

Department of Orthopaedics and Traumatology
Helsinki University Central Hospital
University of Helsinki
FINLAND

CLAVICLE INJURIES

Treatment of midshaft clavicle fractures and
acromioclavicular joint dislocations in adults

Kaisa Virtanen

ACADEMIC DISSERTATION

To be publicly discussed
with permission of the Faculty of Medicine, University of Helsinki,
in main lecture hall 1 of Töölö Hospital, Topeliuksenkatu 5, Helsinki
on 23 May 2014, at 12 noon.

Helsinki 2014

Supervised by

Mika Paavola, MD, PhD

Department of Orthopaedics and Traumatology, Töölö Hospital
Helsinki University Central Hospital, Helsinki, Finland

Docent Ville Remes, MD, PhD

University of Helsinki, Finland

Reviewed by

Docent Tapio Flinkkilä, MD, PhD

Department of Surgery

Oulu University Hospital, Oulu, Finland

Docent Heikki Mäenpää, MD, PhD

Department of Musculoskeletal Diseases

Tampere University Hospital, Tampere, Finland

To be discussed with

Professor Jan Erik Madsen,

Orthopaedic Department, Oslo University Hospital, Ullevaal, Oslo, Norway

University of Oslo, Norway

ISBN 978-952-10-9766-9 (paperback)

ISBN 978-952-10-9767-6 (PDF)

<http://ethesis.helsinki.fi/>

Unigrafia Oy

Helsinki 2014

Ars longa, vita brevis!

To Ilkka

TABLE OF CONTENTS

TABLE OF CONTENTS	1
ORIGINAL PUBLICATIONS.....	4
ABBREVIATIONS.....	5
ABSTRACT	7
1. INTRODUCTION.....	10
2. REVIEW OF THE LITERATURE.....	12
2.1. The clavicle in mammals.....	12
2.2. Embryonic, fetal, and postnatal development of the human clavicle.....	13
2.3. Anatomy of the clavicle	14
2.4. Function and kinematics of the clavicle	20
2.5. Injuries to the clavicle	24
2.5.1. Fractures of the clavicle.....	24
<i>Diaphyseal fractures of the clavicle</i>	27
<i>Fractures of the lateral end of the clavicle</i>	28
<i>Fractures of the medial end of the clavicle</i>	29
2.5.2. Injuries in the articulations of the clavicle	29
<i>Acromioclavicular joint dislocation</i>	29
<i>Sternoclavicular joint dislocation</i>	30
2.6. Diagnosis of clavicle injuries	32
2.6.1. Clinical examination.....	32
2.6.2. Radiological examination.....	32
<i>Radiograph</i>	32
<i>Computed tomography</i>	36
<i>Magnetic resonance imaging</i>	37
<i>Ultrasound</i>	37
2.7. Treatment of clavicle injuries.....	38
2.7.1. Diaphyseal fractures	39
<i>Nonoperative treatment of diaphyseal fractures</i>	39
<i>Operative treatment of diaphyseal fractures</i>	40

Table of contents

<i>Randomized studies comparing operative to nonoperative treatment</i>	42
2.7.2. Fractures of the lateral end	43
<i>Nonoperative treatment of lateral-end fractures</i>	43
<i>Operative treatment of lateral-end fractures</i>	44
2.7.3. Fractures of the medial end	45
<i>Nonoperative treatment of medial-end fractures</i>	45
<i>Operative treatment of medial-end fractures</i>	46
2.7.4. Acromioclavicular joint dislocations.....	46
<i>Nonoperative treatment of acromioclavicular joint dislocations</i>	46
<i>Operative treatment of acromioclavicular joint dislocations</i>	47
2.7.5. Sternoclavicular joint injuries.....	50
<i>Nonoperative treatment of sternoclavicular joint injuries</i>	50
<i>Operative treatment of sternoclavicular joint injuries</i>	51
3. AIMS OF THE STUDY	52
4. PATIENTS AND METHODS	53
4.1. Study I: Systematic literature review of clavicle fractures.....	53
4.2. Study II: Randomized clinical trial of midshaft clavicle fractures.....	54
4.3. Study III: Long-term results of surgery in type V acromioclavicular joint dislocations	56
4.4. Study IV: Surgical treatment of chronic acromioclavicular joint dislocation.....	57
4.5. Statistical methods in Studies II, III, and IV	58
5. RESULTS.....	60
5.1. Study I: Systematic literature review of clavicle fractures.....	60
5.2. Study II: Randomized clinical trial of midshaft clavicle fractures.....	64
5.3. Study III: Long-term results of surgery in type V acromioclavicular joint dislocations	67
5.4. Study IV: Surgical treatment of chronic acromioclavicular joint dislocation.....	69
6. DISCUSSION	73
6.1. Evidence for treatment of clavicle fracture (I)	73
6.2. Nonoperative or operative treatment for displaced midshaft clavicle fractures (II)	75
6.3. Operative treatment of acromioclavicular joint injuries (III, IV).....	77
6.4. Future prospects	80
7. CONCLUSIONS	82
APPENDIX	83

Table of contents

ACKNOWLEDGEMENTS	85
REFERENCES.....	88
ORIGINAL PUBLICATIONS.....	111

ORIGINAL PUBLICATIONS

This thesis is based on the following original publications, which are referred to in the text by Roman numerals I to IV. Publications I to III are reprinted with the kind permission of their copyright holders.

- I Virtanen KJ, Malmivaara AO, Remes VM, Paavola MP. Operative and nonoperative treatment of clavicle fractures in adults. A systematic review of 1 190 patients from the literature. *Acta Orthop*. 2012 Feb; 83(1):65-73.
- II Virtanen KJ, Remes V, Pajarinen J, Savolainen V, Björkenheim JM, Paavola M. Sling compared with plate osteosynthesis for treatment of displaced midshaft clavicular fractures: a randomized clinical trial. *J Bone Joint Surg Am*. 2012 Sep 5; 94(17):1546-1553.
- III Virtanen KJ, Remes VM, Tulikoura IT, Pajarinen JT, Savolainen VT, Björkenheim JM, Paavola MP. Surgical treatment of Rockwood grade-V acromioclavicular joint dislocations. 50 patients followed for 15-22 years. *Acta Orthop*. 2013 April; 84(2): 191-195.
- IV Virtanen KJ, Savolainen V, Tulikoura I, Remes V, Haapamäki V, Pajarinen J, Björkenheim JM, Paavola M. Surgical treatment of chronic acromioclavicular joint dislocation with autogenous tendon grafts. *Submitted*.

ABBREVIATIONS

3D	Three-dimensional
4D-CT	Four-dimensional computed tomography
AC	Acromioclavicular
AO/ASIF	Association for Osteosynthesis/Association for the Study of Internal Fixation
AO/OTA	Association for Osteosynthesis/Orthopaedic Trauma Association
AP	Anteroposterior
CA	Coracoacromial
CC	Coracoclavicular
CCT	Controlled clinical trial
CCTR	Cochrane Controlled Trials Register
CDSR	Cochrane Database of Systematic Reviews
CI	Confidence interval
CINAHL	Cumulative Index to Nursing and Allied Health Literature
CS	Constant shoulder score
CT	Computed tomography
DARE	Database of Abstracts of Reviews of Effects
DASH	Disabilities of the Arm, Shoulder and Hand score
DCP	Dynamic compression plate
ESIN	Elastic stable intramedullary nailing
GH	Glenohumeral
GRADE	Grading of Recommendations Assessment, Development and Evaluation
IM	Intramedullary
LC-DCP	Limited contact dynamic compression plate
LCP	Locking compression plate
MRI	Magnetic resonance imaging
RCT	Randomized controlled trial
ROM	Range of motion
SC	Sternoclavicular
SST	Simple shoulder test
TOS	Thoracic outlet syndrome

Abbreviations

US	Ultrasound
VAS	Visual analogue scale

ABSTRACT

Introduction

In Western countries, the incidence of clavicle injuries has increased along with the mobile and energetic way of life. Traditionally, clavicle fractures and acromioclavicular (AC) joint dislocations have been treated nonoperatively. However, recent studies have shown that surgical treatment may diminish nonunion and sequelae. Although articles discussing clavicle fractures and AC joint dislocations are abundant, the quality of evidence is still poor. This study aimed to investigate the results of various treatment modalities for clavicle fractures by way of systematic review and to compare the results of nonoperative and operative treatment for completely displaced midshaft clavicle fractures. The goal in AC joint dislocation treatment was to assess the long-term results after surgery for acute type V injury and to assess the results of surgery for chronic AC joint dislocation.

Patients and methods

For *Study I*, an information specialist performed an electronic database search of the literature without language restrictions. The available literature was observed from 1966 until the end of March 2011. The aim was to find potential high-quality comparative studies discussing acute clavicle fractures in adults. Findings were summarized by strength of evidence.

For *Study II*, we randomized 60 patients with completely displaced acute midshaft clavicle fractures. Treatment modalities were sling or plate fixation. Primary outcomes were shoulder function and disability. Secondary outcomes were pain, fracture healing, and complications. Follow-up time was one year.

For *Study III*, we examined retrospectively 50 patients treated surgically for acute type V acromioclavicular joint dislocation. Our aim was to assess the long-term results of surgery. Outcomes were shoulder function, disability, pain, and complications; we also evaluated subacromial impingement, AC joint dysfunction, and AC joint stability.

In *Study IV*, we examined retrospectively 25 patients treated surgically for chronic AC joint dislocation. Our aim was to evaluate the results of delayed surgery. Outcomes were shoulder function, disability, pain, AC joint dysfunction, AC joint stability, complications, patient's satisfaction, and length of sick leave.

Results

Study I. From electronic databases came 1072 abstracts discussing clavicle fractures. After exclusion, 230 reports remained, from which 13 were assessed for review: 12 studies concerned midshaft fractures, one study lateral fractures, and none medial fractures. Evidence was mainly low or very low.

Study II. Of 60 patients, 32 were randomized to a nonoperative group and 28 to an operative group. At 1-year follow-up, we found no difference between these groups in function, disability, or pain. All fractures in the operative group healed. In the nonoperative group were 6 (24%) nonunions. Other complications were minor. Fracture displacement was associated with nonunion.

Study III. These 50 patients were examined after a mean 18-year follow-up, with no difference found in function or disability between the injured and uninjured shoulders. In 8 patients, the AC joint was unstable. Reduction loss after primary surgery appeared in 12 patients, of whom six had anatomical reduction in the AC joint after long-term follow-up.

Study IV. These 25 patients were examined after a mean 4-year follow-up. The mean delay from injury to reconstructive surgery was 435 days. Function of the injured shoulder was inferior to that of the uninjured one. Pain and sense of disability were mild. In 11 patients (44%), the AC joint remained unstable. Lateral clavicle osteolysis (56%) and tunnel widening (80%) were common.

Conclusions

Due to the lack of high-quality evidence, no conclusions can be drawn as to the best treatment for medial or lateral third fractures. Regarding midshaft fractures, it appears that after short-term follow-up, operative treatment leads to better function and less disability than does nonoperative treatment; benefits of operative treatment are small after six months; union is better secured with surgery; nonoperative treatment usually leads to adequate function, pain relief, and union rates; and the osteosynthesis method has no effect on incidence of delayed union or nonunion. Nonoperative and operative treatment of acute displaced midshaft clavicle fractures achieved an equal functional outcome at 1-year follow-up. Nonoperative treatment is associated with a high nonunion rate. After long-term follow-up, results of surgery in acute AC joint dislocation are good. Lateral clavicle osteolysis seems to be related to constant AC

joint dislocation. Operative treatment of chronic AC joint dislocation is demanding. Surgery may not necessarily restore shoulder function, and the complication rate is high.

1. INTRODUCTION

The very first textbook or treatise on traumatology already mentions the proper handling of dislocated midshaft clavicle fractures. In the Edwin Smith Papyrus (ca 1600 BC) is written: *“If you treat a man for a dislocation in his collarbone, whose shoulders are found drooping while the head of his collarbone is facing toward his face, then you say about him: One who has a dislocation in his collarbone; an ailment I will handle.”* So the ancient Egyptians already knew that clavicle fractures are treatable *“by bandage with stiff rolls of cloth and with oil and honey.”* Thereafter, thousands of papers have been published, but are we at all wiser? Thus far, the weaknesses in the published studies are their low quality and poor evidence, since they are mainly retrospective case series reporting various treatment methods. The main issue is still more or less unclear; what type of injuries need surgical intervention?

In adults, clavicle fractures comprise 3% of all fractures. Of shoulder-region injuries, clavicle fractures comprise 37 to 45%, AC joint dislocations 8%, proximal humerus fractures 33%, scapular fractures 5%, and glenohumeral (GH) joint dislocations 17% (Nordqvist and Petersson 1995, Postacchini et al. 2002). The incidence of clavicle fractures is 50-64/100 000, and AC joint dislocations 8/100 000. Both injuries are more common among men (Nordqvist and Petersson 1995, Nowak et al. 2000).

