination. Adding up doses from several CT examinations or complicated

angio-intervention procedures can push the CT dose above the low level. Deterministic damages can only have doses described with Gy[41,42].

Equivalent dose is the estimated dose after the absorbed dose is corrected by the weighted radiation factor (w_R). The w_R is a value factor compensating for the different potential for biological damage (detriment) called the relative biological effectiveness that the radiation source induces. The damage depends on the source, which can be either particle radiation (alpha, protons, neutrons, and beta) or electromagnetic photon radiation (gamma or X-rays). The equivalent dose unit is Sievert (Sv), joules per kilogram. The ICRP introduced the first "prototype equivalent unit" in 1977, and modified it in 1991 to the unit used today. For X-rays, gamma rays and electrons the conversion factor is 1 (w_R=1), implying one absorbed dose of Gy corresponds to one Sv in diagnostic medical imaging. Photons are classified as low linear energy transfer (Low-LET). A radiation with low average energy transfer delivers energy in the radiated medium per lengths with <10 kilo eV per micro metre (keV/ μm), giving them high penetrance though tissues. This penetrance requires all stationary X-ray installations to have lead shielding in the walls. Photons impart approximately 0.3 keV/μm to the medium passed and are used as the reference radiation in ionizing radiation protecting recommendations. Heavy charge particles such as alpha particles (w_R 20) are classified as high-LET, with ≥10 keV/μm. Heavy charged particles interact easily with surrounding particles/atoms, due to their size and charge, which cause a fast reduction in their energy[104]. Alpha particles, with approximately 100 keV/ μm, deliver all energy to the first 1.2 mm of the skin, thereby they cause deterministic ionizing harm in a human only if ingested. Most stochastic damages come when LET approaches 100 keV/μm. For LET > 100 keV/μm the potential to damage decreases again[41,42].

Organ dose is the absorbed dose to a specific organ or tissue after an exposure. The organ/tissue dose is derived from multiple calculations and approximations of either anthropomorphic phantoms with validated internal dosimeters or by theoretical Monte Carlo simulation on computer phantoms[105]. The unit is mGy. Anthropomorphic phantoms exist for males and females of different ages. Monte Carlo simulations are routinely used in fields solving problems in physics, economics and mathematics, for multiple testing of random samples of the matter of interest. Monte Carlo simulations are used when sampling of data for estimation of organ doses is difficult, such as for conventional radiographic examinations or CT examinations[106–111].

Effective dose is the equivalent adjusted organs or tissue dose corrected with weighted organ/tissue specific sensitivity factors for ionizing radiation (w_T). The effective dose is expressed in Sv, as joules per kilogram, and was introduced by the ICRP in 1991. Effective doses cannot be measured directly. The conversion factors (w_T's) makes it possible to assess the likelihood of cancer and genetic effects for different delivered doses in different organs from different modalities, but w_T only works for lower doses like those used in medical imaging. ICRP has published w_T factors three times, in the *Publication 26* as H_E, in *Publication 60* as E_{60} and in *Publication103* as E_{103} [42]. The acronyms H_E, E_{60} and E_{103} used in this thesis are adopted from Shrimpton et al.[112]. In ICRP *Publication 103*, the w_T factors were estimated to express "risk for radiation-associated lifetime risk for cancer incidence modelled as a function of life lost, lethality and loss of quality of life", contrary to the previous publications in which the factors were estimates for cancer mortality[42]. Some tissues, such as the gonads and mammary glands, have had different factors in all three publications. The organs less sensitive to ionizing radiation are grouped together as the remainder tissues. The remainder factor represents a mean of 13 organs or tissues per gender. The total sum of all the w_T factors is 1 (for one human). Factors correspond to the mean risk of detriment estimated for the organ in a reference human for both genders and all ages, so an estimated effective dose is not the actual risk in that specific individual with the delivered dose. Martin state[113], "There is an uncertainty in the assessed estimated effective doses. Reliance on the estimates should be influenced by this". Effective dose reported in publications depends highly on which w_T factor is used, thus the factor version used should be described in the publication. Table 1 displays the factors H_E and E_{60} and Table 2 the factors E_{103}. Tables are reused from the ICRP publication 103[42,114].

Table B.1. ICRP Recommendations for tissue weighting factors in *Publication 26* (1977) and *Publication 60* (1991b).

Tissue	Tissue weighting factor, w_T	
	1977 *Publication 26*	1991 *Publication 60*[2,3]
Bone surfaces	0.03	0.01
Bladder		0.05
Breast	0.15	0.05
Colon		0.12
Gonads	0.25	0.20
Liver		0.05
Lungs	0.12	0.12
Oesophagus		0.05
Red bone marrow	0.12	0.12
Skin		0.01
Stomach		0.12
Thyroid	0.03	0.05
Remainder	0.30[1]	0.05
TOTAL	1.0	1.0

[1] The five most highly irradiated other organs and tissues are included in remainder, each with a $w_T = 0.06$.

[2] The values have been developed from a reference population of equal numbers of both sexes and a wide range of ages. In the definition of effective dose they apply to workers, to the whole population, and to either sex.

[3] Further footnotes in *Publication 60*. Table 5.2, page 68.

Table 1 *Equivalent tissue weighting factors as published by the international commission on radiological protection (ICRP) in table B.1, page 261 in ICRP publication 103, Annals of ICRP 34 (2-4). Permission to reuse provided by Hiroki Fujita, Scientific secretary of ICRP.*

Table B.2. Tissue weighting factors, w_T, in the 2007 Recommendations.

Organ/Tissue	Number of tissues	w_T	Total Contribution
Lung, stomach, colon, bone marrow, breast, remainder	6	0.12	0.72
Gonads	1	0.08	0.08
Thyroid, oesophagus, bladder, liver	4	0.04	0.16
Bone surface, skin, brain, salivary glands	4	0.01	0.04

1. The w_T for gonads is applied to the mean of the doses to testes and ovaries.
2. The dose to the colon is taken to be the mass-weighted mean of ULI and LLI doses, as in the *Publication 60* formulation.
The specified remainder tissues (14 in total, 13 in each sex) are: adrenals, extrathoracic tissue (ET), gall bladder, heart, kidneys, lymphatic nodes, muscle, oral mucosa, pancreas, prostate (♂), small intestine (SI), spleen, thymus, uterus/cervix (♀).

Table 2 *Equivalent tissue weighting factors as published by the international commission on radiological protection (ICRP) in table B.2, page 261 in ICRP publication 103, Annals of ICRP 34 (2-4). Permission to reuse provided by Hiroki Fujita, Scientific secretary of ICRP.*

Protective dose quantities are available for assessing effective dose in personnel working with radiation in order to estimate the mean organ dose and skin dose. A thermoluminescent dosimeter obtain to measures a personal dose equivalent called H_p (10), which estimates an effective dose 10 mm into the person where the person dosimeter is worn approximating the whole body dose and H_p (0.07) estimates a dose 0.07 mm under the skin approximating the skin dose[42].

5.2.13 DAP = the delivered dose from a X-ray machine

For conventional X-ray examinations, dose area product (DAP) is the delivered dose in Gy multiplied by the area ionized in cm^2 with unit $Gycm^2$. Compared to the absorbed dose which decreases with 1/ (distance to the ionizing radiation source)^2, DAP is the same at all distances from the X-ray source. To put this simply, if you step one meter away from the X-ray source, the absorbed dose is reduced to 25%. However, DAP will be the same because the X-ray beam fan widens and hits a larger area. DAP is displayed in the X-ray examination log in the digital imaging and communication in medicine (DICOM) archiving system[42].

5.2.14 DLP = the delivered dose from a CT machine

CT dose index (CTDI) is measured in a cylindrical acrylic phantom (size 16 or 32 cm) placed at the scanner isocenter exposed by a 100-mm-long pencil-shaped ionizing chamber. Data is stored in the CT machine log. CTDI is used in CT dosimetry. $CTDI_{vol}$ approximates the average dose during a scan. Thus, it gives the average dose in an infinitesimal (minimal) slice of the phantom. $CTDI_{vol}$ is independent of patient size and scan length, and indicates the intensity of the radiation the patients are exposed to by this specific machine. CT scans from two different machines with identical mAs and kVp might give two different $CTDI_{vol}$, due to differences in machines x-ray tube design and use of filters. Dose length product (DLP) is the $CTDI_{vol}$ multiplied by scan length in centimetres, or to put it simply, average dose multiplied irradiated body length, or the total amount of radiation used to perform a CT examination with unit mGycm on this patient. The DLP per scan and per examination (summarizing all scans in one examination) is displayed in the DICOM output per exam together with $CTDI_{vol}$, kVp, mAs and pitch. The spiral pitch factor definition is the ratio of table motion per 360^o tube rotation to the total collimation radiation beam width. Collimation width (in millimetre) is the same as the width of the radiation beam hitting the human body[42,115].

The diagnostic reference level DLP dose in Norway for a SWBCT is DLP 2400 mGycm. The dose is for a typical SWBCT examination. The reference SWBCT DLP data reported by NRPA is mean 1784 (median 1838), range 495-3502, SD 868 mGycm[103].

5.2.15 Effective dose calculation from DAP and DLP

Calculations of effective dose from DAP through estimates from anthropomorphic phantom or Monte Carlo techniques depend on the anatomical body region exposed and the conversion factors used[105]. The different anatomical X-ray examinations have individual conversions factors in mSv/Gycm^2. The published conversion factors are for adults. For X-ray examination in chest and abdomen areas, effective doses are approximately 18-30% of DAP. Table 3 displays the factors as published in *Guidance No. 5* by NRPA[102]. The converting factors in *Guidance No. 5* rely on w_T E_{60}.

Tabell B 5-2: Omregningsfaktorer fra DAP til Effektiv dose for konvensjonelle røntgenundersøkelser av voksne (referanse 8).

Undersøkelse	Omregningsfaktor [mSv/Gycm^2]
Urografi	0,18
Thorax	0,18
Ls-columna	0,21
Thoracalcolumna	0,19
Pelvis	0,29
Abdomen	0,26
Colon DK	0,28
Coronar angiografi	0,2

Table 3 *Estimated factors for converting DAP to effective dose, as publised in Guidance No. 5 by NRPA,Table B 5-2, the latest revision released 29.01.18. Permission to reuse by Anders Widmark, NRPA.*

Calculation of effective dose from DLP also depends on estimates, the special anatomy of the body region examined and the conversions factors used for the CT examination type[105,112,115,116]. Different CT scan regions have individual conversion factors in mSv/mGycm. These factors also vary with age. Effective dose is approximately 1.5% of DLP in thorax and abdomen scans. Table 4 displays the conversion factors as published in *Guidance No. 5* by NRPA[102]. These conversions factors in *Guidance No. 5* rely on w_T E_{60}.

Tabell B 5-3: Omregningsfaktorer fra DLP til Effektiv dose for CT undersøkelser (referanse 9).

Undersøkelse	Omregningsfaktor [mSv/mGycm]				
	0 år	1 år	5 år	10 år	Voksne
CT hode og hals	0,013	0,0085	0,0057	0,0042	0,0031
CT hode	0,011	0,0067	0,0040	0,0032	0,0021
CT hals	0,017	0,012	0,011	0,0079	0,0059
CT thorax	0,039	0,026	0,018	0,013	0,014
CT abdomen og pelvis	0,049	0,030	0,020	0,015	0,015
CT urografi	-	-	-	-	0,015 *
CT colon	-	-	-	-	0,015 *
CT lumbalcolumna	-	-	-	-	0,015 *

* Antatt omregningsfaktor

Table 4 *Estimated factors for converting DLP to effective dose, as published in Guidance No. 5 by NRPA Table B 5-3, latest revision released 29.01.18. Permission to reuse by Anders Widmark, NRPA.*

In the NRPA report *Diagnostic reference levels in Norway 2018*, new estimated effective doses for the adult CT reference levels were published (Table 5)[103]. The converting factors rely on w_T E_{103}[42]. The conversions factors in tables 4 and 5 are not identical, illustrating the uncertainties that arise when estimating effective dose by multiplying with different conversion factors[114].

Tabell 32: Beregnede effektive doser ved ny nasjonal referanseverdi for undersøkelser med dose angitt i dose-lengde produkt [mGycm].

CT undersøkelse	Ny NRV [mGycm]	Omregningsfaktor [mSv/mGycm]	Effektiv dose [mSv]
Caput	950	0,0049	4,7
Cervicalcolumna	350	0,0107	3,7
Thorax m/ kontrast	350	0,0204	7,1
HRCT (volumopptak)	300	0,0204	6,1
Thorax+abdomen+pelvis	950	0,0186	17,7
Thorax+øvre abdomen	700	0,0186 *)	13,0
Colon	800	0,0171	13,7
Urografi - hematuri/tumor	1300	0,0171	22,2
Urografi - steinproblematikk	250	0,0171	4,3
Hjerte	200	0,026	5,2

*) Antatt overgangsfaktor

Table 5 *Norwegian radiation protection authority report (NRPA) 2018:3 reporting diagnostic reference levels for dose length products in 2017 and new conversion factors for estimated effective doses (table 32). Permission to reuse by Anders Widmark, NRPA.*

5.2.16 NCICT estimations of effective dose

A more reliable method for estimation of effective dose is the estimation of absorbed organ doses and effective dose with the National Cancer Institutes (NCI) shareware computer software CT dosimetry programme (NCICT). NCICT builds on ICRP's reference paediatric and adult phantoms and Monte Carlo simulations. Calculations for (estimated) organ doses are thereafter multiplied with w_T E_{103}[109].

The NCICT result is based on the patient age (grouped), gender, machine manufacture and machine type, kV, mAs, $CTDI_{vol}$ and spiral pitch factor. The data put into the NCICT is retrieved from the DICOM elements in the exam protocol in the picture archiving and communication system (PACS) for each CT scan of interest. Scan length, corresponding to the actual scan length, is marked on a body figure manually in the program window. The NCICT estimates effective dose for a reference person per sex in an age group. The reference person's height and weight is shown in the NCICT programme window. DLP in the NCICT programme will match the DLP in the DICOM exam protocol for a scan if the height and weight of the patient is similar to the reference person. A smaller patient will have a lower DICOM DLP, and a larger person a higher DICOM DLP, compared to the estimated NCICT DLP for the reference person.

5.2.17 The risk of future cancer

Stochastic effects causing cancers such as leukaemia, thyroid cancer and bone marrow cancer appear a few years post irradiation, whereas solid cancers develop later[41,82,84]. As background ionizing radiation exists, and induces cancer, which can have a late onset, it is difficult to know what caused a particular cancer[78]. In addition, the effective dose estimates are uncertain[113,114].

5.2.18 The Life span studies

The Life span study (LSS) cohort (1950 – ongoing) includes atomic bomb survivors from Hiroshima and Nagasaki. The cohort also includes inhabitants not in the city at the time of bombing. The Radiation effects research foundation and its predecessor the Atomic bomb casualty commission have produced cohort studies since 1950. The last report, *number 14*, was published in December 2011[82]. As previous reports, it shows an increased risk of death throughout life from cancer in most cancer sites, and also for some non-cancer diseases, in a linear proportion to the exposed radiation dose.

The LSS cohort is a major source for epidemiological data, used for assessing the risk of ionizing radiation harm after medical diagnostic imaging[79]. Amongst those in the cohort who were under 20 years at the time of bombing, 80% are still alive and soon reaching the age of 60 to 70 years, when cancer incidence normally increases. Future reports on this subgroup will be important. The LSS cohort is divided into subgroups according to the person's distance in kilometres from the epicentre, their age at the time of the exposure and exposure dose estimates in Gy. *Report 14* shows differences between leukaemia and solid

cancers pathogenesis. Leukaemia incidences rose soon after the bombing and may be underrepresented in the LSS cohort because of early deaths in individuals before the cohort study started in 1950. However, mortality due to leukaemia seemed to be continuously high during the period 1991-2000, for individuals exposed to >0.005 Gy (5 mGy)[81]. In 2012, Goto et al.[83] published a study comparing the LSS cohort aged 0-14 years at the time of the bombing (excluding inhabitants not in the city) to the entire population of Japan 0 -14 years in 1945. The study showed a higher standardised mortality rate (observed/expected) for the LSS boy cohort overall for all deaths, all cancers, leukaemia and liver cancer. For girls they did not find this for overall deaths, but for all cancers, solid cancers, liver cancer and breast cancer. Interestingly they also found that male individuals only exposed to very low doses (<0.005 Sv, (5 mSv)) had a significantly higher standardised mortality ratio for all deaths and liver cancers. Girls showed the same for liver cancer and uterine cancer.

5.2.19 Studies of estimated radiation risk

Brenner et al.[117] published their first often-cited study in 2001. This study focussed on the increased use of CT in children, estimating the lifetime cancer mortality risk from medical CT irradiation. The estimations were based on data derived from the LSS atomic bomb survivor *Report 12* and from ionizing radiation authorities, for example, *Report 60* from ICRP. Brenner et al. concluded that paediatric CT examinations will result in significantly increased lifetime radiation risk over adult CT examinations. At that time, CT exposures were not age adjusted. They proposed that mAs should be adjusted down in child CT examinations to reduce the dose. They concluded that although the risk-benefit balance is still strongly tilted towards benefit, because the frequency of paediatric CT examinations is rapidly increasing, estimates that quantitative lifetime radiation risk for children undergoing CT are not negligible may stimulate more active reduction of CT exposure settings in paediatric patients.

In 2004, Brenner et al.[118] published a study on the risk of long-term cancer after WBCT in adults. Their estimated result was that a 45 year old adult undergoing a WBCT (not including the head) had an increased risk of 0.08% for cancer induction during the lifetime, which they translated as one in 1250 patients examined. In 2012, Brenner and Hall[119] addressed their concerns about the risk of long-term cancer from CT due to the published results from Pearce et al.[120] (see below). Brenner and Hall summarised that a medically justified CT scan is beneficial for a patient, but that clinically unnecessary CT scans can cause harm from long-term irradiation problems. In 2014, Brenner[121] again addressed the

problem with a commentary, summarising that the risk for cancer from a CT is very small but unlikely to be zero, for very low dose (X-ray) we do not know.

5.2.20 CT cohort studies

Pearce et al.[120] estimated and associated the bone marrow dose and brain dose for CT body parts scanned in patients younger than 22 years between 1985 and 2002. They published the study in 2012 and studied leukaemia and brain cancer incidence and mortality in the cohort. The minimum follow-up time was six years and the maximum 23 years. For the leukaemia patients, they excluded all with incidence within two years of their first CT scan. They extended the lag period to 5 years for brain tumour patients. In the discussion, they estimate from their data that patients younger than 10 years from Great Britain have an excess risk of developing brain cancer of 1 in 10,000 (0.01%) after one head CT. The same was found for leukaemia (1 in 10,000 (0.01%)). However, questions have been raised as to whether the reported risks are biased from the underlying reason for having the CT (reverse causation), and some syndromes cause a higher cancer incidence (confounding bias)[122]. In 2016, Pearce's group published a re-estimation of the risks in the same cohort after collecting and reviewing additional clinical information. They found some bias due to unreported cancers, but their data still showed an increased risk of cancer after undergoing CT[123].

In 2013, Mathews et al.[124] published a similar large-scale public cohort registry study of Australians younger than 20 years. Inclusion time was between 1985 and 2005 with follow up until the end of 2007. To escape confounding bias they excluded patients with diagnosed cancer within one year of a CT scan. They showed an excess incidence of all types of cancer with a rate of 9.38 in 100,000 = 0.0000938 (approximately 0.01%) after CT exposure. Interesting, 82 % had only one CT scan during the study period and most had a CT brain scan. After excluding all brain cancer diagnoses after undergoing a CT caput examination, they found one excess cancer for every 1800 CT scans at a one-year follow-up and one in 2200 at a 10-year follow-up in 31 December 2007.

A French study from 2015 by Journy et al.[125] included patients who had undergone a CT examination between 2000 and 2010, with a mean follow-up time of four years, and assessed cancer risk in children younger than ten years with an adjustment for cancer predisposing factors. They found that adjusting for suspected cancer or predisposing factors for cancer decreased the risk of cancer associated with CT and they found no significant excess risk of cancer after undergoing a CT examination. Without adjustment for cancer and

predisposing factors, the results were comparable to those reported by Pearce et al.[120] for leukaemia and Mathews et al.[124] for brain cancer (with the one year exclusion period). Journy et al.[125] only observed cancer incidence until patients attained 15 years of age. This limited follow-up time is a weakness with their study.

Krille et al.[126] published a German cohort study in 2015. It included 44,584 patients younger than 15 years who had at least one CT scan between 1980 and 2008. They found higher than expected incidence of cancer in the CT group. Excluding confounding bias and reverse causation reduced the overload of cancers, but not completely. The follow-up time was limited to the age of 15. The authors addressed this limitation.

Several of the cohort studies above[120,123,125,126] are part of the European paediatric EPI-CT study that was initiated in 2011. The study includes 950,000 paediatric patients (0-21 years), undergoing at least one CT scan between 1977 to 2014, accounting for a total of 8.7 million person-years of passive cancer incidence follow-up through linkage with population-based cancer and mortality registries[127]. Results show an increased standardised mortality ratio (observed/expected) for all types of death in children exposed to CT in the follow-up years 2-5, decreasing in the follow-up for years > 5. This indicates that children undergoing CT are less healthy than children not undergoing CT. The total cancer incidence dose-response data have not yet been published, except from in the different countries' studies reviewed above. EPI-CT uses the NCICT software to estimate the radiation harm. Only 4.8 % of the total EPI-CT cohort had multiple scans, so the SWBCT population may be included in the cohort, but it does not represent the main part of the EPI-CT population. There is no clinical register for ionizing radiation doses in Norway, except for the one for children included in the European EPI-CT study from 1980 to 2014[127].

In September 2019, a South Korean study that included over 12 million young people aged 0-19 years, was published. The study associated incidence of cancer after exposure to low ionizing radiation (CT and intravenous radiographic examinations). They used lag periods to compensate for reverse causation and adjusted their result for age and gender. In the CT exposed cohort with a 2 year lag period of cancer incidence after the first CT 84% had undergone one CT scan. They found that 0.1% in the group exposed to CT got a cancer diagnosis after a 2-year lag period, and the incidence was significantly ($p<0.001$) increased for exposed individuals compared to unexposed. The incidence rate ratio for exposed compared to unexposed was 1.64 (95% CI 1.56-1.73). Their conclusion states that medical

professionals should weigh the benefits with the associated risks to justify each ionizing radiation exposure decision[128]. In the limitations, they point to a major weakness, which was that they did not know the reasons for the exposures. Some of the exposures could have been for early symptoms of cancer, thus reverse causation and/or existing pre-disposing cancer syndromes are unknown data in the study.

UNSEAR/UNEP estimate the lifetime risk of cancer after ionizing radiation in a child to be double compared to adults[41]. The Royal college of radiologists estimates that the additional lifetime risk of fatal cancer and non-fatal cancer is x 1.38 for a female, x 4 for a child under 1 year and x 0.5 for an 80-year-old man compared to the risk a male 50-year old has after undergoing a CT examination[129].

5.3 Non-ionizing radiation diagnostic imaging

5.3.1 Ultrasound

Ultrasound in trauma was introduced before CT and showed early good results in identifying free fluid (blood) in the pericardial and peritoneal cavities. In 1999, the focused assessment with sonography for trauma (FAST) method was defined[130]. FAST is included in the ATLS® manual[131]. Radiologists in Tromsø have used FAST during trauma admissions since approximately year 2000. The extended FAST (EFAST) method, which also includes examination of the pleural cavities, became part of the UNN trauma admission examinations in 2014[132]. The pleural examination can identify fluid indicating bleeding, but it also easily identifies free air, representing pneumothorax. Ultrasound is more precise than a chest X-ray in identifying a small pneumothorax in patients examined in the prone position[132]. The ultrasound machine development in recent years has made it possible to introduce EFAST pre-hospital, and at UNN the helicopters were equipped with ultrasound machines during the spring of 2015. The first FAST examination on a trauma patient in flight was undertaken in the summer of 2015.

5.3.2 Magnetic resonance imaging

MRI was introduced in the 1970's and- 1980's[133]. An MRI examination takes some time and is not used during trauma admissions at UNN. I will not explain the method, as it is not a primary examination in trauma admissions. On the other hand, MRI is an imaging method without the burden of ionizing radiation harm. When the logistic context is optimal, as for example in hospitals with MRI in the ED, MRI is for some injuries a better diagnostic choice

than CT examination. During the subsequent hospital stay, MRI examination in severely injured patients is undertaken in most hospitals, for example to characterise head injuries.

5.4 Vital parameters

At the accident site and in the ED, patients present their injuries as symptoms. Penetrating injury symptoms are easier to detect than symptoms from blunt trauma, which can show only as disturbance of consciousness, changed hemodynamics, pain, pain by palpation or just as skin hematomas. Symptoms are sometimes exaggerated due to fear or mental stress experienced by the patient. Vital parameters include both measurable physiological parameters and parameters measurable in blood samples. All patients have a unique presentation. The team on duty needs to distinguish between all these different types of presentations in order to be able to offer the most appropriate help at the right place and time for optimal patient survival.

Admittance in accordance with the Advanced trauma life support (ATLS®) manual [131], offers a systematic approach to the use of vital parameters. The Norwegian trauma system demands that all surgeons admitting trauma patients are ATLS® certified[31,134]. Most hospitals admitting trauma patients train and organise their trauma admissions according to the Better and systematic team training (BEST) concept[135]. Figure 5 shows an example of how vital parameters are recorded in the BEST patient record.

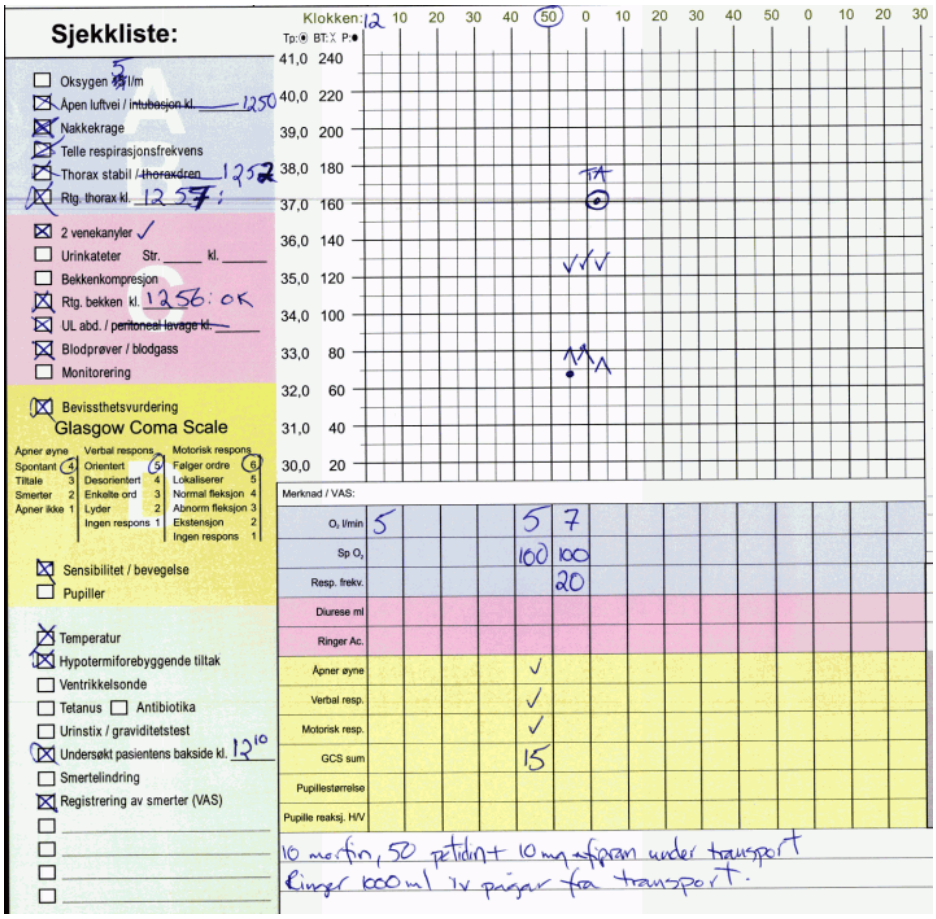


Figure 5 *The Better and systematic team training (BEST) medical patient record for reporting vital parameters as used during a trauma admission at UNN in 2015.*

5.4.1 Adults versus children

Physiologic parameters vary with age. In literature, there is a high degree of consistency with respect to normal ranges and cut-off levels for vital parameters in adults. For children, this is less consistent[136,137].

