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IMAGING OF SEVERE THORACIC TRAUMA

with special focus on costal cartilage fractures and penetrating thoracic trauma

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DOCTORAL DISSERTATION

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ABSTRACT

Radiologists are familiar with identifying rib fractures and coinciding injuries in chest trauma patients. However, costal cartilage fractures (CCFX) are not as known among radiologists or clinicians. In study I we investigated the incidence of CCFX in blunt chest trauma patients in the largest level I trauma center in Finland. CCFXs contribute to anterior chest wall instability and may remain symptomatic months and years after trauma. The incidence of CCFX among chest trauma patients was 19.9%, and in all trauma patients 7.8%. A total of 221 CCFXs in 114 patients were found in trauma CT (computed tomography) studies over a 3-year period. CCFXs were associated with high trauma energy, and major coinciding injuries (multiple rib fractures, blunt aortic injury, liver laceration).

The existing literature is sparse on CCFX and their healing process. In study II we summoned patients with previously diagnosed CCFX for a clinical and radiological follow-up study. A total of 21 patients voluntarily participated in the study. Multimodality imaging (ultra-low-dose-CT, MRI and US) was performed at an average of 34 months after initial trauma. Most of the fractures had healed, but four patients (19%) reported persistent symptoms. Cross-sectional imaging with CT or MRI, and a combination of clinical and radiological workup aided in overall evaluation of patients with posttraumatic symptoms and findings from CCFX.

Studies III and IV focused on penetrating trauma, a far less common entity than blunt trauma in the Nordic countries. Penetrating trauma features are crucial to identify for all on-call radiologists. Stab wounds (SW) are more commonly seen than gun shot wounds (GSW), yet the incidence of gun violence has increased during the last decades. Patients with penetrating injuries were identified from trauma registry data in Traumacentrum Karolinska, Stockholm. In study III, the spectrum of injuries and imaging findings of penetrating chest trauma were discussed. Regarding the penetrating injury site, caution for injury to adjacent body compartment and imaging techniques to exclude vascular injury were described. GSW patients had higher injury severity scores than SW patients, and were more likely to undergo emergency surgery on arrival (OR 5.5 (95% CI 1.22 – 24.81)).

In study IV, the value and use of postoperative CT within 48 hours after emergency surgery in penetrating trauma patients was evaluated. In this 7-year cohort, 38 patients met the study criteria. Of these, 20 patients (52.6%) had additional findings in postoperative CT. Based on the imaging findings, six patients (15.8%) required further surgical or angiographic treatment for their injuries. Benefits of WBCT (whole body computed tomography) imaging after emergency surgery include detecting unexpected injuries in and outside the surgical field, discovering potential surgical complications and active bleeding.

LYHENNELMÄ

Kylkiluunmurtumat ja niiden liitännäisvammat ovat tavanomaisia löydöksiä rintakehävammapotilailla. Kylkirustomurtumat (KRM) sen sijaan ovat vähemmän tunnettuja niin radiologien kuin potilaita hoitavien lääkäreiden keskuudessa. Väitöskirjan ensimmäisessä osatyössä (I) selvitettiin KRM:n esiintyvyyttä tylpän vamman saaneilla potilailla suurimmassa suomalaisessa tason I traumakeskuksessa. Kylkirustomurtuma lisää osaltaan rintakehän etuseinämän epävakautta, ja murtuma voi olla oireinen kuukausia tai vuosia alkuperäisen vamman jälkeen.

Kylkirustomurtumien esiintyvyys oli 19.9 % tylpän rintakehävamman saaneilla ja 7.8 % kaikilla tylpän vamman saaneilla potilailla. Kokonaisuudessaan 221 KRM:a löytyi 114:ltä potilaalta TT-kuvauksessa (tietokonetomografia) kolmen vuoden tarkastelujakson aikana. Kylkirustomurtumat olivat yhteydessä korkeaan vammaenergiaan ja vakaviin samanaikaisesti esiintyviin vammoihin (sarjakylkiluunmurtumat, aortta- ja maksavammat).

Kylkirustomurtumia ja niiden paranemista käsittelevä kirjallisuus on niukkaa. Toisessa osatyössä (II) jo aiemmin todettuja KRM-potilaita kutsuttiin kliiniseen ja radiologiseen seurantatutkimukseen. Vapaaehtoiseen tutkimukseen osallistui 21 potilasta. Potilaat tutkittiin toisiaan täydentävillä kuvantamismetelmillä (erittäin-matala-annoksinen-TT, magneettikuvaus ja ultraääni) n. 34 kuukautta alkuperäisen vamman jälkeen. Suurin osa murtumista oli parantunut oireettomiksi, mutta neljä potilasta (19 %) raportoi edelleen jatkuvista oireista. Leikekuvantaminen TT- ja magneettikuvauksella – sekä kuvantamisen ja kliinisen tutkimuksen yhdistäminen – auttoi kokonaiskäsityksen saamisessa ja KRM-potilaiden vammaperäisten oireiden ja löydösten arvioinnissa.

Kaksi viimeistä osatyötä (III ja IV) keskittyvät lävistäviin vammoihin, jotka ovat esiintyvyydeltään huomattavasti tylppiä vammoja harvinaisempia Pohjoismaissa. Lävistävien vammojen erityispiirteiden tunteminen on ensisijaisen tärkeää päivystäville radiologeille. Puukotukset ovat yleisempiä kuin ampumavammat, mutta ampumavammojenkin esiintyvyys on kasvanut Pohjoismaissa viimeisten vuosikymmenten aikana.

Lävistävän vamman saaneet potilaat kerättiin Karoliinisen Yliopistosairaalan traumarekisteristä (TCK, Tukholma). Osatyössä III kuvattiin lävistävien rintakehävammojen vammakirjoa ja kuvantamislöydöksiä. Vamman sijaintiin nähden viereisen ruumiinontelon vaurioitumista ja verisuonivammojen kuvantamistekniikkaa selvitettiin. Ampuvammapotilaat olivat vaikeammin loukkaantuneita kuin puukotusvammapotilaat, ja heille oli myös todennäköisempää päätyä hätäleikkaukseen heti sairaalaan saavuttuaan (OR 5.5 (95% CI 1.22 – 24.81)).

Osatyössä IV tutkittiin lävistävän vammaan saaneen potilaan hätäleikkauksen jälkeisen, 48:n tunnin aikaikkunan sisällä tehdyn TT-kuvantamisen käyttöä ja arvoa. Seitsemän vuoden tarkasteluajanjaksolta kerätyssä potilasryhmässä 38 potilasta täytti mukaanottokriteerit. Kahdellakymmenellä potilaalla (52.6%) todettiin uusia löydöksiä leikkauksen jälkeisessä koko vartalon TT-kuvauksessa. Näistä kuudella (15.8%) kuvantamisessa löydetty vamma tai muutos johti uuteen kirurgiseen tai toimenpideradiologiseen hoitoon. Hätäleikkauksen jälkeisen kuvantamisen hyötyihin lukeutuvat leikkausalueen ja sen ulkopuolisten odottamattomien vammojen löytäminen, mahdollisten leikkauskomplikaatioiden, sekä ei-tyrehtyneiden verenvuotojen löytäminen.

LIST OF ORIGINAL PUBLICATIONS

This thesis is based on the following publications, which are referred to in the text by their Roman numerals I-IV:

I **Nummela MT**, Bensch FV, Pyhältö TT, Koskinen SK. Incidence and Imaging Findings of Costal Cartilage Fractures in Patients with Blunt Chest Trauma: A Retrospective Review of 1461 Consecutive Whole-Body CT Examinations for Trauma. Radiology. 2018 Feb;286(2):696-704. doi: 10.1148/radiol.2017162429. Epub 2017 Nov 2. PMID: 29095676.

II **Nummela MT**, Pyhältö TT, Bensch FV, Heinänen MT, Koskinen SK. Costal cartilage fractures in blunt polytrauma patients - a prospective clinical and radiological follow-up study. Emerg Radiol. 2022 Jun 4. doi: 10.1007/s10140-022-02066-w. Epub ahead of print. PMID: 35661281.

III **Nummela MT**, Thorisdottir S, Oladottir GL, Koskinen SK. Imaging of penetrating thoracic trauma in a large Nordic trauma center. Acta Radiol Open. 2019 Dec 20;8(12):2058460119895485. doi: 10.1177/2058460119895485. PMID: 31903225; PMCID: PMC6926989.

IV Halldorsson K, **Nummela M**, Thorisdottir S, Oladottir G, Koskinen S. CT after emergency surgery in penetrating trauma: a seven-year experience in a level I Nordic trauma center. Acta Radiol. 2022 May 3:2841851221094966. doi: 10.1177/02841851221094966. Epub ahead of print. PMID: 35502810.

ABBREVIATIONS

CCFX	costal cartilage fracture
CI	confidence interval
CT	computed tomography
CTA	computed tomography angiography
ER	emergency room
GSW	gun shot wound
ICD-10	WHO International Classification of Diseases and Related Health Problems, 10th revision
ICU	intensive care unit
ICU-LOS	intensive care unit length of stay
IOA	interobserver agreement
IRB	Institutional Review Board
ISS	Injury Severity Score
LOS	lenght of stay
MBiR	Model based iterative reconstruction
MIP	maximum intensity projection
MOI	mechanism of injury
MRI	magnetic resonance imaging
NISS	New Injury Severity Score
OR	odds ratio
PACS	Picture Archiving and Communication System
POA	proportion of agreement
QoL	quality of life
RAND-36	a dedicated QoL questionnaire from the RAND company
ROM	range of motion
STIR	short tau inversion recovery
SW	stab wound
TCK	Traumacentrum Karolinska
TIRM	turbo inversion recovery magnitude
ULD-CT	ultra-low-dose-computed-tomography
WBCT	whole-body-computed-tomography

1 INTRODUCTION

The rib cage consists of twelve paired ribs, of which ribs 1 to 7 are attached anteriorly to the sternum. Sternum consists of two parts, manubrium and body. In between these two parts is the manubriosternal junction, that sometimes ossifies. Ribs 8 to 10 have a shared cartilage in the subcostal angle, and ribs 11 and 12 are so called floating ribs, without the anterior attachment (Fig. 1). (1)

Rib 1 forms a synchondrosis with the manubrium of sternum. This synchondrosis can be open with a cleft like appearance, or it can ossify to a rigid union. The cleft (if open) has often degenerative osseous spurs on its edges and air inside the cleft. These qualities make it sometimes hard to determine, whether an acute injury is present. (2,3)

Ribs 2 – 7 form a synovial joint with the sternum, that is covered with strong ligaments to hold the joint in place. Rib 2 forms the joint usually at the junction on manubrium and the body of sternum, and ribs 3 – 7 to the body of sternum.