Traditionally, clavicle fractures and AC joint dislocations have both been treated nonoperatively with a sling. During recent decades, increasing interest in operative treatment has arisen (Huttunen et al. 2013). Fortunately, over the last seven years some randomized controlled trials comparing operative to nonoperative treatment in midshaft clavicle fractures have emerged. On the strength of these studies, it appears that nonoperative treatment results in more nonunion than does operative treatment, but any concrete influence on shoulder function has been unclear (Canadian Orthopaedic Trauma Society 2007, Smekal et al. 2009). As to the results of AC joint dislocation treatment, the literature provides inadequate data, especially concerning long-term follow-up and chronic injuries. Despite the treatment modality and injury nature, the goal is to restore shoulder function and prevent residual pain and constant disabilities.

The aim of this study series was to assess systematically from the literature the results of nonoperative and operative treatment modalities for acute clavicle fractures in adults, to

prospectively compare the results of nonoperative and operative treatment for completely displaced acute midshaft clavicle fractures, to assess long-term results after surgery for acute type V acromioclavicular joint dislocations, and to assess results of surgery for chronic acromioclavicular joint dislocations.

2. REVIEW OF THE LITERATURE

2.1. The clavicle in mammals

The clavicle is phylogenetically an ancient structure. It is regarded as a dermal bone, since the mesenchymal source of the bone lies within the dermis of the skin. It is a remnant of a more extensive dermal exoskeleton or armor that covered early vertebrates. In the whole body skeleton of mammals, the clavicles are the only relics of the dermal skeleton (Hall 2001, Kardong 2012).

The presence and extent of the clavicle varies among mammals. Depending on the importance and use of a mammal's forelimbs, the clavicles are present, rudimentary, or absent. Mammals, whose forelimbs are more specialized than their hind limbs, have complete clavicles. In contrast, if the hind limbs are highly specialized, the clavicles are rudimentary or absent. A clear correlation exists between development of the clavicles and the work done by the forelimbs. Clavicles are more or less perfectly developed in arboreal (climbing), fossorial (digging), aerial (flying), and in all other forelimb-active mammals. Rudimentary or absent clavicles appear in hoofed mammals, carnivores, marine species, and all other species whose forelimbs play a secondary role in work (Trotter 1885).

Primates have morphological features in the shoulder region that differ from those of other mammals. All primates have a wide and shallow chest, well-developed clavicles, prominent acromion and spina of the scapula, a dorsally shifted wing of the scapula, and a ball-and-socket shoulder joint (Schultz 1930, Preuschoft et al. 2010). These features enable varied and extensive motion in the shoulder joint, a high degree of pronation and supination in the forearm, and use of a specialized hand (Trotter 1885).

In apes, as in humans, the clavicle is elongated compared to its length in other primates (Gebo 1996, Larson 1998). The clavicle plays an important role in maintaining the position of the shoulder joint in locomotion and feeding (Preuschoft et al. 2003). The elongated clavicle in apes is considered to contribute to their extensive shoulder mobility (Kagaya et al. 2010).

2.2. Embryonic, fetal, and postnatal development of the human clavicle

Unlike other long bones, the clavicle develops without prior enchondral ossification. In this intramembranous ossification, primitive mesenchymal tissue differentiates directly into bone (Wheater 1987). The first sign of a clavicle is in the fifth postovulatory week when a fibrocellular proliferation, a blastema, appears. Cells in this blastema form an organic matrix which is mineralized almost immediately as it forms. Ossification of the clavicle begins in two separate centers, a medial and a lateral, about 5 to 6 weeks postovulatory. Within 5 to 6 days from blastema formation, the two ossification centers have blended, and within 9 to 10 days, the two centers are fully united, and a single, 2-mm clavicle appears. The clavicle grows as osteoblasts continue to be formed in their centers. In the acromial and in the sternal aspect of the clavicle, the cells remain chondrogenous and form the acromioclavicular and sternoclavicular joints. Soon after, the bone marrow cavity starts to form when cells invade clavicular bone and differentiate into osteoblasts, osteoclasts, and blood-forming cells. From this time forward, the clavicle grows like a long bone. At the end of the embryonic period (8 weeks), the clavicle is S-shaped and is similar to its adult form (Mall 1906, Brandt 1934, Gardner 1968).

The fetal period (>8 weeks postovulatory) is characterized by growth and maturation, as well as remodeling and reconstruction processes. These enable a bone to maintain its characteristic shape. During the fetal period, the central invasive process extends toward the cartilaginous ends of the clavicle. The cartilage cells calcify and form growth zones (epiphyses) in the acromial and in the sternal end. The cartilages become thinner during the fetal period, and by term they are reduced to a thin surface. Throughout the fetal period, the clavicle is S-shaped and has trabeculated compacta and a little bone marrow (Gardner 1968).

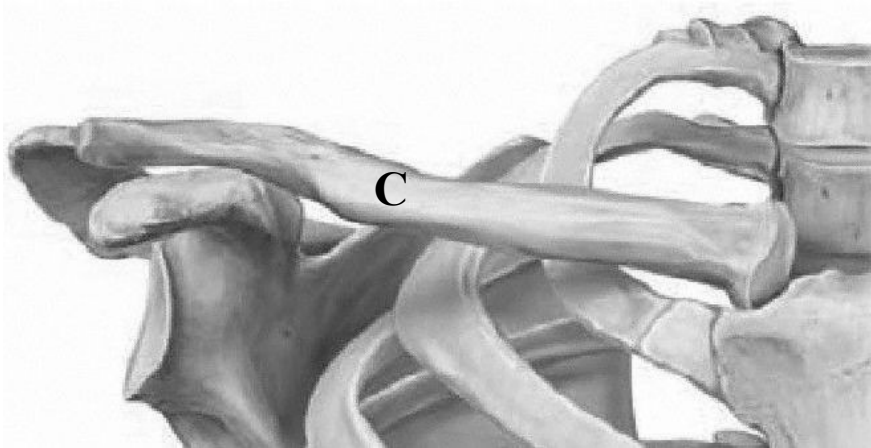
The clavicle displays a prolonged period of growth-related activity after birth. Cartilaginous growth develops at both sternal and acromial epiphyses, the previous being evidently more active. Throughout postnatal development, and especially during the first 5 years after birth, the most active growth takes place in the diaphyseal membranous ossification area. During adolescence, a secondary ossification center appears in the medial end of the clavicle. In females it appears between ages 11 and 19

and in males between 14 and 19. The sternal epiphysis commences to ossify around age 21 to 22, and complete union appears between ages 24 to 26. During the first 2 years of life, the clavicle lengthens about 2 cm (from 4.4 cm to 6.3 cm). From 2 years to adolescence, the clavicle grows fairly linearly to its average adult length (14-15 cm) (Stevenson 1924, Todd and D'Errico 1928, Jit and Kulkarni 1976, Ogden et al. 1979, Black and Scheuer 1996).

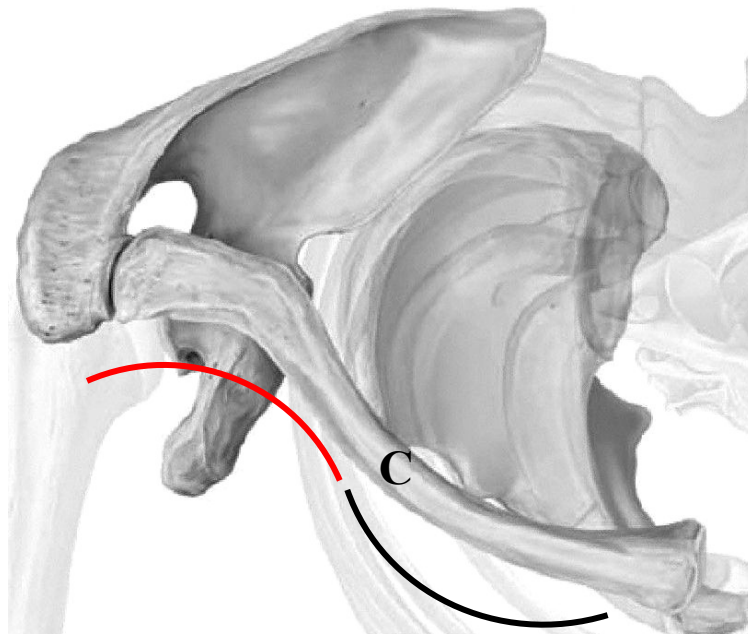
2.3. Anatomy of the clavicle

The human clavicle shows high variability in shape (Grant 1971). The clavicle is classified as a long bone with a shaft and two ends. The shaft constitutes the central two-quarters, while the medial and the lateral end each accounts for one-quarter of the bone. It has double curvature, a convex anterior curve in the medial (sternal) half and a concave anterior curve in the lateral (acromial) half. In the lateral portion, the clavicle also has a slight superior curve, whereas the medial aspect of the superior surface is comparatively flat (*Figure 1*) (Huang et al. 2007). Gender and racially specific differences exist in clavicle length, diameter, and shape (Parsons 1916, Terry 1932, Andermahr et al. 2007, Huang et al. 2007, Daruwalla et al. 2010). Clavicles in men are longer than in women, mean lengths (men-women) of 156-146 mm, 152-140 mm, and 153-137 mm (Andermahr et al. 2007, Huang et al. 2007, Daruwalla et al. 2010). The male clavicle has also a larger diameter and stronger curves (Andermahr et al. 2007, Daruwalla et al. 2010).

The clavicle consists of cancellous bone enveloped by cortical bone. The bone cortex is thickest in the middle part of the clavicle, and it linearly decreases towards its medial and lateral ends. The narrowest diameter of the double funnel-shaped medullary canal is exactly at the meeting point of the sternal convexity with the acromial concavity, the location where the clavicle most frequently fractures. The central region has the highest cross-sectional area of cortical bone and the lowest porosity, whereas the sternal and acromial ends are 2 to 3 times as porous as the central region (*Figure 2*) (Harrington et al. 1993, Andermahr et al. 2007).



a) Anterior view. The clavicle (C) is fairly straight. The lateral end is thin, whereas the medial end is robust and bulbous.



b) Cranial view. The clavicle (C) has a double curvature: in the medial half is a convex anterior curve (black line) and in the lateral half is a concave anterior curve (red line).

Figure 1. Anatomical illustrations of the right clavicle: a) anterior view and b) cranial view. (Schuenke *et al.*, *Thieme Atlas of Anatomy - General Anatomy and Musculoskeletal System*. All rights reserved. ©Thieme 2007, www.thieme.com).

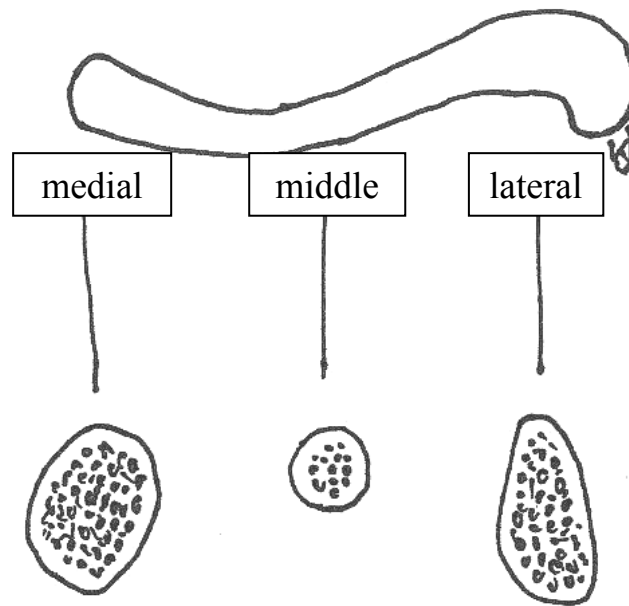


Figure 2. Cranial view of left clavicle and cross-sections from the medial, middle, and lateral part. Bone porosity increases towards both ends.

Terry found a difference in absolute length between sides, the left clavicle being longer than the right. He also observed the variability and asymmetry of clavicles in humans and also noticed their rich intra-individual asymmetry (Terry 1932). After Terry's work, others have also found in their anatomical studies that the left clavicle is approximately 2 mm longer than the right (Andermahr et al. 2007, Daruwalla et al. 2010). The true reason for difference in lengths between sides is still unknown.