5.4.2 Heart rate and blood pressure

Heart rate (HR) is counted as beats per minute. In a severely injured patient, the absence of a palpable pulse will guide the assessment of the systolic blood pressure (SBP). SBP is measured in millimetres of mercury (mmHg)[138]. According to ATLS® manuals prior to the 8th edition, a palpable pulse found only over the carotid artery indicates a SBP of 60-70 mmHg, a palpable pulse over the carotid and femoral arteries a SBP of 70-80 mmHg, and if a radial pulse is present, a SBP >80 mmHg. Studies show that this method often overestimates SBP in patients with severe hypovolemia[131,139,140]. Deking et al.[140] confirmed, however, that that when SBP is decreasing, the first pulse to disappear is the radial, next the femoral and finally the carotid. HR and SBP are used to estimate circulating blood volume.

An adequate blood volume is necessary for an optimal global oxygenation of the patient. Figure 5 shows individually recorded HR and SPB in the BEST patient record. Children have age dependent reference ranges for HR and SBP.

5.4.3 Respiratory rate

The respiratory rate (RR) is found by counting breaths for 15 or 30 seconds, and thereafter calculating rate per minute. A high RR rate can indicate that a compensatory mechanism for metabolic acidosis is occurring in severely injured patients. A low RR can indicate that the patient is cold, has a brainstem injury or is dying. Children have age dependent reference range.

5.4.4 Glasgow coma scales and outcome score

Teasdale and Jennett introduced the Glasgow Coma Scale (GCS) in 1974[141]. The GCS scores states of altered consciousness. The scale assesses eye motoric-, verbal- and motor response on three independent scales. The GCS total score, ranging from 3 (deep unconsciousness) to 15 (normal level of consciousness) is the sum of the scores from the three different sub-scales[142]. Figure 5 shows an example of scoring in the BEST medical report.

In 2014, Teasdale et al. summarised 40 years of experience with the GCS, and concluded that the scale is an effective instrument to monitor trends in level of consciousness for individual patients. For this purpose, scores for each of the three sub-scales should be reported separately. For characterisation of groups, for research purposes and outcome predictions, the total score should be used[143]. Important to bear in mind is that an individual patient can have a different outcome than the GCS total score group the patient is assigned to[141–144].

Patients who are intubated, medicated or intoxicated are difficult to assess for GCS sub-scale values, and thereby also for the GCS total score. The verbal scale is challenging to use in small children. In children, however, the motor function sub-scale score is validated to be equal to the total score for outcomes in patients with brain injuries[145].

5.4.5 Blood parameters

Haemoglobin (Hb) is the transport medium for oxygen in the blood. It is measured in grams per decilitre (g/dL). A low value in trauma patients under resuscitation can indicate bleeding due to resuscitative hemodilution. A value above reference range can be found in hypothermic patients, due to hypovolemia induced by fluid leakage to the lungs and soft tissues, and/or due

to an induction of increased urine production[146]. The reference range for adult men is 13-17 g/dL and for women 11.5-16 g/dl[147]. Children have age dependent reference range.

Lactate can be analysed in arterial, capillary or venous blood. It is measured in milli mols per litre (mmol/L). The reference range for arterial blood (0.4-1.8 mmol/l) is not age dependent[147]. Values above 5 mmol/L indicate lactate acidosis, a complication seen in shock and hypoxia (metabolic stress response), but also in several chronic illnesses due to decreased tissue perfusion. Increased physical activity also induces increased lactate. Hypothermic patients can have increased lactate due to shivering, reduced tissue perfusion, and impaired hepatic function[146].

Base excess is measured in arterial whole blood in mmol/L. The reference range (-3 – 3 mmol/L) is not age dependent[147]. A value outside the range indicate that metabolic compensating mechanisms to adjust for abnormal acid/base balance are active. Large deviations indicate that the patient needs interventions to survive. Base deficit is the opposite of base excess and describes how much base you need to add to induce a normal acid balance. Some laboratories (countries) measure base deficit instead of base excess.

Paladino et al.[148] showed that abnormal arterial lactate and base excess could identify the severely injured patients in a group of potentially severely injured trauma patients. Lactate and base excess can be outside the reference range in patients with otherwise normal vital parameters. Lactate above 1.8 mmol/L is correlated with increased mortality in severely injured patients[149]. The prognostic value in hypothermic patients is low, however[146]. Lactate clearance measured soon after trauma admittance (0-2 hours) is also shown to be a valuable prognostic tool for predicting death[150].

5.5 Identifying trauma patients with high mortality risk

Methods for stratification of mortality risk (triage) should work in all situations, be fast and easy to use. Optimal mortality risk stratification reduces suboptimal treatment decisions and thereby increases survival. In mass casualty situations, the triage focus is on identification of patients with impaired oxygenation and reduced circulating blood volume, to initiate immediate treatment for those with highest probability of survival[148,151,152]. For individual patients, at accident sites with one or few victims, the triage focus is selection of transport method and destination to the most appropriate hospital. Patients with obstructed airways, coagulopathy and bleeding are most important to identify[26,30,148,153]. Roy et

al.[154] compared different trauma severity scoring systems in trauma admissions, and concluded that physiological models outperformed anatomically based methods in prediction of early trauma mortality. The Revised Trauma Score (RTS), is recommended by Roy et al.[154] and others as the preferred triage tool[144].

5.5.1 RTS

Champion et al.[155] introduced the trauma score as a field triage tool in 1981. In 1989, they revised the score, and the RTS was introduced[156]. The RTS is composed of three independent scales based on the GCS, SB and RR. It is mostly used in the pre-hospital services. The measured SB and counted RR and assessed GCS total score are coded into RTS scale values 0 (very abnormal) to 4 (normal). Figure 6 displays the RTS variable breakpoints as published by Champion et al.[156].

TABLE I
Revised Trauma Score variable breakpoints

Glasgow Coma Scale	Systolic Blood Pressure	Respiratory Rate	Coded Value
13–15	>89	10–29	4
9–12	76–89	>29	3
6–8	50–75	6–9	2
4–5	1–49	1–5	1
3	0	0	0

Figure 6 *The RTS scale values as displayed by Champion et al. in Table 1 in the article A revision of the trauma score; The Journal of Trauma 1989. Vol. 29; No.5. Permission to reuse provided by Wolters Kluwer health, Inc.*

Triage RTS (T-RTS) adds the coded scale values[156]. In the original publication, Champion et al.[156] found that patients with the highest possible sum of 12 had a predicted survival chance of 99.5%. The study also showed, however, that calculation of T-RTS sum was unnecessary a coded value 3 in any of the sub-scales identified patients in need of transportation to a trauma centre. The authors highlighted, that patients with all coded values of 4 (normal) still can be severely injured. This is one of the reasons for also sending potentially severely injured patients to trauma centres, based on information about the mechanism of trauma[156]. In 2008, Lichtveld et al.[157] described that a deteriorating T-RTS sum between the time of the accident and patient's arrival in the ED independently

predicted intra-hospital morality. The pre-hospital transportation time did not influence the risk for mortality[157].

Tepas et al.[158] developed and validated the Paediatric trauma score. Two studies compared it with the T-RTS, and found no significant differences between scores, after adjustment for increased respiratory rate in children from 0-3 years[159,160].

Champion et al. also introduced the RTS outcome score in 1989, for outcome predictions, characterisation of groups and research purposes[156]. In this weighted score, the coded values 0-4 are multiplied with a constant per value. The calculation follows the equation RTS outcome score = 0.9368 x (GCS_c) + 0.7326x (SB_c) + 0.2908 x (RR_c). The high weighting of head injuries indicates that they were most important for prediction of outcome. The RTS outcome score varies between 0 (worst) and 7.841 (best predicted outcome)[153,156]. Champion et al.[161] used the Major trauma outcome study population, which includes children, for their validation of the RTS outcome score.

5.5.2 Shock index

Calculation of shock index (SI) was introduced in 1967. SI is calculated as a ratio (HR/SPB). The normal range is 0.5-0.7[162,163]. An elevated value >0.9 in adults and children above 12 years might identify critically ill patients, in the absence of hypotension. SI identifies early left ventricular dysfunction before the onset of hypotension and increased heart rate[163]. In 2007, Nakasone et al.[164] showed that increased SI was associated with higher chance of extravasation of arteriogram contrast, indicating ongoing haemorrhage. In 2009, Cannon et al.[165] reported that an increase in SI from the field to the ED might predict higher mortality. In 2017, Ginnakopoulos et al.[166] showed that trauma patients with SI >0.9 had more injuries detected by diagnostic examinations than those with a lower index. SI is validated for children. The age adjusted cut-off for increased value is >1.0 for children between six and twelve years and >1.22 for children less than six years[167]. In children, SI (age adjusted) predicts severe trauma likely to require surgical emergency intervention better than hypotension[168].

5.5.3 Trauma hospital levels

Patients with a 10 % risk of death are thought to be in need of trauma centre competence. The RTS methods initiators advocate that patients with GCS <13, SB<90 or RR <10 or >29 should be triaged to a trauma centre[156]. The regional trauma system in Northern Norway

has triage destination criteria for patient transport to a trauma centre that include GCS<14, SBP<90, RR<10 or >30[169].

The classifications of hospital levels in the Norwegian trauma system is different from that in the ASC – COT manual[30,31,134]. The ASC – COT manual defines a Level I centre based on availability of resources and patient volume, for Level I the ASC – COT manual requires admittance of more than 1200 trauma patients or 240 admissions of patients with ISS >15 per year. In Norway, only the trauma centre at Oslo university hospital fulfils these criteria. The classification in the Norwegian trauma system is based only on the availability of advanced resources. There is one Level 1 centre in each of the four health regions. An ASC – COT Level II trauma centre is the lead trauma facility in a rural area supporting smaller institutions in the area. This corresponds to three of the four Norwegian Level 1 centres. Norwegian acute care hospitals correspond to ASC – COT Level III, and the smallest Norwegian hospitals, like the Svalbard archipelago hospital, to Level IV.

5.5.4 Trauma team activation

Alarming the multidisciplinary trauma team is a systematic mortality risk decreasing intervention for potentially severely injured patients. Alarm criteria depend on vital functions, the extent of the injury and the mechanism of the injury. In 2015, UNN used the criteria in Table 6 [170].

Table 7 The new revised criteria for activation of the trauma team at the University Hospital of North Norway Tromsø

Criteria category	Criterion
Vital functions	1. Airway obstruction, stridor
	2. Respiratory rate <10 or >30 (adults)
	3. Heart rate >130 (adults)
	4. Systolic BP <90 mmHg
	5. Lowered level of consciousness (GCS <13) >5 min
Extent of injuries	6. Flail chest
	7. Pelvic fracture. Fracture in two or more long bones
	8. Traumatic amputation or crush injury above wrist/ ankle
	9. Injury in two or more body regions (head/neck/ chest/abdomen/pelvis/femur/back)
	10. Paralysis
	11. Penetrating injury of the head/neck/chest/ abdomen/pelvis/groin/back
	12. 2. or 3. degree burn injury >15% body surface (children >10%)
	13. Burn injury with inhalation injury
	14. Hypothermia (core temperature <32°C)
Mechanism of injury	15. Ejected from vehicle
	16. Co passenger dead
	17. Trapped in wreck
	18. Pedestrian or cyclist hit by motor vehicle
	19. Fall from >5 m
	20. Avalanche accident

Table 6 *The criteria for activation of the trauma team used at the University Hospital of North Norway (UNN) in 2015. The Table was published in the article Evaluation of a university hospital trauma team activation protocol; SJTREM (2011) 19:18. Permission to reuse by first author Trond Dehli*

6 The aims of this thesis

1. To describe the characteristics of potentially severely injured trauma patients admitted with TTA at the trauma centre in northern Norway in 2015 (Papers I-III).

2. To validate the injury codes and severities registered in the trauma centre's trauma registry in 2015, secondarily to examine causes for missing and discordant codes, to guide improvements of registry data (Paper I).

3. To describe all diagnostic imaging and report the ionizing radiation dose delivered during trauma-associated hospitalization at the trauma centre in 2015 (Paper II).

4. To describe the degree of adherence to ICRP's level three justification, the individual dose limitation principle, at the trauma centre in 2015. To achieve this, we describe

the identified injuries, and the use of CT examinations and interventions in suspected severely injured trauma patients. In addition, we analyse associations between parameters that could influence CT use during trauma admissions, and the observed actual use of CT (Paper III).

7 Materials and Methods

7.1 Study type

This thesis builds on three papers, analysing data from the same trauma population audit done by the thesis author. An audit is retrospective in nature. A clinical quality audit is a thorough and careful description using all existing data from the patients' medical health record notes in order to answer the purpose of the audit. In a quality audit, therefore, missing values is only data that was not recorded in the medical health record. Some call a clinical quality audit a quality revision.

A quality audit concerning approximately 20 percent of the patients is the gold standard before start of research on register data. Hence, an audit study itself needs no validation before use. On the other hand, a re-audit of some of the data can be of importance if it is central for the result. The injury scores for this audit population underwent an extra validation in the form of a consensus validation described in paper I. The extra validation identified and secured the correct injury description in the population, data of high importance for a valid result in papers II and III.

Smith[171] says, "research is concerned with discovering the right thing to do whereas audit is intended to make sure that the thing is done right". Wilson et al.[172] writes a common definition is that "research is finding out what you ought to be doing; audit is whether you are doing what you ought to be doing". *The Norwegian health research act* and its guidance (20.06.2008 no. 44) define research and audit in accordance with these two definitions[173]. However, the distinction between a retrospective quality control research study and a retrospective quality audit is grey[173–175].

7.2 Study population

Trauma coders continuously survey emergency admissions and prospectively register all trauma patients who fulfil the definitions for registration in the national Norwegian trauma

registry[39]. The audit population included all patients registered in the trauma registry as admitted with TTA at UNN, from 01.01 to 31.12.15. The thesis author double-checked that patients admitted with TTA registered on lists in the ED also were registered in the trauma registry. UNN receives approximately 150 TTA per year, and the hospitals in northern Norway admit approximately 500-600 patients with TTA per year[32].

The study patients may undergo diagnostic imaging and interventions during four phases; the pre-hospital phase (phase one); trauma admission 1, at a referring hospital or at the trauma centre for patients transported directly to the Level 1 trauma centre (phase two); trauma admission 2 for referred patients (phase three) and the subsequent hospital stay following the trauma admission (phase four). We define phase two to four as the total hospitalization.

7.3 Study area

In 2015, northern Norway consisted of the counties Finnmark, Troms and Nordland, spread over an area larger than the rest of Norway but similar in size to the United Kingdom (Figure 7). As illustrated in Figure 7, northern Norway is sparsely populated. The population is distributed with about 50% in Finnmark and Troms and 50% in Nordland. The long Norwegian coastline of 12,000 km caused the medical institutions to develop close to harbours. The locations of the 11 hospitals in the region are almost unchanged over 200 years[176].

Figure 7 *Area, inhabitants and inhabitants/km^2 in 2015, for northern Norway, the rest of Norway and for the United Kingdom. Map background from Google maps. Statistics from www.ssb.no and www.ons.gov.uk, accessed in October 2018.*

The development of a regional hospital for northern Norway located in Tromsø began in 1922. In 1971, the work to establish a university hospital began. This was initiated following the Norwegian parliament's decision in 1968, to establish a university in Tromsø. The first medical students started their education in 1973[177]. The number of employed physicians in the radiology and intensive care departments at UNN over the last 40 years has increased from five to 46 and seven to 42, respectively (information found in annual year books for the hospital in Tromsø and from personal communication with the administration at UNN).

In northern Norway, there is one university hospital campus, ten local hospitals and one remote small hospital, located in Longyearbyen on the Spitsbergen (in Norwegian Svalbard) archipelago. The Longyearbyen hospital admits an increasing number of trauma patients due to the increase in cruise tourism. It is located 2 hours and 30 minutes away from UNN by fixed wing propeller air ambulance planes. There is no rescue airport between UNN and Longyearbyen as almost all of the flight is over the sea. The trauma centre at UNN was

formally established in 2012, and became one of the four trauma centres in Norway, as a result of the *Trauma system 2007* report[31–33]. The UNN trauma centre offers all types of medical services except for two treatments. Severely injured burn patients are transported to the national burn department at the trauma centre in Bergen. Patients with severe pelvis fractures are transported to the trauma centre in Trondheim. These two patient groups can have stabilising treatment at UNN before transportation or be transported directly to Bergen or Trondheim. Follow-up after pelvis fracture operations in Trondheim continues at UNN.

Current pre-hospital care is a newer development when compared to the establishment of the hospitals. Pre-hospital care has turned from a transport service without medical service into a mobile intensive care facility over the last 50 years[176]. The northern Norway region has, due to its rural area, a pre-hospital system of multiple road, boat, fix-wing and rotor wing ambulances that support the health care system (Figure 8).

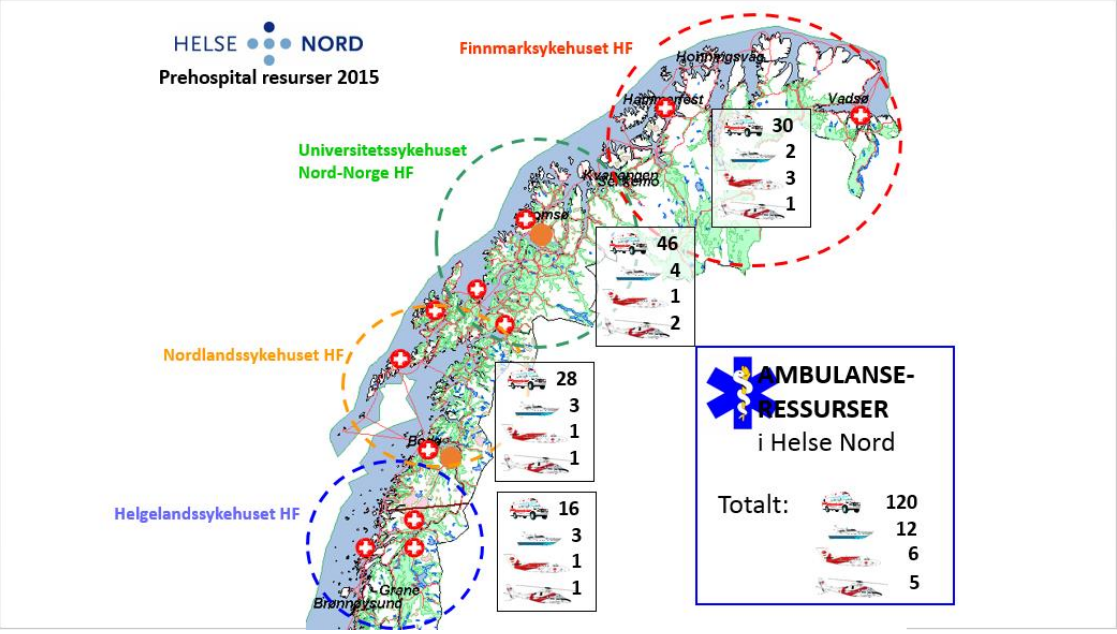


Figure 8 *Pre-hospital transportation resources in the four health trusts in northern Norway in 2015. Map courtesy of the Northern Norway Regional Health authority. Permission to reuse from Nina Hesselberg, University Hospital of North Norway.*

7.4 Data collection

The thesis author manually retrieved and registered all audit data into Microsoft Excel 2013 and SPSS 24. The audit included all pre- and intra-hospital electronic medical health records notes from all different personnel categories. The audit data retrieval started on 29 February

2016 and continued until the 31 of July 2016. Study data entry continued for a patient until death, discharge home or discharge to rehabilitation.

7.4.1 Demographics

We categorised demographical data according to the definitions in the national trauma registry's definition catalogue[39]. Variables not in use in the trauma registry, but important for the audit were also retrieved; for example, all types of diagnostic imaging and all types of interventions. Children were defined as ≤ 16 years, according to UNN's definitions.

7.4.2 Registrations of injuries

During the audit, the thesis author interpreted all the diagnostic imaging examinations without knowledge of the reported injuries, except from countersigning 27 CT examinations back in 2015. Thereafter, the thesis author checked the new interpretations against the reports in the radiology information system (RIS). This was done to identify all codes missing in the original registry coding due to incomplete radiology reports. The thesis author also read all medical record notes from all types of health professionals. All identified injuries got an AIS code by the thesis author following the new examination interpretation and the medical health records audit. Injuries were categorized using AIS codes following the *AIS 2005 update 2008 manual*[10]. The audit injury codes assessed by the thesis author were thereafter validated in the period January to March 2017 in consensus between by the thesis author and Ina Lundberg (IL), a medical doctor licensed in 2017, employed as a trauma registrar coder at UNN from 2014 until 2017. Paper I describes the injury consensus coding validation process and the concordant and discordant codes found comparing the trauma registry codes to the validated reference consensus codes. Both doctors contributing to the audit consensus coding were certified in the *AIS 2005 update 2008 manual*. AIS certified coders in 10 % coding employments coded all injuries into the trauma register. The coders coded according to the AIS convention. One of the consensus coders (IL) coded 81 (56%) of the patients in the trauma registry. The consensus coding became the reference coding in papers II and III.

7.4.3 Registration of vital parameters and blood samples

First recorded HR, SBP, RR, GCS, SI at the accident site and the values from immediately before the first trauma admission CT examination strategy decision were retrieved. Hb, lactate and base excess were retrieved immediately before the first trauma admission CT examination strategy decision. We used the Norwegian modified paediatric early warning score and its normal values to dichotomise vital parameter values as abnormal in children. For adults, we

used the RTS definition of abnormal values for SBP (<90 mmHg) and RR (<10 or >29 breath/minute). HR was dichotomised according to our trauma team activation manual as abnormal if <40 or >130 beats per minute. The reported median values of physiological parameters for the population do not include the children parameters. For the GCS total score, we defined <13 as the limit for dichotomisation into our abnormal group. Patients intubated, medicated or intoxicated are difficult to assess for GCS scale values and total score. We included these patients in our abnormal group for GCS total score. For children, it is valid to use GCS without adjustments[145]. SI was dichotomised as abnormal if >0.9 in adults and children above the age of 12 years, >1.0 for children between six and twelve years and >1.22 for children less than six years[167]. The blood sample values for lactate and base excess were dichotomised as normal/abnormal according to our hospital's reference[147]. The 26 children were excluded from the median calculation of Hb.

7.4.4 Registrations of X-ray images and DAP

We registered the number of X-ray images per anatomical parts of the body per patient, and the corresponding DAP per image as filed in the PACS DICOM archive. The total DAP during trauma admission 1, trauma admission 2 and total hospitalisation was registered as continuous variables for each patient. The total DAP during the total hospitalisation was also calculated per body part (upper extremity including the clavicle, the chest/abdomen including the vertebral column, and the lower extremity including the pelvis). A retake was defined as an anatomical body part that was examined more than one time.

7.4.5 Registrations of CT scans and DLP

We registered the number of CT scans per body parts scanned per patient, with corresponding DLP per scan as filed in the PACS DICOM archive. We calculated delivered DLP per patient into four continuous variables; SWBCT DLP dose in trauma admissions, total CT DLP in trauma admissions, DLP for the total hospitalisation, DLP for the total hospitalisation and DLP per body part for the total hospitalization (SWBCT examination split into body part scans). A complement CT scan was defined as a CT scan during the subsequent hospital stay for a body part not examined during trauma admissions, and a duplicated CT scan as a body part scanned more than one time.

The SWBCT protocol includes caput and neck scan without intravenous contrast, chest scan with intravenous contrast in arterial phase (including the spleen), and abdomen/pelvis scan with intravenous contrast in the portal phase (Appendix 2). Shoulders

and hips are often included in the chest and pelvis scan. All other scans of extremities were registered as a separate body part examination. A selective CT was defined to exclude one or more of the four SWBCT body scans. On the trauma surgeon's discretion, duplicate CT scans of one or more body parts during one examination could be ordered. For example, an examination of a complicated neck fracture justifies an extra arterial contrast phase of the neck during the chest scan and a complicated pelvis fracture an extra late contrast phase of the pelvis.

Siemens CT machines include the scout image DLP in the total examination DLP. It varies between CT manufacturers whether or not the scout image DLP is included in the total DLP output. The scout scan of the head and neck is one image and the scout scan of the chest/abdomen/pelvis one image. In the audit, the two scout DLP's were manually added to the examination DLP output for the head and chest scan, to ensure that all the ionizing radiation given to patients in this study, were included in the DLP burden.

7.4.6 Estimation of effective dose

We used NCICT for estimations of the effective dose[109]. NCICT estimations were done for all CT scans in the population, estimating the organ doses for all organs and the total effective dose for the scan. The total effective dose for one examination was found by summarizing the effective dose from all scans in one examination. The scout doses the patients had during the examination are not included in the NCICT scan calculations reported in the paper II.

On 9 May 2018, we estimated the effective dose for the same SWBCT protocol in all the three similar CT machines at UNN by scanning a CT whole body phantom, the Kyoto Kagaku co. LTD PBU-60. Scan length and scan positions where the same in the three machines. Complete information about the machines, scan parameters and estimated doses are described in Appendix 3.

7.4.7 Scoring method for CT findings

Inspired by the 2 x AIS > 2 method by Butcher et al.[22,23], the CT scoring method described by Sampson et al.[24] and Davis et al.[25], the thesis author constructed an injury severity CT body part variable. The variable includes the AIS 2 injuries, to include all severe injuries that are possible to identify with a CT examination. The variable categorized patients into three groups based on the trauma admission CT examination findings. High injury grade group was defined as AIS ≥ 2 injuries identified in two or more SWBCT body parts scans, moderate

injury grade group as AIS ≥ 2 injuries in one body part and low injury grade group as either AIS 1 injuries or no injuries.

7.4.8 Registration of non-ionizing radiation examinations

For each trauma patient, the thesis author retrieved data on whether FAST and EFAST examinations were undertaken by the helicopter emergency medical services, or during trauma admissions. The thesis author also registered whether FAST/EFAST changed the treatment decision in each case. After TTA, during the subsequent hospital stay, the number of all ultrasound examinations for each patient (excluding FAST/EFAST) was retrieved. Use of intravenous ultrasound contrast examinations and ultrasound guided pleuracentesis was registered separately. The MRI examinations undergone during the subsequent hospital stay were retrieved as the total number of examinations per patient and subcategorised into the body parts scanned.

7.4.9 Registrations of interventions

Interventions were defined as actions to improve outcome of an injury, or to prevent it from getting worse. For each patient, we registered whether the patient had undergone intervention(s) or not, and eventually the type(s) and number(s) of intervention(s). Interventions were categorized as active procedures or conservative treatment decisions, such as observation. Repeated interventions for the same injury were registered as one. Emergency interventions were defined as those listed in the Norwegian trauma registry manual and done within 24 hours after the accident[39]. In addition, we defined active internal and external rewarming as emergency interventions. We registered whether patients were intubated pre-hospital or within the first 24 hours of admission. We also registered the total number of interventions per patient done during hospitalization in areas examined with a trauma admission CT. Interventions for injuries in the skin were only registered if, for example, they were sutured.