Ribs 8 to 10 have a shared piece of cartilage at subcostal angle that varies in appearance. The cartilage forms a union to the adjacent cartilage, not to the sternum itself. This subcostal angle is formed with extensive segments of cartilage, and often the fracture is located here in the lower part of the thoracic cage.

The costal cartilage is covered by perichondrium, which allows blood supply to the underlying cartilage tissue. Sternochondral joints allow the flexible movement for the anterior chest wall during breathing cycle. (4)

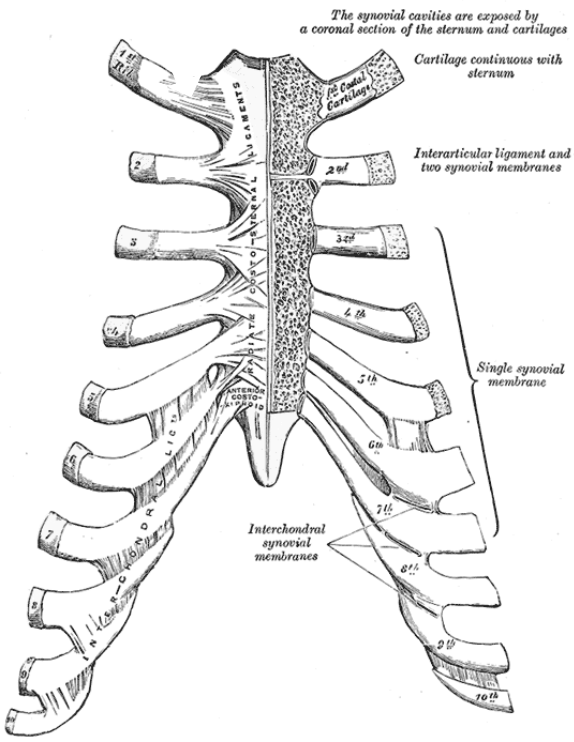


Figure 1 An illustration of the costal cartilages and their attachment to the sternum. Original diagram from Gray's Anatomy 20th US edition. (https://commons.wikimedia.org/wiki/File:Gray315.png)

The rib cage is a flexible structure that allows respiratory movements, and protects the vital organs of thorax and upper abdomen; heart, lungs, aorta liver, spleen and kidneys. Blunt chest trauma is common, and chest injuries are a major source of morbidity and mortality in polytrauma patients. (5–10) Among other injuries, rib fractures are diagnosed with chest radiographs or trauma WBCT (11–16). Cross sectional imaging with CT or MRI allows the detection of anterior chest wall injuries including sternum and anterior rib fractures, but also costal cartilage fractures (CCFX). (17,18)

Costochondral fractures may remain overlooked (17), and have in recent years gained more attention among radiologists and clinicians alike. The ICD-10 classification does not separate CCFX on its own, but instead it falls under the category of osseous rib fractures (19). As such, CCFX remains outside of structured statistical coding in trauma registry data. Also, there is an ongoing effort to find consensus in nomenclature for CCFX based on anatomic location (20).

Costochondral fractures add to the chest trauma burden. If there are multiple fractures or CCFX are coinciding with rib fractures, the formation of

a flail segment may result in chest wall instability and cause significant pain and discomfort. As such, trauma radiologists must carefully look for CCFX in addition to other injuries in chest trauma patients. CCFX can also occur as isolated injuries in direct blunt trauma, and have previously been acknowledged in case reports as sports injuries. (21–25)

The sequalae of chest wall injuries include the development of respiratory distress, pneumonia, empyema and chest wall deformity (26–28). Knowledge of the overall spectrum of chest wall injury aids the trauma surgeon in charge of patient management, to assess the situation thoroughly and decide on the proper course of action and treatment. As the rib cage cannot be entirely immobilized for the recuperation period, proper analgesia and assisted ventilation play a crucial role in managing these patients. In most severe cases even surgical rib fixation may be called for. (29–34)

The healing process of CCFX is not completely known and the data on this matter is sparse. (17,35) Chronic injuries present as vertical dense calcifications on the fracture site in subsequent images, such as thoracoabdominopelvic CT studies. Sometimes we overlook these findings that are right in front of our eyes, and reveal previously occurred injuries.

Penetrating trauma is far more infrequently encountered in Nordic trauma centers than blunt trauma (36–42). Some patients may succumb before reaching the hospital. In general, violent crimes are less frequent in the Nordic countries than for example in the United States or South Africa. Most commonly used weapon is a knife, although gun shot injuries have increased due to organized crime violence and acts of terror and war in Europe over the past decade. In the most sinister chain of events, a mass casualty incident can bring to emergency departments a sudden influx of patients with a mix of multiple co-existing injuries. (43–46)

The spectrum of penetrating trauma should be familiar to all on-call and trauma radiologists regardless of where we work. Penetrating trauma follows different patterns than blunt trauma and often catches radiologists off guard (47–51). The protective rib cage is not enough to hold the heart or aorta unharmed, as the wound trajectory depends on the weapon used and force implied. The tip of a knife may reach the pericardium and injure the cardiac structures, or the ricochets of a bullet can create an unexpected trajectory inside the rib cage. (52–54)

To prepare for diagnosing penetrating trauma in sudden occasions, our CT protocols should be standardized to avoid any confusion, and based on published data of state-of-the-art imaging (15,53). Diagnosis of active bleeding requires imaging with intravenous contrast media, and preferably multiphase imaging to show active extravasation over time (55–57). In life threatening injuries, the increased radiation dose of multiphase imaging should not raise undue concern or dictate the choice of protocol. (15,49,53,58)

Hemodynamically unstable penetrating trauma patients may have to be rushed straight to operating room for life saving surgery (59,60). The initial trauma survey that usually includes a thorough CT evaluation, can also be

performed postoperatively (61,62). Imaging aids in identifying all traumatic injuries; injuries inside and outside the surgical field, ongoing bleeding, and potential complications of the emergency surgery.

In some cases, the non-life-threathening but none the less attention acquiring injuries are found only after the acute situation has resolved. These can include solid organ injuries and skeletal injuries (62). The radiology report can create a roadmap for the surgeon in determining following steps in trauma patient management, whether further intervention is needed or conservative management can be relied on. At the moment, postoperative imaging after emergency surgery is not a standard procedure in all trauma centers. However, it should be considered as an overall assessment in the same way as WBCT has become a widely accepted and implemented routine in severe blunt trauma evaluation (13,15,55,57).

This thesis focuses on two topics within imaging of severe thoracic trauma. First, to explore costal cartilage fractures; the incidence, imaging features and comorbidities of this fairly unknown injury type (I and II). Second is to investigate imaging features of rarely encountered penetrating thoracic trauma in Nordic countries, including the utility of postoperative CT imaging following emergency surgery (III and IV).

2 REVIEW OF THE LITERATURE

2.1 COSTAL CARTILAGE FRACTURES

Rib fracture is a well known injury (12,63–65), and it has been shown that multiple rib fractures may result in a worse outcome especially among elderly patients (66,67). Radiological diagnosis of CCFX has been described roughly 20 years ago, in a study about their appearance on CT and sonography in eight patients (17) and the MRI appearance in a small series of 13 patients (68). CCFX have been described in many contact sports related case reports (21–23,25,69,70). Larger series of CCFX patients remain scarce. An examplatory axial CT image of a CCFX is shown below (Fig. 2).

The healing process of CCFX is not well established. As the costal cartilage is covered with perichondrium, it is propable that the healing is more favourable than in joints, where the articular cartilage lacks blood supply. A study from 2007 on mice showed, that the union of a healed cartilage was not stable at the time point of 12 weeks (35). The numerous case reports of CCFX, related mainly to sports injuries, have described nonhealed injuries that caused prolonged symptoms and discomfort (24,71,72).

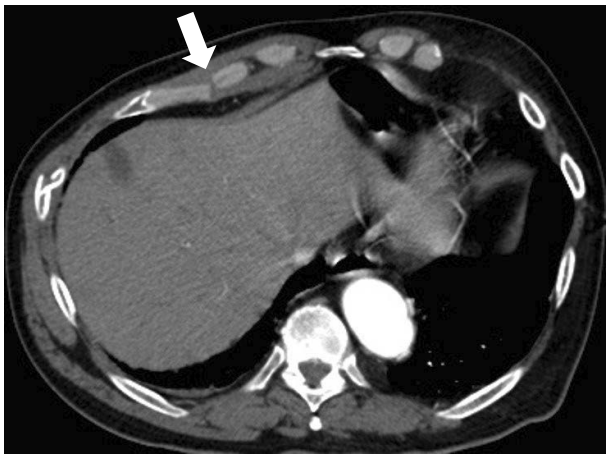


Figure 2 An axial CT-image reveals a traumatic costal cartilage fracture on the right (arrow). The anterior chest wall is slighty depressed on the right due to the multiple rib and cartilage fractures.

2.1.1 IMAGING OF COSTAL CARTILAGE FRACTURES

Costal cartilage fractures can be detected with cross sectional imaging (MRI, CT) and sonography (17,68,73–75). Plain radiopraphs do not reveal CCFX, and thus the anterior chest wall injury may remain undetected (75,76). In contact sports, MRI has been the modality of choice in diagnosing cartilage injuries, but CT can also be used (21,25). Sonography shows the fracture line and the degree of fracture dislocation, and can also be used as a dynamic study with sonopalpation to discover persistent movement on the fracture site (75).

In addition to cartilage anatomy, fractures and fragment displacement, CT reveals calcifications in the costal cartilages. Physiological calcifications differ in form and distribution according to patient age and gender (77,78). This feature has been used in forensic medicine to determine the sex or age of a patient (79).