The medial end of the clavicle is articulated to the clavicular notch of manubrium sterni and the cartilage of the first rib (Brossmann et al. 1996, Barbaix et al. 2000, Emura et al. 2009). This sternoclavicular (SC) joint is the diarthrodial (synovial) saddle joint and has only a little intrinsic stability. The articulating surface of the clavicle is larger than the corresponding surface in the sternum; less than half of the medial clavicle articulates with the sternum. This mismatch of articulating surfaces causes joint instability, and stability depends primarily on the surrounding strong ligaments. Ligaments stabilizing the SC joint consist of the anterior and posterior ligaments, the costoclavicular ligament to the first rib, and the interclavicular ligament. The latter occurs in 90% of humans and prevents the upward displacement of the clavicle during forceful depression of the

humerus and the shoulder (*Figure 3*) (Tubbs et al. 2007, Restrepo et al. 2009, Bontempo and Mazzocca 2010, Li et al. 2012, van Tongel et al. 2012, Wijeratna et al. 2013). The SC joint's articular disc is attached to the joint capsule and anterior SC ligament (Emura et al. 2009, van Tongel et al. 2012). One hypothesis is that the function of this disc is to protect the articulate surfaces (DePalma 1963), enable the rotation of the clavicle (Tillmann 2003), compensate for the mismatch between the sternal end of the clavicle and the clavicular notch of the sternum (Tillmann 2003), prevent medial displacement of the clavicle (Terry and Chopp 2000), and resist the compressive load to the clavicular surface (Emura et al. 2009). Articular discs are of three types: discoid (completely joined to the joint cavity, no defect within the articular surface), ring (defect in the central part, like a finger ring), and meniscoid (lunular shape, like the meniscus in the knee). The shape of the medial end of the clavicle relates to the shape of the disc (Emura et al. 2009).

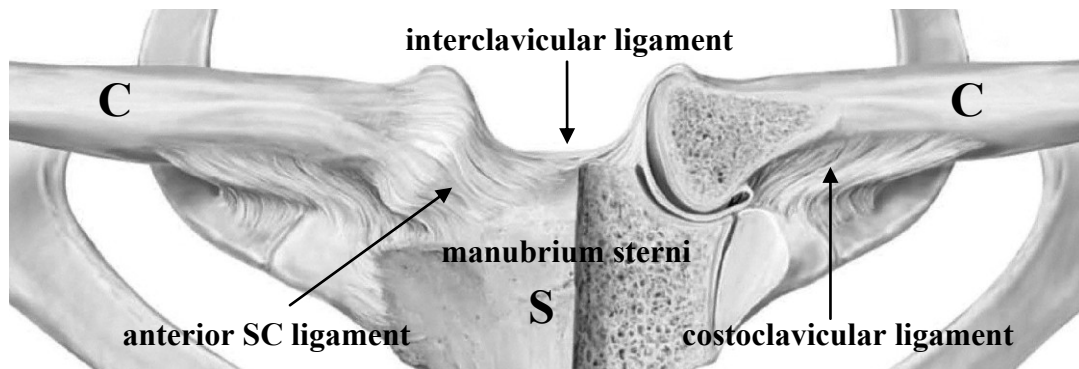


Figure 3. Anatomy of the SC joint. A clear mismatch in the size of articulating surfaces is visible between clavicle (C) and sternum (S). Ligaments in the figure are the anterior SC ligament, costoclavicular ligament, and interclavicular ligament (*Schuenke et al., Thieme Atlas of Anatomy - General Anatomy and Musculoskeletal System. All rights reserved. ©Thieme 2007, www.thieme.com*).

The lateral end of the clavicle articulates with the anterior aspect of the acromion, the anterior extension of the spina scapulae. Like the SC joint, the AC joint is a diarthrodial joint with four planes of motion: anterior/posterior and superior/inferior. The AC joint is

stabilized by the joint capsule, the AC ligaments, the muscle attachments, and the coracoclavicular (CC) ligaments (*Figure 4*) (Fukuda et al. 1986, Klimkiewicz et al. 1999). Of the four AC ligaments (superior, inferior, anterior, and posterior), the superior and posterior ligaments are the most important in restraining the posterior translation of the lateral clavicle (Klimkiewicz et al. 1999). The study of Fukuda et al. (1986) confirmed the importance of the AC ligament in lateral clavicular stability. They found it to be the primary constraint against posterior and superior displacement of the clavicle. The AC ligament is very short, starting in the clavicle 0.7 to 1.4 mm from the articular surface and in the acromion 1.1 to 2.0 mm from that surface (Renfree et al. 2003). The AC joint has a disk that undergoes rapid disintegration beginning in the second decade and is rarely evident after the fifth decade (DePalma 1963).

The CC ligaments consist of a posteromedial conoidal part and an anterolateral trapezoidal part. This ligament complex attaches the lateral clavicle to the coracoid process of the scapula and restrains the superior and posterior translation (Fukuda et al. 1986, Salzman et al. 2008). The trapezoid ligament originates from the lateral side of the coracoid process and attaches to the undersurface of the clavicle approximately 5 to 13 mm from the lateral edge of the clavicle. The conoid ligament originates from the posteromedial margin of the coracoid process and attaches to the conoid tubercle at the posterior margin of the clavicle approximately 15 to 36 mm from the lateral edge of the clavicle. The length of the trapezoid ligament is 14 to 16 mm, and of the conoid ligament, 10 to 11 mm. The trapezoid ligament has a footprint area in the clavicle and in the coracoid process that is 3 to 4 times as large as that of the conoid ligament (Takase 2010).

Several muscle attachments appear in the clavicle (*Figure 5*). The deltoid muscle has its origin in the anterolateral third and the trapezius muscle its insertion in the posterolateral third of the clavicle. The subclavius muscle has its insertion inferiorly in the shaft. Medially we find the origins of the pectoralis major and sternohyoid muscles and the insertion of the sternocleidomastoideus muscle. The pectoralis major muscle has a long attachment in the anteromedial half, whereas sternohyoid and sternocleidomastoideus muscles have attachments in the posteroinferior and superior part of the clavicle. This complex arrangement of muscle attachments may in part explain the unique shape of the clavicle (Abdel Fatah et al. 2012).

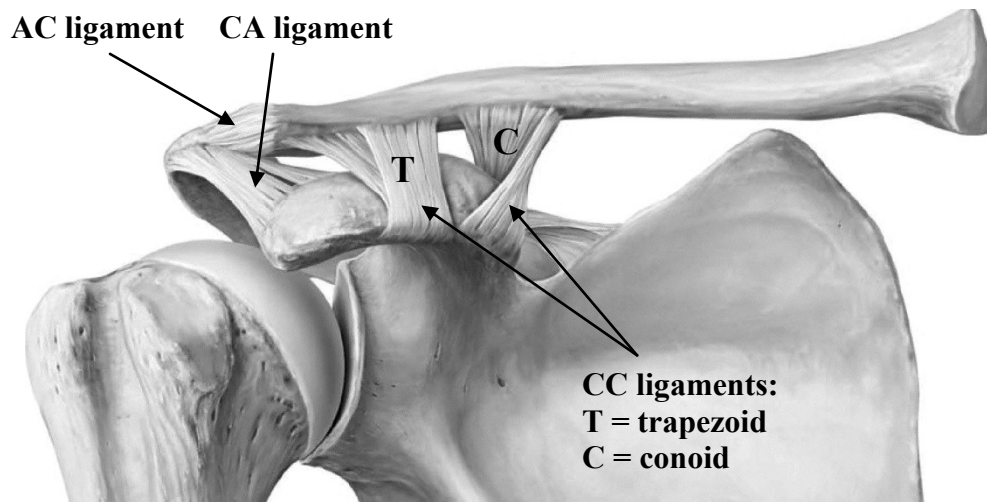


Figure 4. Ligaments stabilizing the lateral end of the clavicle. Anterior view of right clavicle. (Schuenke et al., *Thieme Atlas of Anatomy - General Anatomy and Musculoskeletal System*. All rights reserved. ©Thieme 2007, www.thieme.com).

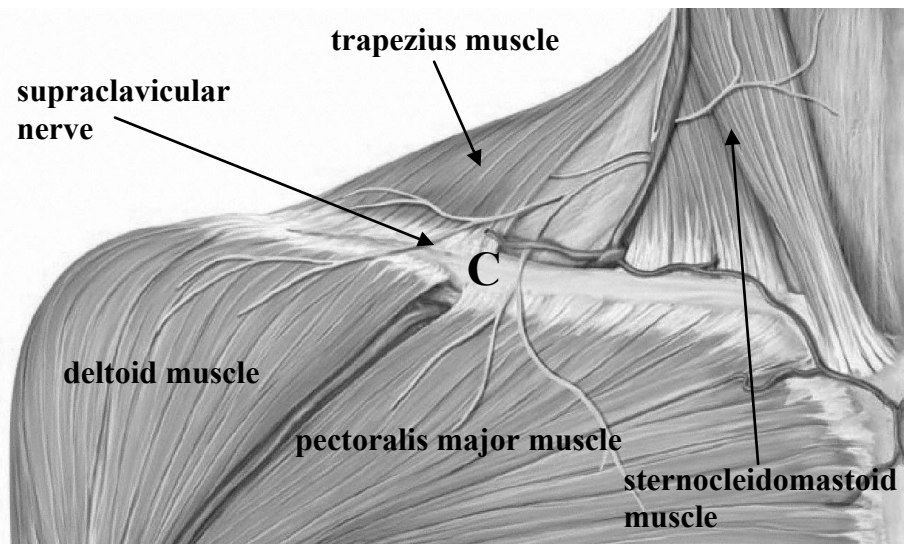


Figure 5. Muscle attachments of the right clavicle (C). The supraclavicular nerve and superficial veins are also visible in this anterior view (Schuenke et al., *Thieme Atlas of Anatomy - General Anatomy and Musculoskeletal System*. All rights reserved. ©Thieme 2007, www.thieme.com).

The literature includes two different theories of clavicle vascularization. Knudsen et al. (1989) found in their cadaveric study that the primary arterial supply to the clavicle is periosteal, through numerous Volkmann canals into the cortex. They found three arteries that supply the clavicle: the suprascapular, the thoracoacromial, and the internal thoracic, but found no well-developed nutrient artery. Havet et al. (2008) reported the periosteal vascularization as being the clavicle's main blood supply, and also noticed nutrient foramina at the lateral end of the clavicle in all their cases. Neurovascular foramina occur in several locations in the clavicle. Murlimanju et al. (2011) found the neurovascular foramen to be present typically in the middle third region, but was also in the medial and the lateral portions. The foramen is directed to the lateral end and transmits the nutrient artery. Fischer and Carret (1978) found a branch of the suprascapular artery that penetrated into the clavicle via the foramina at the level of the middle-to-lateral-third union.

Some uncertainty still exists regarding sensory innervation of the clavicle. At present, the impression is that the clavicle receives its main sensory supply from supraclavicular, suprascapular, and long thoracic nerves (Tran de et al. 2013).

2.4. Function and kinematics of the clavicle

The function of the clavicle is oftentimes ignored. Modern investigative implements (open MRI, 4D-CT, and 3D electromagnetic tracking system) have substantially enhanced understanding of clavicle function and kinematics.

The human clavicle is the only bony connection between the upper limb and the axial skeleton. The clavicle is functionally connected to the internal and external jugular veins as well as to the subclavian vein through the muscles and fascia of the neck and pectoral regions. Contraction of these muscles and movement of the clavicle work together as a circulation and ventilation pump for the arm, head, and neck. The clavicle stabilizes the shoulder girdle with its ligaments and muscle attachments and acts as a strut allowing more degrees of freedom in the shoulder joint. Due to the clavicle, the great nerves and vessels situated beneath have a bony shelter. Another consideration is that the elevation of the upper limb and the motion of the clavicle assist high costal inspiration (Ljunggren 1979).

Harmonious and continuous motion in the shoulder joint requires simultaneous action in three bones: the humerus, scapula, and clavicle, and in four joints: the glenohumeral, acromioclavicular, sternoclavicular, and scapulothoracic. Any interruption in this delicate scapulohumeral rhythm may cause dysfunction in the human being's most mobile joint (Inman and Saunders 1946, Fung et al. 2001).

Kinematics of the clavicle is closely connected to the scapulohumeral rhythm. Flexion and abduction of the upper limb at the GH joint is accompanied by scapulothoracic and clavicular movements. In the first 30 degrees of abduction and 60 degrees of flexion, the stability of the scapula is highly irregular. This early phase of motion is related to the setting action of muscles. Between 30 and 170 degrees of abduction and flexion, for every 15 degrees of motion, 10 degrees occurs at the GH joint, and 5 degrees by rotation of the scapula on the thorax. In the upper limb's flexion and abduction, the total range of scapular motion is 60 degrees and of GH motion 120 degrees (Inman and Saunders 1946). Fung et al. (2001) found in cadaveric shoulders that the majority of the scapular and clavicular rotation occurs after 90 degrees of humeral elevation. During limb elevation, the scapula retracts, rotates laterally, and tilts backward.