7.5 Statistical methods

We used IBM SPSS 24 to analyse the data. Continuous variables are presented with means and standard deviations (SD) or medians and lower (Q1) or upper quartiles (Q3), depending on the distribution of the variables. Normality was tested with Kolmogorov-Smirnov and Shapiro-Wilk tests and distribution assessed with histograms and Q-Q plots. In Paper I, we used inter quartile range (IQR) for presenting the quartile 25 and quartile 75 (example; IQR (quartile 25, quartile 75)) instead of Q1 and Q3[178]. Categorical variables are presented with

frequencies and percentages. Group differences were tested with independent-t-test for continuous variables and the chi-square test or Fisher's exact test for categorical variables.

A Bland-Altman analysis was used to report agreement for ISS and NISS in the trauma registry compared to the reference standard (Paper I). We plotted the mean between the paired measured ISS in a Bland-Altman scatter plot, calculated for each patient by summarizing the ISS in the trauma registry and the reference standard, and divided by two on the X-axis. The Y-axis shows the difference between the paired ISS, calculated as ISS in the trauma registry subtracted the reference standard ISS. With ideal agreement, the difference equals zero[179,180]. NISS was plotted in the same way. This method requires normality distribution of the difference variable.

Associations between clinical data assessable for 113 adult patients examined in the ED before the trauma admission CT strategy decision, and the use of SWBCT versus a selective or no CT approach, were analysed with logistic univariable and multivariable regression in Paper III. The analysis excludes the five hemodynamically unstable adults sent directly to the operation room. Unadjusted and adjusted odds ratios are presented. We used 95% confidence intervals (CI) and $p\text{-values} < 0.05$ were considered statistically significant.

7.6 Legal issues influencing the audit

The Regional committee for medical and health research ethics (REK-Nord) defined the protocol as a quality control (case number 2014/1883) (Appendix 4). The data-protection officer at UNN approved the analysis of data from UNN (case number 0446), without approved consent from the patients in the population, due to the quality control design.

7.7 Ethics

Quality audits are important and ethically defensible without informed consent from the patients. The audit does not change patients' treatments, but it can improve treatments for future patients.

8 Main Results

8.1 Demographics Papers I-III

In total, 144 patients were admitted with TTA at UNN in 2015. The median time from accident to first hospital admission with CT possibility was 1 hour and 54 minutes (Q1=1.0, Q3=2.7 in hours). Fifty-two (36.1%) patients arrived within 1 hour and 30 minutes and 21 (14.6%) after five or more hours. In total, 36 (25.0%) patients arrived in a hospital with CT possibility within 1 hour. Six (4.2%) of these underwent CT examination within 1 hour after the accident, and none within 30 minutes. The median time from accident to arrival at UNN for the transferred patients was 8 hours and 15 minutes (Q1=6.17, Q3=12.3 in hours). More data on time observations are provided in Appendix 5. The number of patients admitted intubated in the first hospital was 19. Among the 36 transferred patients, five arrived intubated at UNN. The surgeon made the CT examination strategy decision in 34 patients without the GCS assessment because the patients were intubated, intoxicated or medicated. Table 7 displays the characteristics for the study population.

Table 7 Characteristics of the trauma population (n=144)

Characteristics	
Male sex, n (%)	114 (79.2)
Tourist, n (%)	28 (19.4)
Age, years in median (Q1, Q3)	31 (19, 49)
Age groups, n (%)	
<5	9 (6.3)
5 – 16	17 (11.8)
>16	118 (81.9)
Transport to first hospital by	
Ambulance helicopter, n (%)	80 (55.6)
Fixed wing air ambulance, n (%)	9 (6.2)
Road ambulance, n (%)	53 (36.8)
Private transportation, n (%)	2 (1.4)
Transported accompanied by physician to first hospital, n (%)	87 (60.4)
Trauma mechanism	
Penetrating traumas, n (%)	5 (3.5)
Blunt, n (%)	139 (96.5)
Road traffic, n (%)	63 (45.3)
Snowmobile, n (%)	11 (7.9)
Falls, n (%)	31 (22.3)
Hit by object/explosion/fire, n (%)	21 (15.1)
Avalanches and/or hypothermia, n (%)	8 (5.8)
Other causes, n (%)	5 (3.6)

Transferred from other hospitals, n (%)	36 (25.0)
RTS outcome score at accident site	
RTS <5, n (%)	10 (6.9)
RTS 5-7, n (%)	14 (9.7)
RTS >7, n (%)	53 (36.8)
RTS not possible to calculate, n (%)	67 (46.5)
ISS, (Q1, Q3, Range)	9 (2, 22, 0-59)
NISS, (Q1, Q3, Range)	12 (3, 27, 0-66)
ISS >15, n (%)	52 (36.1)
ISS >15 among 26 children ≤16 years, n (%)	5 (19.2)
ISS >15 among 118 adults, n (%)	47 (39.8)
NISS >15, n (%)	64 (44.4)
Length of stay, median days (Q1, Q3)	4 (1.2, 11.5)
Total hospitalization >20 days, n (%)	20 (13.9)
30-day mortality, n (%)	10 (6.9)

Q1 lower quartile, *Q3 upper* quartile, *RTS* Revised trauma score, *ISS* Injury Severity Score, *NISS* New Injury Severity score

Table 7 *Demographics for the 144 patients admitted with trauma team activation at the University Hospital of North Norway in 2015.*

Among the ten patients who died within 30 days, six had RTS outcome score calculated at the accident site (RTS < 5, n=3 and RTS 5-7, n=3). In total, 77 patients had RTS outcome score calculated at the accident side.

8.2 Paper I

The total number of registered AIS codes was 582 in the registry and 766 in the reference standard. All injuries were concordantly coded in 62 (43.1%) patients. Most non-registered codes (n = 166 in 71 (49.3%) patients) were AIS1, and information in the electronic health record overlooked by the coders was the domination cause. Discordant coding of head injuries and extremity fractures were the most common cause for 157 discordant AIS codes in 74 (51.4%) patients. Median ISS (9) and NISS (12) for the total population did not differ between the registry and the reference standard. The Bland – Altman scatter plots of the mean (x-axis) between the paired measure of ISS and NISS in the trauma registry and the reference standard versus the difference between them (y-axis) showed no proportional bias. Regression analysis showed no statistically significant difference neither for ISS ($p=0.078$) nor NISS ($p=0.656$).

8.3 Paper II

During hospitalization, 134 (93.1%) underwent X-ray, 122 (84.7%) CT, 92 (63.9%) FAST, 14 (9.7%) ultrasound (FAST excluded) and 32 (22.2%) MRI. 116 (80.5%) underwent CT

examination during trauma admissions, and 73 of 144 (50.7%) SWBCT. DAP values were below national reference levels. Median DLP and effective dose were 2396 mGycm and 20.42 mSv for all CT examinations, and 2461 mGycm (national diagnostic reference level 2400mGycm) and 22.29 mSv for a SWBCT at the trauma centre. There was no statistically significant difference between children and adults with regard to use of X-ray (p=0.387), MRI (*p=0.442*) or ultrasound *(p=1.0*) during the subsequent hospital stay.

8.4 Paper III

Majority, 138 (95.8%) of potentially severely injured patients had an identified injury. One hundred and five (72.9%) patients had at least one AIS ≥2 injury, 26 (18.1%) in more than two body regions. During trauma admission, at least one vital parameter was abnormal in 46 (32.4%) patients, and 73 (50.7%) underwent SWBCT, 43 (29.9%) selective CT and 28 (19.4%) no CT examination. No or only minor injuries were identified in 17 (23.3%) in the SWBCT group. Two in the selective group and two in the no CT group were examined with a complement CT, with no new injuries identified. A significantly (*p<0.001*) lower proportion of children (61.5%) than adults (89.8%) underwent CT examination despite similar injury grades and use of interventions. In adjusted regression analysis, patients with a high-energy trauma mechanism had significantly (*p=0.028*) increased odds (odds ratio=4.390, 95% confidence interval 1.174-16.413) for undergoing a SWBCT. In total, 50 different emergency interventions were done in 35 (24.3%) patients. During the total hospital stay, 409 interventions were undertaken in 118 (81.9%) patients.

9 Discussion

Diagnostic imaging is important for timely initiation of treatments to reduce compromised oxygenation in trauma patients[51,52,55,181,182]. However, the ionizing radiation used in diagnostic imaging, might induce a small, but not negligible, cell mutation risk, which increases the risk of developing cancer in the exposed patient later in life. For the healthy and young trauma population this might have unwanted long-term consequences[42,79,84]. The lack of international guidelines for CT in trauma patients, and the advocated use of immediate SWBCT from large urban trauma centres have contributed to an increased use during the last two decades[53,54,183]. ICRP advocate that ionizing radiation should do more benefit than harm to the individual patient. The decision-making process should have risk of radiation

harm included, but in the decision, everything concerning the activity should be considered, such as other risks, costs and benefits of the activity[42].

9.1 Demographics

The 144 patients included in this study were predominantly young males exposed to blunt trauma, and transported to hospital by physician staffed air ambulance. The number of TTA and the demographic characteristics of the study population is comparable to estimates published by the Northern Norway regional health authorities in 2010[32] and by Dehli et al.[1,170,184], who studied patients admitted with TTA at the UNN trauma centre in the years 2006-2007 and 2013-2014. Accordingly, it is reasonable to assume that our study population is representative for the trauma patients admitted with TTA to UNN in an average year. This could be further validated by reviewing data in the national trauma registry[35].

The external validity of the present study depends on the populations it is compared with, as demographic characteristics, predominating injury mechanism and pre-hospital transport times vary significantly between countries and hospitals. The median age, proportion of males, median ISS and the mechanisms of trauma are comparable to selected studies from other European trauma centres[25,185–187]. The median time from accident to arrival at hospital was long (almost two hours) compared to studies from urban trauma centres, but comparable to transport times in other rural populations[188].

The case fatality rate in the admitted population was 6.9 %. This is comparable to subsequent years (personal communication, trauma coordinator UNN). Studies that are not directly comparable, due to a difference in regional context and ISS, report mortalities from 9 to 20%[161,189,190]. The case fatality rate includes two patient categories, unavoidable and avoidable deaths. The last category is important to identify and audit in order to improve trauma care. Mortality comparisons between hospitals and regions should distinguish between these two categories. Accordingly, a dichotomised variable separating unavoidable and avoidable death should be included in trauma registries.

This would require a national committee for continuous audit of all trauma death to identify system factors causing avoidable deaths. In northern Norway, 16 severely injured patients died at local hospitals in 2015, without being transferred to the trauma centre (personal communication, Norwegian National trauma registry).

Standardised assessment and reporting of the RTS outcome score has a potential to improve the quality of benchmarking in trauma. The RTS outcome score calculated from the values registered at the accident site might differ from a score calculated from values registered in the ED. This is because transportation time, pre-hospital interventions and pre-hospital resources influence the score. A RTS outcome score calculated in the ED might be lower in urban trauma centres because a higher proportion of severely injured patients survive the transportation. In rural centres, a higher proportion may die on the way to hospital. Few papers state whether the reported RTS outcome score is calculated from values registered at the accident site, or in the ED. This could be because registration of vital parameters from the accident site often is lacking.

The national trauma registry in Norway registers for each patient, the first recorded vital parameter values from the accident site and in the ED, and then calculate and report RTS outcome scores from both locations[39]. Accordingly, this study reports the RTS outcome score calculated form values registered at the accident site. Use of RTS outcome score based on values registered at the accident site in all trauma registries and studies, would improve benchmarking across hospitals and adjustments for case-mix in studies of trauma patients admitted to hospitals.

It is important to have the trauma regions' context in mind when comparing hospitals, regions and countries. Assumption of comparable contexts introduces a risk for incorrect inferences concerning trauma organisations' performance in benchmarking comparisons[144,153].

9.2 Paper I

9.2.1 Summary

The main finding in paper I was the identification of moderate concordance between the injury codes registered in the trauma registry and the reference standard established as a consensus validation audit. The audit shows that concordant coding in a trauma registry is challenging to achieve even with AIS certified and trained coders. However, the discordant individual codes did not affect the aggregated ISS/NISS reliability for the population. The consequence, if our results can be generalised, is that, for an individual patient, the trauma registry injury output seems only moderately valid, which illustrates the importance of validating the injury codes before comparing individual patients in studies for reliable

results[191–193]. However, for a benchmarking comparison between institutions, the aggregated population ISS/NISS in the registry might be valid.

ISS is not a continuous variable and is usually not normally distributed[15]. However, the Bland-Altman plot, as used in our study, only requires a normal distribution of the difference variable between the trauma registry and the reference standard. This variable showed normality-like distribution. Confirmation of our finding that suboptimal individual patient AIS code quality does not influence population median ISS and NISS reliability, would improve the confidence in benchmarking across institutions using routine trauma registry AIS codes. We advocate validation of this finding in a multicentre study of registry data.

However, even if such a study would validate comparison of ISS/NISS across institutions, differences in hospital case-mix and inclusion criteria must also be taken into consideration in benchmarking. A known problem with ISS is that blunt and penetrating trauma, with the same ISS cause different mortality rates[194]. Different ISS triplets with the same total ISS score also show different mortality rates. For example, ISS triplets 2.2.1 and 3.0.0 both have ISS 9 but different mortality rates[195]. In addition, there is inconsistency with regard to whether values from uninjured patients with ISS 0 are included in calculations of median ISS. In our study, median ISS increased from ISS 9 to 10 after exclusion of the uninjured. Accordingly, studies should clarify whether values from uninjured patients with ISS 0 are included in calculations of median ISS.

9.2.2 Studies of injury coding

The use of clinical quality registry data, like trauma registers, is increasingly seen as important in healthcare for improving patient safety and the quality of clinical care[37,191–193]. Optimal coding in a trauma registry is important, but it demands enough time and effort in the form of education for both coders and physicians. UNN's approach is to bring coders and surgeons together by educating surgeons in AIS coding, without requiring them to enter codes in the register. This improves the conversation between coders and surgeons, which indirectly improves surgeons' notes in the medical record, and facilitates coders' retrieval of data into the registry. Others advocate regular audits of injury codes attended by both coders and surgeons to improve data quality[196].

There are three different methodological approaches for studies of types of injury coding quality. Their results must be interpreted separately.

Firstly, inter-rater agreement between the codes in a registry and a new reference coding can be studied. To our knowledge, this has not been done as rigorously as in this thesis. Horton et al.[197] quantitatively compared the number of codes in the registry and a new-blinded re-registration done by one trauma coder, and found almost perfect agreement. The occurrence of, and causes for discordant codes were, however, not studied. Confirmation of high inter-rater agreement on the number of codes does not necessarily imply a corresponding level of agreement on the specific coding. Another audit study found that the registry code quality increased after introduction of a weekly one-hour audit meeting between coders and trauma surgeons, who audited coding from the previous week[196].

Alternatively, intra- and inter-rater agreements of coding the same patient using the same AIS manual can be studied[198–200]. Low inter-rater agreement is a known problem with the AIS coding system[198,199,201]. For example, Ringdal et al.[199] used electronic health record data from 50 patients registered in a trauma registry, and compared coding by 10 coders with a new reference standard. They concluded that ISS and NISS were not reliable for summarising anatomical injury severity. However, they did not test the quality of the original coding in the registry. We compared the original coding in a registry with a reference standard and found corresponding results on the individual level. On the aggregated level, however, median ISS and NISS did not differ between the registry and the reference standard. Accordingly, in our study, we suggest that under- and over-scoring of injury severity on the individual level counterbalance each other on the aggregated group level, indicating that comparison between institutions based on registry data could be reliable. This should be validated in a multicentre audit. However, consensus validation of individual codes is necessary before comparison of specific patient treatments within or across institutions.

Finally, concordance between coding according to different versions of AIS coding manuals can be studied, as the manual is updated on regular basis (1998, 2005, 2008, and 2015)[202]. Such studies are necessary for development of conversion tools to convert AIS codes from one manual version to an update. Publications should specify which version of the AIS manual that has been used.

9.3 Paper II

9.3.1 Summary

The main finding in Paper II is that most patients underwent at least one ionizing radiation examination. CT was used in 84.7%, and 50.7% underwent a SWBCT. The median DLP and effective dose for all CT examinations during the total hospitalisation was 2396 mGycm and 20.42 mSv, respectively. Only 36.1% were severely injured. Most of the ionizing dose was delivered during trauma admissions, as the median DLP increased by only 300 mGycm during the subsequent hospital stay. The highest dose given to one patient was 159 mSv during the hospitalisation.

We found that median DLP for a SWBCT at the trauma centre was 2461 mGycm, which is slightly above the diagnostic national reference level (2400 mGycm). All DAP values were well below national references[103]. It is known that the mean body mass index in the population in northern Norway is slightly above the national average. We find it unlikely that mean body mass index in the study population, which also included children, was higher in the patients that the national reference level is based on[203]. Five (8.8%) of the 57 examinations included medically justified duplicated scans (DLP range of 2883-3118). We used a scan protocol in which for example, the spleen is examined in both the arterial and venous phase for pseudo aneurysm identification[56,57]. The overlapping body scan protocol and the justified duplicated scans probably contribute considerably to the high dose [60,61]. However, our CT whole body phantom scanning of the same protocol was well below the reference DLP value. It has been shown that a single pass CT protocol of the thorax/abdomen/pelvis with dual contrast phase reduces the dose[58–61]. However, this protocol can cause interpreting problems and influence diagnostic precision[62].

The diagnostic reference levels are influenced by average body mass index. Globally, mean population body mass index is increasing. One country with high reported mean DLP per person per year due to medical imaging, the United States, was also the country with the second highest mean body mass index in 2015, according to the World Health Organization (Table 8) [204]. This, and high CT availability may both contribute to their high mean ionizing radiation dose from medical imaging per year.

Mean body mass index (BMI) for both sexes per country by WHO [a]

Country	Mean BMI (kg/m^2) for both sexes, age – standardized estimate)
Estonia	20.5 (19.9-21.2)
Bangladesh	21.6 (21.2-21.9)
India	21.7 (21.4-22.1)
Japan	22.7 (22.4-23.0)
Denmark	25.3 (24.8-25.8)
Portugal	25.7 (25.0-26.3)
Spain	26.0 (25.5-26.4)
Sweden	26.0 (25.3-26.7)
Belgium	26.1 (25.6-26.6)
Iceland	26.2 (25.5-26.9)
Russian Federation	26.2 (25.7-26.7)
Finland	26.4 (25.8-26.9)
Slovakia	26.4 (25.8-27.0)
Germany	26.5 (25.9-27.1)
Norway	26.6 (25.8-27.5)
Canada	26.9 (26.5-27.3)
Australia	27.1 (26.7-27.5)
UK	27.1 (26.9-27.4)
Saudi Arabia	28.4 (27.9-28.9)
USA	28.8 (28.4-29.9)
Egypt	29.5 (29.1-29.8)

WHO World health organization, [a] Global health observatory data repository by WHO, accessed 29.05.19.

Table 8 *World health organisation global health observation data on body mass index for both genders in different countries in 2015, extracted and tabulated by the thesis author 29.05.19.*

We used whole body phantom scanning to show that all our CT machines delivered the same amount of radiation dose. We report the phantom scanning scan parameters, DLP and effective dose estimated with NCICT. This opens a possibility for other institutions to compare the technical performance of their protocols with ours, without the influence of body mass index. Increased reporting of this information could support protocol optimisation according to ICRP's justification level two.

To our knowledge, few have reported the use of non-ionizing examinations in addition to the use of ionizing radiation examinations in trauma populations. The use of ultrasound and MRI did not differ between children and adults in the present study. We found that, except for the use of FAST and EFAST during trauma admissions, the use of ultrasound and MRI was low during the subsequent hospital stay. This suggests that a potential for future dose limitation by replacing some of the ionizing radiation examinations with non-ionizing examinations exists[205,206]. Such individual dose limitations may decrease the dose more than changing to a single pass CT protocol of the thorax, abdomen and pelvis.

9.3.2 Ionizing radiation dose studies

Most studies that describe diagnostic imaging in populations comparable to ours include between 50 and 200 patients, and the study period is usually restricted to parts of the trauma-associated hospitalisation period[71,189,190,207–211]. None of the previously published studies includes all the variables that we have included, but all were conducted in ASC-COT Level I or II trauma centres in university hospitals. One publication reported a total of 1505 X-rays images and 400 CT scans for 177 patients admitted to a Level I trauma centre[209]. The numbers are comparable with the present study.

To our knowledge, only one study reports DLP. Salottolo et al.[189] included 165 patients admitted to the intensive care unit, and reported DLP for 57 patients. The median DLP for the total hospitalization (1700.22 mGycm) and effective dose (9.38 mSv) were lower than those observed in the present study. A number of studies report estimations of effective doses in trauma population comparable to ours[71,166,189,190,207–210]. However, effective dose was not intended to be applied for studies of populations with variation in age and gender-composition[42,112]. There is an understandable reason for the use of effective dose, as it is the only method for addition of radiation risk from different modalities[42,113]. Effective dose is very abstract. It estimates whole body exposure from partial body exposure. It is not used for routine monitoring of delivered doses to patients, restricting its usefulness. In addition, there is methodological inconsistencies in the published articles, for example in the use of conversion factors, and the estimates for the reference person have a relative uncertainty of ± 40%[113,114]. In trauma populations, the focus ought to be on dose limitation to patients. Reporting DAP and DLP, as we do in Paper II, supports individual dose limitation, and facilitates comparison between future studies, especially if patient weight and height are included as variables for the CT examination DICOM report. In addition, diagnostic reference levels are published in DAP and DLP[103,212].

9.3.3 The risk of future cancer

The harm from a very low (X-ray) and low (CT) ionizing radiation dose is under debate[41,78]. We do not know whether these doses are protective or harmful[213,214], but most argue that several CT examinations over a short time in one patient will increase the lifetime risk for developing cancer[79,101,118]. One middle aged adult male in our study undergoing several examinations, including 6 CT examinations of the abdomen/pelvis, who was exposed to the highest delivered dose in the study, received a total DLP of 10,604

mGycm. The estimated effective dose was 159 mSv over the total hospitalization period. One published guideline from the Royal college of radiologists *Making the best use of clinical radiology services 6th edition* estimates the additional lifetime risk of cancer in a 50-year-old male receiving 10 mSv from one CT abdomen to 1/1000 (=0.001). This small risk of 0.1% multiplied by 15.9 (159 mSv/10 mSv) gives the patient in our study an estimated additional lifetime risk of cancer of 1.6 %. If the study patient had been an 80 year old male, the risk would have been estimated to 1.6 % x 0.5 (0.8%), corresponding estimates for a 50 year-old female are 1.6% x 1.38 (2.2%) and for a child under 1 year 1.6% x 4 (6.4 %)[129]. Children's increased sensitivity to ionizing radiation and their long life expectancy giving induced cell mutations time to develop cancer, gives persons exposed to radiation in childhood a higher cancer incidence than other adults[41,42,129]. The young and healthy trauma population is therefore, a patient group for which the increased use of CT in the last 20 years might result in a higher cancer incidence in the years to come compared to non-exposed persons[124,205,206,210,215–217].

Publications that highlight that there is uncertainty regarding harm from medical imaging argue there is no real proof of harm, but there is a proven benefit of justified diagnostic examinations. If a patient chooses not to undergo the justified examination to avoid a small risk of cancer, the cost can be higher for society; therefore, information on the risk from ionizing radiation needs to be appropriate in order to guide decisions[79,213]. The published studies of cancer induction risk in cohorts undergoing diagnostic imaging with CT would benefit from a longer follow-up time[120,124–126,128]. However, until this risk has been established, the ALARA statement is valid[79].

It is a weakness with previous cohort studies that the CT examination leading to inclusion in the study is requested because of symptoms. This could cause an inclusion bias leading to over-recruitment of individuals with an increased risk of cancer. A cohort study including potentially severely injured, but otherwise healthy young trauma patients would not be hampered by such bias. The protocol should exclude patients with an established cancer diagnosis or symptoms to isolate the effect of the radiation exposure connected to the trauma. Cancer incidence among long-term survivors (40 years) should be censored in groups examined with SWBCT, selective CT or No CT during the hospitalization, without and with lag periods of 2 and 5 years.

9.3.4 Future problems with increased dose from medical imaging

On the individual level, the likely risk of cancer induction from medical imaging is small, but on the aggregated population level, the sum of induced cancers is probably significant. Today, most CT machines are installed in industrial countries, where only 25% of the world's population live. Introduction of the same CT availability and use in the rest of the World will increase radiation exposure from medical imaging proportionally, which is concerning [72,218–221]. In consequence, health care systems in developing countries should be advised to implement the justification principles recommended by the ICRP in parallel with development of their radiological services[42].

9.4 Paper III

9.4.1 Summary

Our study result indicates that examinations with CT in potentially severely injured patients are in accordance with the ICRP's justification principle level one. On the other hand, the results indicate that examinations of a higher proportion with selective CT would have approximated the ICRP's level three, the individual dose limitation, better[42,84,220]. Our data shows that it might be possible to reduce duplicated CT scans during the subsequent hospital stay by increasing the number of clinical examinations and introducing stricter CT indications, as most of the duplicated scans in our study were controls for known findings and none of the scans induced new active interventions[205,206,222].

In the group examined with SWBCT during the trauma admissions, 23.3% had ISS 0-3 and, among these, 76.5% had no injury identified and no intervention in the area examined by CT. Previous studies reported SWBCT without identified findings ranging from 14%, in studies with strict CT indications, to 60% in studies with wide indications[24,185,186]. It is unclear whether these examinations match the ICRP's individual dose limitation principle (level three) because the trauma teams meet potentially severely injured trauma patients in the ED. An unconscious circulatory stable patient may show no visible signs of trauma, while the CT identifies several injuries. An awake and afraid patient can show symptoms indicating severe injuries, while the CT shows no injuries. Hence, a prospective study assessing whether SWBCT examinations are justified in individual patients, would imply registration of the injuries suspected by the trauma team before the CT examination strategy decision. To our knowledge, such studies have not been published. Many studies are biased by using the

frequency of injuries identified by CT examination in selected patients as an outcome for evaluation of the justification of the same examination[25,223–225].

In addition to vital parameters, the clinical symptoms and the reported trauma mechanism influence decisions for diagnostic imaging in ED. Testing possible predictors for the CT examination strategy decision among our patients identified that the odds for having a SWBCT compared to a selective CT or no CT was significantly higher only for the TTA criterion high-energy trauma.

Hence, the CT examination strategy in the study population was individualised and the majority of patients had normal vital parameters. However, most still underwent CT examinations. Our study did not analyse what reasons the team used for the CT examination strategy decision. Surveying this prospectively would be an interesting future study. One conclusion that it is possible to draw from our data, is that achieving a higher proportion of adults with selective or no CT examination at the trauma centre might be possible just by applying the indications already practiced by the trauma teams for children.

9.4.2 CT screening versus individual imaging

A screening CT method among potentially severely injured patients identifies most injuries and might improve short-term survival[52–55,183]. Sierink et al.[71] published the only prospective randomised study to test the immediate SWBCT screening approach versus individual imaging. They did not identify increased short-term survival, but instead showed a small increased mean ionizing radiation dose in the immediate group, that might influence long-term survival. It is important to distinguish between studies of potentially severely injured patients, such as the unselected population included by Sierink et al.[71], and studies of patients with verified severely injuries, such as those registered in some trauma registries[53,54,226]. The external validity of studies in the latter category may be limited.

9.4.3 Missed injuries in patients undergoing trauma admission

Several studies indicate that important injuries are missed in trauma patients not undergoing an SWBCT or CT during TTA[223,227,228]. Giannakopoulos et al.[229] identified that most of these missed injuries were suspected during or after a tertiary survey. Most were extremity fractures, identified due to X-ray examinations, and treated with observational treatment. Stratification of the missed injuries reported (in the four studies referred in this sections) into

injury types (Table 9), highlights that they normally show symptoms like tenderness from clinical palpation or visible hematoma and/or bruising in the relating skin area[223,227–229].