MRI can be used to identify the fracture line, and also to determine if there is persistent edema on the fracture site (68). Image quality may be compromised by the artifacts from breathing motions and underlying air in the lung tissue. Prone positioning reduces artifacts from chest wall movement. (80)

2.1.2 CLINICAL ASPECTS

Costal cartilage fracture can remain symptomatic, and cause a palpable mass on the chest (81). In some case reports, even a hepatic injury has resulted from a subcostal injury (22). Many CCFX case reports are related to contact sports, including wrestling, American football, weight lifting and rugby. (21,25,68,82) In blunt trauma patients, small patient series of trauma related chest pain revealed to originate from a previous CCFX (17).

2.1.3 TRAUMA REGISTRY DATA

Trauma registry data consists of structured reporting of clinical parametres and injury classifications. Injuries are reported with AIS (abbreviated injury scale) codes (83) according to a specific dictionary (84). Trauma registry entries are made by trained nurses who have the specific and unified skills to accurately collect the data. For chest trauma, the AIS score does not differentiate CCFX, but the presence of rib fractures, sternal fracture, flail chest and haemo/pneumothorax, haemo/pneumomediastinum are noted. If CCFX is mentioned in the radiology report, it could be counted parallel to a rib fracture. Injury severity score and new injury severity score (ISS and NISS) are also included to describe the trauma burden in each patient. Major trauma is determined as ISS/NISS score of ≥16. (85)

2.1.4 NOMENCLATURE AND REPORTING

In 2000, Malghem et al. study classified CCFX by location to 1) “chondrosternal junction” or 2) “chondrocostal junction” in the first rib, and 3) the “middle region of the costal cartilage” in other ribs. In a study conducted by Subhas et al (2008) majority of injuries were junctional injuries: involving the “sternochondral junction” or “costochondral junction”. No injuries affecting the middle part of the cartilage were reported.

In a 2016 study about professional American football players (McAdams et al.) CCFX were referred to as “chondral rib fractures”. Occasionally “costochondral fracture” and “costal cartilage fracture” have been used as synonyms. This cross use of terms can create confusion as “costochondral” may also refer to a lateral fracture near the costochondral junction. Some native English speakers would argue whether for example “chondrosternal” or “sternochondral” rolls of the tongue more easily, or whether one or the other is grammatically more correct.

2.1.4.1 ICD 10 codes

The ICD-10 classification does not differentiate CCFX as a separate injury, but instead it falls under the category of osseous rib fracture, S22.3, or multiple rib fractures S22.4. Unspesicified injury of thorax S29.9 can also be used. Costochondritis (Tietze’s syndrome) M94.0 and costal cartilage sprain S23.4 are recognized as their own entities (Fig. 3-4).(19)

The new revised ICD 11 coding does not include CCFX, it has been published in January 2023 (86). The new revised version has not yet been clinically implemented at our hospital.

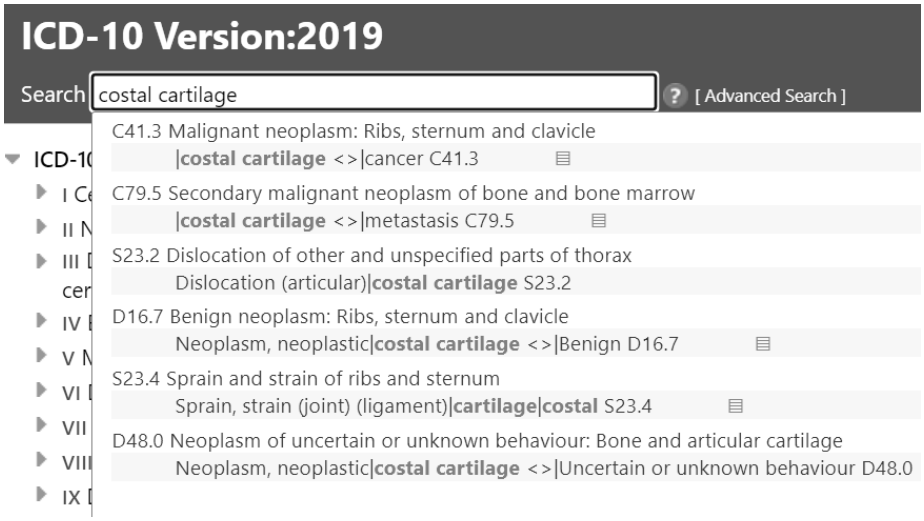


Figure 3 Search results for key word “costal cartilage” in ICD 10 database. Costal cartilage fracture is not listed. https://icd.who.int/browse10/2019/en

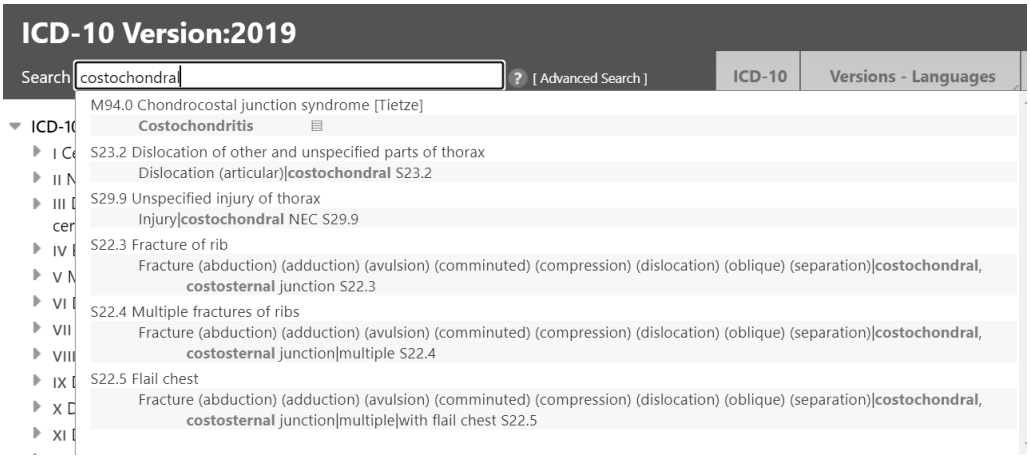


Figure 4 Search results for key word “costochondral” in ICD 10 database. https://icd.who.int/browse10/2019/en

2.2 PENETRATING THORACIC TRAUMA

Traditionally, stab wound injuries have been more common than gun shot wounds in the Nordic countries (36,41). The incidence of firearm injuries has increased in Sweden, and additionally a rise in vascular injury occurrence was noted during a study period between 2005 and 2016 (40). Penetrating injuries may pose a challenge for the on-call radiologist, since penetrating trauma is far more rarely encountered in the ER than blunt trauma. In penetrating trauma, the role of vascular injuries, solid organ injuries and hollow viscus injuries is highlighted (49,52,62).

2.2.1 PENETRATING INJURY TYPES

2.2.1.1 Stab wounds (SW)

Stabbing incidents commonly occur among young men acting under the influence of alcohol (36). If the stab injury affects the heart or major vessels in the thoracic cavity, patient may succumb on scene. The scale of injuries depends on the type of knife used, width and length of the blade, level of force and degree of intent. Vascular injury often results in active bleeding and exposes the patient to life risk. Terrorist attacks tend to be more severe than random acts of violence, due to the intent to cause as much harm as possible, and to as many people as possible. (47,87–89)

On CT imaging, SWs may be very subtle as the wound closes after impact. Wound marking is therefore essential in pointing out the injuries, especially if there are multiple wounds. The marked entry sites guide the radiologist in defining all injuries. Vitamin E-capsules can be used to mark the wounds as they do not create artifacts in images and can be easily identified (Bellou S, Beckman MO, Sundin A. Penetrating trauma and the usage of E-vitamin capsules. Scientific poster at 25th Annual Meeting of American Society of Emergency Radiology (ASER), Cambridge, MA, USA, 9–12 October)

Wound marking is also crucial for second readings, when the patient has possibly been already released from care and is no longer available for clinical status control. If the referral text is not thorough in description, it might be impossible for the second reader to evaluate the course of events solely from tissue injuries.

2.2.1.2 Gun shot wounds (GSW)

Gun shot wounds vary greatly due to the different weapons and ammunition used. The impact of the bullet or shrapnels causes direct tissue damage, but also creates a secondary cavity where the injury may present significantly larger than originally anticipated. Bullet velocity and the range from where the shot was fired also impacts the end result. (90,91) The affected tissue plays a significant part; a bullet may go through lung tissue with fairly little damage in comparison to ricochet from bone structures that creates diverted wound tracts. Shot gun ammunition creates multiple wounds with several small pellets entering the tissues. Appearance and distribution of pellets are usually well observed in the CT scout images.

Wound marking is important in GSWs as it allows the retained or dislodged bullets to be counted. Both entry and exit wounds should be marked. Not all shrapnels or bullets are surgically removed (92,93). The detailed description of retained foreign bodies is also important regarding follow up imaging years later; especially in MRI for safety reasons, but also in CT due to the artifacts they create (94,95). In forensic medicine, CT has been used to evaluate gunshot residue, shooting distance, bullet trajectory, and retained bullet fragments. (96)

2.2.1.3 Other types of penetrating injuries

Impalement is an injury type that can be seen for example in contact with yard fences, industry machines and tools, and construction sites (reinforcement bars). Self inflicted injuries include penetrating injuries with pens, pieces of glass, metal wire or other sharp objects found in every home.

In terrorist attacks, a common weapon is an improvised explosive device (IED): a self-made bomb with a large volume of metallic pieces as ammunition (nails, screws, pieces of metal) that penetrate clothes and tissues

during the explosion. (97) In some cases, also pieces of other victims' tissues (especially bone), gravel, wood or other debris from the environment may enter the patient's tissues.

2.2.2 POSTOPERATIVE IMAGING

Unstable patients entering the ER may be directly transferred to operating room in case a massive bleed, cardiac tamponade or other immediate life threathening injury is suspected. In some cases surgical intervention is required immediately in the ER (93). Entering the operating room for emergency surgery, these patients skip the routinely performed whole body CT scan on arrival. There is an ongoing discussion, whether postoperative CT imaging would bring added value to patient management.