During elevation of the upper limb, the continuous rotation of the scapula on the thoracic wall is possible only due to the motion permitted at the two clavicular joints. The clavicle rises in the SC joint during the upper limb elevation. This movement begins early and is almost complete during the first 90 degrees, when for every 10 degrees of limb elevation, the clavicle rises 4 degrees. Above 90 degrees, clavicular elevation in the SC joint is almost negligible. In the AC joint, the angle change between clavicle and spina scapulae totals 30 degrees during limb elevation. The clavicle motion occurs early in the first 30 degrees, and late, after 135 degrees of limb elevation. The clavicle also rotates around its long axis during upper limb elevation. The total backward rotation of the clavicle is 50 degrees during limb elevation. During the first 90 degrees of elevation, only 10 degrees of clavicle rotation occur, whereas the other 40 degrees of rotation occur after 90 degrees of elevation. Motion in the SC joint during elevation is characterized by increasing clavicular retraction, elevation, and backward rotation relative to the thorax. In the AC joint, only minor (15-20 degrees) backward rotation occurs. In protrusion and retraction of the shoulders, movement of the clavicle takes place at the SC joint, and no substantial motion happens at the AC joint, nor does

the clavicle rotate (Inman and Saunders 1946). During upper limb elevation, the CC ligaments lengthen approximately 3 mm. The last 30 degrees of scapular rotation are possible only by clavicle rotation and CC ligament lengthening (Inman and Saunders 1946, Sahara et al. 2007, Ludewig et al. 2009, Izadpanah et al. 2012).

To understand the relevance of clavicle shortening to shoulder function, we may refer to one congenital disorder and certain abnormalities caused experimentally. Cleidocranial dysplasia is an autosomal dominantly transmitted disorder that affects bones undergoing intramembranous ossification. This rare congenital defect (prevalence $1/10^6$) features skeletal anomalies, including clavicular hypoplasia or absence of the clavicle (Wang et al. 2013). Clinical examination of these individuals demonstrates their shoulder function and kinematics as in an abnormal anatomical condition. Due to a hypoplastic or aplastic clavicle, the range of motion in the GH joint is enhanced, as is protrusion and retraction, and elevation of the upper limb is increased beyond 180 degrees (*Figure 6*) (Inman and Saunders 1946).

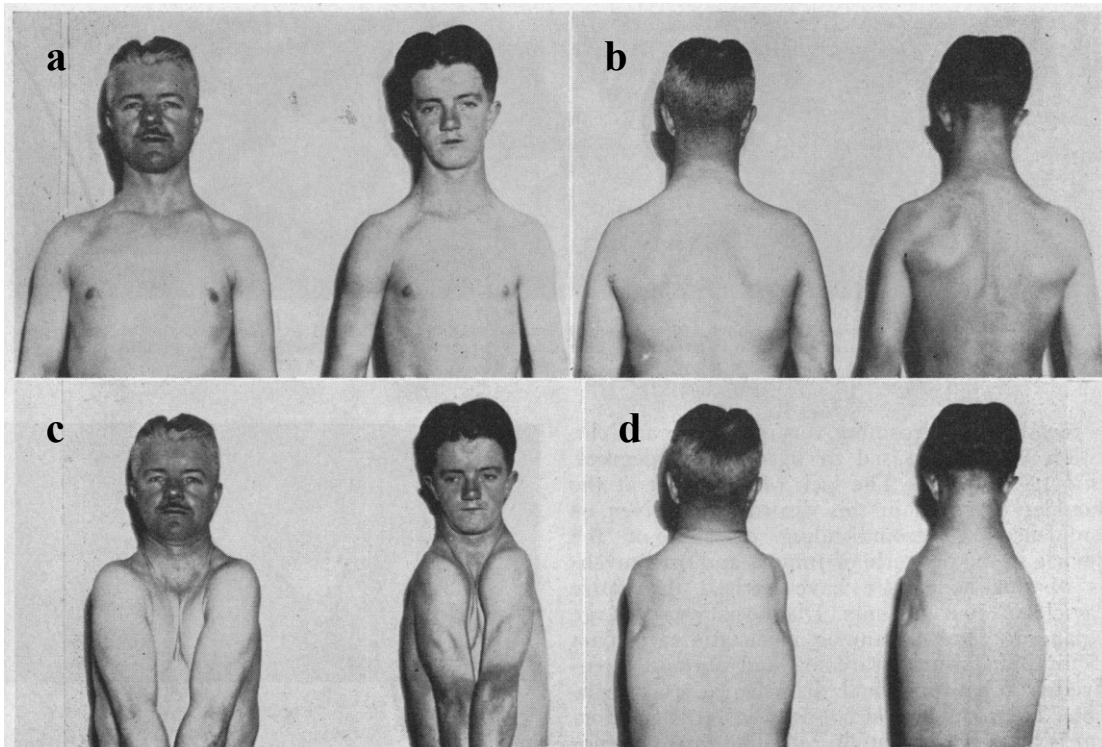


Figure 6. Photographs of two individuals having cleidocranial dysplasia with hypoplastic clavicles. Anterior (a) and posterior (b) views at rest: The habitus is narrow-shouldered but shoulder position is not markedly disturbed. The capacity of shoulder protrusion (c) and (d) is very extensive (Adapted with permission from the BMJ Group: Inman VT, Saunders JB. Observations on the Function of the Clavicle. *Calif Med.* 1946; 65: 158-166).

Sometimes a resection of the clavicle is indicated. In the literature are only case reports discussing shoulder function after a total claviclectomy (Krishnan et al. 2007, Wessel and Schaap 2007, Li et al. 2011, Oheim et al. 2012, Camargo et al. 2013). Total resection of the clavicle appears to result in excessive scapular motion, restored or increased range of motion in the GH joint, and creation of minimal strength deficits and a sense of fatigue in the scapular musculature. No difference in shoulder kinematics between sides is evident during limb elevation (Krishnan et al. 2007, Oheim et al. 2012, Camargo et al. 2013).

When the clavicle is shortened experimentally or after malunion (i.e. union in a faulty position), some changes in shoulder kinematics occur. In experimental 3.6-cm shortening of the clavicle, the scapula moves to increased lateral rotation and increased protraction, and its decreased tilt leads to an altered resting position of the shoulder girdle and of the acromion, and to altered orientation of the glenoid fossa. All these changes may result in subacromial impingement, change in the rotator-cuff contribution to joint stability, degeneration of the SC joint, and scapular dyskinesia. Shortening seems not to limit the limb elevation, but may affect the muscular balance and result in a reduced moment-arm of the pectoralis major muscle. Moreover, the altered position of the scapula may result in secondary changes in all surrounding muscles (Hillen et al. 2012). Malunion of the clavicle may affect shoulder function and muscle mechanics. Clavicular shortening reduces the moment-generating capacity and the force-generating capacity of the shoulder-area muscles. Clinically these changes can demonstrate the adverse effects of clavicular shortening on abduction, internal rotation, and flexion of the GH joint as well as in the SC joint (Patel et al. 2012). Any natural-born difference in clavicle lengths between sides (2 mm) fades into insignificance and probably has no influence on the shoulder-joint function.

2.5. Injuries to the clavicle

Clavicle injuries can be grouped into fractures and joint dislocations. In urban adults, clavicle fractures are common, comprising 2.6 to 5% of all fractures and 37% of all shoulder-area injuries (Nordqvist and Petersson 1994, 1995, Postacchini et al. 2002). Incidence is notably higher in men (68-71/100 000) than in women (23-31/100 000) (Nordqvist and Petersson 1995, Nowak et al. 2000). AC joint dislocation accounts for 8% of shoulder-area injuries, with an incidence of 18/100 000 in men and 1/100 000 in women (Nordqvist and Petersson 1995). Compared to clavicle fractures and AC joint injuries, SC joint dislocations are very rare. The ratio of SC injuries to AC injuries is reportedly 1/10 (Nettles and Linscheid 1968).

2.5.1. Fractures of the clavicle

The most common mechanism of injury is a direct fall onto the shoulder during outdoor leisure activity. The single most frequent cause of injury is cycling (Nowak et al. 2000). As a result of the blow to the shoulder, the force proceeds along the long axis of the clavicle between the acromion and the sternum. The critical force for clavicle buckling is approximately 1 to 3 times body weight. According to geometrical and biomechanical studies, the diaphyseal area of the clavicle seems to be the weakest in resisting torsion and bending loads. During axial loading, the S-shaped curvature of the clavicle imposes significant bending or torsional moments, or both, upon the diaphyseal area of the bone (Harrington et al. 1993). It is extremely uncommon for clavicle fracture to be complicated. According to epidemiologic studies, only 0.2 to 0.4% of all clavicle fractures are open (Robinson 1998, Postacchini et al. 2002).

Fractures of the clavicle can be classified according to anatomical site, displacement, and morphology. In the traditional Allman classification, clavicle fractures are categorized into three groups and three subgroups. Group I includes middle-third fractures, group II lateral-third fractures, and group III medial-third fractures. Subgroups a, b, and c include undisplaced, displaced, and comminuted fractures (*Figure 7*) (Allman 1967). A more accurate classification is Robinson's, whose type 1 is fracture in the medial 1/5 of the clavicle, type 2 is fracture in the intermediate 3/5 of the clavicle, and type 3 is fracture in the lateral 1/5 part. The Robinson classification has subgroups A (less than 100% translation) and B (greater than 100% translation), depending on

displacement of the major fragments, and additionally second subgroups 1 and 2 divide the medial and lateral end fractures into extra- or intra-articular. The diaphyseal fractures also have second subgroups 1 and 2; 1 meaning undisplaced in subgroup A or simple in subgroup B, and 2 meaning angulated in subgroup A or comminuted in subgroup B (Figure 8) (Robinson 1998). In practice, the Robinson classification is slightly complex and difficult to remember, and therefore less often used in daily clinical work.

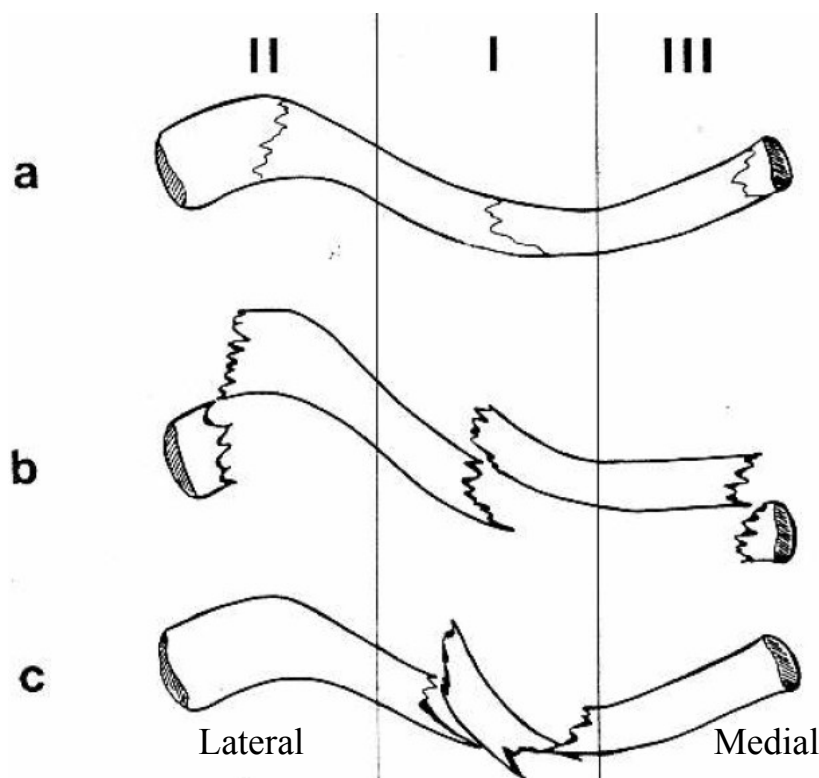


Figure 7. Allman classification of clavicle fractures. Based on anatomical site, there are three main groups: I middle-third, II lateral-third, and III medial-third fractures. The displacement is graded as undisplaced (a), displaced (b), and comminuted (c) fractures (Adapted with permission from Lippincott Williams and Wilkins/Wolters Kluwer Health: Nordqvist A, Petersson C. The incidence of fractures of the clavicle. *Clin Orthop Relat Res.* 1994 (300): 127-132).