Table 9 Missed injuries in patients met with trauma team activation[a]

Subarachnoid, sub-dural or epidural bleeding or cerebral contusion
Rib fractures
Pneumothorax
Lung contusion
Hemothorax
Tracheal laceration
Suspected Aortic injury
Sternal fracture
Clavicle/Scapular fracture
Pericardial effusion
Vertebral and sacrum dislocation/fracture
Renal injury
Adrenal injury
Liver injury
Spleen injury
Retroperitoneal hematoma
Bowel injury
Hemoperitoneum
Air in peritoneum
Acetabular fracture
Pelvis fracture/dislocation
Femur hip fracture
Arm fracture

[a] Injury types identified as missed injuries in at least one of the following four publications: Salim et al. Arch Surg 2006; 4;468-475, Deunk et al. J. Trauma 2007;63:757-763, Tillou et al. The Journal of Trauma, injury, infection, and critical care volume 67, number 4, October 2009, Giannakopoulos et al. Int. J. Care Injured 43 (202)1517-1521

Table 9 *Injury types identified as missed injuries in four different trauma population studies, the identified injured in the publications are stratified into injury types by the thesis author.*

Some have tried to identify clinical decision tools to identify patients who would gain most from undergoing a trauma CT[25,223–225]. A review published by Hare et al.[230] found limited evidence for increased sensitivity of the examination from use of such tools. Davis et al.[25] recorded external signs and included them in the decision tool. When tested prospectively, the tool had a high sensitivity for significant CT findings. In conclusion, clinical identification of hematoma and bruising seems to be important for the CT examination strategy decisions in a trauma population.

9.4.4 Identifying trauma patients with high mortality risk

None of the studies proposing decision tools for CT includes SI, lactate or base excess in the decision algorithm[25,223–225]. For patients with normal vital parameters, an abnormal SI, lactate or base excess may facilitate the CT examination strategy decision[143,148–150,156,162,163,166–168]. SI correlates with contrast extravasation in angiographic examinations of gastrointestinal haemorrhage[164]. In areas with a high percentage of hypothermic victims, it is important to remember that a hypothermic victim's survival after abnormal lactate is different from a normothermic person illustrated in the present population in Appendix 6 [146].

The patient's independent T-RTS values (SBP and RR) from the accident site might be possible to use as decision tools for the CT examination strategy decision[156]. Assessing the change in the independent T-RTS value in an individual patient between the accident site and after admittance to the ED might also be helpful[157]. However, a study at UNN indicated that the trauma team in the ED does not focus on the pre-hospital vital signs[231]. Our audit also identified that vital parameters from the accident site were documented less frequently than those in the ED, indicating that focus on change in the vital status between the accident site and in the ED is a potential field for improvement of morality risk stratification[157].

9.4.5 It is important to take the logistical context into consideration

The technical developments between 1995 and 2015 have changed CT machines from slow machines with image quality problems to fast machines with high diagnostic accuracy[51,52,55,182,232]. Most radiologists are able to distinguish between patients with a normal versus abnormal circulating blood volume, with just one look at a CT abdomen[181]. For the trauma team, such experience from a radiologist can influence the team's treatment decisions, but this depends on good logistics for a timely CT examination.

Time from admittance to the start of the CT scan influences survival and treatment decisions. In our population, this time was similar to that in urban centres[71,185,233,234]. Centres with CT in the ED, and centers with installation of hybrid room (CT, angiography and operation) interventional radiology features (IVR-CT) room, some even with a dual room and sliding CT gantry, show a shorter time to start of CT, a higher use of interventional radiology and possibly a trend towards increased survival in severely injured patients[55,182,232,235,236]. The developments in CT technology and installations of IVR-

CT might, combined with a more consequent use of the ICRP's justification principles, change future trauma admission CT strategy decisions to advocate an immediate CT for unconscious hemodynamic unstable patients, or for those with spinal injuries, and a selective CT among the others.

10 Strengths and limitations

The major strength of this study is the rigorous registration of vital signs, injuries, diagnostic imaging and all active and conservative interventions in a clinical audit form. Compared to a retrospective register based quality control study, a clinical quality audit is a more reliable method. In a retrospective quality control, the data input is set per definitions and many different registrars contribute to the registry data input. The research questions asked can only be analysed based on the registry data output. The registry output can thereby have missing research data because data was not defined as an input variable, data was found to be difficult to classify (according to the variable definition) and thereby entered incorrectly or as a summary variable, or data can be missing because the values was not recorded in the patient record. In a quality audit, like this one, missing variables are limited to values not recorded in the patient record. The audit for this thesis identified few missing values. Furthermore, the consensus validation of the injuries in Paper I is an extra strength, together with reporting data from a rural Level 1 trauma centre, which highlights that results from large urban centres cannot be generalised without considering the geographical context.

In order to assess whether diagnostic examinations induce interventions, we considered it important to register all interventions done during the entire hospitalisation, including all conservative treatment decisions. The reason for this rigorous intervention registration is that a spleen laceration or a head injury treated conservatively with hospitalisation, including pain treatment and observation is a justified medical indication for a CT examination. Reporting both DLP and the effective dose (using NCICT) for all CT scans is a strength. Whole body phantom scanning, reporting the protocol parameters and an estimation of the effective dose with NCICT has not been done before and, if adopted by others, may improve protocol optimisation in different hospitals.

The most important limitation is the low number of patients, implying a risk for type 2 errors (failing to reject a null hypothesis that is actually false). For example, the true proportion of injuries missed with the selective CT examination strategy could be higher than identified by us. Furthermore, any study of the justification of CT use requires registration of

the possible injuries suspected immediately before a CT examination strategy decision is reached, and the retrospective design precluded retrieval of such data. Power analysis with sample size calculation was not done, which is a limitation. The quality audit study design, with one year of data entry, connected to the first year of registration in the Norwegian trauma registry was the reason for the fixed sample size and the exclusion of a power analysis. In Paper 1, a recall bias risk is possible due to the thesis author's involvement in the 27 original CT examination reports and the 81 patients coded originally in the trauma registry by (IL), but we consider it unlikely that this has influenced the consensus validation result significantly. Finally, the recently introduced Berlin-definition of injury severity represents an improvement of the 2 x AIS > 2 method [27]. This new development was not validated when the present study was conducted[28].

11 Conclusions

In 2015, the trauma teams admitted 144 potentially severely injured patients at UNN, 36 transferred from local hospitals. Most were transported to the first hospital by air ambulance accompanied by physician. Median time from accident to first hospital admittance was almost two hours. Most patients were young males, exposed to vehicle accidents, not severely injured with normal vital parameters. Children and adults had comparable injury grades and number of interventions.

Concordance between the codes registered in the trauma registry and the reference standard was moderate, influencing individual patients' injury codes validity and ISS/NISS reliability. The aggregated median group ISS/NISS reliability was acceptable. Information in the electronic health record overlooked by coders was the dominating cause for non-registered codes, and discordant coding of head injuries and extremity fractures were the most common causes for discordant AIS codes.

The majority of the patients were examined with an ionizing radiation method. Most of the dose came from CT examinations and was delivered during the trauma admission as SWBCT examinations. The use of non-ionizing radiation methods was low without significant difference between children and adults. DLP for a SWBCT was above the Norwegian diagnostic reference level, but the effective dose similar to previous studies.

The high proportion of patients with no or only minor injuries detected in the SWBCT group, and the significantly lower use of CT among children, indicate that use of a selective

CT examination strategy in a higher proportion of the patients would have approximated the ICRP's justification level three, the individual dose limitation principle, better. Only patients fulfilling the high-energy trauma mechanism criterion for TTA showed significantly increased odds for undergoing a SWBCT among the variables in the adjusted regression analysis.

12 Future perspectives

Reducing potentially avoidable deaths is important. The case fatality rate includes two patient categories, unavoidable and avoidable deaths. The last category is important to identify and audit in order to improve trauma care. Mortality comparisons between hospitals and regions should distinguish between these two categories. Accordingly, a dichotomised variable separating unavoidable and avoidable death should be included in trauma registries. I recommend that a national group should be responsible for dichotomizing and auditing all dead patients included in the national trauma registry.

Use of RTS outcome score based on values registered at the accident site in all trauma registries and studies, would improve benchmarking across hospitals and adjustments for case-mix in studies of trauma patients admitted to hospitals. The annual comparisons made today on ISS/NISS and mortality rates registered in trauma registries is not reliable.

A multicentre injury code audit to verify if our finding of reliable aggregated population ISS and NISS from original trauma registry codes is important. It would be interesting in the same study to hypothesize and test on the individual patient level if an SI > 0.9 is associated with higher injury identification and if severe injury severity defined by ISS, NISS and the Berlin definition is associated with a higher proportion of discordant coding.

A cohort multicentre study of cancer incidence within 40 years, including potentially severely injured, but otherwise healthy young trauma patients would not be hampered by inclusion bias. Cancer incidence among long-term survivors (40 years) should be censored in groups examined with SWBCT, selective CT or No CT during the hospitalization, without and with lag periods of 2 and 5 years. Including all exposure to ionizing radiation done before, under and after the accident, added the yearly natural background radiation, might be a study that could identify if high CT exposure doses in young individuals induce increase in cancer. However, such a study is difficult to achieve.

A prospective study analysing the reasons used by the trauma team for their trauma CT examination strategy decisions, would be interesting. The set-up of such a study can be difficult to achieve without an interview approach. A more easy study to administrate would be to study the proportions of SWBCT, selective CT or No CT in a TTA population at UNN one year after introducing a teaching intervention based on the conclusions in my thesis, and to compare UNN to similar hospitals in Norway.

Finally, more focus in the ED, on the change in vital parameters from the accident site, SI, lactate, base excess and the symptom presentation, might facilitate the CT examination strategy decision. The most potent approach for accomplishing the ICRP justification level three principle is probably to make selective CT examinations in awake trauma patients. SWBCT examinations should be limited to patients presenting in the ED unconscious, with spinal injuries or with suspected injuries in all SWBCT body areas.

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14 Erratum

Paper III. On page 8 in the third paragraph the reference 34 refers to the paper Wurmb et al. Emerg Med J 2011;28: 300-4, the correct reference for this cite should be Wurmb et al. Am J Emerg Med. 2007;25:1057-63. In the thesis the correct reference is cited in appropriate places.

Paper I

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RESEARCH ARTICLE Open Access

Injury coding in a national trauma registry: a one-year validation audit in a level 1 trauma centre

Anna Bågenholm[1,2*], Ina Lundberg[3], Bjørn Straume[4,5], Rune Sundset[2,6], Kristian Bartnes[2,3], Tor Ingebrigtsen[2,7] and Trond Dehli[2,8]

Abstract

Background: Hospitals must improve patient safety and quality continuously. Clinical quality registries can drive such improvement. Trauma registries code injuries according to the Abbreviated Injury Scale (AIS) and benchmark outcomes based on the Injury Severity Score (ISS) and New ISS (NISS). The primary aim of this study was to validate the injury codes and severities registered in a national trauma registry. Secondarily, we aimed to examine causes for missing and discordant codes, to guide improvement of registry data quality.

Methods: We conducted an audit and established an expert coder group injury reference standard for patients met with trauma team activation in 2015 in a Level 1 trauma centre. Injuries were coded according to the AIS. The audit included review of all data in the electronic health records (EHR), and new interpretation of all images in the picture archiving system. Validated injury codes were compared with the codes registered in the registry. The expert coder group's interpretations of reasons for discrepancies were categorised and registered. Inter-rater agreement between registry data and the reference standard was tested with Bland–Altman analysis.

Results: We validated injury data from 144 patients (male sex 79.2%) with median age 31 (inter quartile range 19–49) years. The total number of registered AIS codes was 582 in the registry and 766 in the reference standard. All injuries were concordantly coded in 62 (43.1%) patients. Most non-registered codes ($n = 166$ in 71 (49.3%) patients) were AIS 1, and information in the EHR overlooked by registrars was the dominating cause. Discordant coding of head injuries and extremity fractures were the most common causes for 157 discordant AIS codes in 74 (51.4%) patients. Median ISS (9) and NISS (12) for the total population did not differ between the registry and the reference standard.

Conclusions: Concordance between the codes registered in the trauma registry and the reference standard was moderate, influencing individual patients' injury codes validity and ISS/NISS reliability. Nevertheless, aggregated median group ISS/NISS reliability was acceptable.

Keywords: Trauma registry, Validation, Patient record, Audit, Abbreviated injury scale, Injury scoring

Background

Faced with increasing pressure to reduce costs, hospitals must minimize waste through continuous improvement of patient safety and quality. Timely provision of process and outcome data from clinical quality registries to clinicians has been shown to drive such improvements in healthcare [1–4]. In 1976, the American College of Surgeons Committee on Trauma introduced the trauma registry as part of the trauma system [5]. Injury description and grading of injury severity are systematically registered [6–8]. This provides benchmarking data for comparisons of quality of care between patients and institutions, and facilitates continuous improvement [1, 9]. Norway introduced a national trauma system in 2007 [10] and the national trauma registry (NTR) was established in 2015 [11].

* Correspondence: anna.bagenholm@unn.no
[1]Department of Radiology, University Hospital of North Norway, Sykehusveien 38 -, PO box 103, N-9038 Tromsø, Norway
[2]Department of Clinical Medicine, Faculty of Health Science, UiT-The Artic University of Norway, Tromsø, Norway
Full list of author information is available at the end of the article

Many studies on validation of the Abbreviated Injury Scale (AIS) injury coding have been published [12–14]. They typically report inter-rater variability between trauma registry coders based on samples where several AIS-coders code the same patient, and generally show low inter-rater agreement between coders for actual AIS codes. Such studies do not, however, validate the injury data quality in the trauma registry itself. Few report validation of injury codes in trauma registries. Horton et al. [15] compared the initial registration in a registry with a second blinded re-registration by an AIS certified audit coder, and found satisfactory inter-rater agreements on the number of AIS codes. A more comprehensive approach is to establish a reference standard by using an expert coder group to review all information in the patient record and recode all injuries. To our knowledge, this has not been done for trauma registries. The University Hospital of North Norway Tromsø campus (UNN) is the Level 1 trauma centre for northern Norway and started registration in the NTR 01.01.2015. This is a validation study of the injury coding quality during the first year. We compare a consensus coding by an expert coder group to the routine NTR data entry. The primary aim was to validate the injury codes and severities registered in the trauma registry. Secondarily, we aimed to examine causes for missing and discordant codes, to guide improvement of registry data quality.

Methods

Study type, population and region

This is a clinical audit. An expert coder group validated injury codes and compared them to the routine injury code input in a trauma registry. Trauma registry coders continuously survey lists of emergency admissions and prospectively register all trauma patients fulfilling predefined criteria in the NTR. In this study, we included all patients admitted with trauma team activation (TTA) in 2015, registered in NTR at UNN. Criteria for TTA include vital functions, extent and mechanism of injury, and have been described previously [16]. The UNN trauma centre covers a population of 486,792 spread over a rural area of 257,000 km^2 (1.9 inhabitants per km^2) [17, 18]. It supports ten referring hospitals. Study data entry continued until death, or discharge home or to rehabilitation.

Injury coding

The registry codes injuries according to the AIS code manual [6, 19]. The AIS classifies injuries with a six-digit anatomical code, and adds a severity score ranked from one (injuries minimal in severity, such as subcutaneous hematomas) to six (injuries maximal in severity, currently untreatable). Only certified AIS coders have access to the manual [6]. Coders manually assign all injuries an AIS code, and the registry automatically calculates the Injury Severity Score (ISS) and the New ISS (NISS). Baker et al. introduced the ISS in 1974 after showing that summarizing the square of the highest AIS score in three of six body regions shows a good correlation to survival [7]. Patients with an ISS > 15 are defined as severely injured. The same group introduced the NISS in 1997 [8]. The NISS is the summation of the square of the three highest AIS score injuries, regardless of body region. NISS is easier to calculate and predicts survival better than the ISS [8]. Three coders certified in the AIS 2005 Update 2008 manual [6] did the injury coding according to the AIS convention. They had 10% coding employments and no clinical role. Coding was performed after patient death or hospital discharge. They were two medical students with two (IL) and 3 years coding experience, and one nurse with 6 month coding experience. They used pre- and intra-hospital electronic health records (EHR) including the radiology information system (RIS) to identify and code all injuries.

Reference standard

The expert group consisted of the first (AB) and second (IL) authors. AB is a AIS certified coder and a senior radiologist with 10 years of experience in trauma care. IL is a AIS certified junior medical doctor with experience as trauma coder since 2014. AB made a blinded new AIS injury assessment of all study patients between February 29 and July 31 2016. This included review of the EHR, and new interpretations of all diagnostic imaging in the picture archiving and communication system (PACS). The new interpretation was compared to the RIS report to identify all codes missing in the original registry coding due to incomplete radiology reports. Injury codes were set using the AIS 2005 Update 2008 manual. ISS and NISS were calculated manually, and all study data were registered in a Microsoft Excel spreadsheet. Next, IL retrieved AIS codes, ISS, and NISS from the NTR, and the data were entered into the same spreadsheet during the autumn of 2016. Finally, AB and IL made an expert coder group consensus coding on all patients during January through Mars 2017, and thereby established a reference standard. In cases of complete agreement between AIS codes, this was verified. In cases of discrepancies between a registry code and the new assessed AIS code, a consensus code was set. This included a second reassessment of diagnostic imaging in cases of discrepancies between the new radiological interpretations and the RIS reports. When appropriate, the expert coder group discussed cases with other senior radiologists or other specialists. When in doubt about a correct understanding of the AIS coding manual, they consulted a senior AIS code instructor at the largest trauma centre in Norway. Causes for missing and discordant AIS codes in the registry were categorised as

related to the patient record, radiology report, AIS manual or as other causes. Discordant AIS codes were categorised as either coding of a non-existent injury, or discordant AIS code with concordant or discordant severity grade. To assess the overall completeness of AIS coding per patient, we divided the concordant number of AIS codes in the registry by the total number of reference standard codes. According to the AIS manual, all injuries, including subcutaneous hematomas, shall be coded separately, even when multiple AIS severity 1-codes do not influence ISS. We report overall completeness with and without correction for more than one missing multiple AIS 1-code [14].

Statistics

Statistical analysis was performed with IBM SPSS Statistics 23. Descriptive and frequency statistics were used and normality tested with histograms, Kolmogorov–Smirnov and Shapiro–Wilk tests. Abnormally distributed data are presented as medians with 25 and 75 inter-quartile range (IQR).

A Bland–Altman analysis was used to report agreement for ISS and NISS in the registry compared to the reference standard. We plotted the mean between the paired measured ISS in a Bland–Altman plot, calculated for each patient by summarizing the ISS in the trauma registry and the reference standard, and dividing by two on the X-axis. The Y-axis shows the difference between the paired ISS, calculated as ISS in the trauma registry subtracted the reference standard ISS. With ideal agreement the difference equals zero [20, 21]. NISS was plotted in the same way. This method requires normality distribution of the difference variable [22]. In the regression analysis, p values < 0.05 were considered significant.

Results

Descriptive analysis of the population

Table 1 shows characteristics of the 144 patients in the study population. The ten patients, who died within 30 days after trauma, had an ISS range 22–45.

Table 1 Characteristics of the trauma population ($n = 144$)

Characteristics	
Male sex, n (%)	114 (79.2)
Age, years in median (IQR)	31 (19–49)
Age groups, n (%)	
0–16	26 (18.1)
> 16	118 (81.9)
Trauma mechanism	
Penetrating traumas, n (%)	5 (3.5)
Blunt, n (%)	139 (96.5)
Cause of incident, n (%)	
Road traffic	63 (45.3)
Snowmobile	11 (7.9)
Fall	31 (22.3)
Hit by blunt object	13 (9.3)
Explosion/fire	8 (5.7)
Avalanches and/or hypothermia	8 (5.8)
Other causes	5 (3.6)
Transferred from other hospitals, n (%)	36 (25.0)
Length of stay, median days (IQR)	4 (1.2–11.5)
30-day mortality, n (%)	10 (6.9)
Head injuries	6 (4.2)
Other causes	4 (2.8)

IQR Inter-quartile range.

Quality of registered AIS codes

The total number of registered AIS codes in the 144 patients was 582 in the registry and 766 in the reference standard.

The total number of missing and discordant AIS codes in the registry was 369. In 17 patients, we found 46 missing codes, all identical with another AIS code recorded in the same patient. The data retrieval from the NTR returned only one of these identical codes. After correction for this error, a total of 323 missing and discordant codes remained for analysis. Table 2 shows the results from division of the concordant number of AIS codes in the registry by the total number in the reference standard per patient. More than 75% agreement was reached for 47.2% of the patients. Subtracting the minor external lacking AIS 1 injuries not affecting ISS ($n = 94$) increased the proportion to 62.5%.

Missing AIS codes

In total, 212 missing AIS codes were found in 75 (52.1%) of the 144 patients (range 1–14 missing codes per patient). After correcting for the 46 codes not included in data retrieval from the NTR, 166 missing codes in 71(49.3%) patients (range 1–10 missing codes per patient) remained for analysis.

Table 3 shows the causes for the 166 missing codes. We analysed on the level of each patient and registered the missing codes into the cause-categories. Each cause was counted only one time for each patient. Information in the EHR overlooked by the coders was the dominating cause. Most overlooked injuries were minor (AIS 1). Examples are hematomas only described in nurse reports or injuries identified on radiology examinations described in the RIS only. Also, three injuries described as suspected in the RIS,

Table 2 Quality of concordant AIS codes in UNN Trauma registry

Concordant number of AIS codes in UNN trauma registry divided with the total number of expert group codes per patient	Original AIS data output from the Norwegian national trauma registry		Original data output adjusted for minor external missing injuries not affecting injury severity	
	Frequency n (%)	Cumulative %	Frequency n (%)	Cumulative %
100% concordant	47 (32.6)	32.6	62 (43.1)	43.1
99–75% concordant	21 (14.6)	47.2	28 (19.4)	62.5
74–50% concordant	43 (29.9)	77.1	35 (24.3)	86.8
49–25% concordant	17 (11.8)	88.9	10 (6.9)	93.8
24–0% concordant	16 (11.1)	100.0	9 (6.3)	100.0

AIS Abbreviated Injury Scale, *UNN* University Hospital of North Norway

Table 3 Causes for missing and discordant AIS codes in the UNN trauma registry 2015

	Missing AIS code		Discordant AIS code			
	AIS ≥ 2 [b] injury grades	AIS < 2 [b] injury grades	Injury not existing	AIS [b] injury grade discordant	AIS [b] injury grade concordant	
Decided audit cause [a]						Total
Related to the patient record						
Trauma registrar overlooked information	22	42				64
Trauma registrar misinterpreted information [c]	6	3	9	0	0	18
Trauma registrar chose incorrect AIS code [d]			0	26	22	48
Trauma registrar got information difficult to interpret			0	2	1	3
Trauma registrar used radiological DAI criteria [e]			0	2	0	2
Trauma registrar used NFS code instead of a more specified code			0	2	14	16
Trauma registrar coded injury but other AIS code chosen included the injury			6	0	0	6
Trauma registrar double coded injury by mistake			2	0	0	2
Related to the radiology report						
Injuries not described	4	8				12
Injuries inaccurate described	3	0	7	8	12	30
Related to the AIS manual						
AIS guide lacks code for cardiac arrest due to hypothermia			2	0	0	2
Related to other reasons						
Physician described fracture not existing, radiology report correct			1	0	0	1

AIS Abbreviated Injury Scale, *UNN* University Hospital of North Norway, *DAI* diffuse axonal injury, *NFS* Not further specified, [a] Analysed on the level of each patient, each cause was counted only one time for each patient, [b] AIS Injury grade severity ranking 1–6, [c] Misinterpreted information corresponds to patient record information understood incorrectly, [d] Correct understanding of information but an incorrectly chosen code, for example, a mix of intracerebral contusion bleeding AIS code with the brain contusion code, [e] DAI criteria for radiological description do not fully comply with the DAI criteria in the AIS code manual

not coded in the registry in accordance with the AIS manual, were concluded to be injuries in the reference standard.

Discordant AIS codes

Table 3 also shows the 157 discordant AIS codes registered in 74 (51.4%) of the 144 patients (range 1–9 discordant codes per patient). We analysed on the level of each patient and registered the discordant codes into the cause-categories. Each cause was counted only one time for each patient. Discordant coding and injury grading of existing injuries were most common, followed by use of an unspecified code for injuries that could have been coded with a specific code.

Table 4 shows an overview of the 157 discordantly coded injuries. Discordant coding of head injuries and extremity fractures were most frequent.

Agreement between ISS/NISS

For the total population, ISS and NISS were positively skewed towards less severe injuries (mode ISS 1) both in the registry and the reference standard. Median ISS score was 9 in both data sets (range 0–75 and IQR 2–17 in the registry, range 0–59 and IQR 2–22 in the reference standard). Median NISS score was 12 in both data sets (range 0–75 and IQR 2–27 in the registry, range 0–66 and IQR 3–27 in the reference standard). After exclusion of the eight uninjured patients (ISS score 0), median ISS score was 9 (range 1–75, IQR 4–19) in the registry. After exclusion of the six patients with ISS 0 in the reference standard median ISS was 10 (range 1–59, IQR 4–22). Median NISS score remained 12 in both data sets (range 1–75, IQR 4–27 in the registry and range 1–66, IQR 4–27 in the reference standard) after exclusion of the uninjured patients.

In the reference standard, 52 (36.1%) patients had an ISS > 15, and 64 (44.4%) a NISS > 15. Fifty-two (36.1%) had a change in ISS from the registry to the reference standard. Six (4.2%) with ISS ≤15 in the registry got an ISS > 15, and two (1.4%) with ISS > 15 in the registry got an ISS ≤15. Fifty-eight incorrect AIS codes among 40 patients in the registry had a discordantly chosen injury grade. Thirty-eight had injuries which severity were graded to low. AIS 2 changed to 3 were most common (16 changes). Twenty patients had injuries which severity were graded

Table 4 Description of the 157 injuries with discordant AIS codes in the trauma registry

Type of injury	Discordant AIS code for a injury not existing	Discordant AIS code with discordant AIS injury grade [a]	Discordant AIS code with concordant AIS injury grade [a]	
Head/face/spine				Total
Spinal and cranial fracture	0	12	11	23
Face fracture	0	2	4	6
Intracranial parenchymal haemorrhage	0	6	9	15
Intracranial subarachnoid haemorrhage	0	5	0	5
Intracranial epi/subdural haemorrhage	0	1	1	2
Diffuse axonal injury	0	3	1	4
Cerebral concussion	0	3	0	3
Thorax				
Lung contusion	2	2	0	4
Pneumothorax	0	6	0	6
Costa fracture	0	6	3	9
Abdominal				
Thoracoabdominal injury	0	5	0	5
Extremity				
Fracture/joint dislocation	14	3	33	50
External and other reasons				
External (hematoma, laceration, burn injury)	2	4	9	15
Hypothermia	1	0	0	1
Other reason	9	0	0	9
Total	28	58	71	157

AIS Abbreviated Injury Scale, [a] AIS Injury grade severity ranking 1–6.

to high. AIS 3 changed to 2 was most common (6 changes).

Histograms (not presented) of differences between the trauma registry and the reference standard ISS and NISS, approximated normal distribution. Figure 1 shows Bland–Altman scatter-plots of the mean (x-axis) between the paired measure of ISS (a) and NISS (b) in the trauma registry and the reference standard versus the difference between them (y-axis). The plots show no proportional bias. Regression analysis showed no significant differences neither for ISS ($p = 0.078$) or NISS ($p = 0.656$). The outlier in the plot represents one patient registered with an AIS 6 crush injury code, scoring the patient to ISS 75, while the reference standard set ISS to 22 due to the lack of diagnostics, autopsy or surgery, according to the AIS manual.