In a 2016 study, Haste et al. published a cohort of 90 patients (both blunt and penetrating trauma), who were scanned with abdominopelvic CT within 48 hours of emergency surgery (62). Majority on patients suffered from penetrating trauma (82%), and 21% had additional findings in the surgical field, that were not identified in laparotomy. Solid organ injuries were found in 17 patients, and 11 patients had persistent active bleeding. In eight patients (8.9%), the newly discovered findings in CT resulted in additional surgery or angiographic intervention. One diaphragmatic injury and one spinal canal violation was also noted, as well as a variety of skeletal injuries in 56 patients 62.2%). These results showed the benefit of immediate postoperative imaging both within and outside of the surgical field.

Mendoza et al. (2017) investigated the use of postoperative CT after recent operative exploration for penetrating trauma. Of the 225 patients who met the inclusion criteria, 73 (32%) underwent postoperative CT scanning. Occult injuries were identified in 38 (52%) of the imaged patients. The newly detected injuries were mainly orthopedic and genitourinary. Ten (26%) of the 38 patients required additional intervention (98).

Additional injuries may also present themselves clinically, yet thorough investigation with CT would provide a comprehensive evaluation of the patient's situation. The radiation dose from imaging is justified as severe trauma, and emergency surgery itself expose the patient to complications and risk of death. (99–102)

3 AIMS OF THE STUDY

I COSTAL CARTILAGE FRACTURES

To evaluate incidence and imaging findings of costal cartilage fractures in whole-body-CT studies of blunt chest trauma patients.

II FOLLOW-UP OF COSTAL CARTILAGE FRACTURES

To examine the posttraumatic changes of previously diagnosed costal cartilage fractures with follow-up imaging, clinical status control and quality of life questionnaires.

III PENETRATING CHEST TRAUMA

To evaluate the imaging protocols, injury spectrum and outcome in penetrating chest trauma in a large Nordic trauma center.

IV CT AFTER EMERGENCY SURGERY IN PENETRATING TRAUMA

To determine the utility and benefits of postoperative whole-body-CT studies in penetrating trauma patients, who underwent emergency surgery on arrival.

4 MATERIALS AND METHODS

4.1 COSTAL CARTILAGE FRACTURES (I)

A retrospective study was designed to determine the incidence of costal cartilage fractures (CCFX) in blunt trauma patients in a level I trauma center over a three-year period (years 2013 – 2015). Included were patients aged 18 years and older that were admitted in the Töölö Trauma Center emergency unit and underwent WBCT for trauma. These WBCT studies were manually searched from hospital PACS (Picture Archiving and Communication System), and meticulously evaluated to find CCFX. No threshold for Injury severity score (ISS) was used in patient selection. Patients were categorized as no trauma, chest trauma and other than chest trauma. All patients with penetrating injuries were excluded.

Of the 1461 patients included in the initial evaluation, 574 (39.3%) had signs of thoracic trauma (74.0% male/26.0% female). This thoracic trauma cohort was independently reviewed by a second reader blinded to preliminary results and initial reports. Thoracic trauma subgroup was further divided in "thoracic trauma with CCFX" group and "thoracic trauma without CCFX" group.

The anatomical location and distribution of CCFX was evaluated, and the fractures were classified by location to medial (chondrosternal, CS), central (midchondral, MC) or lateral (costochondral, CC) (Fig. 5). In addition, concomitant injuries, mechanism of injury and effect on 30-day mortality were evaluated. The initial reports were examined to determine accuracy of cartilage fracture detection. x^2 and odds ratios (ORs) with 95% confidence intervals (CIs) were used to compare the two chest trauma groups, patients with and without CCFX. Interobserver agreement was described with Cohen kappa values. SAS/STAT software (SAS/STAT, version 9.3; SAS Institute, Cary, NC) was used for statistical analysis.

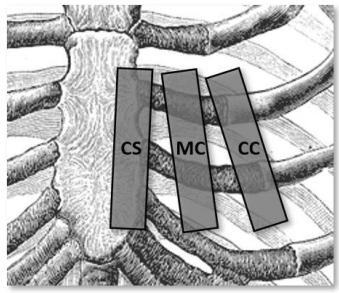


Figure 5 *Costal cartilage fractures were classified by anatomical location to medial (chondrosternal, CS), central (midchondral), MC) or lateral (costochondral, CC).*

4.2 FOLLOW UP OF COSTAL CARTILAGE FRACTURES (II)

The prospective study design was approved by the IRB. Patients with identified CCFXs on WBCT for trauma (from study I) were invited to voluntarily participate in a clinical and radiological follow-up study. Additionally, more recent cases (year 2016) were added to the invitation list to create chronological variation between initial trauma and follow-up images. Hospital PACS system was used to identify the cases.

Letters were sent to 75 patients via regular mail. Of the original cohort of 114 patients, 61 were invited, and 16 participated (26.2%, 16/61). To include more recent cases from 2016, 14 patients were invited and 5 participated (28.6%, 5/14).

All recruited patients underwent ULD-CT, MR and sonography examinations of thorax, and all images were interpreted separately by two radiologists. MR imaging consisted of five obtained sequences (Table 1). Image orientation was coronal oblique (Fig. 6), and axial images were perpendicular to this orientation.

A clinical status control was performed by an experienced trauma surgeon. In addition, patients filled QoL questionnaires. A dedicated Helsinki Chest Trauma questionnaire was created by the authors to include specific symptoms from blunt chest trauma. RAND-36 QoL questionnaire was used as a standardized generalized form to potentially compare the results with other patient groups. RAND name originated as a "contraction of research and development" from the RAND corporation. RAND began in 1946 as a research project (Project RAND) backed by a single client, the U.S. Army Air Forces. (rand.org/about). Interobserver agreement (IOA) was assessed with Cohen's kappa, and proportion of agreement (POA) was used for testing agreement in dichotomous variables between the two readers. SAS/STAT software was used for statistical analysis.

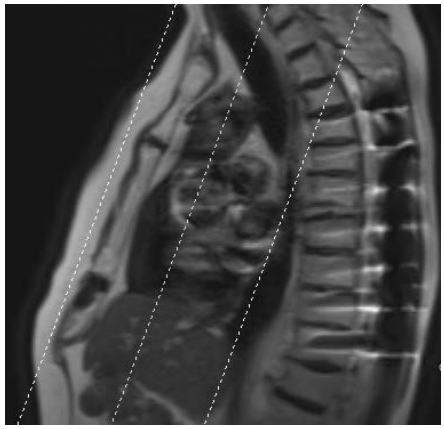


Figure 6 *Imaged area of the anterior chest wall shown on image. Orientation of image slices was perpendicular to sternum in axial images and parallel to sternum in coronal images.*

Table 1 *MRI protocol sequences.*

Parameter	Coronal T2 TIRM	Coronal T2 TSE	Axial T2 (Blade) FatSat	Axial T1 TSE	Axial T2 (Blade)
EchoTime, TE (ms)	43	90	80	10	75
Repetition Time, TR (ms)	4000	5000	4500	600	4800
Echo Train Length, ETL	11	17	18	4	18
Matrix size	256x179	320x272	320x320	512x384	320x320
Field of View (cm)	380x380	380x380	350x350	350x350	350x350
Slice Thickness/space (mm)	4/0.3	4/0.3	4/0.3	3/0.3	3/0.3

4.3 PENETRATING CHEST TRAUMA (III)

The retrospective study was based on penetrating chest trauma patients identified from Trauma Registry data in Trauma Center Karolinska (TCK). From a four-year period, 2013 – 2016, all patients with penetrating trauma were included. Patients were categorized in subgroups by injured body part.

Two radiologists investigated the data in consensus, and the subgroup of penetrating thoracic trauma cohort formed the sample for this study.

Trauma registry data was used to gather specific information about age, gender, mechanism of injury (MOI), injury severity scores (ISS, NISS), time from door to CT, use of assisted ventilation and 30-day mortality. Hospital PACS system was used to manually go through all trauma imaging, to identify used modalities and protocols, wound marking, and use of contrast material. Scout images were assessed for detection of metallic foreign bodies.

Following the preliminary work, all penetrating chest trauma CTs were manually re-evaluated by a third radiologist regarding active bleeding, depth of injuries, involvement of lung tissue, pleural space and bone. Also, the use and positioning of chest tubes was described. Imaging findings between SW and GSW patients were compared. In patients with subsequent follow-up imaging after emergency surgery, additional findings in and out of the operated area were reported.

Data of SW and GSW patients were analyzed to compare characteristics between two injury mechanisms. T-test was used for parametric data and Man-Whitney U test for non-parametric data. Also, Fisher's exact test and odds ratio (OR) with 95% CI was used for dichotomous data. SAS/STAT software was used for statistical analysis.

4.4 CT AFTER EMERGENCY SURGERY IN PENETRATING TRAUMA (IV)

Patient selection for study IV was collected from a seven-year cohort (2013 – 2019) of all penetrating trauma patients in TCK. Trauma database was screened to detect patients who were transferred to emergency surgery on arrival, without initial trauma-CT evaluation. All patients aged 17 and older who were screened with postoperative CT within 48 hours of surgery were included. A part of this patient group (penetrating thoracic trauma) was evaluated in study III. In study IV groups of GSW and SW were identified; additionally, a small minority of patients suffered from impalement.

Medical records were obtained to compare surgical findings to CT images. All postoperative WBCT studies were reviewed by a senior radiology resident. Imaging findings were evaluated both inside and out of the area of operation. Radiographs taken on arrival to the shock/trauma room were included in the evaluation, as well as clinical reports prior to emergency surgery. Medical records were studied to determine whether the findings in postoperative CT studies resulted in change of management. Re-operations and angiopraphic interventions were categorized as major changes in treatment.

Independent samples were calculated with Wilcoxon test, and differences between SW and GSW patients were assessed with chi-square test and Fischer's exact test. SAS/STAT software was used for statistical analysis.

Table 2 *Time span of data collection and number of patients in each study (I-IV).*

	years	nr	male	mean age	female	mean age
I	3 (2013-2015)	114	99 (86.8%)	48.6	15 (13.2%)	45.1
II	4 (2013-2016)	21	21 (100%)	59.8	0	.
III	4 (2013-2016)	161	151(93.8%)	34.9	10 (6.2%)	40.7
IV	7 (2013-2019)	38	36 (94.7%)	31.5 (all)	2 (5.3%)	.