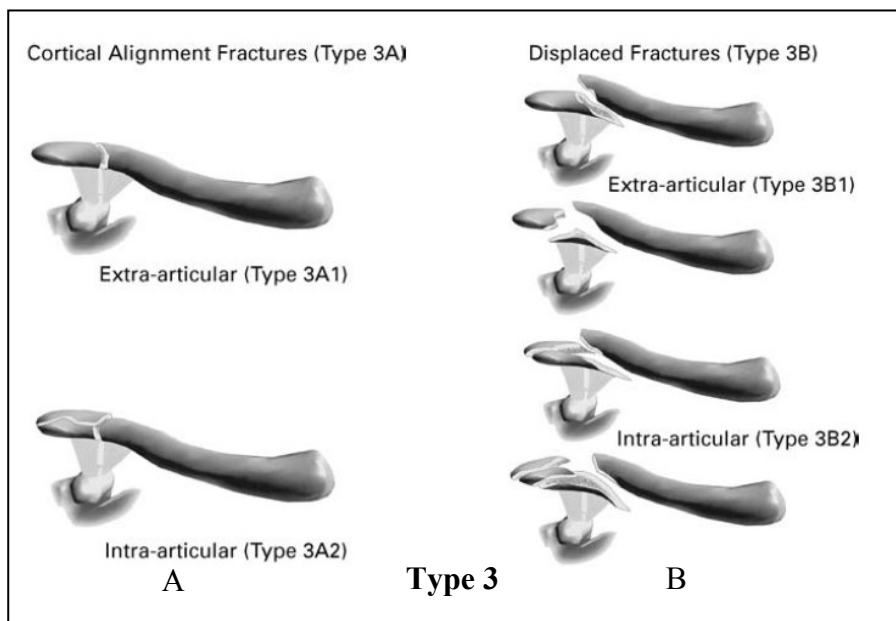
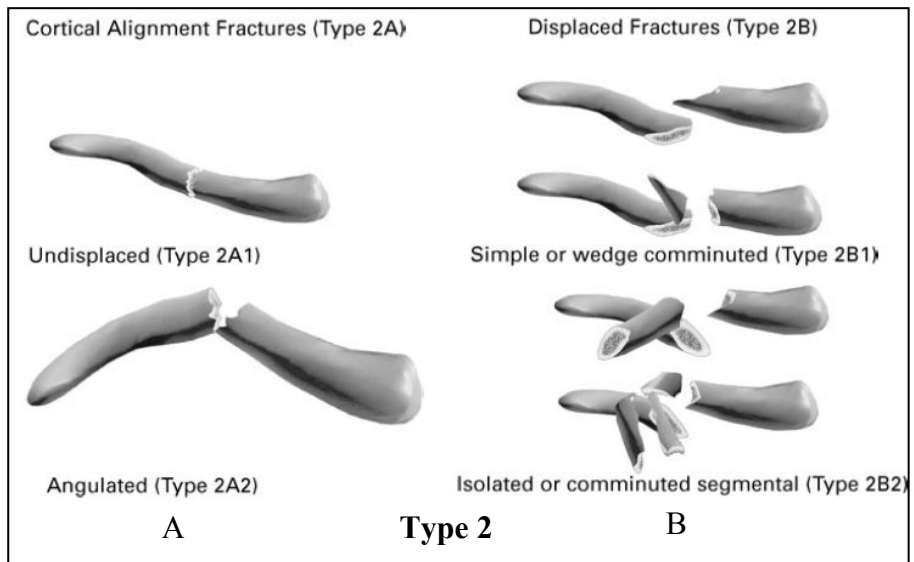
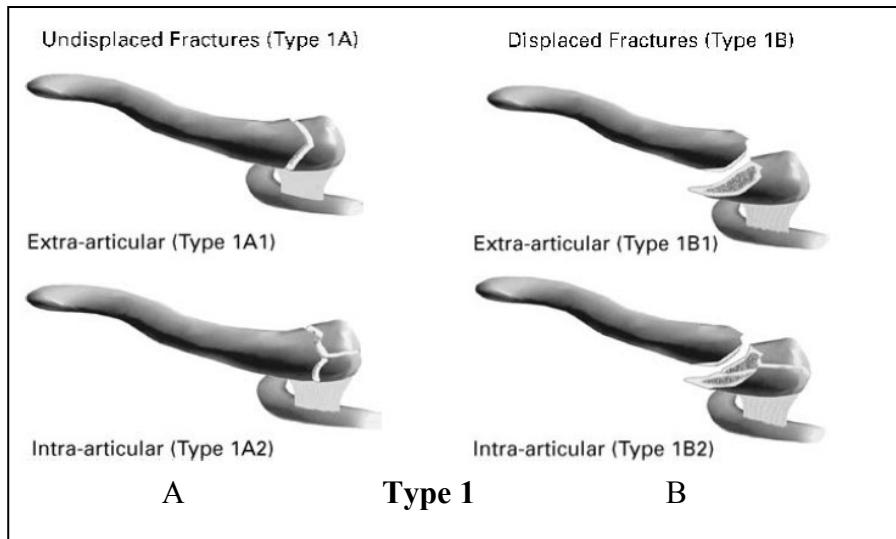


Figure 8. Robinson classification of clavicle fractures. (Reproduced with permission and copyright © of the British Editorial Society of Bone and Joint Surgery. Robinson CM. Fractures of the clavicle in the adult. Epidemiology and classification. *J Bone Joint Surg Br.* 1998; 80: 476-484).

Diaphyseal fractures of the clavicle

Midshaft or diaphyseal fractures, the most common clavicle injuries, account for 70 to 80% of all clavicle fractures and are typically caused by simple falls, motor-vehicle accidents, and sports. The male-to-female ratio is 2.5:1. After childhood and adolescence, the peak incidence is at 20 to 40 years for men and over 80 years for women. The typical patient is male and under 35 years old (Robinson 1998, Nowak et al. 2000, Postacchini et al. 2002). Signs of injury to the brachial plexus may be apparent at the time of fracture of the clavicle. This is the result of pressure from a displaced bone fragment or of axonotmesis consequent to stretching of the brachial plexus. Similarly, narrowing of the space between the clavicle and the first rib may cause compression of the subclavian vessels or brachial plexus (Howard and Shafer 1965). Vascular injury relating to diaphyseal clavicle fracture is rare because the outer fragment is displaced downward and forward by the weight of the limb, and the inner fragment is pulled slightly upward and backward, which prevents the bone ends from impinging on the subjacent vessels (*Figure 9*). Secondly, the subclavius muscle and the thick deep cervical fascia act as a barrier between the bone ends and the vessels (Penn 1964).



Figure 9. Typical morphology of comminuted diaphyseal clavicle fracture in an AP radiograph. The main inner fragment (*) is pulled upward, and the outer fragment (**) is slightly displaced downward.

Fractures of the lateral end of the clavicle

Depending on the classification method, fractures of the lateral end account for 17 to 25% of all clavicle fractures. The male-to-female ratio is 1.5:1, and the mean age 37 to 45 years. The most common injury mechanism is a low-energy fall (Robinson 1998, Postacchini et al. 2002). Incidence is relative high in the elderly, probably related to senile osteopenia, making the trabecular bone in the lateral end more prone to fracture than the cortical bone of the diaphyseal area (Postacchini et al. 2002).

Lateral fractures are divided according to the Neer classification, widely used in the literature and in clinical practice. Depending on CC ligament damage, fracture displacement, and fracture site, Neer classified lateral fractures into three types. In type I, the CC ligaments are intact, and the fracture undisplaced and stable. Type II fractures are unstable and occur at the level of CC ligaments, which are detached, leading to displacement. Type III fractures are stable, situated lateral to ligaments and extending to the articular facet (*Figure 10*) (Neer 1963, 1968).

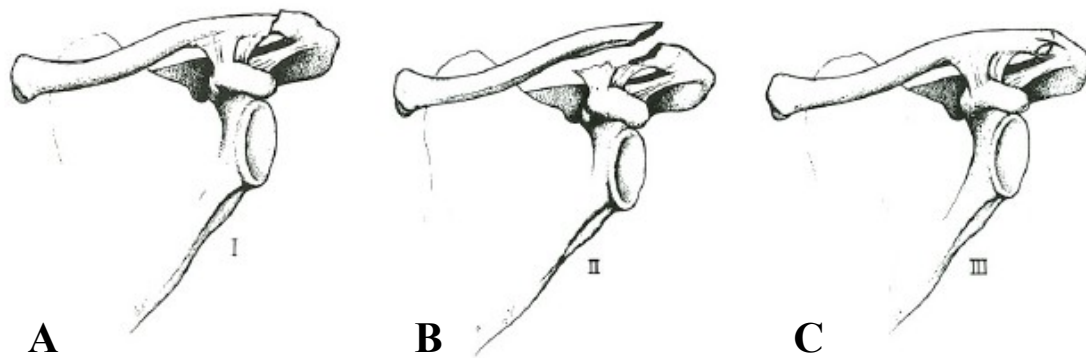


Figure 10. Neer classification of lateral clavicle fractures. A is type I, B is type II, and C is type III. (Adapted with permission from Lippincott Williams and Wilkins/Wolters Kluwer Health. (Rockwood and Green 1975) *Fractures*, vol 1: 1975. p. 611).

Fractures of the medial end of the clavicle

Fractures of the medial end of the clavicle are rare, accounting for less than 5% of all clavicle fractures (Robinson 1998, Nowak et al. 2000, Postacchini et al. 2002). Medial-end fractures are usually caused by high-energy trauma such as motor-vehicle accidents. Patients with medial-end fractures often have associated injuries such as rib fractures, pneumothorax, hemothorax, pulmonary contusion, head or neck injuries, or limb injuries (Postacchini et al. 2002, Throckmorton and Kuhn 2007).

2.5.2. Injuries in the articulations of the clavicle

Acromioclavicular joint dislocation

Injury to the AC joint occurs typically by a direct blow to the superolateral aspect of the shoulder when the upper arm is adducted. It is usually a sport-related or cycling injury. During a fall, force is transmitted through the AC and CC ligaments and may cause them damage (Mazzocca et al. 2007). Injuries vary from mild sprains to complete joint dislocation. Tossy et al. (1963) and Allman (1967) originally described three types of AC joint injuries. Later, Rockwood advanced this classification by describing three additional injury types. This classification is based on degree of soft tissue injury and clavicle dislocation. Type I is sprain of the AC ligament with the AC joint intact; type II

is a tear in the AC ligament with CC ligaments intact, and the AC joint widened; in type III, both AC and CC ligaments are torn, and the CC interval is widened 25 to 100%; type IV is a complete tear in AC and CC ligaments, but the clavicle is directed posteriorly and buttonholed into the trapezius muscle; type V is a complete tear in AC and CC ligaments, additionally, the deltoid and trapezial fascias are disrupted, and the CC interval is widened 100 to 300%; and finally type VI, a very rare injury, in which the clavicle is displaced beneath the coracoid process (*Figure 11*) (Rockwood 1984). The most common injury is type III dislocation, accounting for 40% of all AC joint injuries (Chillemi et al. 2013).

Sternoclavicular joint dislocation

Acute complete SC joint dislocation results from high energy either directly or indirectly, with traffic accidents and sport-related accidents the most common injury mechanisms. SC joint dislocations are usually divided into anterior or posterior dislocations. Anterior dislocation may occur when the shoulder moves backward and outward forcefully. Then the clavicle is pulled back beyond its limit of motion, and the first rib and thorax act as a fulcrum to spring the sternal end of the clavicle forward out of its articulation. Due to the strong posterior capsular ligaments, posterior dislocation is much less frequent than anterior (Spencer et al. 2002). Direct force to the anteromedial aspect of the clavicle may push the clavicle posteriorly behind the sternum. Alternatively, if the shoulder is rolled forward during forceful lateral compression, the SC joint may be dislocated indirectly (Nettles and Linscheid 1968, Wirth and Rockwood 1996). Sometimes posterior dislocation may be life-threatening due to respiratory distress, vascular injuries, and tracheal or mediastinal compression injuries (Howard and Shafer 1965, Gardner and Bidstrup 1983, Gale et al. 1992, Nakayama et al. 2007). Due to late union of medial epiphysis between age 24 to 26 (Black and Scheuer 1996), it is often difficult to differentiate a true SC joint dislocation from a physeal separation (Wirth and Rockwood 1996, El Mekkaoui et al. 2011).

Injury to the SC joint ligaments may also be a sprain. Grade I sprain is mild, and no laxity in the SC joint appears. In grade II sprain, the SC ligaments are ruptured, but the costoclavicular ligament is intact, and no complete joint dislocation occurs (Allman 1967).