Discussion

The main finding in this validation study is that complete coding in a trauma registry is challenging to achieve, even with AIS certified and trained coders. Full concordance between the original coding in the trauma registry and the reference standard occurred in 43.1% of the patients. Most of the observed disagreement was at the lower injury severity. The most common causes for missing or discordant codes were that coders overlooked information in the EHR, or assigned discordant AIS codes. This caused a discordant ISS in 53 (36.8%) patients. It did not, however, influence median ISS or NISS for the total population in the registry, as the median scores were the same for ISS (9) and NISS (12) in the registry and the reference standard.

AIS coding quality

Horton et al. [15] studied a randomly selected sample of 450 patients from the Dutch national trauma registry. They compared the registered number of AIS codes with the number in a second, blinded re-registration by an experienced audit coder, and found agreement in 63% of cases. The causes for disagreement and the frequency of discordant codes were not studied. Ringdal et al. [14] studied inter-rater agreement in a representative group of Norwegian trauma registry coders, and compared with a reference standard set by a panel of AIS coding experts. Fifty patient cases were selected from the registry at Oslo University Hospital. Overall, 61.5% of the AIS codes assigned by the coders agreed with the reference standard, but comparison with the codes originally entered into the registry was not done. Neale et al. [13] also studied inter-rater agreement between registry coders. They randomly selected 120 cases from the Queensland trauma registry for re-coding, and found that on average, 39% of the codes used by any two coders for each of the injured persons were identical. Again, comparison with the original registry data was not done. Summarised, the inter-rater agreement between coders, and between coders and reference standards generally is low.

To our knowledge, the present study is the first to compare all injury codes in a registry population with a

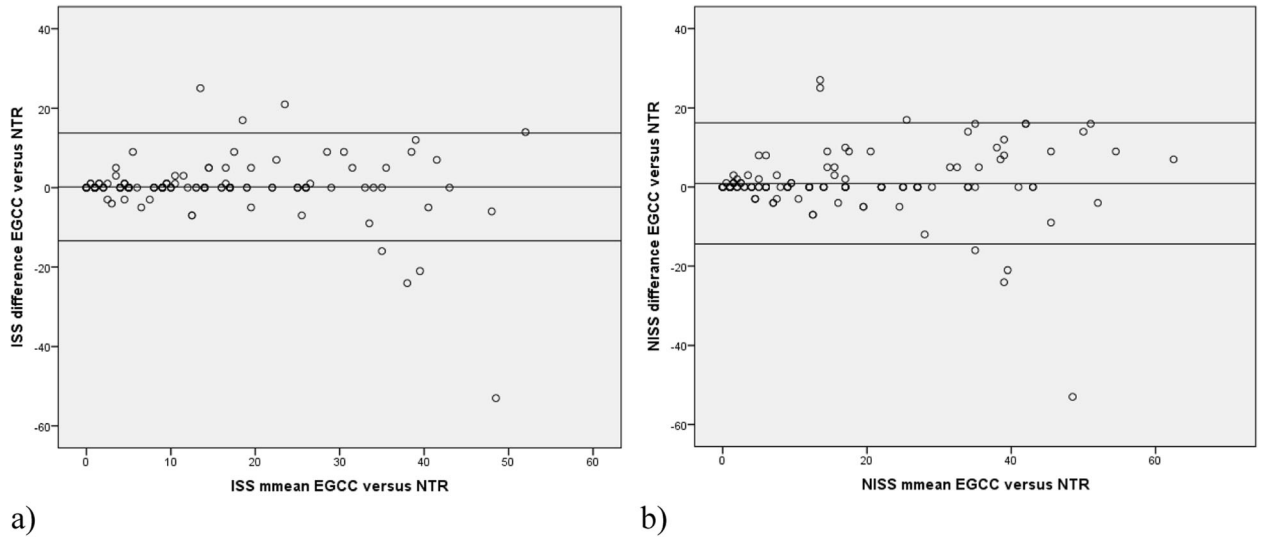

Fig. 1 Bland–Altman plot for ISS and NISS in NTR versus the reference standard. Bland–Altman ISS and NISS plot for 144 patients quantify agreement in the national trauma registry (NTR) compared to the expert group consensus coding (EGCC). The X -axis presents the mean between the paired measured (**a**) ISS and (**b**) NISS in the EGCC and the NTR. Y-axis presents the difference between the paired a) ISS b) NISS in the EGCC versus the NTR. Mean difference ISS 0.194, 95% CI (± 2SD of the mean difference) upper limit + 13.8 and lower limit − 13.4. Mean difference NISS 0.924, 95% CI (± 2SD of the mean difference) upper limit + 16.2, and lower limit–14.4

reference standard. Agreement between registry AIS codes and the reference standard was moderate. Accordingly, validation of data quality is necessary when individual level registry injury codes are used for quality improvement or research purposes [2].

The most common causes for missing or discordant AIS codes were information in the EHR overlooked by the coders. We consider incomplete summaries of the available information in physicians' notes as the most likely underlying root cause. This could be more common among trauma patients as many clinicians from different specialties often share responsibility. In comparison, discordant radiological descriptions were a minor problem. Routine audit by trauma responsible senior clinicians could improve injury coding quality, but is resource demanding [23]. Instead, we have trained and certified trauma care physicians in AIS coding to improve their skills in describing injuries in the EHR. We anticipate this will facilitate communications between physicians and coders, and thereby improve the coding. Further, we now suggest coding review is included in our monthly trauma audit.

Two coding problems related to the AIS code manual were identified by the expert group. First, radiological criteria routinely used to diagnose diffuse axonal injuries and brain contusion do not fully comply with the AIS manual. This caused incorrect coding, and coder education and better code instructions could improve this. Second, two patients with hypothermic cardiac arrest were incorrectly coded as asphyxia cardiac arrest. Hilmo et al. [24] reported only 9 (26%) survivors among 34 patients with hypothermic cardiac arrest. This suggest an ISS of 50 as more accurate than the score of 25 [7] this patient group receives following the present AIS manual, lacking a hypothermic cardiac arrest code. We suggest that a specific code for hypothermic cardiac arrest should be added to the AIS code manual.

Our study revealed a software error causing underreporting of injuries in data retrieved from the NTR. The error has been corrected by the registry administration. Unnoticed registry code retrieval problems may exist in other registries as well. This highlights the importance of early validation studies of new quality registries [25, 26].

ISS and NISS scores

In some patients, different AIS codes in the trauma registry and the reference standard did not influence the ISS, but discordant AIS coding can influence prediction of mortality risk. This is a known problem with ISS and NISS. Different AIS triplets with the same ISS have different mortality [27]. Blunt and penetrating traumas with the same AIS values also show different mortality [28].

Interestingly, suboptimal AIS code quality in the registry did not influence population median ISS and NISS. This is in accordance with previous studies of AIS coding inter-rater variability and ISS/NISS [13–15, 23]. Accordingly, comparison of median ISS and NISS between institutions might be acceptable without correction of AIS codes in the trauma registry, allowing benchmarking across institutions. We advocate validation of this finding in a multicentre trauma registry study, as confirmation of this finding would improve trust in such benchmarking across institutions using routine trauma registry AIS codes.

Limitations and strengths

Our study sample is relatively small, because the study was done as a quality audit of our data entry during the first year of registration in the NTR. Power analysis with sample size calculation was not done. This is a limitation. Results may not be generalizable, as different registries have different patient profiles and different injury pattern. Also, 57 patients registered in the trauma registry without TTA were not included. This entails a risk for selection bias, but we find it unlikely that inclusion of these less severely injured patients would have changed the impression of our overall injury coding quality. Further, one expert coder (AB) countersigned 27 trauma CT examination reports written by residents. The other expert coder (IL) participated in the original data registration in the registry by coding 81 (56%) of the patients. Thus, a risk for recall bias during establishment of the reference standard is present, but we consider it unlikely that this has influenced the results significantly. A bias caused by propensity to miscode particular injuries could also exist. However, a sensitivity analysis (not presented) in which we compare the analysis presented in Table 2 stratified by coders showed no such tendency. Further, in case of discrepancy, a risk for bias towards systematically weighting one of the expert coders more than the other could exist. This was counteracted by consulting other specialists in most cases of disagreement.

The major strength, compared to previous studies, is the rigorous validation through establishment of a reference standard for comparison with registry codes.

Conclusions

Concordance between the codes registered in the trauma registry and the reference standard was moderate, influencing individual patients' injury codes validity and ISS/NISS reliability. Nevertheless, aggregated median group ISS/NISS reliability was acceptable.

Abbreviations
AIS: Abbreviated Injury Scale; EHR: Electronic health records; IQR: Interquartile range; ISS: Injury Severity Score; NISS: New Injury Severity Score; NTR: National Trauma Register; RIS: Radiology Information SystemPACSPicture Archiving and Communication System; TTA: Trauma team activation; UNN: University Hospital of North Norway

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Authors' contributions
AB provided literature search and study design. AB and IL participated in data collection, data analysis, data interpretation and writing. AB, IL, BS, RS, KB, TD, TI participated in data interpretation and drafting of the article. All authors participated in the critical revision of the article and have read and approved the final manuscript.

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Availability of data and materials
Some parts of the data that supports the findings of this study are available from the corresponding author upon request, but most of the data are due to the form of a clinical audit not available. Important data are included in the article.

Ethics approval and consent to participate
The Regional Medical Ethic Committee defined the study as a quality control project (case number 2014/1883), and therefore the data protection officer approved analysis of anonymised data (case number 0446) without approved consent from the patients.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

Author details
[1]Department of Radiology, University Hospital of North Norway, Sykehusveien 38 -, PO box 103, N-9038 Tromsø, Norway. [2]Department of Clinical Medicine, Faculty of Health Science, UiT-The Artic University of Norway, Tromsø, Norway. [3]Division of Cardiothoracic and Respiratory Medicine, University Hospital of North Norway, Tromsø, Norway. [4]Centre for quality improvement and development, University Hospital of North Norway, Tromsø, Norway. [5]Department of Community Medicine, Faculty of Health Science, UiT-The Artic University of Norway, Tromsø, Norway. [6]PET imaging Centre, University Hospital of North Norway, Tromsø, Norway. [7]Department of Neurosurgery, ENT and Ophthalmology, University Hospital of North Norway, Tromsø, Norway. [8]Department of Gastrointestinal Surgery, University Hospital of North Norway, Tromsø, Norway.

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Publisher's Note

Paper II

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DIAGNOSTIC IMAGING AND IONIZING RADIATION EXPOSURE IN A LEVEL 1 TRAUMA CENTRE POPULATION MET WITH TRAUMA TEAM ACTIVATION: A ONE-YEAR PATIENT RECORD AUDIT

Anna Bågenholm[1,2,*], Pål Løvhaugen[3], Rune Sundset[2,3] and Tor Ingebrigtsen[2,4]
[1]Department of Radiology, University Hospital of North Norway, Tromsø N-9038, Norway
[2]Department of Clinical Medicine, Faculty of Health Science, UiT—The Arctic University of Norway, Tromsø N-9037, Norway
[3]PET-Imaging Center, University Hospital of North Norway, Tromsø N-9038, Norway
[4]Department of Neurosurgery, ENT and Ophthalmology, University Hospital of North Norway, Tromsø N-9038, Norway

*Corresponding author: Anna.Bagenholm@unn.no

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This audit describes ionizing and non-ionizing diagnostic imaging at a regional trauma centre. All 144 patients (males 79.2%, median age 31 years) met with trauma team activation from 1 January 2015 to 31 December 2015 were included. We used data from electronic health records to identify all diagnostic imaging and report radiation exposure as dose area product (DAP) for conventional radiography (X-ray) and dose length product (DLP) and effective dose for CT. During hospitalization, 134 (93.1%) underwent X-ray, 122 (84.7%) CT, 92 (63.9%) focused assessment with sonography for trauma (FAST), 14 (9.7%) ultrasound (FAST excluded) and 32 (22.2%) magnetic resonance imaging. One hundred and sixteen (80.5%) underwent CT examinations during trauma admissions, and 73 of 144 (50.7%) standardized whole body CT (SWBCT). DAP values were below national reference levels. Median DLP and effective dose were 2396 mGycm and 20.42 mSv for all CT examinations, and 2461 mGycm (national diagnostic reference level 2400) and 22.29 mSv for a SWBCT.

INTRODUCTION

The introduction of conventional radiography (X-ray) in 1895 and computer tomography (CT) in 1971 has increased the burden of manmade ionizing radiation to humans[1]. In Norway, radiation from medical imaging adds an extra 1.1 mSv to the natural background of 4.1 mSv per year[2]. The use is considered acceptable if the expected health gain from an examination exceeds the possible harms[3, 4]. The risk for harm, especially cancer, after use of X-ray and CT, is under debate[5].

Improved availability and recommendations for CT use in trauma patients[6–8] contribute to the increased radiation exposure[9–11]. During the last decade, radiologists and surgeons have debated the use of standardized whole body CT (SWBCT) in trauma patients[12]. Evidence-based guidelines for use of CT in severely injured trauma patients are not available. Some retrospective register studies advocate immediate SWBCT[6, 13], while one prospective study[14] and some reviews[15–17] argue that mortality is not reduced with this method. The majority of patients with severe trauma are between 20 and 60 years[6, 9, 13, 14, 18, 19]. For this patient group, a high ionizing radiation dose can be more harmful than the injuries, if injuries are not severe or life threatening. Optimization of patient dose is therefore important[3, 4]. Age, body size, irradiated body area, machine protocol parameters and use of non-ionizing methods influence the dose the patient receives[2, 20–22].

Numerous studies report radiation exposure risk for subgroups of trauma populations, admissions and/or hospitalizations[9–11, 18, 19, 23, 24]. To our knowledge, no previous study describes all ionizing and non-ionizing diagnostic imaging and the total dose delivered for trauma patients in all age groups, from the accident until the start of rehabilitation. Therefore, the aims of this study were to describe all diagnostic imaging and report the dose delivered during trauma-associated hospitalization at a Level 1 trauma centre.

MATERIAL AND METHODS

Study type and inclusion criteria

This is a retrospective clinical quality audit focused on diagnostic imaging[25, 26]. We included all patients admitted to a Level 1 trauma centre with trauma team activation (TTA) from 1 January 2015 to 31 December 2015. There were no exclusion criteria.

Study region

This Norwegian health region is a rural area (257 450 km^2, 1.9 inhabitants per km^2)[27]. The regional Level 1 trauma centre, as defined by the Norwegian trauma system, admits approximately 150 TTA's per year and supports 10 referring hospitals. The region has one common digital picture archiving and communication system (PACS). Thus, all diagnostic examinations are digitally available at the other hospitals immediately after an examination.

The region has predefined criteria for TTA[28] and follows the Advance Trauma Life Support system[29]. Decision on the use of diagnostic imaging, such as choice of modalities, number of examinations and timing is on discretion of the trauma surgeon in charge. The technical protocol for SWBCT in adults (>16 years) is standardized. Patients may undergo diagnostic imaging during four phases: pre-hospital (Phase 1); trauma admission 1, at a referring hospital or at the trauma centre for patients transported directly to the Level 1 trauma centre (Phase 2); trauma admission 2 for referred patients (Phase 3) and the subsequent hospital stay following the trauma admissions (Phase 4). We refer to all phases as the total hospitalization.

Data collection

Trauma registrars continuously survey emergency admissions and prospectively register all trauma patients fulfilling predefined criteria in the national trauma registry. In the present study, we included all patients registered with a TTA in 2015, registered in the national trauma registry. The first author thereafter manually retrieved and registered all study data from pre- and intra-hospital electronic health records, including the radiology information system and the radiology examinations (and logs) in the PACS. Injury severity was reported as injury severity score (ISS)[30] and new ISS[31]. The first author and another AIS certified physician employed at UNN as trauma registry coder scored the injuries in a consensus process[32]. Study data entry continued until death, discharge home or to rehabilitation.

The Regional Medical Ethic Committee defined the study as quality control (case number 2014/1883), and therefore, the data protection officer approved analysis of anonymized data (case number 0446) without approved consent from the patients.

Ionizing radiation units

We registered delivered dose from X-ray examinations as the dose area product (DAP) in Gray-centimetre squared. Dose from CT was registered as the dose length product (DLP) in milliGray centimetre. DLP is the volume CT dose index ($CTDI_{vol}$) in mGy multiplied with the scan length in cm. The $CTDI_{vol}$ expresses the weighted average dose in an infinitesimal slice in a polymethyl methacrylate phantom.

The estimated long time risk (for cancer) is assumed to be associated with the delivered dose. This risk is assessed by estimating the effective dose in mSv. We estimated the effective dose with a computer software from the National Cancer Institute (NCI) dosimetry system for CT (NCICT)[33]. This software estimates the effective dose based on input of the patients age group, gender and exact scan protocol parameters retrieved from the PACS digital imaging and communications in medicine (DICOM) scan log archive. We adjusted the scan length to match the patient CT scan length by interpreting the actual scan length in PACS. For each scan, NCICT estimates the organ doses for all different organs in mGy and the effective dose to the patient in mSv. The risk weighting factors in the software consider age group and gender based on the factors published in the International commission on radiological protection's Publication 103. Effective doses from all scans in one examination were added to find the total effective dose of that examination.

For comparison of the SWBCT protocol in the three CT machines (Siemens Somatom Definition Flash) at the trauma centre, the delivered dose and effective dose estimates were compared by scanning a whole body CT phantom PBU-60 Kyoto Kagaku[34] and estimating with NCICT. The phantom was scanned according to protocol, with arms fixed on a pillow on the abdomen, as in patients incapable of lifting their arms above the head. The same scan positions and scan lengths were used in the three similar machines. The total DLPs for the SWBCT protocol were 1646, 1630 and 1647 mGycm, respectively. We estimated the total effective dose to the phantom to 11.21, 11.04 and 11.70 mSv, respectively (Appendix 1).

X-ray examination registrations

We registered the number of X-ray images per anatomical part of the body per patient and the corresponding DAP per image as filed in the PACS DICOM archive. Before every exposure, a specific X-ray protocol adjusted to the patient's age, size and diagnostic purpose was chosen by the radiographer. We registered the DAP calculated by the X-ray machine for each specific image. The total DAP during trauma admissions and total hospitalization was calculated as continuous variables for each patient. The total DAP during the total hospitalization was also calculated per body part (the upper extremity including the clavicle, the chest/abdomen including the vertebral column, and the lower extremity including the pelvis). A retake

was defined as an anatomical body part examined more than one time.

CT examination registrations

We registered the number of CT scans per body part (caput, neck, chest, abdomen, pelvis and extremities) scanned per patient, with corresponding DLP per scan (abdomen and pelvis reported as one category) as filed in the PACS DICOM archive. Before every CT scan, a specific CT protocol adjusted to the patient's age, size and diagnostic purpose was chosen by the radiographer. We registered the DLP calculated by the CT machine for each specific scan. Effective dose was estimated for each scan using NCICT as described above. We calculated delivered DLP per patient into four continuous variables: SWBCT DLP dose in trauma admissions, total CT DLP in trauma admissions, DLP for the total hospitalization and DLP per body part for the total hospitalization (SWBCT examination split into body part scans). A complement CT scan was defined as a CT scan during the subsequent hospital stay for a body part not examined during trauma admissions and a duplicated CT scan as a body part scanned more than one time.

The SWBCT protocol includes caput scan without intravenous contrast, neck scan without intravenous contrast, chest scan with intravenous contrast in the arterial phase (including the spleen) and abdomen/pelvis scan with intravenous contrast in the portal venous phase. Shoulders and hips are often included in the chest and pelvis scan. All other scans of extremities were registered as separate body part scans. A selective CT was defined to exclude one or more of the four SWBCT body scans. On the trauma surgeon's discretion, duplicate CT scans of one or more body parts during one examination could be ordered. For example, an examination of a complicated neck fracture justified an extra arterial contrast phase of the neck during the chest scan.

Non-ionizing diagnostic exams: Ultrasound and MRI

Focused assessment with sonography for trauma (FAST)[35] is included in the ATLS manual as a method for identification of free fluid in the pericardial and peritoneal cavities. The extended FAST (EFAST) also includes examination of the pleural cavities[36]. Pre-hospital FAST/EFAST was gradually introduced in the trauma centre helicopter emergency medical service during 2015. We registered the number of FAST and EFAST examinations per patient performed pre-hospital and during trauma admissions. We also registered the sum of all ultrasound examinations for each patient (excluding FAST/EFAST) during the subsequent hospital stay. Use of intravenous ultrasound contrast examinations, pleural ultrasound and thoracentesis (ultrasound guided) were registered separately.

At the trauma centre, magnetic resonance imaging (MRI) examination is not in routine use during trauma admissions. We registered the number of MRI examinations per patient during the subsequent hospital stay, in total and categorized by body parts.

Statistics

We used IBM SPSS 24 for data analysis. Normality was tested with Kolmogorov-Smirnov and Shapiro-Wilk tests and distributions assessed with histograms and Q–Q plots. We tested differences in category data between children and adults with chi-square statistics or Fisher's exact test (when $n < 5$). Values of $p < 0.05$ were considered statistically significant. We report medians with lower and upper quartiles (Q1, Q3) for non-normally distributed data. We report the number of X-ray images and CT scans with missing DAP and DLP values. We calculated DAP, DLP and effective dose values after exclusion of missing values.

RESULTS

Demographics

Table 1 displays characteristics for the 144 patients admitted with TTA in 2015. The patients were 26 children ≤16 years and 118 adults.

X-ray examinations

Table 2 displays the number of patients stratified by the number of X-ray images per body part and the number of images per anatomical body part for all 144 patients during the total hospitalization. In total, 134 (93.1%) underwent one or more X-ray examinations during the total hospitalization. X-ray of the chest and pelvis was most frequent. During trauma admission 1, 114 (79.2%) underwent chest and 95 (66.0%) pelvis X-ray. For the 36 patients in trauma admission 2, the corresponding numbers were 28 (77.8%) and 18 (50.0%). Thirteen (36.1%) underwent chest and seven (19.4%) pelvis X-ray in both trauma admissions. Other X-ray examinations were used in 31 (21.5%) during trauma admission 1, 7 (19.4%) during trauma admission 2 and 1 (2.8%) during both trauma admissions 1 and 2.

CT examinations

In total, 122 (84.7%) of the 144 patients underwent one or more CT examinations during the total hospitalization. The majority (116 (80.5%)) underwent these examinations during the trauma admissions. Table 3 displays the number of patients stratified by the number of CT scans per body part and the

Table 1. Characteristics of the trauma population (n = 144).

Characteristics	
Male sex, *n* (%)	114 (79.2)
Tourist, *n* (%)	28 (19.4)
Age, years in median (Q1, Q3)	31 (19, 49)
Age groups, *n* (%)	
<5	9 (6.3)
5–16	17 (11.8)
>16	118 (81.9)
Transport to first hospital by	
Ambulance helicopter, *n* (%)	80 (55.6)
Fixed wing air ambulance, *n* (%)	9 (6.2)
Road ambulance, *n* (%)	53 (36.8)
Private transportation, *n* (%)	2 (1.4)
Trauma mechanism	
Penetrating traumas, *n* (%)	5 (3.5)
Blunt, *n* (%)	139 (96.5)
Road traffic, *n* (%)	63 (45.3)
Snowmobile, *n* (%)	11 (7.9)
Falls, *n* (%)	31 (22.3)
Hit by blunt object, *n* (%)	13 (9.4)
Explosion/fire, *n* (%)	8 (5.7)
Avalanches and/or hypothermia, *n* (%)	8 (5.8)
Other causes, *n* (%)	5 (3.6)
Transferred from other hospitals, *n* (%)	36 (25.0)
ISS, (Q1, Q3, range)	9 (2, 22, 0–59)
ISS > 15, *n* (%)	52 (36.1)
NISS, (Q1, Q3, range)	12 (3, 27, 0–66)
NISS > 15, *n* (%)	64 (44.4)
Length of stay, median days (Q1, Q3)	4 (1.2, 11.5)
30-day mortality, *n* (%)	10 (6.9)

Q1: lower quartile; Q3: upper quartile; NISS: new injury severity score.

number of CT scans per body part for all 144 patients during the total hospitalization. Scans obtained during SWBCT examinations are split into body part scans and distributed accordingly in the table. Scans of the same body part in both the arterial and venous phases are counted as two scans. The patient with six abdomen and pelvis scans had an ISS of 43 and 34 full days of hospitalization.

In total during trauma admissions, 73 (50.7%) patients underwent SWBCT, 43 (29.9%) a selective CT, and 28 (19.4%) no CT examination. Eleven different selective CT combinations were registered. CT caput/neck was most frequent, followed by CT chest/abdomen/pelvis. Eleven (7.6%) patients underwent CT in both trauma admissions. In trauma admission 1, 11 underwent 10 SWBCT and one CT caput. In trauma admission 2, two underwent a duplicated SWBCT, and the other eight with previous SWBCT underwent selective CT. The patient with CT caput in trauma admission 1 underwent CT caput/neck and abdomen in trauma admission 2. Only six (21.4%) of 28 without CT during the trauma admissions received a complementary CT during the subsequent hospital stay.

Non-ionizing radiation examinations

Table 4 displays the non-ionizing radiation examinations used pre-hospital and during hospitalization. Among the 36 patients with two trauma admissions, nine (25.0%) underwent a FAST and one (2.8%) an EFAST re-examination in trauma admission 2.

There was no significant difference in use of MRI and ultrasound during the subsequent hospital stay between children and adults. Four (15.4%) children versus 28 (23.7%) adults (p = 0.442) underwent MRI, and 1 (3.8%) child versus 8 (6.8%) adults (p = 1.0) underwent ultrasound.

Ionizing radiation exposure

During trauma admission 1, 118 (81.9%) of 144 patients underwent X-ray examination. DAP values were missing for 10 images. Three patients had no DAP registered (five missing values). They were excluded in calculation of the median DAP value. One patient had a DAP registered for one of six images and was included despite five missing DAP values (Table 5).

Table 2. The number of patients stratified by the number of X-ray images per body part and the number of images per body part for 144 patients during the total hospitalization.

	Number of patients stratified by the number of images (0–28 images)																							Number of images per body part
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	…	20	21	…	28	Total	
Clavicle	139	1	3		1																			144	11
Shoulder	137		4	1		1	1																	144	22
Humerus	139		4	1																				144	11
Elbow/lower arm	130		5	4	2	1	1	1																144	48
Wrist	133	1	3	2	2	2							1											144	31
Hand	130		3	7		1	1			1			1											144	50
Chest	12	75	21	9	4	8	2	1	4	1	1	1	1		1	1		1		1				144	359
Neck	139	2	2		1																			144	10
Thoracic vertebral column	139	2	3																					144	8
Lumbar vertebral column	139		3	2																				144	12
Abdomen	139		3		1			1																144	17
Pelvis	39	86	14	2	2	1																		144	133
Hip	134	3	4		3																			144	23
Femur	130	2	3	2			1	1		1	3													144	66
Knee	128		8	1	2	2	1		1				1											144	63
Fibula/tibia	131		4	2	3	1	1	1															1	144	44
Ankle	134		2	2		2				1	1	1									1			144	71
Foot	136		1	5		1											1							144	38

X-ray: conventional radiographic examination.

Table 3. The number of patients stratified by the number of CT scans per body part and the number of scans per body part in 144 patients during the total hospitalization.

	Number of patients stratified by the number of scans[a] (0–6 scans)								Number of scans per body part
	0	1	2	3	4	5	6	Total	
CT caput	38	77	18	8	2	1		144	150
CT neck	34	93	13	3	1			144	132
CT chest	51	73	17		2	1		144	120
CT abdomen	53	70	15	3	1	1	1	144	124
CT pelvis	56	69	14	3	1		1	144	116
CT extremities	124	15	3	2				144	27

[a]SWBCT examination split into body part scans, examinations with scans in both the arterial and the venous phases of the same body part registered as two scans.

Table 4. Non ionizing diagnostic examinations per patient admitted with TTA.