4.5 ETHICS (I-IV)

4.5.1 RETROSPECTIVE STUDIES (I, III AND IV)

Ethics committee approval was obtained for all three retrospective studies (I, III and IV) for the use of image sets in the hospital PACS system, patients records and trauma registry data. Patients were not contacted during the study period, data collection or data analysis period.

Patients could not be identified from the processed data sets. The original images were screened in hospital environment at all times to ensure data protections and GDPR confidentiality. All connecting information between actual patient information and the collected data was only available to the primary investigators.

4.5.2 PROSPECTIVE STUDY (II)

For the prospective follow-up study (II), detailed patient information letters and consent formswere written in both official languages: finnish and swedish. Participation in the study was voluntary, and did not affect the patient's treatment or diagnostics of the trauma of interst or any other health conditions in any way. All patients participating in the follow-up study had the right to withdraw from the rest of the study at any time during the study period, regardless of the phase of imaging or physical examination. QoL questionnaires were also reviewed by the ethics committee, as well as imaging methods used. Due to the low dosage of the ULD-CT examination, approval for imaging was granted. The results were considered beneficial for the patient compared to the low risk of harm from an ultra low dose examination.

Patients were contacted by paper mail. Two scheduled hospital visits were arranged, one for clinical examination, ULD-CT and sonography, and the

other for the MRI study in another hospital facility. QoL questionnaires were included in the letters. As these follow up visits were not routine visits after thoracic trauma, the funding for the imaging was granted from the study funds of Helsinki University Hospital /Department of Radiology. Travel costs were reimbursed for the participating patients, but no rewards or other monetary compensations were given.

All connecting information between actual patient information and the collected data was only available to the primary investigators and shielded with passwords. Only the investigators included in this group met the patients personally, as well as imaging technicians who are bound to confidentiality. Trauma registry data was collected through established formal routes within the hospital. The access to data was exclusive to the dedicated personnel connected to trauma registry data processing.

5 RESULTS

5.1 COSTAL CARTILAGE FRACTURES (I)

Costal cartilage fractures were found in 114 of 574 thoracic trauma patients in WBCT studies for trauma. Incidence was 19.9% in thoracic trauma patients, and 7.8% (114 of 1461) in all trauma patients in this study. Of these, only 13.2 % were women (15 of 114) resulting in a male-to-female OR of 2.71 (95% CI :1.52, 4.84: p=.0005).

5.1.1 COSTAL CARTILAGE FRACTURE TYPES

In total, 221 costal cartilage fractures were found. The most common type of fracture was in the central part of the cartilage – midchondral – in 52.9% (117 of 221). Second most common fracture type was in the lateral part of the cartilage – costochondral – 41.2% (91 of 221), and only a few were chondrosternal (5.9%, 13 of 221), near the tight junction between the rib's medial end and sternum. Midchondral fractures were most commonly seen in ribs 3 – 7 (Fig. 7), costochondral fractures in ribs 1 and 6 – 8, and chondrosternal in ribs 1 and 3 (Fig. 8).

In 12.3% (14 of 114) no osseous rib fractures were found in addition to CCFX. Majority of patients had multiple CCFX (52.6%) and 14.9% had bilateral fractures. Isolated CCFXs without any coinciding injuries were found in two patients (1.8%).

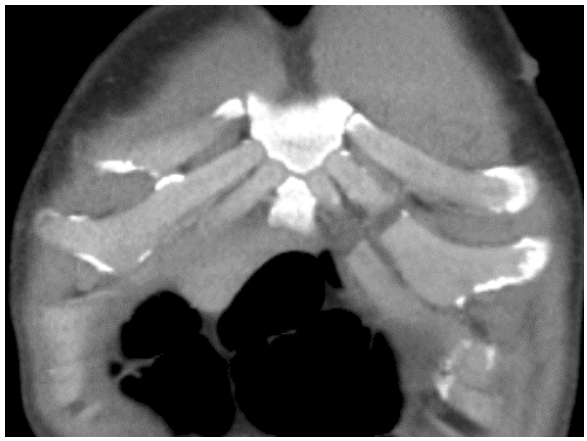


Figure 7 Examplatory case of typical midchondral fractures in ribs 6 and 7 (left side) on a coronal CT image. Fractures of the subcostal angle are more easily detected in coronal plane.

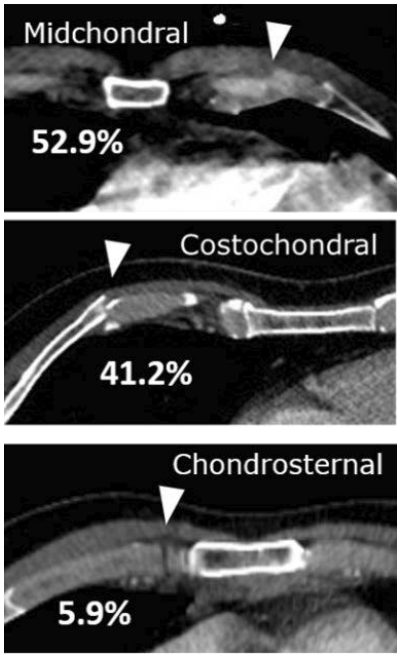


Figure 8 Types of costal cartilage fractures (arrow head). Midchondral fractures were most common (upper image), followed by costochondral (lateral) fractures near the bone/cartilage junction (middle image). Chondrosternal fractures were rare (lower image), and sometimes presented as a posterior dislocation of the medial rib end (Fig. 9).

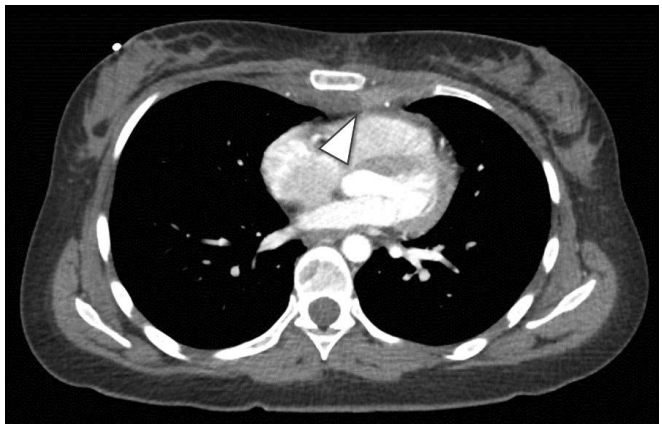


Figure 9 22-year-old female, fall from height (5 metres). Axial CT image shows a posterior dislocation of the rib; the medial end of the rib is locked behind the sternum. This injury type is also called separated rib or sternocostal dissociation.

5.1.2 ADDITIONAL INJURIES

In addition to rib cage injuries, pneumothorax (65.8%), pulmonary contusions (52.6%) and hemothorax (51.8%) were common. Pulmonary lacerations were found in 17.5% and pneumomediastinum in 7.9%. No adjacent vascular injuries to internal mammary arteries or subclavian arteries were detected in this cohort. Aortic injuries (n=4, 3.5%) were all found in the group with CCFX, and none in the group with thoracic trauma without CCFX.

Thoracic spine fractures were fairly common (24.6%) as well as fractures to sternum (24.6%) and clavicle (21.9%). Sternum as an adjacent skeletal structure was more often injured in the CCFX group, than in patients without CCFX (24.6% vs 11.5%). Consecutive rib fractures were found in vast majority in both groups (80.7% vs 69.8%), but in the CCFX group bilateral fractures were significantly more common (36.0% vs 13.9%, p <.0001). One fifth of patients (22.8%, 26 of 114) had intra-abdominal injuries. Of these, liver injury was most common (13.2%, 15 of 114).

In patients with CCXF, pneumothorax, hemothorax and aortic injury were significantly more common when compared to the group with thoracic trauma without CCFX (p <.0001). A significant difference was also seen in clavicle and thoracic spine fractures. Hepatic injuries were significantly more common in CCFX group, but the incidence of splenic injuries was similar in both.

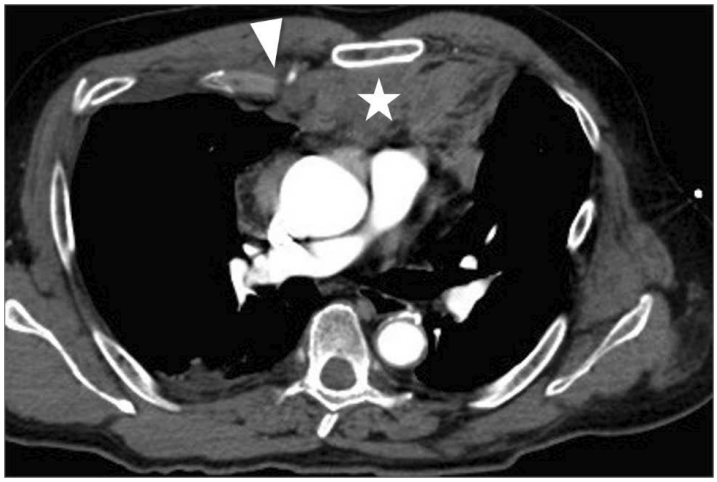


Figure 10 Axial CT image reveals multiple rib fractures and anterior chest wall depression on right. Among other injuries, a posteriorly dislocated costal cartilage fracture (arrow head) and a large retrosternal hematoma (star) are seen.

5.1.3 MECHANISM OF INJURY, DETECTION RATE AND MORTALITY

No statistically significant difference was found in injury mechanisms between the two thoracic trauma groups – with or without CCFX. In the CCFX group, motor vehicle accidents and falls were most common, covering 62.3% of all cases.

The CCFX detection rate in written reports was 39.5%, with dislocated fractures more easily detected. At the time of this study, CCFX was not commonly known among radiologists as a separate injury to traditional rib fractures. Interobserver agreement, between two radiologists who screened the CCFX, grew over time as the fracture detection became more familiar. It was also noted that occasional subsequent imaging eased the detection of nondislocated CCFX, as there was a tendency for the fractures to dislocate over time (Fig. 11).