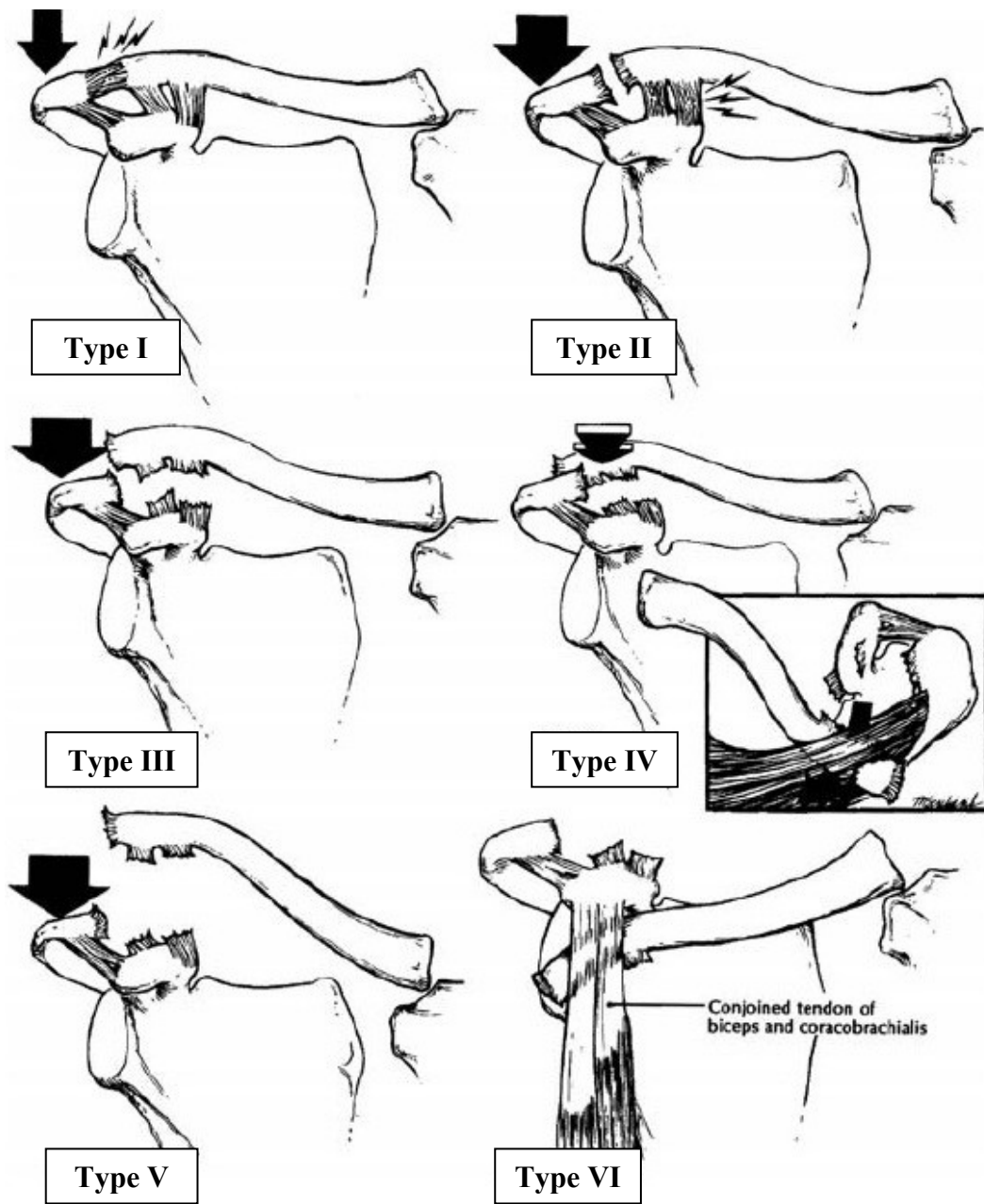


Figure 11. Rockwood classification of AC joint injuries, based on degree of soft tissue injury and clavicle dislocation. More detailed information about injury types is provided in the text. (Adapted with permission from Lippincott Williams and Wilkins/Wolters Kluwer Health. (Rockwood). *Fractures in Adults: Injuries to the AC joint*, 1984. p. 860-910).

2.6. Diagnosis of clavicle injuries

If possible, the exact injury mechanism should be discovered through a good anamnesis that allows visualization of the event. Trauma energy should be evaluated to learn whether the energy exerted its effect directly or indirectly. Understanding the injury mechanism and the energy impact upon various tissues improves accuracy of diagnosis. The patient may complain of pain, weakness, crepitation, or snapping in the clavicle region.

2.6.1. Clinical examination

The patient should, during the examination, be undressed. Inspection will reveal any deformities, bruises, swelling, signs of a blow, and condition of the skin. When the patient is in a standing position, arms hanging beside the trunk, the position of the shoulders and shoulder blades are evaluated, as well as atypical appearance of the clavicle region. The arms can be gently pulled downwards to observe potential changes in clavicle position. Comparison with the uninjured side may help in discerning deformities.

Palpation helps in finding anatomical abnormalities and tenderness. Clavicular stability is tested at both ends. Possible instability is tested both vertically and horizontally. In a fresh injury, this palpation has to be done cautiously. It is not uncommon that an unstable clavicle appears stable in palpation, since muscle tone and tension may conceal the actual injury. Sensation is checked in the chest and shoulder. Upper-limb function, sensation, and pulse are verified, as well range of motion of the joints. With suspicion of high-energy trauma, complete status must be determined. Presence of stridor, dysphagia, shortness of breath, or venous congestion must be checked.

2.6.2. Radiological examination

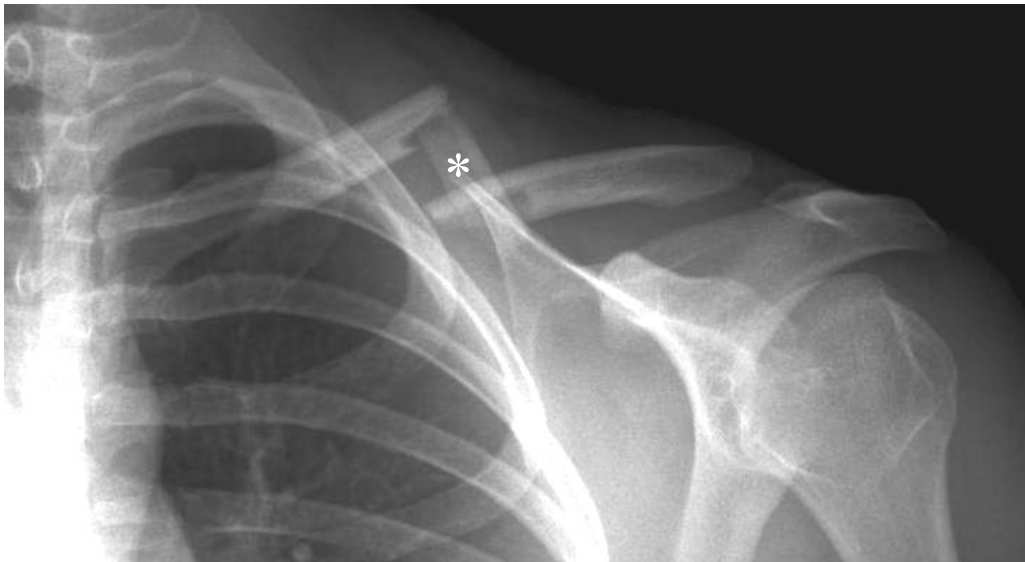
Radiograph

Standardized radiographs are necessary to illustrate the injury's character. Radiographs are the most important and nearly always a sufficient examination for diagnosing the injury. Diaphyseal fracture is verified from anteroposterior (AP) and some degree (15-45°) horizontally tilted radiographs (*Figure 12*) (Nowak et al. 2004, Robinson et al. 2004, Austin et al. 2012). Tilted projection is important, since transversely placed

fragments and ventrodorsal displacement cannot be fully visualized in plain AP view (Nowak et al. 2004). Radiographs should make visible the fracture site, displacement, shortening, and comminution. True clavicle shortening is impossible to define reliably only from radiographs of the injured side. Thus a radiograph from the contralateral side is sometimes indicated, especially in comminuted fractures (Sharr and Mohammed 2003).



a) AP radiograph.



b) AP radiograph with 15° caudocranial tilt.

Figure 12. AP (a) and caudocranially tilted AP (b) radiographs of left clavicle. In the tilted radiograph is clearly visible the fracture comminution and transversely placed fragment (*).

Radiographic evaluation of a lateral clavicle fracture and AC joint dislocation should additionally include AP and axillary views of the shoulder and a 5 to 15° caudocranially tilted view of the AC joint (*Figure 13*). The axillary view is important in differentiating type III AC joint injury from type IV injury. Comparing the contralateral side is sometimes helpful, and therefore a radiograph showing bilateral clavicles is useful in assessing fracture displacement and AC joint dislocation type (*Figure 14*) (Mazzocca et al. 2007, Banerjee et al. 2011). A Zanca view of the AC joint is the most accurate view to evaluate the AC joint and possible intra-articular fracture involvement. This view is performed by tilting the radiograph beam 15° toward the cranial direction (Zanca 1971). A weighted or stress view of the AC joint (i.e. an AP radiograph of the clavicle in the standing position with a 5- to 8-kg weight suspended from the hand) has previously served to diagnose the occult type III AC joint injuries when initial radiographs are not definitive (Dias et al. 1987, Beim and Warner 1997). Bossart et al. (1988) found that weight rarely caused any increase in the injured CC distance and concluded that unmasking of type III injuries is impossible on plain films. A weighted view has been of limited clinical value in evaluation of AC joint injuries (Yap et al. 1999).

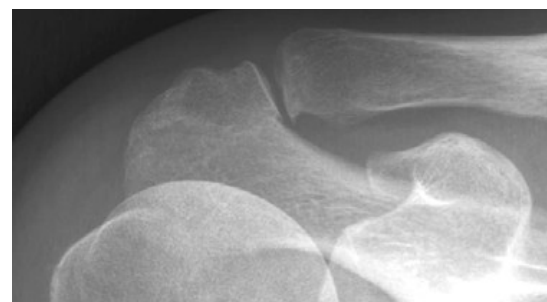
In conventional clavicle and chest radiographs, the SC joint dislocation is often underestimated. Posterior dislocation is especially often misdiagnosed, since the clinical signs may be indefinable, and the AP radiograph may seem normal (Ernberg and Potter 2003). Rockwood described the 40° cephalic-tilt view with the radiograph beam projecting caudocranially. In this view, the anterior dislocation presents as a superiorly displaced medial clavicle, and posterior dislocation as an inferiorly displaced medial clavicle (Rockwood 1975). In Heinig view, the radiograph beam is directed perpendicular to the SC joint (i.e. oblique to the patient) when the patient lies supine. In this view, the dislocation can be identified by its relationship to the laterally projected manubrium (Waskowitz 1961). Like SC joint injuries, the diagnosis of medial-end fractures is also challenging on plain films. Throckmorton and Kuhn (2007) found that 22% of medial-end fractures were not visualized on plain radiographs.



a) AP radiograph with humerus internally rotated.



b) Axillary radiograph. From this view it is possible to assess the position of lateral clavicle (C) to acromion (A).



c) AP view with 10° caudocranial tilt of right AC joint. Margins of articular surfaces are clearly visible.

Figure 13. AP (a) and axillary (b) views of left shoulder and caudocranially tilted view (c) from right AC joint.



a) AP radiograph of right clavicle.



b) AP radiograph of both clavicles.

Figure 14. AP radiographs of one patient having type V acromioclavicular joint dislocation. View a) shows cranial dislocation of the clavicle and a widened CC interval. View b) shows better the CC interval widening when compared to the uninjured side. The CC interval is broadened more than 100%.

Computed tomography

Computed tomography (CT) has excellent sensitivity in identifying fractures of the shoulder girdle region. Fracture morphology and displacement are defined precisely with multiplanar reformats (Adams et al. 2011), but CT is not a standard examination for clavicle injuries. In high-energy blunt trauma patients, multidetector CT is routine (Deunk et al. 2007). In medial-end fractures, CT is suggested because of possible high trauma-energy and the good visualization (Throckmorton and Kuhn 2007).

To evaluate SC joint injuries, CT is the best imaging modality. It distinguishes injuries of the joint from fractures of the medial clavicle and also defines minor subluxations of the joint (Wirth and Rockwood 1996). For accurate evaluation of SC joint injuries,

intravenous contrast administration is mandatory. This procedure allows evaluation of any major vascular and soft tissue injuries (Salgado and Ghysen 2002).

In AC joint dislocation, CT may be helpful in difficult cases to improve visualization of dislocation type and trajectory of bony displacement. CT can also better demonstrate subtle fractures in the lateral end of the clavicle (Kim et al. 2012a).

Magnetic resonance imaging

In clavicle fractures, magnetic resonance imaging (MRI), with its superior soft tissue contrast, can be extremely useful for imaging suspected neurovascular complications, pseudoaneurysm formation, impingement of the brachial plexus and adjacent vessels, and hematoma formation (Melenevsky et al. 2011).