Type of examination	At accident site (n = 144)	In trauma admission1 (n = 144)	In trauma admission 2 (n = 36)	During subsequent hospital stay (n = 144)
FAST, n (%)	3 (2.1)	88 (61.1)	13 (36.1)	0
EFAST, n (%)	12 (8.3)[a]	18 (12.5)	8 (22.2)[a]	0
Ultrasound (excluding FAST/EFAST), n (%)	0	0	0	14 (9.7)
With intravenous contrast, n (%)	0	0	0	0
Pleural, n (%)	0	0	0	7 (4.9)
Thoracentesis, n (%)	0	0	0	2 (1.4)
MRI (all types of examinations), n (%)		0	0	32 (22.2)
MR caput, n (%)		0	0	21 (14.6)
MR neck, n (%)		0	0	10 (6.9)
MR spine, n (%)		0	0	10 (6.9)
MR chest, n (%)		0	0	2 (1.4)
MR upper extremity, n (%)		0	0	1 (0.7)
MR upper extremity, n (%)		0	0	1 (0.7)

[a]One patient had only pleural scan excluding FAST.

Table 5. DAP in trauma patients admitted with TTA.[a]

	Patients with X-ray (n)	Median DAP (Gycm^2 (Q1, Q3))	DAP range (Gycm^2)
During trauma admissions			
Trauma admission 1	118	1.67 (0.97, 1.91)	0.01–5.01
Trauma admission 2	28	0.81 (0.12, 1.83)	0.02–3.37
Trauma admissions 1 + 2	130	1.67 (0.95, 2.07)	0.01–5.01
During total hospitalization			
X-ray including all types of images	134	1.86 (1.12, 2.87)	0.02–34.00
X-ray images of chest/column	132	0.13 (0.11, 0.43)	0.01–13.78
X-ray images of pelvis/lower extremities[b]	113	1.68 (1.36, 2.45)	0.05–32.28
X-ray images of upper extremities	35	0.32 (0.10, 1.05)	0.03–3.26

X-ray Conventional radiographic examination, *Gycm2* Gray-centimetres squared

[a]DAP values for 16 (1.6%) of 1018 images from 134 patients were missing, 10 from trauma admission 1 (in 4 patients) and 6 during the subsequent hospitalization (in two other patients).

[b]All DAP values for pelvis/lower extremities were missing in one patient, data from 112 patients included in calculations.

During trauma admission 2, DAP values for all 28 patients exposed to X-ray were available. All patients with missing values in trauma admission 1 had DAP values registered in trauma admission 2, so no patients were excluded from calculations of central tendency in trauma admission 2 or trauma admissions 1 + 2 (Table 5).

During the total hospitalization, all 134 patients examined with X-ray had DAP values registered. In addition to the 10 missing DAP values from trauma admission 1, six more from mobile C-arm X-ray imaging in the operating room in two more patients were missing. Calculations of the median DAP value for the total hospitalization therefore include data from all patients, but 16 (1.6%) of 1018 DAP values from six (4.5%) of 134 patients are missing. They were for images of the chest/column region (n = 3) and the pelvis/lower extremities (n = 13) (Table 5).

There was no significant difference in use of X-ray imaging during the total hospitalization between children and adults. The number examined with X-ray was 23 (88.5%) children versus 111 (94.1%) adults (p = 0.387). The number examined with more than five X-ray images was 10 (38.5%) children versus 44 (37.3%) adults (p = 0.911).

In addition, seven (4.9%) patients underwent angiographic examination and/or intervention. DAP values were registered in four. Median DAP was 43.49 (Q1 = 7.58, Q3 = 379.87, range 6.12–481.48) Gycm^2.

Table 6 displays DLP values and estimated effective doses from CT scans during trauma admissions and the total hospitalization. In trauma admission 1, one CT neck DLP and effective dose value was missing. All other values were available. Accordingly, during the total hospitalization DLP and effective dose value were missing for one (0.1%) of 669 scans.

There was a significant difference in the proportion of patients undergoing CT examination during hospitalization between children and adults. Sixteen (61.5%) children versus 106 (89.8%) adults were examined with CT (p < 0.001). The number examined with more than five CT scans was 4 (15.4%) children versus 48 (40.7%) adults (p = 0.023).

DISCUSSION

The main findings in this study are that most (97.2%) of the patients met with TTA underwent at least one ionizing radiation examination. CT was used in 84.7%, and 50.7% underwent a SWBCT. Median DLP and effective dose for all CT examinations during the total hospitalization were 2396 mGycm and 20.42 mSv, respectively. Most of this dose was delivered during trauma admissions, as the median DLP increased with only 300 mGycm during the subsequent hospital stay. The use of MRI and ultrasound was low during this phase. Patients were young, and most were not severely injured.

Radiation protecting authorities publish national diagnostic reference levels for X-ray and CT in DAP and DLP, respectively, and hospitals are encourage to adhere to this quality and safety standard[2, 37]. The Norwegian radiation protection authority (NRPA) has published DAP reference levels for a range of X-ray examinations[2]. Our median DAP values for the total hospitalization were well below reference levels.

NRPA published its first diagnostic reference level for a whole body trauma CT in 2018[2]. It is based on representative doses for adult sized patients examined in 2017 from 28 different CT laboratories in Norway using independent whole body trauma CT protocols. Median DLP was 1838 (upper quartile 2357) mGycm, and the reference level was set at 2400 mGycm.

The median DLP (2461 mGycm) for trauma patients examined with a SWBCT at the trauma centre in the present study was slightly above the national diagnostic reference level. Five (8.8%) of the 57 examinations included medically justified duplicated scans (DLP range of 2883–3118). This probably contributed to the relatively high median DLP. Further, our protocol uses overlapping body area scanning. The overlap can be avoided by using multiphase intravenous contrast injections in a combined chest, abdomen and pelvis scan[20]. Finally, DLP increases with body weight. Accordingly, mean weight above the national average could influence DLP. Such data were not available. We find it unlikely that our study population, which included children, was heavier than the population the national reference level is based on. However, it is known that mean body mass index in the population in this Norwegian region is slightly above the national average[27].

Direct comparison with and between previous studies of trauma populations is difficult because they do not report DAP or DLP. Instead, most report estimated mean effective dose using different estimation methods. Tien *et al.*[9] reported a total mean hospitalization effective dose of 22.7 mSv for 171 Level 1 trauma patients. Their population only included adults admitted directly and excluded patients who died. Surface doses were measured with optically stimulated luminescence dosemeter, and effective doses estimated with impact CT patient dosimetry calculator (version 0.99v)[38]. They made the assumption that all radiations measured were from CT scanning. In addition, they estimated effective doses by multiplying the number of X-ray images and CT scans with standard effective dose conversion factors published by the National radiological protection board (NRPB). For CT, they used the NRPB-SR250 (1993) factors, and for X-ray, the NRPB-SR262 (1998). Interestingly, the use of conversion factors (17.8 mSv) underestimated the dose to the patients compared to dosimeter data.

Table 6. DLP and effective dose in patients admitted with TTA. [a]

	Patients with CT (*n*)	Median DLP (Q1, Q3) mGycm	DLP range mGycm	Median effective dos (Q1, Q3) mSv	Effective dose range (mSv)
During trauma admission					
CT trauma admission 1	108	2048 (1263, 2637)	156–4365	19.21, (8.45, 25.2)	1.23–46.81
CT trauma admission 2[b]	19	1793 (1030, 2627)	329–3118	15.90 (6.73, 27.16)	1.12–46.26
CT trauma admissions 1 + 2	116	2096 (1294, 2715)	156–6444	19.48 (11.15, 16.16)	1.23–73.17
SWBCT trauma admission 1[b,c]	68	2553 (2116, 2782)	1516–4041	22.72 (17.72, 27.81)	11.36–45.15
SWBCT trauma admission 2[b,c]	7	2376 (1793, 2918)	801–3118	19.99 (15.52, 27.16)	11.91–27.84
SWBCT at trauma centre[b,c]	57	2461 (2048, 2695)	801–3871	22.29 (17.80, 27.28)	11.41–40.81
SWBCT at referring hospitals[b,c]	18	2673 (2454, 3279)	1659–4041	22.06 (16.55, 29.71)	11.36–45.15
During total hospitalisation[d]					
CT including all types of scans	122	2396 (1396, 3510)	36–10604	20.42 (11.29, 29.75)	0.12–158.79
CT caput scan	106	1098 (939, 1676)	36–4060	1.51 (1.26, 2.41)	0.21–6.90
CT neck scan[e]	109	268 (213, 349)	27–1843	2.28 (1.92, 3.45)	0.24–27.40
CT chest scan	92	306 (237, 434)	100–2636	6.27 (4.55, 9.22)	2.70–54.98
CT abdomen/pelvis scan	91	843 (595, 1104)	254–6179	13.93 (9.90, 17.59)	2.64–95.76
CT extremities scan	20	210 (130, 496)	64–2639	0.08 (0.03, 1.11)	0.01–25.08

mGycm milligraycentimeter, *mSv* milliSivert,
[a]The DLP value was missing for one (0.1%) of 669 CT scans from 122 patients.
[b]Effective dose normally distributed.
[c]DLP normally distributed.
[d]SWBCT examination split into body part scans.
[e]All DLP values for CT neck missing for one patient, data from 108 patients included in calculations.

Winslow *et al.*[18] reported a total mean effective dose of 40.2 mSv for 86 adult Level 1 trauma centre patients. Most (92%) underwent SWBCT. Doses were for the first 24 h only, and the most severely injured patients and those lacking dose information were excluded. Dose estimates for CT were calculated by multiplying machine DLP values with standard conversions factors[39, 40] (corrected for age), and for X-ray by using the radiation dose assessment resource calculator[41]. Sharma *et al.*[11] estimated mean cumulative effective doses for both the first 24 h (11.76 mSv) and the total hospitalization (14.56 mSv) for 177 Level 1 trauma patients. They included transferred patients but not the examinations at referring hospitals. Dose estimates were from the literature reported conversion factors for each X-ray image and DLP for each CT scan[39, 42]. The majority of examinations were done during the first 24 h. A total of 1505 X-ray images and 400 CT scans were undertaken during the total hospitalization. CT accounted for 21% of the examinations and 93% of the total cumulative effective dose. The use of SWBCT was low (13%), with a mean effective dose of 31.5 mSv. Sierink *et al.*[14] randomized patients to SWBCT or individualized imaging, and estimated doses were 20.9 and 20.6 mSv, respectively. Doses were estimated from calculated representative doses for single-pass CT body scans of various body regions on the basis of optimised trauma CT protocols at one of the study sites multiplied with the number of scans per patient. They estimated effective dose using impact CT dosimetry calculator[38]. Salottolo *et al.*[19] reported median hospitalization DLP (1700.22 mGycm) for 57 of 165 trauma patients admitted to intensive care. They estimated the median total effective dose (9.38 mSv) by multiplying conversion factors with DLP per scan[43, 44].

For comparison, we used NCICT and estimated effective dose for all CT scans. Our values correspond with the doses reported in the studies mentioned above.

In our opinion, reporting DAP and DLP instead of effective doses would support a better understanding of ionizing radiation exposure and facilitate comparison of results between future studies. DAP and DLP are the measures routinely used for monitoring dose delivered to patients. The effective dose unit is not intended to be used for populations or individual risk estimates, especially not in populations composed of different sexes and ages[45]. The effective dose estimate is useful for comparison of ionizing radiation risk from different modalities, such as X-ray, CT and angiography for individuals. When effective dose estimates are reported, the definitions and use of conversion factors should be reported in detail for all estimates, as the conversion factors change with time[46].

Dose to patients from ionizing radiation may be reduced in three ways. First, quality audits like the present study or implementation of dose-tracking software can contribute to dose reduction through protocol optimization[47–49]. These methods support an active use of national reference levels. The CT machines and SWBCT protocol at our trauma centre were unchanged between 2015 and 2018. The DLP to the anthropomorphic phantom (50 kg heavy and 165 cm tall) as measured in 2018 was below the national median in all three machines. Presentation of SWBCT protocol parameters, including DLP for a standardized whole body phantom, would facilitate comparisons across laboratories. Such data have not been published from NRPA or others.

Next, replacing ionizing radiation examinations with other methods, such as MRI or ultrasound, will reduce dose. Especially, increased use of MRI and ultrasound instead of duplicated CT scans during the hospital stay subsequent to trauma admissions is advocated[21, 22]. The present study identified a low use of non-ionizing radiation examinations during this phase, which represent a potential for future improvements.

Finally, the probably most potent way for reducing delivered dose to patients is to reduce unjustified ionizing radiation examinations[3, 4, 21, 22]. In a follow-up of the present study population, we will associate CT use and identified injuries. We believe such data can contribute to guide trauma surgeons' decision making.

STRENGTHS AND LIMITATIONS

In the present study, we report delivered dose data for all patients in detail. We included patients at all ages, both transferred patients and those who died during the hospitalization. Patients who die are severely injured and typically receive high doses. DAP and DLP were collected from PACS for every single image and scan, and the estimated effective doses came from NCICT calculations. The audit approach ensured that only values not documented in the electronic health records were missing in the analyses.

The study population was small but comparable with previous studies. The inclusion of children reduces the median DAP and DLP values. This must be taken into consideration when results from our study are compared with national diagnostic reference levels. We chose not to calculate effective dose for X-ray examinations because they would be insignificant compared to the doses from CT.

CONCLUSION

The majority of trauma patients were examined with an ionizing radiation method, and most of the radiation dose from CT examinations was delivered during the trauma admissions as SWBCT examinations. The use of non-ionizing radiation methods was low. DLP for a SWBCT was above the Norwegian diagnostic reference level, but the effective dose was comparable to previous studies. We suggest measures to optimize our protocol, and advocate reporting of DAP and DLP in future studies for comparison of doses delivered to trauma populations.

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APPENDIX 1: CT whole body phantom scanning using the multi-trauma protocol 09.05.18.

CT whole body phantom: Kyoto Kagaku co. LTD PBU-60(E), length 165 cm, weight 50 kg.

Effective dose estimates by National cancer institute's software for dosimetry the NCICT. Reference: Lee *et al.* NCICT: a computational solution to estimate organ doses for paediatrics and adult patients undergoing CT scans. J. Radiol. Prot. 35(4), 891–901 (2015).

Protocol: University Hospital of North Norway's multi-trauma whole body CT protocol. Head first, supine, Spiral (tube A), Slice/collimation 128 × 0.6 (total collimation 38.4). CT head/face and neck scan without intravenous contrast. CT thorax including spleen and liver in arterial contrast phase, abdomen/pelvis scan with intravenous portal contrast phase. The arms fixed on a pillow on the abdomen, as in patients incapable on lifting their arms above the head. The scan length and scan position were the same in the three machines.

Machine name	Siemens Somatom definition flash		
CT in room	7	8	12
Installation year	2013	2012	2012
Caput scan			
Care kV	Off	Off	Off
Reference kV—70 kg	120	120	120
kV used	120	120	120
Care dose	On	On	On
Reference mAs—70 kg	390	390	390
Mean mAs used	343	345	336
Reference $CTDI_{vol}$	59.76	59.76	59.76
$CTDI_{vol}$ used	52.53	52.81	51.42
Dose slider	—	—	—
Rotation time (s)	1	1	1
Pitch	0.55	0.55	0.55
DLP (mGycm)	978.7	979.1	959.8
Effective dose (mSv)	1.437	1.437	1.409
Neck scan			
Care kV	On	On	On
Reference kV—70 kg	120	120	120
kV used	120	120	120
Care dose	On	On	On
Reference mAs—70 kg	195	195	195
Mean mAs used	87	92	91
Reference $CTDI_{vol}$	13.24	13.24	13.24
$CTDI_{vol}$ used	5.9	6.28	6.19
Dose slider	2	2	2
Rotation time (s)	1	1	1
Pitch	0.7	0.7	0.7
DLP (mGycm)	114.9	117.9	121.2
Effective dose (mSv)	0.831	1.057	0.98
Chest scan			
Care kV	On	On	On
Reference kV	120	120	120
kV used	100	120	120
Care dose	On	On	On
Protocol mAs—70 kg	107	65	65
Mean mAs used	81	53	54
Reference $CTDI_{vol}$	4.39	4.39	4.39
$CTDI_{vol}$ used	3.36	3.63	3.66
Dose slider	3	3	3
Rotation time (s)	0.5	0.5	0.5
Pitch	1.2	1.2	1.2
DLP (mGycm)	138.8	146.9	149.2
Effective dose (mSv)	2.68	2.774	2.753

(Continued)

Appendix 1: Continued

Abdomen/pelvic scan			
Care kV	On	On	On
Reference kV—70 kg	120	120	120
kV used	120	120	120
Care dose	On	On	On
Reference mAs—70 kg	160	160	160
Mean mAs used	126	117	128
Reference $CTDI_{vol}$	10.79	10.79	10.79
$CTDI_{vol}$ used	8.53	7.93	8.64
Dose slider	7	7	7
Rotation time (s)	0.5	0.5	0.5
Pitch	1	1	1
DLP (mGycm)	382.6	356.1	387
Effective dose (mSv)	6.173	5.773	6.56
Total examination			
DLP (mGycm, without scout DLP)	1615	1617	1600
Effective dose total (mSv)	11.121	11.041	11.072

CT: computer tomography, kV: kilo volt, mAs: milliampere seconds, $CTDI_{vol}$: volume CT dose index, DLP: dose length product.

Paper III

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Clinical guided computer tomography decisions are advocated in potentially severely injured trauma patients: a one-year audit in a level 1 trauma Centre with long pre-hospital times

Anna Bågenholm[1,2*], Trond Dehli[1,3], Stig Eggen Hermansen[4], Kristian Bartnes[1,4], Marthe Larsen[5] and Tor Ingebrigtsen[1,6]

Abstract

Background: The International Commission on Radiological Protection's (ICRP) justification principles state that an examination is justified if the potential benefit outweighs the risk for radiation harm. Computer tomography (CT) contributes 50% of the radiation dose from medical imaging, and in trauma patients, the use of standardized whole body CT (SWBCT) increases. Guidelines are lacking, and reviews conclude conflictingly regarding the benefit. We aimed to study the degree of adherence to ICRP's level three justification, the individual dose limitation principle, in our institution.

Methods: This is a retrospective clinical audit. We included all 144 patients admitted with trauma team activation to our regional Level 1 trauma centre in 2015. Injuries were categorized according to the Abbreviated Injury Scale (AIS) codes. Time variables, vital parameters and interventions were registered. We categorized patients into trauma admission SWBCT, selective CT or no CT examination strategy groups. We used descriptive statistics and regression analysis of predictors for CT examination strategy.

Results: The 144 patients (114 (79.2%) males) had a median age of 31 (range 0–91) years. 105 (72.9%) had at least one AIS ≥ 2 injury, 26 (18.1%) in more than two body regions. During trauma admission, at least one vital parameter was abnormal in 46 (32.4%) patients, and 73 (50.7%) underwent SWBCT, 43 (29.9%) selective CT and 28 (19.4%) no CT examination. No or only minor injuries were identified in 17 (23.3%) in the SWBCT group. Two (4.6%) in the selective group were examined with a complement CT, with no new injuries identified. A significantly ($p < 0.001$) lower proportion of children (61.5%) than adults (89.8%) underwent CT examination despite similar injury grades and use of interventions. In adjusted regression analysis, patients with a high-energy trauma mechanism had significantly ($p = 0.028$) increased odds (odds ratio = 4.390, 95% confidence interval 1.174–16.413) for undergoing a SWBCT.

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* Correspondence: anna.bagenholm@unn.no
[1]Department of Clinical Medicine, Faculty of Health Science, UiT-The Artic University of Norway, PO box 6050 Langnes, N-9037 Tromsø, Norway
[2]Department of Radiology, University Hospital of North Norway, Sykehusveien 38, PO box 103, N-9038 Tromsø, Norway
Full list of author information is available at the end of the article

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Conclusion: The high proportion of patients with no or only minor injuries detected in the SWBCT group and the significantly lower use of CT among children, indicate that use of a selective CT examination strategy in a higher proportion of our patients would have approximated the ICRP's justification level three, the individual dose limitation principle, better.

Keywords: Trauma audit, Trauma population, Injury, Multi trauma, Diagnostic imaging, Whole body computer tomography, Decision tool, Dose limitation

Background

Medical imaging adds 1.1 millisievert (mSv) to Europeans and 3 mSv to Americans to the average natural background dose of 2–3 mSv per year. Approximately 50% of this dose comes from computer tomography (CT) [1, 2]. The International Commission on Radiological Protection (ICRP) introduced a system for dose limitation to humans in 1977. The system has three justification levels [3, 4]. Level one deals with the use of radiation in medicine in general, level two with specified procedures, and level three with the application of a procedure to an individual. At level three, an examination is justified if the given dose gains the patient more than the potential ionizing harm [3–5]. It is established that young and healthy persons have increased risk for long-time harm after ionizing radiation [3, 4, 6, 7].

Recently, dose limitation to individuals has been emphasized due to the increased use of CT, for example in the Triple "A" (awareness, appropriateness, and audit) advice from 2009 [8], the Nordic radiation protecting agencies' statement concerning high CT examination use from 2012 [9] and the European society of radiology's clinical decision support for imaging referral "iGuide" from 2016 [10].

A trauma system should therefore diagnose the mostly young and healthy trauma patients with an individually optimized diagnostic strategy [3–5, 7–11]. During the last 20 years, the use of standardized whole body CT (SWBCT) has increased due to better availability and functionality of CT machines and numerous publications recommending this examination as routine [12–18]. Generally accepted guidelines for use of SWBCT in trauma patients are, however, lacking [19–23]. Reviews assessing survival after treatment for trauma conclude conflictingly regarding the benefit of SWBCT [24–27]. The only prospective randomised study of immediate SWBCT compared to individual imaging after a clinical examination was published in 2016 by Sierink et al. [28]. They found no difference in mortality, but showed increased radiation exposure in the immediate SWBCT group. Few studies have specifically assessed whether the use of SWBCT fulfils the individual dose limitation criterion for justification at ICRP's level three [29].

SWBCT examination in potentially severely injured patients gives the trauma team a tool for fast decision making on intervention, identifies injuries not suspected and facilitates patient logistics [14, 30–34]. Accordingly, in our institution, the use of SWBCT has increased over the last fifteen years. It is unclear, however, whether the present use is in accordance with ICRP's level three justification, the individual dose limitation principle.

Methods

Study type and aim of the study

This is a retrospective clinical audit [35, 36]. We aimed to study the degree of adherence to ICRP's level three justification, the individual dose limitation principle, in our institution. To achieve this, we describe the identified injuries, and the use of CT examinations and interventions in suspected severely injured trauma patients. In addition, we analyse associations between parameters that could influence CT use during trauma admissions, and the observed actual use of CT.

Study region

The northern Norway health region has 486,792 inhabitants (2015) spread out over a rural area of 257,450 km^2 (1.9 inhabitants/km^2) [37, 38]. The University Hospital of North Norway, Tromsø campus (UNN) is defined as the regional Level 1 trauma centre, by the Norwegian Trauma system. UNN has approximately 150 trauma team activations (TTA) per year, and supports ten referring hospitals, of which none has CT in the emergency department (ED). The region is served by an advanced fixed and rotor wing air ambulance service [39]. The smallest and most remote referring hospital, located on the Spitsbergen islands, has no CT and is situated 2.5 h away with fixed wing propel air-plane.

The region has predefined criteria for TTA [40] and follows the Advanced Trauma Life Support® system [41]. Decision on the use of diagnostic CT is on the discretion of the trauma surgeon in charge. The technical protocol for SWBCT in adults (> 16 years) is standardized. Patients may undergo CT and interventions during three phases: trauma admission one at a referring hospital or at UNN for patients transported directly to the Level 1 trauma centre (phase one), trauma admission two for referred patients (phase

two) or during the subsequent hospital stay (phase three). The total hospitalization includes all three phases.

Inclusion criteria and data collection

Trauma registrars continuously survey emergency admissions and prospectively register all trauma patients fulfilling predefined criteria in the national trauma registry [42]. In the present study, we included all patients registered with a TTA at UNN from 01.01 to 31.12.2015. There were no exclusion criteria.

The first author thereafter manually retrieved and registered all study data from pre- and intra-hospital electronic health records, including the radiology information system (RIS) and the radiology examinations and logs in the picture archiving and communication system (PACS). Study data entry continued until death, or discharge home or to rehabilitation.

Injury code identification and estimation of injury severity

Injuries were categorized with Abbreviated Injury Scale (AIS) codes [43]. We used the AIS 2005 update 2008 manual [44]. The first author and another AIS-certified physician, employed as trauma registry coder at UNN, made a consensus coding on all injury codes. The AIS codes are presented as total number of codes in the population. One code is a combination of a six-digit pre-dot anatomical code and a one digit post dot severity score ranked from one (minor) to six (lethal). We report the total number of codes with severity scores ≥2 for the population.

Total injury severity per patient is estimated with the Injury Severity Score (ISS) [45] and the New ISS (NISS) [46]. ISS uses six body regions. Patients with ISS or NISS > 15 were defined as severely and those with scores between 4 and 15 as moderately injured. To differentiate patients with no injuries or injuries not detectable with CT (AIS 1) from those detectable (AIS ≥ 2), we dichotomized patients as ISS 0–3 or 4–75. Total severity estimates per patient were also reported as the number of ISS regions per patient with identified AIS ≥ 2 codes. We defined polytrauma as AIS > 2 in at least two of the six ISS body regions [47, 48].

Time variables

We registered the time span from the accident to arrival in hospital, and to the start of the first CT scan.

Vital parameters (adults)

We registered the vital parameters (systolic blood pressure (SBP) (mmHg), heart rate (HR) (beats/minute), respiratory rate (RR) (breath/minute) and Glasgow coma scale (GCS) score) as continuous variables at the accident site, during trauma admissions immediately before the first possible CT examination strategy decision, and calculated shock index (SI) = HR/SBP [49–51].

SBP, RR and GCS were dichotomised as normal or abnormal according to the Revised Trauma Score standards [52], and HR according to our trauma team activation manual [40]. SI was categorized as abnormal if > 0.9 [50, 51].

We merged the dichotomized vital parameters SBP, HR, RR and GCS score into a new parameter (merged vital parameter). We defined it as abnormal if one or more of the four were abnormal, also if only one of the four was documented. If one was normal and three were undocumented or if all were undocumented, the merged vital parameter was registered as missing. All other combinations were defined as normal.

Arterial haemoglobin, lactate and base excess, obtained immediately before the first possible CT examination strategy decision, were recorded as continuous parameters. Lactate and base excess were also dichotomized as normal or abnormal according to the reference in our institution [53, 54].

Vital parameters (children)

We registered the same vital parameters for children. GCS is validated for use in children with the same standards as adults and used in this study [55]. We dichotomised SBP, HR and RR as normal or abnormal according to the Norwegian modified paediatric early warning score [56–59], and defined SI as abnormal if > 1.22 up to six years, > 1.0 between six and twelve years and > 0.9 above twelve years [60, 61].

CT examinations

We categorised the patients into three trauma admission CT examination strategy groups; SWBCT, selective CT or no CT. The SWBCT protocol includes scans of the caput and neck without intravenous contrast, scan of the chest with intravenous contrast in the arterial phase (including the spleen), and scan of the abdomen/pelvis with intravenous contrast in the portal venous phase. We defined a selective CT as an examination excluding one or more of the four SWBCT body part scans. It can include extremity scans. In the no CT group, the cause for not undergoing CT examination was categorised as either "no indication for CT" or "patient too hemodynamically unstable for CT".

CT examinations were also categorised as ordered during the trauma admissions or during the subsequent hospital stay. If the trauma admission took place in the operating room (OR), as for some of the hypothermia and burn patients, CT examinations ordered afterwards were registered as done during trauma admission, according to local guidelines. When patients were transported directly to the OR due to hemodynamic instability of other reasons, CT examinations ordered afterwards were registered as done during the subsequent hospital stay.

We defined a duplicated CT examination as a body part examined more than once, and a complement CT as a body part scan done during the subsequent hospital stay for a body part not examined during the trauma admissions.