No significant impact on 30-day mortality was found between the two chest trauma groups; thus, CCFX cannot be described as an independent predictor for worse outcome among blunt chest trauma patients.

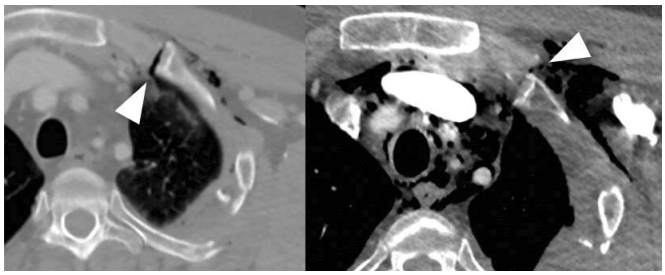


Figure 11 43-year-old male, motor cycle accident. Axial CT images on arrival (left) and on day 3 (right) show that the left sided first rib costal cartilage fracture (arrowhead) has dislocated over time. Also, the amount of free air (emphysema) in the mediastinal fat and soft tissues below the pectoralis muscles has increased.

5.2 FOLLOW UP OF COSTAL CARTILAGE FRACTURES (II)

All 21 participants in this follow-up study were male, with age range from 30 to 77 (mean 59.8 years, median 63 years). Initially, multiple CCFXs had been detected in 66.7% (14 of 21). Most common mechanism of injury was fall from height, followed by motor vehicle accident. The patients were examined and imaged on average 34.1 months (median 36, range 15.8 – 57.7) after the initial trauma. All participants filled out the QoL questionnaires – a dedicated chest trauma survey and a standardized RAND-36 questionnaire.

None of the patients discontinued the study prematurily. All patients were examined with three different imaging modalities; ULD-CT, MRI and

sonography. In 15 of the 21 patients (71.4%), CCFXs were evaluated as healed. None on these cartilage injuries were surgically stabilized.

5.2.1 CLINICAL STATUS

In clinical status control, 19% (4 of 21) reported persisting pain on fracture site. The fracture site was clearly palpable in seven patients (33.3%) and focal tenderness was also detected in seven patients. Two patients had rib cage asymmetry following chest trauma, and range of motion was diminished in two. No signs of restriction in respiration were detected in evaluating breath sounds. In clinical observation no accessory muscles were used for chest wall movement during the breathing cycle.

Table 3 *Clinical status on examination (n=21).*

Finding	n	%
rib cage asymmetry	2	9.5%
restricted breathing	0	0.0%
use of accessory muscles	0	0.0%
palpable fx site	7	33.3%
tenderness	7	33.3%
clinically unstable	1	4.8%
decreased breath sounds	1	4.8%
diminished ROM	2	9.5%

5.2.2 PROSPECTIVE IMAGING

5.2.2.1 ULD-CT

Ultra-low-dose CT of the chest corresponds with the radiation dose of a couple of standard chest radiographs (103). Image quality achieved by model based iterative reconstruction was assessed adequate in detecting calcifications on fracture site, evaluating level of dislocation and visibility of an open fracture line.

All patients had some calcification in previously diagnosed CCFX sites, and in 9 patients of 21 (52.4%), calcifications were dense. In 5 patients (23.8%) CCFX had dislocated over time, and in 6 (28.6%) the fracture line remained visible on CT. In 5 patients (23.8%), CCFX were evaluated as non-healed.

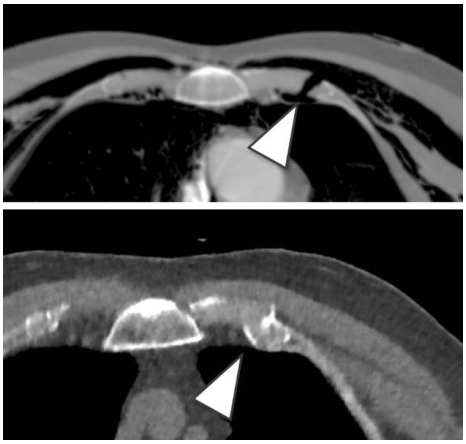


Figure 12 64-year-old male, compression accident. Upper image: axial image from initial trauma CT shows a CCFX of left 2nd rib with diastasis (arrowhead). Lower image: follow-up ULD-CT image of the same CCFX 4 years and 10 months later, reveals dislocation and calcification (arrowhead). The fracture was assessed stable both radiologically and on clinical examination.

5.2.2.2 MRI

Fluid sensitive sequences (TIRM, T2 with fat saturation) were useful in detecting persistent edema on fracture site; edema was found in 8 cases (38.1%). T2 weighted images showed the fracture line within cartilage tissue. Despite calcifications on fracture site, the fracture line was visible in all but one case (20 of 21, 95.2%).

T1 weighted imaging revealed no fatty degeneration of adjacent muscles. As patients were imaged in prone position (lying face down), the artifacts from breathing were reduced to such a level that no breath-holding sequences were necessary to include in the imaging protocol (Table 1).

5.2.2.3 Sonography

Sonography can reveal a CCFX and especially dislocated fractures are easy to detect (Fig. 13). Sonography was used to assess the potential movement on fracture site, and to evaluate increased vascularity surrounding the fracture site. No vascular changes were detected with Doppler sonography. In one patient, movement on fracture site could be seen on dynamic examination by pressing the probe (sonopalpation).

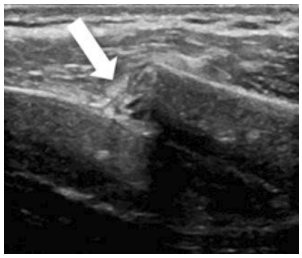


Figure 13 52-year-old male, motor vehicle collision. A sonographic image of an acute dislocated costal cartilage fracture (arrow).

5.2.3 QOL QUESTIONNAIRES

All participants filled out the two QoL questionnaires – a dedicated chest trauma survey and a standardized RAND-36 questionnaire. RAND-36 scores between patients with healed and non-healed CCFX were compared, but there was no statistically significant difference between the groups.

As polytrauma patients, most of the study participants had symptoms affecting daily life from other injuries, than the thoracic trauma (spinal and extremity injuries). A dedicated chest trauma instrument was created to focus on symptoms related to the blunt chest trauma, and to assess use of pain medication and effect on daily life. In these replies, 12 (57.1%) reported thoracic pain, 7 (33.3%) thoracic pain that affected sleeping and 13 (61.9%) other source of pain that affected sleeping.

5.3 PENETRATING CHEST TRAUMA (III)

Trauma registry data revealed 443 patients with penetrating injuries, and of these, 161 patients (36.3%) had thoracic injuries. Thoracic injury subgroup was further divided in two groups comparison, patients with stab wounds (SW) and gun shot wounds (GSW).

5.3.1 DEMOGRAPHICS

Majority of patients (93.8%, 151 of 161) were men, with mean age of 34.9 years (40.7 years in women). Of the 161 penetrating chest trauma patients, 85.7% suffered from SWs (138 of 161) and 9.3% (15 of 161) from GSWs. In eight patients (5.0%) the mechanism of injury was a foreign body (piece of glass, pen) or impalement. GSW victims were all men, and 9 (6.5%) of the SW patients were women.

5.3.2 INJURIES

Injury severity scores were significantly higher in GSW group than SW group. Mean ISS was 17.00 in GSWs and 8.84 in SWs (p=0.0014) and mean NISS 22.87 vs 11.38 (p=0.0006) indicating higher trauma load and more severe injuries in GSW patients. Majority of GSW patients (53.3%) were classified as polytrauma patients (ISS >16), compared to only 16.7% in SW patients (8 of 15 vs. 23 of 115).

Mediastinal injury was significantly more common in GSW group (3 vs 1, p=0.0029) and cardiac injury was rare (1.2%, 2/161). Active bleeding was found in 25.5% (41 of 161). Two patients required interventional treatment for their vascular injuries; another two had their intercostal artery bleed ligated in the OR, and brachial artery injury was operated on one patient. Ruptured diaphragm was operated in 3 of the 8 patients. Nineteen of the 41 patients with active bleeding on imaging were treated conservatively (46.3%).

Abdominal injuries were seen in 33.5% (54 of 161), of which 17 were superficial. Combined thoracic and abdominal injuries were seen in 11.8% (19 of 161). In particular, small bowel injuries were more common in the GSW group than SW group; 26.7% vs 2.9 (p=0.0034, OR 12.18). These results highlight the need to image also the adjacent body compartment in otherwise evident penetrating trauma cases. The wound tract may cross the diaphragm, and in many SW cases there are multiple entry wounds.

5.3.3 TIME TO CT AND IMAGING PROTOCOLS

Nearly all patients underwent CT imaging on arrival, 93.2% (150 of 161). Four patients were transferred directly to the operating room without prior CT imaging and seven were imaged only with chest radiopraphs and sonography. Vitamin E capsules were used to mark the entry and exit wounds in 73.3% (110 of 150).

There was large variation in the range of time to CT; mean time was 40.4 minutes (range 13 – 284) in SW patients and 72.1 minutes (18 - 394) in GSW patients. The median was 29 minutes and 27 minutes repectively. The imaging protocols varied based on which body parts were inflicted. Arterial phase was imaged in 28% (42 of 150) of patients. Enteric contrast media was infrequently used, only in five patients (3.3%), but rectal contrast was used in 18.7% (25 patients with stab wounds and three with GSWs).