In AC joint dislocation, MRI allows adequate assessment of the ligamentous and muscle attachments and can define the true injury type, giving detailed information as to the extent of the injury. Sometimes age-related AC joint changes cannot be reliably differentiated from AC ligament sprains on radiographs, and then MRI is also valuable. The coronal oblique plane, parallel to the distal clavicle and AC joint, displays purposefully the CC ligaments in the same plane in which they tear. Moreover, the AC joint and its ligaments are adequately visible in this plane (Antonio et al. 2003, Schaefer et al. 2006).

In young adults, MRI can serve to distinguish SC joint dislocation from epiphyseal injury. In addition, MRI allows assessment of the trachea, esophagus, and great vessels as well as the integrity of the costoclavicular ligament and the intra-articular disc (Groh and Wirth 2011).

Ultrasound

No study, to our knowledge, discusses ultrasound (US) diagnosis of clavicle fractures in adults. Instead, diagnosing clavicle fractures by US in children and adolescents is considered an accurate alternative to radiography (Cross et al. 2010, Chien et al. 2011). US examination has the potential to rapidly assess vascular injuries related to clavicle fractures, thus expediting additional radiographic studies (Gullo et al. 2013).

In AC joint dislocation, US may be helpful in evaluating soft tissue injuries. Sonographic imaging of the CC ligaments is impossible because of the overlying clavicle, but with US the state of deltoid and trapezoid muscles attachments is accurately assessable. Thus, US, together with radiographs, can be profitable to distinguish between type III and type V injuries (Heers and Hedtmann 2005).

The role of US for the SC joint is limited. Based on a few case reports, US may prove useful as a vital screening method in posterior SC joint dislocation. Color Doppler imaging allows diagnosis of any associated vascular compression rapidly and non-invasively (Pollock et al. 1996, Blakeley et al. 2011).

2.7. Treatment of clavicle injuries

Throughout the history of medicine, clavicle fractures have been treated nonoperatively; or to be precise, they have healed naturally. Even in the 19th century, surgeons passionately debated the best treatment for clavicle fractures. Many forms of bandages and apparatus were devised aiming to maintain accurate reduction of the fragments. The first devices published were various splints, dressings, bandages, or plaster of Paris (Davis 1890, Collins 1912, Kennell 1919, Royster 1919). Since the time of this old-fashioned management, nonoperative treatment has evolved and is nowadays not as restrictive. The primary goal of treatment is ossification and restoration of shoulder function to the preinjury level.

The first reports concerning surgical treatment for clavicle fractures are from the 19th and early 20th centuries. Naturally, the mainstream treatment was noninvasive, but some attempts at surgical treatment had already then appeared. Sometimes in comminuted fractures, the sharp transverse bone fragment was removed without any additional procedure. A rather ordinary method was to bind the fracture with stout silver or bronze wire (Annandale 1873, Davis 1896, Taylor 1905). The first report discussing clavicle plating is by Joseph Bendell. He successfully used double Lane steel plates and postoperatively plaster of Paris and Velpeau bandage for 4 weeks (Bendell 1912). At present, the spectrum of surgical devices is wide, and therefore the surgeon is confronted with an embarrassment of riches.

2.7.1. Diaphyseal fractures

Nonoperative treatment of diaphyseal fractures

The majority of diaphyseal fractures are still treated nonoperatively. The most widely accepted treatment involves use of a sling (i.e. mitella) for support during the initial phase and early mobilization of the shoulder joint as the pain subsides (Robinson et al. 2004). The optimal reported length of immobilization varies, but the most common period appears to be 2 to 4 weeks (Lester 1929, Andersen et al. 1987, Robinson et al. 2004, Postacchini et al. 2010).

Another fairly common treatment option is the figure-of-eight bandage. It demands regular adjustments throughout the treatment period, and is criticized for causing inconvenience, discomfort, and complications such as skin problems, pain, or neurovascular problems without securing better relief from pain or healing in better alignment than a sling (Lester 1929, Nicoll 1954, Fowler 1968). Some studies have compared treatment with figure-of-eight bandage and sling. Andersen et al. (1987) found in a prospective randomized trial that treatment with a sling caused less discomfort and fewer complications than did the figure-of-eight bandage. The functional and cosmetic results were identical, and alignment of the healed fractures was unchanged from the initial displacement. Hoofwijk and van der Werken (1988) found identical results, meaning more complications and nonunion with a figure-of-eight bandage.

Results of nonoperative treatment vary depending on fracture displacement, comminution, and shortening. Functional results are found to decrease and disability increase if the vertical displacement is more than 2 cm or if there is no bony contact between the fragments, if the fracture is comminuted, if there are transverse fragments, or if shortening is more than 2 cm (Hill et al. 1997, Wick et al. 2001, Nowak et al. 2004, Lazarides and Zafiroopoulos 2006, Postacchini et al. 2010).

Incidence of nonunion (*Figure 15*) is approximately 8 to 26% after nonoperative treatment. Predictive factors that increase risk of nonunion are advanced age, female gender, displacement of the fracture, presence of comminution, and smoking (Hill et al. 1997, Robinson et al. 2004, Murray et al. 2013, Robinson et al. 2013).



Figure 15. AP radiograph of left clavicle showing nonunion of diaphyseal fracture.

With nonoperative treatment, it is impossible to influence fracture alignment. One estimation is that 2/3 of diaphyseal fractures end in some degree of malunion (i.e. union in a faulty position). Malunion may sometimes lead to pain, loss of strength, rapid fatigability, and paresthesia of the upper limb (Hill et al. 1997, McKee et al. 2003, Hillen et al. 2010). Some suggestions as to what causes these symptoms in malunion include shortening of the clavicle that changes the orientation of the glenoid fossa with winging of the scapula, shortening of the clavicle with a negative effect on muscle-tendon tension and muscle balance, large callus formation causing thoracic outlet syndrome, and change in the resting angle of the SC joint resulting in a changed load on the AC and SC joint (Chan et al. 1999, Fujita et al. 2001, McKee et al. 2003, Ledger et al. 2005, Andermahr et al. 2006).

Operative treatment of diaphyseal fractures

Some definite indications for surgery exist in the literature, such as skin tenting, open fracture, presence of neurovascular injury, multiple trauma, or floating shoulder. Additionally, relative indications for surgery in active younger patients include fractures with complete displacement, fractures with greater than 1.5- to 2-cm shortening, and fractures with comminution (Hill et al. 1997, Jeray 2007, van der Meijden et al. 2012).

Open reduction and internal fixation can be performed with either plate (*Figure 16*) or intramedullary (IM) pin fixation (*Figure 17*). Pins are popular in countries of central

Europe (Germany, Austria, Switzerland), eastern Asia (Republic of Korea, Taiwan, China), and in the United States. Advantages of surgery are restitution of normal anatomy, immediate rigid fixation facilitating early mobilization and return to activities, and security of the fracture union. A variety of plates and IM pins have been used with varying success (Jeray 2007, Khan et al. 2009, van der Meijden et al. 2012). Biomechanical studies have shown that plate fixation provides a stronger construction than the IM pin for early mobilization (Golish et al. 2008).

When comparing a rigid IM pin to a plate, no difference emerges in union rate or in shoulder function. Instead, it seems that the overall complication rate is higher with plate fixation than with rigid IM fixation (Ferran et al. 2010, Fu et al. 2012, Wenninger et al. 2013). Several studies compare elastic stable intramedullary nailing (ESIN) to plate fixation (Liu et al. 2010a, Assobhi 2011, Chen et al. 2012, Tarng et al. 2012). According to these studies, shoulder function, union rate, and complication rate all appear somewhat equal. Time to union is slightly shorter in ESIN than in plate fixation. This phenomenon is explained by favorable features of ESIN such as preserving the soft tissue envelope, the periosteum, and the vascular integrity of the fracture site (Liu et al. 2010b).

Biomechanical properties of various plates and pins have been surveyed and quite uniform results published. Drosdowech et al. (2011) found that the reconstruction plate, limited contact dynamic compression plate (LC-DCP), and locking compression plate (LCP) were stiffer than the Rockwood pin during bending and torque loads. If the fracture included a cortical defect, LC-DCP and LCP were stiffer than the reconstruction plate. The pin had the poorest resistance to bending and torque loads.

Plate location influences fracture stability. An anteroinferior reconstruction plate provides a more stable construction in bending rigidity than does a superior plate. Avoidance of neurovascular compromise, use of longer screws, and decreased hardware prominence are also advantages of anteroinferior plate location (Partal et al. 2010).

Both plate and pin fixation have specific disadvantages. Typical complications of plate fixation include wound infection, hardware irritation, hypertrophic scar, mechanical failures, nonunion, and refracture after implant removal. Pin-related complications include malunion, nonunion, wound infection, hardware failures, skin erosion, and

migration (Canadian Orthopaedic Trauma Society 2007, Liu et al. 2010a, Assobhi 2011, Millett et al. 2011, Robinson et al. 2013).



Figure 16. AP radiograph of diaphyseal clavicle fracture stabilized with anteroinferiorly situated 3.5-mm reconstruction plate and cortical screws.

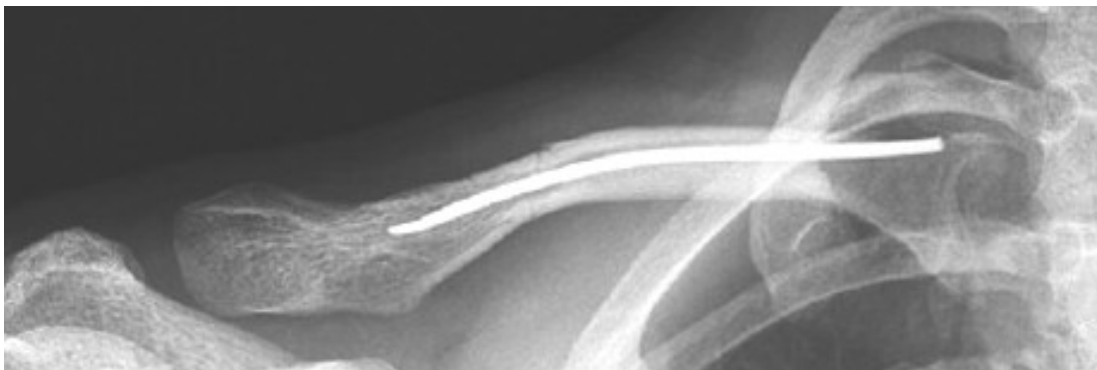


Figure 17. AP radiograph of diaphyseal clavicle fracture stabilized with IM fixation.

Randomized studies comparing operative to nonoperative treatment

Since 2007, randomized controlled trials have compared operative treatment to nonoperative treatment for midshaft clavicle fractures. Based on surgical method, these studies can be grouped into interventions using a plate compared to nonoperative treatment, and interventions using IM fixation compared to nonoperative treatment.

In favor of plate osteosynthesis, these studies reveal that recovery and pain relief occurs faster, union occurs earlier and is better secured, and sense of disability is lower. The favorable effect of plate osteosynthesis on shoulder function is not conclusively shown (Canadian Orthopaedic Trauma Society 2007, Figueiredo et al. 2008, Mirzatooei 2011).

Advantages of IM fixation are not as evident as plate osteosynthesis when compared to nonoperative treatment. IM fixation seems to further the early recovery and may slightly hasten union time. No difference appears in shoulder function. The complication rate seems to be equal to or even higher with IM fixation than with nonoperative treatment (Koch et al. 2008, Judd et al. 2009, Smekal et al. 2009).

2.7.2. Fractures of the lateral end

Nonoperative treatment of lateral-end fractures

The literature shows definite agreement on nonoperative treatment for stable Neer type I and III fractures (Neer 1963, 1968, Brunner et al. 1992, Khan et al. 2009, Banerjee et al. 2011, Oh et al. 2011). As in diaphyseal fractures, nonoperative treatment involves the use of a sling for a couple of weeks and early mobilization of the shoulder. In Neer type I fractures, the results are nearly always good, and complications such as nonunion, AC joint arthrosis, and lateral clavicle osteolysis are rare (Neer 1968, Nordqvist et al. 1993, Robinson 1998). Also in Neer type III fractures, results of nonoperative treatment are good. Because of intra-articular involvement, there is a subtle risk for AC joint arthrosis. Tendency for union is good (Brunner et al. 1992, Nordqvist et al. 1993, Robinson 1998, Oh et al. 2011).

The best treatment option for Neer type II fractures is still somewhat controversial (*Figure 18*). The unstable nature of this fracture entails the risk for nonunion, which is shown to be 22 to 44% (Neer 1963, Deafenbaugh et al. 1990, Nordqvist et al. 1993, Robinson 1998, Rokito et al. 2002). Somehow, many patients with a nonunion are relatively asymptomatic and infrequently require surgical intervention. Nonunion seems not to impair functional outcomes or strength, and patients are often pain-free or have only mild pain (Deafenbaugh et al. 1990, Nordqvist et al. 1993, Robinson 1998, Rokito et al. 2002, Robinson et al. 2004).