We categorised patients into three groups based on the trauma admission CT examination findings. High injury grade group was defined as AIS ≥ 2 injuries identified in two or more SWBCT body part scans, moderate injury grade group as AIS ≥ 2 injuries in one body part and low injury grade group as either AIS 1 injuries or no injuries.

Interventions

We defined interventions as action taken to improve the outcome of an injury, or to prevent it from getting worse. For each patient, we registered whether the patient had undergone intervention(s) or not, and eventually the types and number of interventions. Interventions were categorised as active procedures or conservative treatment decisions, such as for example observations. Repeated interventions for the same injury were registered as one.

Emergency interventions were defined as those listed in the Norwegian trauma registry manual [42] and done within 24 h after the accident. In addition, we defined active internal and external rewarming as emergency interventions. Intubation is not listed in the manual, and was therefore not registered as an emergency intervention, but we registered whether patients were intubated pre-hospitally or within the first 24 h after admission. We also registered the total number of interventions per patient done during hospitalization in areas examined with a trauma admission CT.

Statistics

Continuous variables are presented with mean and standard deviation (SD) or median and lower (Q1) and upper quartile (Q3) depending on the distribution of the variable. Categorical variables are presented with frequencies and percentages. Group differences are tested with independent-t-test for continuous variables and chi-square test or Fisher's exact test for categorical variables. Associations between clinical parameters assessable for the 113 adult patients examined in the ED before trauma admission CT strategy decision, and the use of SWBCT versus a selective or no CT approach were analysed with logistic univariable and multivariable regression. Unadjusted and adjusted odds ratios are presented with 95% confidence interval (CI) and *p*-values. Five hemodynamically unstable adults sent directly to OR and the children were excluded from this analysis. *P*-values < 0.05 were considered statistically significant. IBM SPSS 24 was used to analyse the data.

Results

Demographics

Table 1 displays characteristics for the 144 patients.

ISS and NISS were positively skewed. Twenty-four (16.7%) had polytrauma. The 10 patients dying within 30 days had ISS between 22 and 45, and seven were polytraumatized. Three patients (2.1%) died within 24 h after the accident.

Identified injuries

We identified 766 AIS injury codes in 138 (95.8%) of the 144 patients. The majority 469 (61.2%) were AIS ≥2 injuries in 105 (72.9%) patients, of which 54 (37.5%) had at least one AIS ≥ 2 injury in one, 25 (17.4%) in two, and 26 (18.1%) in three or more ISS body regions.

Time variables

Median time from the accident to arrival in the first hospital with CT possibility was 1 h and 54 min (Q1 = 1.0, Q3 = 2.7 h). Fifty-two (36.1%) patients arrived within 1 h and 30 min and 21 (14.6%) after five or more hours. Median time from the accident to start of the first CT examination (n = 116 patients) was 2 h and 36 min (Q1 = 1.8, Q3 = 4.0 h), and median time from arrival in hospital to start of the first CT 43 min (Q1 = 0.6, Q3 = 0.9 h). Twenty (17.2%) had the examination within 1 h and 30 min after the accident and 23 (19.8%) after five or more hours.

Vital parameters

Table 2 displays the parameters registered at the accident site and immediately before the first possibility to order a CT examination, and the proportions with abnormal findings. These patient specific data were available to the trauma surgeon before a decision about trauma admission CT examination strategy was reached.

The merged vital parameter was abnormal in 46 (32.4%) of 142 patients immediately before trauma admission CT examination strategy decision. The proportion with abnormal SI (21.7% versus 8.3%, $p = 0.017$), base excess (41.3% versus 7.0%, $p < 0.001$), lactate (41.3% versus 16.7%, p = 0.06) was higher among these 46 patients compared to those with a normal merged vital parameter.

CT examinations

Among the 144 patients, 116 (80.5%) underwent CT examination during the trauma admissions. Seventy-three (62.9%) underwent a SWBCT and 43 (37.1%) a selective CT examination among the 116 with CT. During the total hospitalization, 122 (84.7%) underwent CT. Table 3 shows the distribution of patients in the three trauma admission CT examination strategy groups.

In the selective CT group, two adults underwent a complement CT without detection of previously undiagnosed injuries.

Table 1 Characteristics of the trauma population ($n = 144$)

Characteristics	
Male sex, n (%)	114 (79.2)
Tourist, n (%)	28 (19.4)
Age, years in median (Q1, Q3)	31 (19, 49)
Age groups, n (%)	
< 5	9 (6.3)
5–16	17 (11.8)
> 16	118 (81.9)
Transport to first hospital by	
Ambulance helicopter, n (%)	80 (55.6)
Fixed wing air ambulance, n (%)	9 (6.2)
Road ambulance, n (%)	53 (36.8)
Private transportation, n (%)	2 (1.4)
Trauma mechanism	
Penetrating traumas, n (%)	5 (3.5)
Blunt, n (%)	139 (96.5)
Road traffic, n (%)	63 (45.3)
Snowmobile, n (%)	11 (7.9)
Falls, n (%)	31 (22.3)
Hit by blunt object, n (%)	13 (9.4)
Explosion/fire, n (%)	8 (5.7)
Avalanches and/or hypothermia, n (%)	8 (5.8)
Other causes, n (%)	5 (3.6)
Transferred from other hospitals, n (%)	36 (25.0)
ISS, (Q1, Q3, Range)	9 (2, 22, 0–59)
NISS, (Q1, Q3, Range)	12 (3, 27, 0–66)
ISS > 15, n (%)	52 (36.1)
ISS > 15 among 26 children ≤16 years, n (%)	5 (19.2)
ISS > 15 among 118 adults, n (%)	47 (39.8)
NISS > 15, n (%)	64 (44.4)
Length of stay, median days (Q1, Q3)	4 (1.2, 11.5)
Total hospitalization > 20 days, n (%)	20 (13.9)
30-day mortality, n (%)	10 (6.9)

Q1 lower quartile, *Q3 upper* quartile, *ISS* Injury Severity Score, *NISS* New Injury Severity score

Among the 28 patients in the no CT group, five (17.8%) went directly to the OR due to hemodynamic instability; four of these were adults examined with a complement CT during the subsequent hospital stay. The remaining 23 (82.1%) had symptoms and/or injuries for which the surgeon decided that a CT was unnecessary or that it was safe to spare the patient for the ionizing radiation. Five had an ISS > 15, seven between 4 and 15 and eleven < 4. Two children underwent a complement CT without detection of previously undiagnosed injuries.

The proportion with abnormal findings on the merged vital parameter immediately before the CT examination strategy decision was significantly lower in the selective CT group (14.3%) compared to the SWBCT group (39.7%, $p = 0.004$) and the no CT group (40.7%, $p = 0.013$). In the no CT group, seven (31.8%) of the 23 patients for whom CT was considered unnecessary and four (80.0%) of the five who went directly to OR had an abnormal merged vital parameter.

Table 4 displays the use of duplicated CT during the sub-sequent hospital stay. None of the control CT examinations led to active interventions.

Interventions

Table 5 displays the 50 emergency interventions done in 35 (24.3%) patients. Twenty-two (62.9%) had abnormal findings on the merged vital parameter immediately before the CT examination strategy decision. Seven (20%) underwent CT within 1.5 h (six SWBCT).

Eleven (31.4%) were transported to the OR without preoperative CT. Two (18.2%) underwent laparotomies, three (27.2%) operations for arterial bleedings in extremities, two (18.2%) chest tube insertions and rewarming, three (27.3%) rewarming, and one (9.1%) burn injury treatment. Among the 52 patients with ISS > 15, 30 (57.7%) had an emergency intervention and five (16.7%) of these 30 died within 30 days after the accident. In addition, 23 (15.6%) patients were intubated pre-hospitally and another eight (5.5%) within the first 24 h.

Table 6 grades the injuries detected with CT and the use of emergency interventions in the three CT examination strategy groups. The proportion undergoing emergency intervention was significantly lower in the selective CT group (7%) compared to the SWBCT group (29%, $p = 0.005$) and the no CT group (39%, $p = 0.001$). Among the 73 patients in the SWBCT group, 17 (23.3%) had no or only AIS 1 injuries detected on CT.

In addition to the emergency interventions, another 359 interventions were done. In total, 409 interventions were undertaken in 118 (81.9%) patients. Two hundred and seventy-seven (67.7%) of the interventions were in a CT examined area.

Children versus adults

When comparing children to adults, the proportion undergoing CT examination was significantly lower both during trauma admissions (53.8% versus 86.4%, $p < 0.001$) and the total hospitalization (61.5% versus 89.8%, $p < 0.001$). The proportion of injuries detectable with CT (ISS 4–75) (65.4% versus 73.7%, $p = 0.64$) and the proportion undergoing interventions during the first 24 h (80.9% versus 75.4%, $p = 0.561$) were not significantly different between children and adults.

Table 2 First documented vital parameters at accident site and during first trauma admission with CT possibility

First documented vital parameters in patient record or assessed/calculated value from the documented parameters	Accident site n = 144	TA with first CT possibility n = 144
Heart rate, n (%)	112 (77.8)	140 (97.2)
Abnormal (< 40 or > 130 beats/minute [a]), n (%)	7 (6.2)	5 (3.6)
Systolic blood pressure, n (%)	107 (74.3)	139 (96.5)
Abnormal (< 90 mmHg [a]), n (%)	10 (9.3)	6 (4.3)
Respiratory rate, n (%)	87 (60.4)	115 (79.9)
Abnormal (< 10 or > 29 breaths/minute [a]), n (%)	20 (23.0)	12 (10.4)
Glasgow Coma Scale value, (%)	126 (87.5)	133 (92.4)
Admitted intubated in trauma admission just before CT decision		11 (7.6)
Abnormal (< 13 at accident site, < 13 or intubated in TA), n (%)	41 (28.5)	35 (23.4)
Shock index, heart rate/systolic blood pressure, n (%)	99 (68.8)	138 (95.8)
Abnorma, (> 0.9, > 1 6–12 years, > 1.22 < 6 years) n (%)	10 (6.9)	18 (12.5)
Blood lactate, n (%)		90 (62.5)
Abnormal (> 1.8 mmol/l), n (%)		35 (24.3)
Abnormal and > 32 degree Celsius, n (%)		30 (20.8)
Blood base excess, n (%)		91 (63.2)
Abnormal (< −3.3 to > 3.3 mmol/l), n (%)		29 (20.1)

CT Computer tomography, *TA* trauma admission, [a] abnormal children values dichotomized according to the Norwegian modified paediatric early warning scores normal values

Possible predictors for SWBCT

Table 7 shows associations between patient and trauma characteristics, vital parameters, blood values and CT examination strategy in 113 adults. The five hemodynamically unstable adults sent directly to the operation room without CT and the 26 children were excluded from this analysis. In unadjusted logistic regression analysis, three parameters were associated ($p < 0.05$) with use of SWBCT: GCS < 13 or intubated, transported with physician to trauma admission and high-energy trauma mechanism. These were included in the adjusted analysis. It showed that patients with a high-energy trauma mechanism had significantly ($p = 0.028$) increased odds compared to low energy trauma (odds ratio = 4.39, 95% CI 1.174–16.413) for being examined with a SWBCT. Patients with GCS < 13 or intubated also had increased odds (odds ratio = 2.448, CI 0.912–6.574) for this examination.

Table 3 CT examinations in patients admitted with TTA

	< 5 years n, (%)	5–16 years n, (%)	> 16 years n, (%)	Total, n (%)
Trauma admission CT examination strategy groups				
Standardized whole body CT	1 (11.1)	6 (35.3)	66 (55.9)	73 (50.7)
Duplicated CT [a] during subsequent hospital stay	0 (0.0)	2 (33.3)	34 (51.5)	36 (49.3)
Selective CT	0 (0.0)	7 (41.2)	36 (30.5)	43 (29.9)
Duplicated CT [a] during subsequent hospital stay	0 (0.0)	1 (14.3)	8 (22.2)	9 (20.9)
Complement CT [b] during subsequent hospital stay	0 (0.0)	0 (0.0)	2 (5.6)	2 (4.6)
No CT	8 (88.9)	4 (23.5)	16 (13.6)	28 (19.4)
Complement CT [b] during subsequent hospital stay	1 (12.5)	1 (25.0)	4 (25.0)	6 (21.4)
Total, n (%)	9 (100)	17 (100)	118 (100)	144 (100)

CT Computer Tomography, *TTA* trauma team activation, [a] CT of a body part examined during trauma admission and at least once during the subsequent hospital stay, [b] CT of a body part not examined during trauma admission but during the subsequent hospital stay

Table 4 Duplicated CT examination per patient during the subsequent hospital stay after a TA CT

CT type during trauma admission	SWBCT $n = 36$	Selective CT $n = 9$
Control CT for findings seen on trauma admission CT [a], n (%)	28 (77.8)	7 (77.8)
New finding identified [b], not described on TA CT	4 (14.3)	1 (16.7)
Active intervention chosen	0 (0)	0 (0.0)
Conservative intervention chosen	4 (100.0)	1 (100.0)
New CT because of new vital indication	8 (22.2)	2 (22.2)
New finding identified [b], not described on TA CT	4 (50.0)	2 (50.0)
Active intervention	3 (75..0)	2 (100.0)
Conservative intervention	1 (25.0)	0 (0.0)

CT Computer Tomography, *TA* trauma admission, *SWBCT* Standardized whole body CT, [a] The main reason per person registered, [b] The main finding registered

Discussion

The main findings in the present study of patients admitted with TTA were that most had at least one AIS ≥ 2 injury (72.9%), underwent a CT examination (84.7%) and an intervention (81.9%). Few had AIS ≥ 2 injury in more than two ISS body areas (18.1%) and (32.4%) had abnormal vital parameters. In the selective CT group, only two (4.6%) patients underwent a complement CT, and no new injuries were identified. Children underwent significantly fewer CT examinations than adults, despite similar injury grades and use of interventions. Information about a high-energy trauma mechanism was the only parameter identified to significantly increase the odds for undergoing a SWBCT.

According to ICRP, an ionizing radiation examination is justified on level three if the potential benefit for the patient outweighs the potential risk for ionizing radiation harm. In the present study, the CT examination strategy was individualized, but the high proportion of patients with no or only minor injuries detected in the SWBCT group and the significantly lower use of CT among children, indicate that use of a selective CT examination strategy in a higher proportion of our patients would have approximated the ICRP's level three justification principle better. The trauma team meets potentially severely injured patients in the ED. An unconscious circulatory stable patient may show no visible signs of trauma while the CT identifies several injuries. An awake and afraid patient can show symptoms indicating severe injuries while the CT shows no injuries. According to ICRP's justification level three both are justified. In our study, 23.3% of the patients in the SWBCT group had only minor or no injuries. In previous studies, this proportion range from 14% in a study with strict criteria up to 60% in studies with liberal criteria for SWBCT [31, 62, 63]. Hence, a prospective study assessing whether SWBCT examinations are justified in individual patients, would imply registrations of the injuries suspected by the trauma team before the CT examination strategy decision. To our knowledge, such studies have not been published.

Table 5 Emergency interventions within 24 h after the accident in patients admitted with TTA

Total number of emergency interventions [a] per age group	< 5 years $n = 4$ (%)	5–16 years n = 3 (%)	> 16 years $n = 43$ (%)	Total number $n = 50$ (%)
Type of emergency intervention [a] within 24 h after the accident [b]				
Burn wound interventions in OR	0	0	1 (2.3)	1 (2.0)
Chest tube	0	1 (33.3)	11 (25.6)	12 (24.0)
Emergency laparotomy	0	0	4 (9.3)	4 (8.0)
Intracranial pressure monitoring	0	1 (33.3)	8 (18.6)	9 (18.0)
Craniotomy/ectomy	0	0	4 (9.3)	4 (8.0)
Active external rewarming	3 (75.0)	1 (33.3)	5 (11.6)	9 (18.0)
Active internal rewarming with ECMO	1 (25.0)	0	1 (2.3)	2 (4.0)
Interventional angiography	0	0	4 (9.3)	4 (8.0)
Other emergency interventions [c]	0	0	5 (11.6)	5 (10.0)
Total interventions	4	3	43	50

TTA Trauma team activation, *OR* operating room, *ECMO* extracorporeal membrane oxygenating, [a] as defined in the Norwegian trauma register manual added active external and internal rewarming, [b] one patient can have several interventions, [c] includes arterial and venous suture, amputation, cranium fracture debridement

Table 6 Distribution of CT use, emergency interventions and CT detected injuries in patients admitted with TTA

Type of CT diagnostics done during trauma admissions	No CT, *n* = 28		SWBCT, *n* = 73		Selective CT, n = 43		Total
Intervention within 24 h after the accident[a]	Emergency intervention	No emergency intervention	Emergency intervention	No Emergency intervention	Emergency intervention	No emergency intervention	
, n	11 (39%)	17 (61%)	21 (29%)	52 (71%)	3 (7%)	40 (93%)	144
Trauma admission CT finding groups							
High injury grade group, (AIS ≥ 2 in ≥2 CT body areas), n			15 (71.4%)	18 (34.6%)	1 (33.3%)	3 (7.5%)	37
Moderate injury grade group, (AIS ≥ 2 in one CT body area), n			3 (14.3%)	20 (38.5%)	2 (66.6%)	17 (42.5%)	42
Low injury grade group, (no injuries or only AIS 1 injuries in CT body areas), n			3 (14.3%)	14 (26.9%)	0 (0%)	20 (50.0%)	37
No findings on TA CT and no intervention in CT examined area, in low injury grade group, n			3 (100.0%)	10 (71.4%)	0 (0%)	13 (65.0%)	26

CT Computer tomography *TTA* Trauma team activation, *TA* trauma admission [a]Emergency intervention group includes patients with emergency interventions as listed in the Norwegian trauma register manual added active external and internal rewarming, the no emergency intervention group include patients with non emergency interventions or no intervention

Demographics, injury pattern, use of emergency interventions and time from trauma admission to start of the first CT scan in our population mainly compares to previously published similar studies [62–65]. The median pre-hospital transportation time of nearly two hours is, however, long when compared to large urban area trauma populations, but comparable to the context in other rural populations in for example Canada [66]. In this setting, the use of immediate SWBCT as advocated by e.g. Huber-Wagner et al. [16, 18, 67, 68] cannot be justified because the long observation time provides time for clinical observation, supporting a selective CT examination strategy, at least in conscious patients [22].

Further, comparison between complete trauma centre case series, like ours, and registry-based studies including only severely injured patients (ISS > 15) may cause biased inferences. In the latter, the pre-test likelihood of an unsuspected injury is high implying that widespread use of immediate SWBCT may be justified. Interestingly, two different analyses of patients included in the TraumaRegister DGU® of the German trauma society concluded conflictingly with regard to the potential survival benefit of immediate SWBCT [16, 18, 69].

The alternative to immediate SWBCT as a screening for injuries would be a clinical decision tool providing evidence based selection criteria for CT examination strategy decision. Hare et al. [70] reviewed the literature to clarify whether such tools improve diagnostic accuracy of whole body CT, and concluded that the evidence to support this is limited. All identified studies were retrospective analyses of predictors for CT findings [32, 34, 65, 71]. Davis et al. [65] recorded all findings from clinical examination, including superficial physical signs as bruising, tenderness and swelling. They suggested a decision rule based on physical signs, vital parameters and information about the mechanism of injury. We found that information about a high-energy trauma mechanism increased the odds for being examined with a SWBCT. This is consistent with the recommendations suggested by Davis et al. [65]. To our knowledge, proposed decision rules have not been validated in prospective observational studies or evaluated against alternative strategies, such as immediate SWBCT, in randomized trials.

We found no differences in the use of duplicated CT between patients undergoing SWBCT and those examined with a selective CT strategy, and the frequency of complement examinations in the selective CT examination strategy group was low. The frequency of new findings causing an active intervention was low and not different between the groups. This indicates that the selective strategy practiced by our trauma teams is safe, despite not following a validated decision rule. This is in accordance with some previous studies [23, 63], while other report risk for missing potentially important injuries with this approach [32, 33]. The interpretation of our findings should, however, take into consideration that the use of SWBCT was relatively high (50.7%).

Strengths and limitations

The major strength of the present study is the rigorous registration of all injuries, imaging and interventions in a clinical audit design. Further, it is a strength that the study contribute data from a rural Level 1 trauma centre, which highlights that results from large urban centres cannot be generalized without considering the geographical context.

The most important limitation is the low number of patients, implying a risk for type 2 errors. For example, the true proportion of injuries missed with the selective CT examination strategy could be higher than identified by us. In addition, variables not registered in our study could influence decisions about CT examination strategy. Further, any study of the justification of CT use requires registration of the possible injuries suspected immediately before a CT examination strategy decision is reached. The retrospective design precludes retrieval of such data.

Table 7 Objective clinical parameters in 113 adult patients during trauma admissions, univariable and multivariable logistic regression[a]

Clinical data just before trauma admission CT examination strategy decision	SWBCT ($n = 66$)	Other choices [b] ($n = 47$)	Missing values "SWBCT" group	Missing values "other choices" group	Unadjusted OR (95% CI)	p-value*	Adjusted OR (95% CI)	p-value*
Scale variables	mean (SD)	mean (SD)	n	n				
Age	41.9 (16.9)	40.2 (18.0)	0	0	1.003 (0.981–1.025)	0.799		
Heart rate, beats/minute	86.7 (19.7)	87.1 (21.0)	0	1	0.999 (0.980–1.018)	0.916		
Systolic blood pressure, mmHg	132.2 (26.4)	134.3 (24.3)	0	1	0.997 (0.982–1.012)	0.670		
Shock index (HR/SPB)	0.7 (0.3)	0.7 (0.2)	0	1	1.785 (0.300–10.607)	0.524		
Respiratory rate, breath/minute	19.6 (6.8)	20.0 (4.5)	18	4	0.989 (0.921–1.062)	0.758		
Blood haemoglobin g/dl	14.2 (1.8)	14.5 (1.2)	1	1	0.887 (0.691–1.138)	0.346		
Blood lactate mmol/l	2.2 (1.8)	1.7 (1.4)	22	14	1.220 (0.899–1.656)	0.202		
Blood base excess mmol/l	−2.9 (3.3)	−2.3 (3.8)	19	15	0.953 (0.832–1.091)	0.484		
Minutes from accident to start of first CT	237 (207)	217 (190)	0	11	1.001 (0.998–1.003)	0.626		
Categorical variables	n (%)	n (%)	n	n				
Male sex	55 (83.3)	40 (85.1)	0	0	1.143 (0.407–3.206)	0.800		
GCS < 13 or intubated	22 (33.3)	7 (14.9)	0	0	2.857 (1.103–7.404)	0.031	2.448 (0.912–6.574)	0.076
Positive finding on chest X-ray	17 (25.8)	7 (14.9)	4	7	1.781 (0.663–4.784)	0.252		
Positive finding on pelvic X-ray	7 (10.6)	1 (2.1)	15	14	5.091 (0.596–43.452)	0.137		
Positive EFAST	7 (10.6)	4 (8,5)	10	10	1.179 (0.319–4.348)	0.805		
Transport with physician to trauma admission	46 (69.7)	25 (53.2)	0	0	2.024 (0.931–4.402)	0.075	1.767 (0.785–3.977)	0.169
High energy mechanism of trauma [c], n(%)	17 (25.6)	3 (6.4)	0	0	5.088 (1.396–18.543)	0.014	4.390 (1.174–16.413)	0.028

SWBCT Standardized whole body computer tomography, *CT* Computer tomography, *OR* Odds ratio, *CI* Confidence interval, *SD* standard deviation, [a] excluded 26 children and five adults hemodynamically unstable sent directly to the operation room from the 144 patients included in the study, [b] Other choices (selective CT and no CT), [c] following the trauma activation criteria for mechanism of trauma at the University Hospital of North Norway dichotomized as high or low energy trauma, * statistically significant ($p < 0.05$)

Conclusion

In the present study, most patients had long pre-hospital transportation times, few were admitted with abnormal vital parameters and few were injured in more than two body regions. The CT examination strategy was individualized. The high proportion of patients with no or only minor injuries detected in the SWBCT examination strategy group and the significantly lower use of CT among children, indicate that use of a selective CT examination strategy in a higher proportion of our patients would have approximated the ICRP's justification level three, the individual dose limitation principle, better.

Abbreviations

AIS: Abbreviated Injury Scale; CI: Confidence interval; CT: Computer tomography; ED: emergency department; GCS: Glasgow coma scale; HR: Heart rate; ICRP: International commission on radiological protection; ISS: Injury severity score; mSv: Millisivert; NISS: New ISS; OR: Operating room; PACS: picture archiving and communication system; Q1: lower quartile; Q3: upper quartile; RIS: Radiology information system; RR: respiratory rate; SBP: Systolic blood pressure; SD: Standard deviation; SI: Shock index; SWBCT: Standardized whole body computer tomography; TTA: trauma team activation; UNN: University Hospital of North Norway

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Availability for data and materials

All the important data are included in the article. The corresponding author will be able to answer specific questions about the material upon request but the material is due to the form of a clinical audit not available in other forms.

Authors' contributions

CAB and TI provided literature search. AB and TD provided study design. AB collected and analysed data. All authors participated in data interpretation, drafting of the manuscripts and the critical revision. AB and TI completed the final manuscript. All authors read and approved the final manuscript.

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Consent for publication

Not applicable

Competing interests

The authors declare that they have no competing interests.

Author details

[1]Department of Clinical Medicine, Faculty of Health Science, UiT-The Artic University of Norway, PO box 6050 Langnes, N-9037 Tromsø, Norway. [2]Department of Radiology, University Hospital of North Norway, Sykehusveien 38, PO box 103, N-9038 Tromsø, Norway. [3]Department of Gastrointestinal Surgery, University Hospital of North Norway, PO box 103, N-9038 Tromsø, Norway. [4]Department of Cardiothoracic and Vascular Surgery, University Hospital of North Norway, PO box 103, N-9038 Tromsø, Norway. [5]Centre for Quality Improvements and Development, University Hospital of North Norway, PO box 103, N-9038 Tromsø, Norway. [6]Department of Neurosurgery, ENT and Ophthalmology, University Hospital of North Norway, PO box 103, N-9038 Tromsø, Norway.

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Appendix 1

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44. The family Soleng Bertnes, Signe Forsdahl, Liv-Hege Johnsen, Kurt Gschib, Hege Bratbak, Geir Ingebrigtsen, Bente Kristiansen, Laila Arvola and Ramez Bahar for showing extra interest in my project on regular basis.

Appendix 2

CT MULTITRAUME

(Caput/cervical, thorax/abdomen)

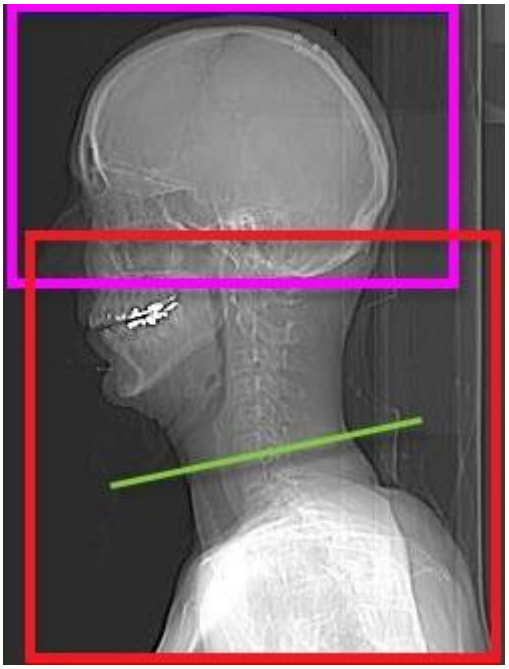
Indikasjon: Multitraume.

Først scannes Caput/Cervicalcolumna, deretter kobler man til kontrast, og scanner Thorax/Abdomen (side 3).

Forberedelse: Gjør klar lab (sjekk O_2, sug, etc). **Grønn** veneflon.

Trekk opp kontrast for thx\abd., skriv inn rekvisisjon og registrer pasient.