5.3.4 EMERGENCY SURGERY, POSTOPERATIVE IMAGING AND MORTALITY

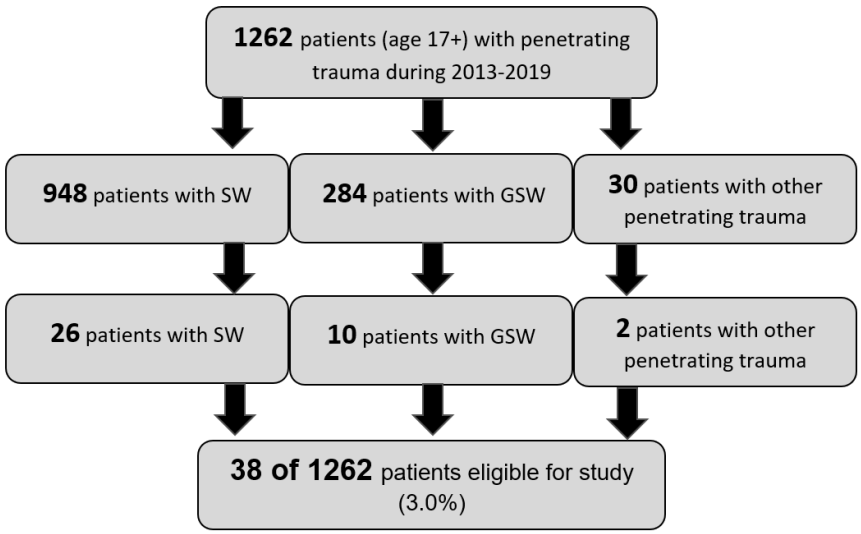
Ten patients underwent emergency surgery on arrival (6.2%; 10 of 161). Four patients had thoracotomy, five laparotomy and one patient had both. GSW patients were more likely to have emergency surgery (20% vs 4.3%, p=0.0450), and one of the SW patients succumbed of cardiac injury during the

operation. Postoperative imaging was performed on all survived nine patients. Findings included a liver injury, two kidney injuries, skeletal fractures in two and suboptimal chest tube positioning in five. These additional findings altered the planned treatment in 5 patients (55.6%, 5 of 10). Mortality rate during the first 30 days was low, 1.2% (2 of 161).

5.4 CT AFTER EMERGENCY SURGERY IN PENETRATING TRAUMA (IV)

Trauma registry data was explored to find all penetrating trauma patients during a seven-year period. Of these 1262 patients, 38 met the study criteria 1) underwent emergency surgery on arrival and 2) were imaged within 48 hours from the surgery with WBCT posteoperatively. Break down of patient selection is presented in table 4. A subgroup of thoracic trauma patients was included in the study cohort of study III.

Table 4 *Patient volumes for study IV. All patients who underwent emergency surgery and subsequent CT imaging within 48 hours were included (third row).*



5.4.1 DEMOGRAPHICS

Of these 38 patiens, 36 were men, and 2 women (5.3%). Mechanism of injury was most commonly SW in 26 and GSW in 10 patients. Of the remaining two, one patient fell from a height on a picket fence, and another was injured from a plough.

5.4.2 TRAUMA REGISTRY DATA

The median NISS was significantly higher for GSW patients than for those with SW (34 vs 26, p=0.045). The average ICU-LOS was 4.8 days, with 7.8 days for GSW and 3 days for SW. This difference was not statistically significant (p=0.092). Two patients died resulting in 30-day mortality of 5.3% (2 of 38). Neither of these two patients had major imaging findings in postoperative CT that would have altered their treatment. One patient succumbed due to multiple GSWs in multiple body regions and the other to self inflicted penetrating neck trauma.

The type of performed emergency surgery is presented in Table 5. Over half of the patients underwent laparotomy (52.7%) and one third thoracotomy (34.3%).

Table 5 *Performed emergency surgery types (all patients, n=38).*

	n	%
laparotomy	15	39.5%
thoracotomy	8	21.1%
laparotomy + thoracotomy	5	13.2%
other	10	26.3%

5.4.3 MINOR IMAGING FINDINGS

Of the 38 patients that were imaged with CT after the emergency surgery, 20 patients (52.6%) had additional findings. Eleven patients (28.9%) had trauma related findings outside the surgical field, eight (21.1%) within the surgical field and one in both (2.6%).

Injuries found included intracranial bleeding, small lacerations in abdominal organs (liver, kidney and spleen), blood found in the renal pelvis, psoas injury, foreign bodies (shrapnels), and different types of fractures in the spine and extremities. Even though most of these injuries required only observation, it is important to evaluate the whole spectrum of injuries in each patient. In some cases, initially observable injuries may progress into bleeds or other complications that need intervention.

5.4.4 IMAGING FINDINGS WARRANTING FURTHER TREATMENT

In 6 cases of the 38 (15.8%) further intervention was warranted. These included a Monteggia fracture repair, angiography in two patients (active

bleed and pseudoaneurysm), and two foreign body removals (craniotomy and neck exploration). Forearm fracture can be diagnosed with plain radiographs, but other injuries found in this patient group would not have been found without the subsequent CT imaging.

6 DISCUSSION

6.1 ADVANCEMENTS IN TRAUMA IMAGING

The continuous development of CT scanners and imaging protocols has provided new information about several traumatic injuries, that have come to our attention during the past few decades (56,104). Proper imaging with adequate contrast enhanced imaging phases, and submillimeter spatial resolution, provide high image quality and allow detection of multiple injuries. (13,15,48) In addition, radiation dose reduction as a result of improved equipment and refined protocols has also led to the benefit of trauma patients. Accurate diagnostics is reached with reduced radiation dose, especially in repeated follow up studies (103,105–107).

Costal cartilage fractures have become more known due to cross sectional imaging. Unawareness of CCFX and their longterm appearance may result in unnecessary imaging due to a palpable mass on the costal margin, that the patient may not connect with previous trauma (17). Knowledge of the full spectrum of thoracic injuries aids in planning the proper treatment that could in some rare cases of unstable chest wall lead to operative intervention (108–110). Volume rendered thick reconstruction slices (maximum intensity projection, MIP images) can show the anatomic structure of the anterior chest wall and ease the detection of multiple injuries.

Vascular injuries especially in aorta, cervical arteries and splenic pseudoaneurysms have the potential of harmful or even fatal complications to patients. Improved diagnostics has therefore led to more favorable prognosis/outcome for the severely injured patients. Blunt cerebrovascular injuries (BCVI) have been detected more precisely, and this may prevent long term neurological effects due to stroke or infarction in trauma patients (104,111,112).

Potentially fatal bleeds from splenic pseudoaneurysms have also been prevented due to the multiphase imaging and increased detection of vessel wall irregularities. Follow up imaging and interventional radiology have been useful in managament of these injuries (56,113)

6.2 COSTAL CARTILAGE FRACTURES (I)

The diagnosis of CCFXs is based on cross-sectional imaging and sonography. In this study, CCFXs were more common among blunt chest trauma patients than originally anticipated. The incidence was especially high in patients with multiple consecutive rib fractures. Also, the rate of additional

injuries suggested that CCFX serve as a marker of high energy trauma. As such, CCFX should also be noted and reported to ensure the understanding of the full scale of thoracic injury in each patient. This would result in more thorough trauma reporting regarding injury severity scores and trauma registry data collection. To ease the reporting and patient management, a dedicated ICD 10 code is warranted for CCFX, as it differs from the osseous rib fracture anatomically.

Cartilage fractures affect the anterior rib cage stability and are associated with severe coinciding injuries. Even though the sample size was fairly small, the presence of aortic injuries in the CCFX subgroup reflected high trauma energy. In one patient, cardiac contusion was associated with posterior dislocation of the second costosternal joint. Lack of adjacent vascular injuries in internal mammary arteries and subclavian arteries showed that these anatomic structures are not at immediate risk, despite the proximity to injury site. This may be explained by the flexibility of there arterial structures.

CCFXs are sometimes difficult to detect, especially if the fracture is non-displaced at the time of imaging. In some cases, a hematoma surrounding the fracture may reveal the fracture. The ends of the fractured cartilage are even and smooth, not splintered as in osseous rib fractures. This quality makes the perception and detection of a fracture difficult, but once the radiologist is familiar with this entity, it becomes a typical sign of blunt chest trauma among all others. (17,18)

The universally agreed definitions for different CCFX types still remains undecided. In this study, the cartilage was divided into three parts; medial (chondrosternal, CS), central (midchondral), MC) or lateral (costochondral, CC). As the costochondral fracture has also been used to describe a CCFX (of any location) it has been proposed that the wording used is misguiding.

In rare cases, the unstable rib cage may require surgical stabilization due to multiple rib fractures (114,115) or CCFX (Fig. 14) (108,109,116). To ease the communication between surgeons and radiologists, a proposal for unified terms is under way from a collaboration group of thoracic surgeons (CWIS; Chest Wall Injury Society) and trauma radiologists (ASER; American Society of Emergency Radiology). The aim is to clarify and agree on taxonomy and descriptions used in radiology reports regarding rib fractures and CCFX. A structured reporting template for chest injuries has also been suggested to improve swift assessment of all injuries, when different treatment options are considered.

In the beginning on data collection, CCFX was not a familiar injury type to resident radiologists on-call, or to the senior radiologists who provided the second reading of all trauma CTs. This resulted in a fairly low detection rate in radiology reports. Since then, the awareness of CCFX has risen and after the publication of this study, CCFX has once been a topic in the Finnish national radiology exam for residents. CCFX has also been addressed in radiological meetings, and covered by the congress news paper twice in 2016: “ECR today” March 3rd, 2016 and “RSNA daily bulletin” November 30th, 2016 (117,118).

Most recent publications on CCFX still focus on anecdotal case reports (116,119–122), some indicating surgical fixation of the anterior chest wall (32,110,123). The optimal treatment for dislocated and unstable injuries may still warrant for further investigation. Individual decisions on surgical treatment are based on the overall assessment of each patient's condition.

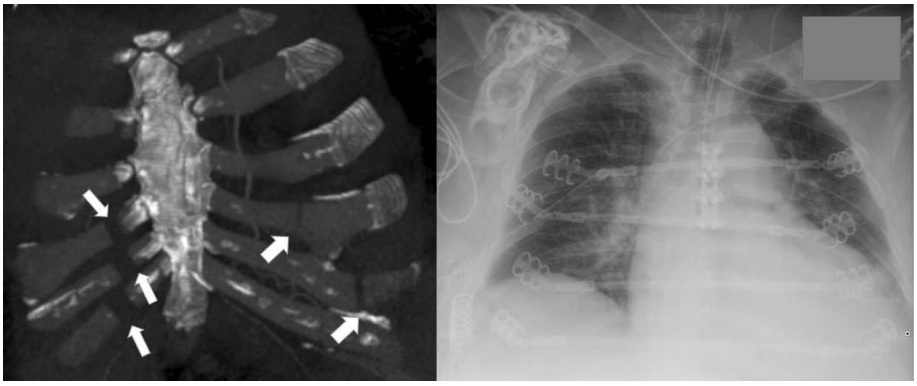


Figure 14 64-year-old male, motor vehicle accident. Flail chest, failure to wean from mechanical ventilation. CT MIP (20 mm) image on the left. Multiple consecutive CCFXs bilaterally (arrows) that result in anterior chest wall instability. The fractures were fixated with struts crossing the sternum. Postoperative chest x-ray on the right.