NB! Hodet må ikke ligge på bordkanten pga artefakter.



Caput:

Få med hele caput, også bløtdeler.

Nakke:

Kjøres fra øregang tom skuldre.
Axialserien må rekonstrueres slik at vi får frem leddflatene, (Se grønn linje).
Få med mandibula, skuldre, og bløtdeler som f. eks. trachea.

Kontrast:

UTEN ivk

Kommentarer:

Langt Topogram 512 mm.

Autorecon er PÅ på recon 1, både på hodet og nakke.

Disse bildene går automatisk over i PACS for å spare tid.

Bruk stort FOV (500mm) i bredden på scanboksen, slik at skuldrene er med.

Lag VRT av kjeve\ansiktsskader (se neste side).

Scanparametere:

	Pas.posisjon	Spiral/ Flash	Care kV	Care Dose	Ref. mAs	Ref. kV	Dose Slider	Rotasjons tid	Slice Collimation	Pitch
Head	Head first Supine	Spiral	Off	On	390	120	-	1 s	128 x 0,6	0,55
Neck	Head first Supine	Spiral	On	On	195	120	2	1 s	128 x 0,6	0,7

NRPA Referansedose(DLP): *Caput:800 .Ls.col: 400 Thorax: <400. Abdomen: 800*

Rekonstruksjoner:

Caput:

- 3 plan MPR i både bein- og bløt-algoritme.
- Bløt; vinkles som CT Caput, Bein; som CT Bihuler.
- VRT av hode/ansikt/kjeve skal lages i 3D kortet, eller SyngoVia.
- Bruk tynnsnittsserien (0,75/0,4) og "Radial Ranges" til å lage en 360º rotasjon.
- Lag 20 bilder, med 20º mellom hvert bilde.
- Se evt. video **"CT VRT 3D rekonstruksjon Ansikt".**
- Lagre og send bildene til PACS.

Cervical:

- 3 plan MPR bein algoritme. Vinkles etter leddflatene aksialt og coronalt.
- Bruk multispine på recon 4(aksialt). Husk Flexible PÅ.

Caput:

	Snittykkelse/increment	Safire	Algoritme	Fast	Window	Auto send
Head axi	0,75 mm/0,4	5	J 30s medium smooth	På	Cerebrum UNN	P/S
Axi vinkl	4mm/4	2	J 30s medium smooth	På	Cerebrum UNN	P
Coronal	4 mm/4	2	J 30s medium smooth	På	Cerebrum UNN	P
Sagittal	4 mm/4	2	J 30s medium smooth	På	Cerebrum UNN	P
Head axi	2 mm/2	2	J 70h very sharp	På	Beinvindu UNN	P
Sagittal	2 mm/2	2	J 70h very sharp	På	Beinvindu UNN	P
Coronal	2 mm/2	2	J 70h very sharp	På	Beinvindu UNN	P
Head axi	4 mm/4	2	J 30s medium smooth	På	Cerebrum UNN	P

Cervical:

	Snittykkelse/increment	Safire	Algoritme	Fast	Window	Auto send
Neck axial	2 mm/2	2	I 30s medium smooth	På	Spine UNN	P
Sagittal	2 mm/1	2	I 70h very sharp ASA	På	Beinvindu UNN	P
Coronal	2 mm/1	2	I 70h very sharp ASA	På	Beinvindu UNN	P
Multispine*	2 mm/1	2	J 70h very sharp ASA	På	Beinvindu UNN	P
Sagittal	2 mm/2	2	I 30 f medium smooth	På	Larynx UNN	P
Skuldre axial	3 mm/3	2	I 70h very sharp ASA	På	Beinvindu UNN	P
Sagittal	3 mm/3	2	I 70h very sharp ASA	På	Beinvindu UNN	P
Coronal	3 mm/3	2	I 70h very sharp ASA	På	Beinvindu UNN	P

*husk Flexible **PÅ** på multispine.

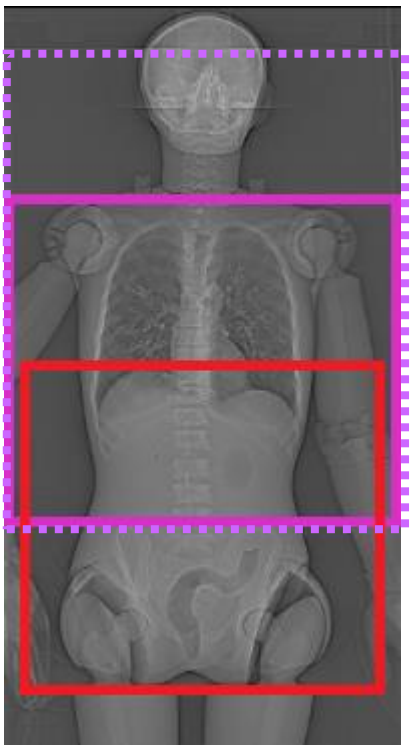
CT TRAUME THORAX/ABDOMEN

Indikasjon: Multitraume.

Forberedelse: **Grønn** veneflon.

- Vurder om traumemadrass kan fjernes ved overflytting.
- Påse at alt metall er fjernet (rett ut evt. slanger og kabler som er festet på pasienten).
- Ved penetrerende skader merk hudskader med binders.
- Det etterstrebes alltid armer over hode ved us. pgr av lavere dose til pasient og mindre artefakter. Armene fikseres over en stor pute på magen hvis armer ikke kan tas over hode.
- Konfererer med traumeleder om halsangio skal kjøres, da alltid armer langs siden.

Thorax:



Delay: 25sek

Dersom CT nakke viser skader, skal halsangio inkluderes i thoraxboksen.

Thorax med halsangio
kjøres f.o.m. circulum vilisi, t.o.m.milt.

Thorax uten halsangio
kjøres fom apex tom milt. Få med bløtdeler/skuldre.

Abdomen:

Delay: 25sek, (totalt ca 60sek).

F.o.m. diafragma, t.o.m. trocanter minor. Få med bløtdeler.

Ved påviste skader i urinveier inkl.blære skal det være en seinserie etter 10 min (lavdose).
Dersom det er mistanke om blæreruptur og pas har urinkateter, kan traumeleder be om at settes kontrast i blære (blandingforhold: 30ml Omnipaque 350 i 500ml NaCl).
Sett minimum 300-400ml, viktig å fylle blæren godt!

Kontrast:

Kontrast 350	NaCl	Flow
120ml	50ml	3,5ml\s

Scanparametere:.

	Pas.posisjon	Spiral/ Flash	Care kV	Care Dose	Ref mAs	Ref kV	Dose Slider	Rotasjons tid	Slice / Collimation	Pitch
Thorax	Head first Supine*	Spiral	On	On	65	120	3	0,5 s	128 x 0,6	1,2
Abdomen	Head first Supine*	Spiral	On	On	160	120	7	0,5 s	128 x 0,6	1,0

**us kan kjøres "Feet first" dersom caput nakke ikke skal taes*

Rekonstruksjoner:

Thorax: 3 plan MPR i bløt algoritme. Aksial plan rekonstrueres også i MIP

	Snittykkelse\ increment	Safire	Algoritme	Fast	Window	Auto send
Thorax	3 mm/1.5	2	I 26f medium smooth ASA	På	Mediastinum UNN	P
Coronal	3 mm/1.5	2	I 26f medium smooth ASA	På	Mediastinum UNN	P
Sagittal	3 mm/1.5	2	I 26f medium smooth ASA	På	Mediastinum UNN	P
MIP thin	10 mm/10	2	I 26f medium smooth ASA	På	Lunge UNN	P
HalsAngio Axial MIP	3mm/3	2	I30 medium smooth	På	CT Angio UNN	P
HalsAngio Cor MIP	3mm/3	2	I30 medium smooth	På	CT Angio UNN	P
HalsAngio Sag MIP	3mm/3	2	I30 medium smooth	På	CT Angio UNN	P
Thorax axi Syngo	1 mm/0.5	5	I 26f medium smooth ASA	På	Mediastinum UNN	P

Abdomen: 3 plan MPR i bløtvev algoritme.

	Snittykkelse/increment	Safire	Algoritme	Fast	Window	Auto send
Abdomen axi	3 mm/3	2	I 26f medium smooth ASA	På	Abdomen UNN	P
Coronal	3 mm/3	2	I 26f medium smooth ASA	På	Abdomen UNN	P
Sagittal	3 mm/3	2	I 26f medium smooth ASA	På	Abdomen UNN	P
Abdomen axi	0,75 mm/0,5	3	I 26f medium smooth ASA	På	Abdomen UNN	S

Abdomen seinserie (10min): 3 plan MPR i bløtvev algoritme.

	Snittykkelse/increment	Safire	Algoritme	Fast	Window	Auto send
Abdomen axi	3 mm/3	2	I 26f medium smooth ASA	På	Abdomen UNN	P
Coronal	3 mm/3	2	I 26f medium smooth ASA	På	Abdomen UNN	P
Sagittal	3 mm/3	2	I 26f medium smooth ASA	På	Abdomen UNN	P
Abdomen axi	0,75 mm/0,5	3	I 26f medium smooth ASA	På	Abdomen UNN	S

- Suppler med rekonstruksjoner i beinalgoritme og beinvindu ved bruddskader i columna, bekken eller skulder/scapula..
  Lag VRT ved kominutte frakturer(brudd med flere fragmenter).

- Bruk kernell I 50f medium sharp ASA for evt. beinrekonstruksjoner. 3\3 snitt.
  Evt. Multispine. Husk å sende bildene til PACS.

- Dersom VRT skal lages, lag en recon i tynne snitt (075/0.4 mm) snitt over aktuelle området.
  Bruk bløt algoritme I 26f medium smooth ASA og Safire 5 for å unngå støy på VRT-bildene.
  Lag en 360º rotasjon (radial ranges). 20º mellom hvert bilde, ca. 20 bilder.
  Husk å sende bildene til PACS.

- Kilder:
    - Traumekurs, Nordic Trauma forum.
    - Ullevål sykehus.

Appendix 3

CT whole body phantom scanning 09.05.18
Using the University Hospital of North Norway's multi trauma protocol

CT whole body Phantom: Kyoto Kagaku co. LTD PBU-60(E), length 165 cm, weight 50 kg

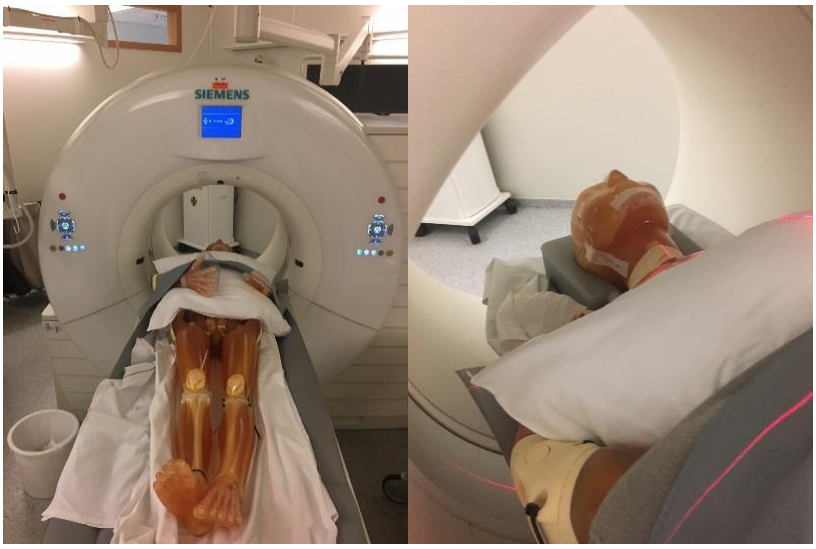
Effective dose estimates by National cancer institute's software for dosimetry the NCICT. Reference: Lee et al. NCICT: A computational solution to estimate organ doses for paediatrics and adult patients undergoing CT scans. J Radiol. Prot. 2015; 35 (4):891-901.

Protocol: University Hospital of North Norway's multi trauma CT protocol. Head first, supine, Spiral (tube A), Slice/collimation 128 x 0.6 (total collimation 38.4). CT head/face and neck scan without intravenous contrast. CT thorax including spleen and liver in arterial contrast phase, abdomen/ pelvis scan with intravenous portal contrast phase. The arms fixed on a pillow on the abdomen, as in patients incapable on lifting their arms above the head. The scan length and scan position where the same in the three machines.

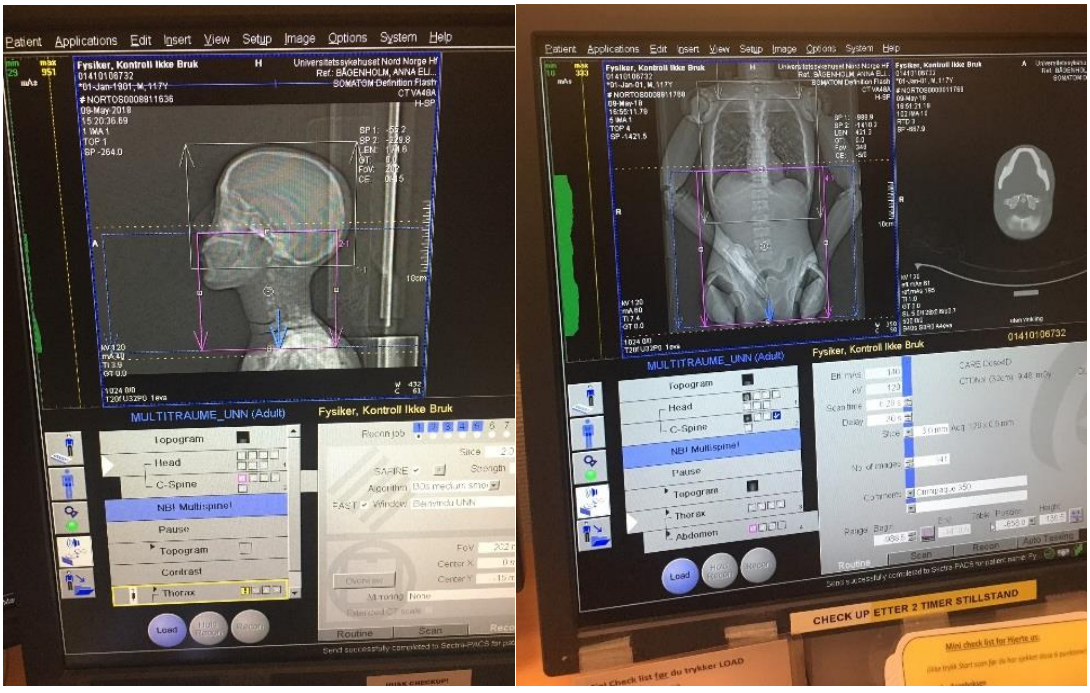
Machine name	Siemens Somatom definition flash.		
CT in room	7	8	12
Installation year	2013	2012	2012
Caput scan			
Care kV	Off	Off	Off
Reference kV-70 kg	120	120	120
kV used	120	120	120
Care dose	On	On	On
Reference mAs -70 kg	390	390	390
Mean mAs used	343	345	336
Reference CTDIvol	59.76	59.76	59.76
CTDIvol used	52.53	52.81	51.42
Dose slider	-	-	-
Rotation time (seconds)	1	1	1
Pitch	0.55	0.55	0.55
DLP (mGycm)	978.7	979.1	959.8
Effective dose (mSv)	1.437	1.437	1.409
Neck scan			
Care kV	On	On	On
Reference kV-70 kg	120	120	120
kV used	120	120	120
Care dose	On	On	On
Reference mAs -70 kg	195	195	195
Mean mAs used	87	92	91
Reference CTDIvol	13.24	13.24	13.24
CTDIvol used	5.9	6.28	6.19
Dose slider	2	2	2
Rotation time (seconds)	1	1	1
Pitch	0.7	0.7	0.7
DLP (mGycm)	114,9	117,9	121,2
Effective dose (mSv)	0.831	1.057	0.98
Chest scan			
Care kV	On	On	On
Reference kV	120	120	120
kV used	100	120	120
Care dose	On	On	On
Protocol mAs -70 kg	107	65	65
Mean mAs used	81	53	54
Reference CTDIvol	4.39	4.39	4.39
CTDIvol used	3,36	3,63	3,66
Dose slider	3	3	3
Rotation time (seconds)	0,5	0,5	0,5
Pitch	1.2	1.2	1.2
DLP (mGycm)	138.8	146.9	149.2
Effective dose (mSv)	2.68	2.774	2.753
Abdomen/pelvic scan			
Care kV	On	On	On
Reference kV-70 kg	120	120	120
kV used	120	120	120
Care dose	On	On	On
Reference mAs -70 kg	160	160	160
Mean mAs used	126	117	128
Reference CTDIvol	10.79	10.79	10.79
CTDIvol used	8.53	7.93	8.64
Dose slider	7	7	7
Rotation time (seconds)	0.5	0.5	0.5

Pitch	1	1	1
DLP (mGycm)	382.6	356.1	387
Effective dose (mSv)	6.173	5.773	6.56
Total examination			
DLP **(**(mGycm, **without scout DLP)**	1615	1617	1600
Effective dose total (mSv)	11.121	11.041	11.702

CT Computer tomography, *kV* kilo Volt, *mAs* milliampere seconds, *CTDIvo*l Volume CT dose index, *DLP* Dose length product



CT whole-body phantom PBU-60 Kyoto Kagaku in scan position in CT machine in room 12 and 7. Machine name Siemens Somatom definition flash. Scan date 09.05.18



Scout view with scan length for CT caput, neck, chest and abdomen/pelvis on CT consol for room 7. Machine name Siemens Somatom definition flash. Scan date 09.05.18

Appendix 4

REK
REGIONALE KOMITEER FOR MEDISINSK OG HELSEFAGLIG FORSKNINGSETIKK

Region: REK nord
Saksbehandler:
Telefon:
Vår dato: 15.12.2014
Vår referanse: 2014/1883/REK nord
Deres dato: 28.10.2014
Deres referanse:

Vår referanse må oppgis ved alle henvendelser

Trond Dehli
Avd. for gastroenterologisk kirurgi

2014/1883 Trauma radiologi i et regionalt traumasystem (Helse Nords Regionale helseforetak)

Vi viser til søknad om forhåndsgodkjenning av ovennevnte forskningsprosjekt. Søknaden ble behandlet av Regional komité for medisinsk og helsefaglig forskningsetikk (REK nord) i møtet 27.11.2014. Vurderingen er gjort med hjemmel i helseforskningsloven § 10, jf. forskningsetikkloven § 4.

Forskningsansvarlig: UNN Tromsø
Prosjektleder: Trond Dehli

Prosjektleders prosjektomtale:
Prospektiv observasjonstudie om den radiologiska diagnostiska utredningen av trauma pasienter som tas emot med traume mottak ved ankomst sykehus i Helse Nord RHF under 1 år. Hoved målet er kvalitetskontroll av de radiologiska undersøkelserne brukt med hovedfocus på bruk av Computer tomografi(CT) pågrunn av dess høye strålebelastning og risk for stråleindusert cancer. Pasientgruppen inkluderer mange unge pasienter som er ekstra strålesensistive. Då bruket av CT har økt kraftig de siste 20 åren pgr av økt tillgjennglighet og vedtatte kriterier for hvordan og når det skal brukes mangler for multitraumapasient gruppen både nasjonellt og internasjonellt er det stort behov av at prøve finne gode data som kan gi veiledning for klinikene når de ska ta beslutt om bruk av ulike radiologiske metoder. Behandlingen og diagnostisken av pasientene som inkluderes i studien påvirkes ikke av studien. Innsamlade data kan redusere strålebelastningen for nye traumepasienter og veilede klinikerne bedre.

Framleggingsplikt
De prosjektene som skal framlegges for REK er prosjekt som dreier seg om "medisinsk og helsefaglig forskning på mennesker, humant biologisk materiale eller helseopplysninger", jf. helseforskningsloven (h) § 2. "Medisinsk og helsefaglig forskning" er i h § 4 a) definert som "virksomhet som utføres med vitenskapelig metodikk for å skaffe til veie ny kunnskap om helse og sykdom". Det er altså formålet med studien som avgjør om et prosjekt skal anses som framleggelsespliktig for REK eller ikke.

Vurdering

Følgende er beskrevet i søknaden: *«Studien er en observasjons kvalitetsikkringstudie av radiologisk behandling og diagnostikk hos pasienter som ikke påvirkes av at studien gjennomføres. Totalanalysen ønskes som grunnlag for å utarbeide kriterer for bruk av Ct hos traumepasienter. Disse kriterer finnes ikke verken nasjonellt eller internasjonellt i skriftlig form. Mange ulike åsikter eksisterer og mange ulike grupper arbeider parrallellt med å finne de rette kriteriene for bruk av strålebelastande undersøkelser versus risk for å overse alvorlig patologi.*
Kvalitetsikringer som dette er en viktig del av det at forbedre helsetjenstene som samfunnet finansierer.»

Selv om dette er en helsefaglig studie og funnene i studien indirekte vil kunne gi en helsemessig gevinst faller ikke prosjektet inn under definisjonen av de prosjekt som skal vurderes etter helseforskningsloven.

Vedtak
Etter søknaden fremstår prosjektet ikke som et medisinsk og helsefaglig forskningsprosjekt som faller innenfor helseforskningsloven. Prosjektet er ikke fremleggingspliktig, jf. hfl § 2 og § 9, samt forskningsetikkloven §4.

Klageadgang
Du kan klage på komiteens vedtak, jf. forvaltningsloven § 28 flg. Klagen sendes til REK nord. Klagefristen er tre uker fra du mottar dette brevet. Dersom vedtaket opprettholdes av REK nord, sendes klagen videre til Den nasjonale forskningsetiske komité for medisin og helsefag for endelig vurdering.

Med vennlig hilsen

May Britt Rossvoll
sekretariatselder

Kopi til:arthur.revhaug@unn.no

Appendix 5

Appendix 5. Summary of time interval data	TA1	TA 2	TA with CT possibility
Time: from the accident to arrival in first hospital (N144)			
Median time in hours (Q1,Q3)	1.82 (0,97, 2.66)		
Number of patients with…			
observation time < 1,5 hours from accident to TA1	55 (38.2%)		
observation time 1,5-5 hours from accident to TA1	76 (52.8%)		
observation time > 5 hours from accident to TA1	13 (9%)		
Patients arriving within 1 hour after the accident	*37 (25.7%)*		
Time: from the accident to arrival at UNN for transferred patients (N36)			
Median time from the accident to TA2 at UNN in hours (Q1, Q3)		8.25 (6.17, 12.30)	
Time: from accident to arrival at a hospital with CT examination possibility (N144)			
Median time in hours (Q1,Q3)			1.94 (1.00, 2.75)
Number of patients with…			
observation time <1,5 hours			52 (36.1%)
observation time 1,5-5 hours			71 (49.3%)
observation time > 5 hours			21 (14.6%)
Patients arriving within 1 hour after the accident			*36 (25.0%)*
Time: from the accident to start of the first CT examination (N116)			
Median time in hours (Q1, Q3)			2.65 (1.83, 4.01)
Number of patients with…			
observation time < 1,5 hours			20 (17.2%)
observation time 1,5-5 hours			73 (62.9%)
observation time > 5 hours			23 (19.8%)
Patients without CT in TA (N144)			28 (19.4%)
Patients with CT arriving within 1 hour after the accident			*6 (4.2%)*
Patients with CT arriving within 0.5 hours after the accident			*0 (0.0%)*
Time: from admission with first CT possibility to start of first CT			
Median time in hours (Q1, Q3)			*0.72 (0.60, 0.95)*

TA1 trauma admittance 1, *TA2* trauma admittance 2, *CT* Computer tomography, *Q1* lower quartile, *Q3* upper quartile, *UNN* University hospital of north Norway

Appendix 6

Association between patient body-core temperature, in trauma admission 1 and the lactate level in mmol/L (measured just before the CT decision). Illustrated in diagrams presenting the patient group surviving (Figure A) or not (Figure B). The reference line for normal/abnormal lactate level is inserted (≤ 1.8 mmol/L) in both diagrams. The breakpoint value is the one used at the University hospital of north Norway.

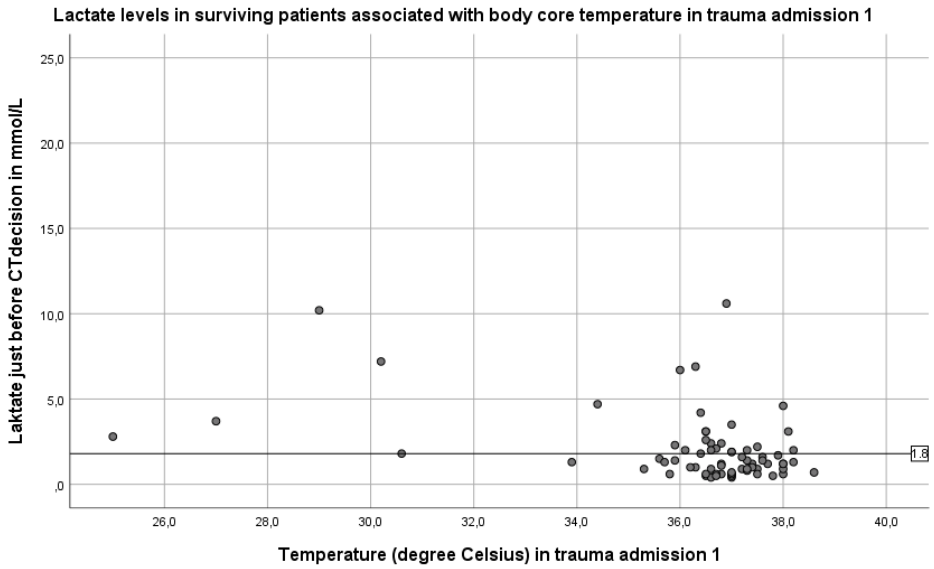


Figure A (the surviving patients, reference line = ≤ 1.8 mmol/L)

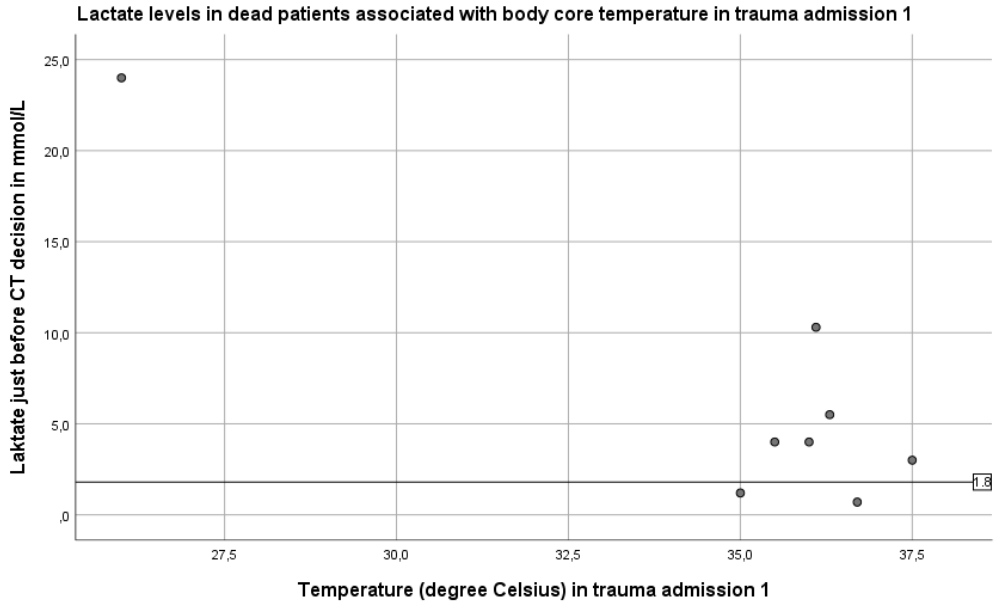


Figure B (the non-surviving patients, reference line = ≤ 1.8 mmol/L)