The limitations of this study include retrospective design and a dedicated subcohort of blunt thoracic trauma patients in a single institution. However, the overall incidence of CCFX among blunt trauma patients has not been investigated previously, thus the sample size in this study was markedly higher than in previously published case report -based studies.

The results provided new information about the incidence of CCFX in blunt trauma patients, the most common location and type of CCFX, typical concomitant injuries and revealed the association to high trauma energy. In the future, multicenter studies with larger time intervals and sample sizes could further verify or challenge these results.

6.3 FOLLOW UP OF COSTAL CARTILAGE FRACTURES (II)

The natural healing course of CCFXs has been fairly unknown. Occasionally we can see vertical dense calcifications on CT studies, originating from a CCFX many years ago. In some cases, an unstable CCFX may create discomfort and clicking of the rib in the subcostal angle. The follow up study provided new information about the healing process, even though the sample size was limited. Most of the patients had multiple other injuries in addition to the

CCFX, which made the evaluation of CCFX originated symptoms challenging. Most commonly their debilitating symptoms came from other injuries of blunt trauma, usually from injuries to the spine or extremities. A non-healed CCFX may explain unresolved parasternal pain and discomfort, if cartilage injury has not been previously detected.

As there are several ribs and they are paired, the anatomy makes a hard entity for research. How to single out or to isolate these injuries? How to investigate their influence in the patient's overall condition? How to describe the healing process of multiple fractures if the healing does not follow an identical course? Maybe the rib cage injury patterns could be evaluated in the same way as spinal fractures, where vertebrae are numerous and injuries often complex. (124,125) This would require collaboration between radiologists and clinicians, to come up with a unified description to meet with both diagnostic and clinical needs.

In our study group, most of the patients became asymptomatic regarding CCFX, and also the imaging supported the healing in most cases. In a few patients the fracture clearly remained unhealed even after several years after the initial injury. The fracture site remained unstable, or there was continuous discomfort and ongoing pain.

Ultra-low-dose-CT imaging was used as a comparable modality to the initial trauma WBCT. Traditional CT imaging yields in high radiation doses, but with advance image processing (model based iterative reconstruction, MBIR) it was possible to render adequate resolution in images with very low dosage (126,127). Dose optimization was important to achieve, as a benign condition was evaluated in presumably healthy population. ULD-CT may serve as an alternative to standard CT or chest radiograph in follow-up imaging of pneumothorax size, lung contusions or rib fracture/CCFX dislocations. (107,128,129)

MRI is expensive, time consuming and not always available. Also, patient related contraindications limit its use in diagnostics (130). In CCFX diagnostics, MRI should be reserved to young patients, unresolved and complex cases, or otherwise non-conclusive results in CT or sonography studies.

Limitations of this study are concentrated on the fairly small cohort. The sample size of 21 patients did not result in high statistical power. It may be argued that the patient selection was biased due to those recovering from their injuries willing to participate. Also, the sosioeconomical status of these patients allowed them to enter the study. Patients in caring homes or other long term care facilities were not included. However, as one of the few papers describing long term results in CCFX, it offers new knowledge on the healing process of this injury. Larger studies with potential multicenter collaboration could bring more information about the clinical significance in different patient and age groups.

6.4 PENETRATING CHEST TRAUMA (III)

The spectrum of penetrating chest injuries varies from superficial flesh wounds to deep intrathoracic violations including pericardial injury, active bleeding and pneumothorax. As the mechanism of injury may be unknown at the time of image interpretation, radiologists must look for subtle clues on imaging. These include fat stranding and air bubbles indicating the wound tract, especially in SWs. Wound marking aids the detection, especially in cases where the clinical history is vague or absent. (47,53,131)

Stab wounds are far more common than GSWs, but the patients with GSWs are usually more severely injured. The secondary cavity in GSWs results in vast damaged areas of tissue, that may not be evident in primary CT imaging, especially regarding the pericardium, stomach and bowel wall. (132)

The lower ribs cover upper abdominal organs, and penetrating trauma to the lower part of the thorax can result in hepatic or splenic injury. Wound tract transversing the diaphragm can violate the abdominal cavity, and it highlights the importance of expanding the area of imaging to the adjacent body compartment. Selective imaging can result in undetected injuries, as penetrating trauma patterns are random depending on the type of violence used. (48,53)

Intravenous contrast media plays a crucial role in detecting parenchymal violation and active bleeding. Arterial phase (CTA) should be included to rule out vascular injury and venous phase for parenchymal injury. (133) In active bleeding, a delayed scan performed 5 - 10 minutes after the initial image acquisition shows the contrast media extravasation. This helps in determining the volume and rate of bleeding.

In SW patients, pneumothorax is a common injury that requires chest tube insertion. In GSWs, the injuries are usually multiple and deep, resulting in longer LOS in the ICU or in the hospital. Also, the ricochet of bullet fragments of shrapnels creates an unpredicted trauma pattern within the body that should be constructed from the images. Wound marking facilitates this evaluation as well.(91,133)

The limitations for this study include the retrospective design, and the fairly low incidence of penetrating injuries in the Nordic countries. However, the spectrum of injuries in this cultural and demographical environment describes the unique circumstances for a large North European trauma center. Preparedness to implement accurate imaging protocols in rare occasions is essential to ensure the proper work flow when encountering a penetrating trauma victim. Collaboration between Nordic trauma centers would provide unified imaging protocols in different trauma scenarios, and mechanisms of injury.

6.5 CT AFTER EMERGENCY SURGERY IN PENETRATING TRAUMA (IV)

Severely injured patients may require life saving surgery immediately after hospital arrival. In those cases, routinely performed trauma scans are bypassed, as the patient is rapidly transferred to the operating room. All body compartments are not possible or reasonable to surgically explore, but the postoperative CT can reveal hidden injuries in and outside the surgical field. (62,98,99) Especially bleeding to the retroperitoneum may be difficult to diagnose without CT. Skeletal injuries, kidney injuries, foreign bodies and ongoing active bleeding were those most commonly observed in the postoperative CT studies.

Even though most of the newly discovered injuries required only observation, it is important to evaluate the whole spectrum of injuries in each patient. Initially observable injuries may progress into bleeds or other complications that require operative treatment or interventional radiology. Some patients may have a combination of blunt and penetrating injuries, especially in cases of explosive devices and terror attacks.(45,97)

Half of the imaged patients had previously undiagnosed trauma related findings in the postoperative CT. A subgroup of patients required further surgical intervention, surgical fixation for fractures or interventional radiology to address the bleeding. These findings emphasize the benefit of imaging, and serve as a guide for the surgeon on how to proceed with the treatment. Emergency surgery on arrival is not common and the patient volumes are moderate. (101,102) The radiation dose from imaging is not a concern in this patient group, as their injuries are severe and life threathening, and sometimes require immediate attention.

The Nordic countries have smaller populations and a different penetrating trauma incidence than for example North American and South American countries. This sets limitations to the study sample size and extends the study period to reach relevant volumes. Trauma registry data aids in patient recognition and organised collection of data.

Stab wounds are common in Nordic countries, but the incidence of fire arm injuries has been steadily rising. (40) Those with GSWs were more severely injured and more likely to end up in follow up surgery. As most penetrating injuries with knives or fire arms are presumably the result of interpersonal violence among young men, they are considered criminal activities. As such, accurate, precise and objective documentation is important also from the legal perspective. CT-imaging provides a comprehensive tool for overall evaluation also in cases where the initial damage control surgery has already been performed on arrival. (102)

7 CONCLUSIONS

7.1 COSTAL CARTILAGE FRACTURES (I)

Costal cartilage fractures increase the thoracic wall instability, and contribute to anterior chest wall trauma. The incidence of CCFXs in blunt trauma patients was 7.8% and 19.9% in blunt chest trauma patients. As our perception of CCFXs has increased, it has been shown that these injuries are not uncommon in severely injured blunt chest trauma patients. CCFXs are a marker for high trauma energy and often coincide with other severe injuries – multiple rib fractures, aortic and hepatic injuries. Cross sectional imaging is key in CCFX diagnosis. Universally accepted taxonomy remains to be decided for different types of CCFXs.

7.2 FOLLOW UP OF COSTAL CARTILAGE FRACTURES (II)

Costal cartilage fractures mostly heal to form a stable union, but in some patients, they remain symptomatic long after the initial trauma. Clinical status control is supplemental to imaging in determining the phase of healing prosess, level of pain and discomfort from these injuries. In healed CCFXs, dense calcifications can be seen on fracture site. These calcifications delineate the vertical fracture line and perichondrium, making the H-shaped calcification an indicator of previous CCFX. In some cases, multiple CCFXs may form a flail segment with other rib fractures.

7.3 PENETRATING CHEST TRAUMA (III)

Stab wounds to the chest are more common than gun shot wounds in Nordic trauma centers. However, patients with GSWs are in general more severely injured and require longer admissions than patients with SWs. The spectrum of penetrating chest trauma should be familiar to all on call radiologists, even though it's not very often encountered. Wound marking facilitates wound tract identification, and thus makes the injury detection easier. The use of i.v. contrast media on multiphase CT studies allows the

detection of parenchymal and vascular injuries, with special focus on active bleeding.

7.4 CT AFTER EMERGENCY SURGERY IN PENETRATING TRAUMA (IV)

Penetrating trauma is often life threatening and may result in immediate emergency surgery on arrival. Early postoperative whole body CT imaging reveals injuries both in and outside the surgical field. Patients with GSWs are in general more severely injured and more prone to end up in emergency surgery. CT images can guide the second look operation, and show vascular injuries, ongoing bleeding and skeletal injuries. Postoperative CT screening should be considered as a routine examination for all penetrating trauma patients, who are rushed to the operating room without initial trauma CT imaging.

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