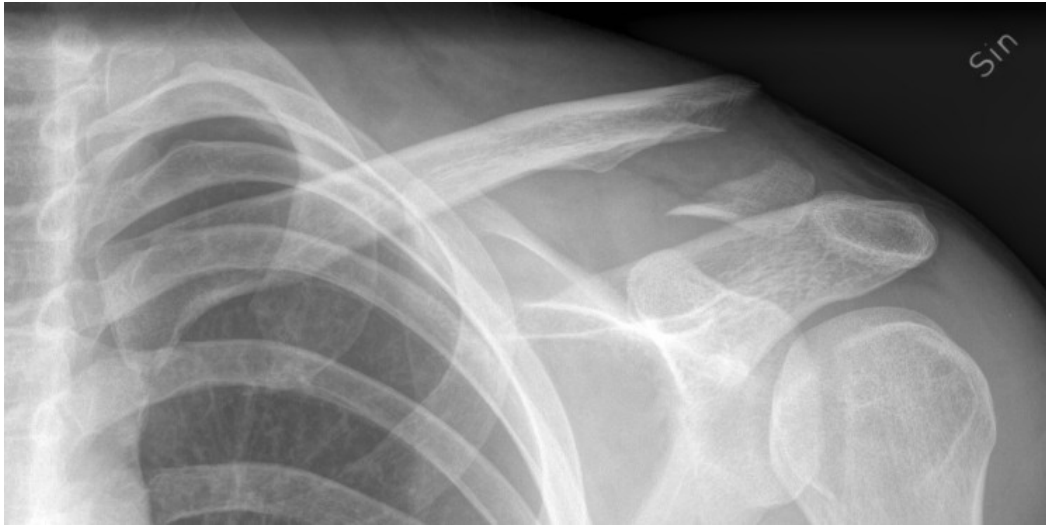


Figure 18. AP radiograph of left clavicle showing unstable Neer type II lateral fracture. The diaphyseal part of clavicle is dislocated cranially due to rupture of CC ligaments.

Operative treatment of lateral-end fractures

Complete unanimity as to indications for surgery in unstable Neer type II fractures is not yet achieved. Indication for surgical treatment should be based on the stability and displacement of the fracture, patient age, and functional requirements. Integrity of the CC ligaments plays a key role in providing stability to the medial fracture segment. Surgery should be considered if the soft tissue is compromised, if the patient is multiply injured, or in the presence of floating shoulder (van der Meijden et al. 2012).

The literature abounds with various methods and devices to treat unstable lateral-end fractures, but no superior method has yet been invented. Surgical methods can be divided into those fixing the fracture (plates, wires, screws, pins) and those replacing or reconstructing the CC ligaments (suture loops, bands, suture anchors, tendon grafts). A combination of fracture fixation and CC ligament repair also exists. In shoulder function, no difference emerges between various surgical modalities. Overall, union with surgery is good (98%), with no difference among the modalities. The complication rate is reportedly higher with a hook plate than with other implants (Oh et al. 2011, Stegeman et al. 2013).

Recently, also arthroscopic-assisted or fully arthroscopic fracture fixation methods have appeared. Their advantage is their minimal invasive character along with minor soft tissue damage. Their disadvantage is that this procedure is technically demanding and requires advanced arthroscopic skills. Like open surgery, the arthroscopic approach does not ensure absolute stability of the fracture, nor does it prevent redislocation (Nourissat et al. 2007, Checchia et al. 2008, Lee et al. 2010, Takase et al. 2012).

Overall, the level of evidence in studies concerning lateral-end fractures is poor. Many studies have an insufficient number of patients and lack control groups. No randomized or non-randomized controlled trials appear in the literature. Hence, the most suitable treatment modality for type II fractures is hard to judge. It seems that precontoured locking plates with or without CC ligament augmentation are going to replace the widely used hook plate (*Figure 19*) (Bhatia and Page 2012, Hohmann et al. 2012, Lee et al. 2013, Schliemann et al. 2013, Tiren and Vroemen 2013).

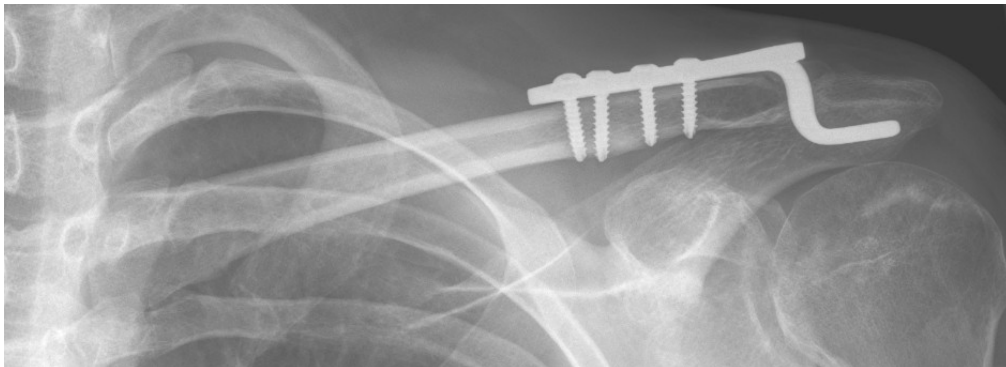


Figure 19. AP radiograph of left clavicle after the unstable Neer type II fracture is stabilized with hook plate.

2.7.3. Fractures of the medial end

Nonoperative treatment of medial-end fractures

Fractures of the medial end should nearly always be treated nonoperatively. As in diaphyseal fracture treatment, the sling is applied for a couple of weeks. As pain allows, the early range of motion is encouraged (van der Meijden et al. 2012). Robinson (1998) found in a retrospective study of 27 medial-end fractures that despite the displacement,

all fractures united nonoperatively. Throckmorton and Kuhn (2007) reported results of 57 medial-end fractures, and in their study, 93% of fractures were treated nonoperatively with or without immobilization. Their primary indication for surgery was the presence of an open fracture. In another study, Robinson found that rate of nonunion at the 24th week in displaced medial-end fractures was 14.3% and in undisplaced fractures 6.7% (Robinson et al. 2004).

Operative treatment of medial-end fractures

Particular indications for surgical treatment in displaced medial-end fractures are open fracture, neurovascular involvement, and threat to the integrity of the overlying skin (Low et al. 2008).

Various established methods or devices exist for internal fixation. Fracture location, morphology, and comminution influence the method, as does bone quality as well. Reports discuss the use of various plates, screws, nonabsorbable sutures, and cerclage wire (Low et al. 2008, Bartonicek et al. 2010, Kim et al. 2011, Koch and Wells 2012).

The use of Kirschner wire in medial-end fractures is not recommended because of risk for migration and its potential lethal consequences (Leppilahti and Jalovaara 1999, Hegemann et al. 2005, Marchi et al. 2008, Orsini et al. 2012).

2.7.4. Acromioclavicular joint dislocations

Nonoperative treatment of acromioclavicular joint dislocations

What is generally accepted is that type I and II AC joint dislocations may be treated nonoperatively (Allman 1967, Nuber and Bowen 1997, Bathis et al. 2001). Even in most athletes, nonoperative treatment leads to a successful outcome (Lemos 1998). As in other clavicle injuries, the arm is immobilized with a sling for 2 to 3 weeks following gradual mobilization. Mouhsine et al. (2003) discovered that the severity of consequences after type I and II injuries is underestimated, since one-third of the patients complained of activity-related pain or had residual AP instability after nonoperative treatment.

The management of type III dislocations is controversial. Nonoperative treatment is proposed because it includes good functional results, a short period of rehabilitation,

and a low complication rate (Bathis et al. 2000, Schlegel et al. 2001). Nonoperative and operative treatment modalities comparing studies on type III dislocations report uniform results, such as a shorter rehabilitation period and better restoration of shoulder movement after nonoperative treatment, similar functional results in both groups, and more complications in the operative group (Imatani et al. 1975, Larsen et al. 1986, Bannister et al. 1989). Nonoperative treatment does not restore joint anatomy, and a sense of instability may remain, but still long-term results are good (Rawes and Dias 1996).

In the literature insufficient scientific evidence exists to assess results of nonoperative treatment in type IV, V, or VI dislocation. Nevertheless, constant joint dislocation leads to a general consensus in favor of surgery for these injuries. Mulier et al. (1993) found that type IV and V injuries had poorer results after nonoperative treatment than did type III injuries. Some studies report sequelae, such as shoulder pain, AC joint instability, and impaired shoulder function after nonoperative treatment of type V injury, and thus prefer surgery (Warren-Smith and Ward 1987, Weinstein et al. 1995, Rolf et al. 2008, von Heideken et al. 2013).

Operative treatment of acromioclavicular joint dislocations

The literature regarding surgery in AC joint injuries is generally limited to retrospective case series of small heterogeneous samples and thus has a low level of evidence. Only four prospective level II studies comparing operative to nonoperative treatment have been published (Imatani et al. 1975, Larsen et al. 1986, Larsen and Hede 1987, Bannister et al. 1989). Although simple in concept, more than 70 surgical procedures have been described to treat AC joint injuries, but none is yet established as the gold standard (Johansen et al. 2011). The abundance of surgical procedures described makes it difficult to discern the best technique or approach to handle AC joint separation. The timing of surgery and type of reconstruction needed in any particular injury is unsolved. To clarify the issue, the surgical options can be divided into (1) AC joint fixation with pins, screws, suture wires, and plates, (2) coracoacromial (CA) ligament transfer, (3) CC interval fixation, and (4) ligament reconstruction. Each of these techniques has numerous modifications and combinations and of course inherent complications.

Early surgical techniques involved temporary AC joint fixation with Kirschner wires, pins, or screws all crossing the AC joint. At present, these are more or less unpopular due to their high complication rate, including migration and the loss of reduction (Norrell and Llewellyn 1965, Sethi and Scott 1976, Lyons and Rockwood 1990). Despite poor reputation of Kirschner wire fixation, it has been widely used, and not all the results are poor. In acute type III injuries, temporary Kirschner wire fixation has achieved good long-term results for shoulder function (Leidel et al. 2009, Lizaaur et al. 2011). Another widely used method is temporary AC joint stabilization with a hook plate. Advantages of the hook plate are stable fixation maintaining the AC joint biomechanics and thus allowing early postoperative mobilization (ElMaraghy et al. 2010). One retrospective study of 23 patients found good functional results after a 30-month follow-up, although in 35% of patients, after plate removal loss of reduction occurred (Salem and Schmelz 2009). Di Francesco et al. (2012) performed MRI one year after hook plate removal in a cohort of 42 patients with type III or V injuries. The MRI showed CC ligament healing with continuous scar tissue in 88%. In the remaining patients, healing occurred with non-continuous scar tissue, and the manifestation was recurrence of joint dislocation. Use of the hook plate is criticized because it may overcorrect the AC joint, it requires removal (a second operation), it may induce osteolysis in or erosion of the acromion, or cause subacromial impingement. Another danger is risk of fracture of the acromion or the clavicle (Nadarajah et al. 2005, Flinkkila et al. 2006, Haidar et al. 2006, Meda et al. 2006, ElMaraghy et al. 2010, Eschler et al. 2012).

Weaver and Dunn first published a case series of 15 patients treated with CA ligament transfer. In their technique, 1.5- to 2-cm resection of the lateral clavicle is performed, and after clavicle resetting, the CA ligament is transferred from the acromion to the lateral end of the clavicle to replace torn CC ligaments (Weaver and Dunn 1972). Since then, numerous modifications of this ligament-transferring procedure have appeared, and it has also been combined with various other methods. Sood et al. (2008) published a literature review covering all studies discussing CA ligament transfer in AC joint dislocations. They found that all published studies were low-level case series (level IV evidence) with variability in surgical techniques and outcome measures. They discovered low-level evidence to support the use of CA ligament transfer in AC joint

dislocations, but this was associated with a high rate of dislocation recurrence. Adjunct fixation did not improve clinical results when compared to simple CA ligament transfer. Biomechanical studies have shown inferior characteristics of the CA ligament compared to those of the native AC joint (Deshmukh et al. 2004, Grutter and Petersen 2005).

Coracoclavicular interval fixation has involved screws, wires, sutures, endobuttons, and suture anchors. The commonality in these techniques is that they transfer the combined forces that the AC joint complex and CC ligaments are normally exposed to fixation points on the clavicle and coracoid process (Johansen et al. 2011). Rigid screw fixation thorough the clavicle into the base of the coracoid process was first described by Bosworth (1941). It is biomechanically too rigid and may lead to hardware failure, screw pullout, and osteolysis or fracture of the clavicle or coracoid process (McConnell et al. 2007, Johansen et al. 2011). Recently, studies have evaluated the use of absorbable and nonabsorbable sutures, endobuttons, and suture anchors. No clear difference emerges in usability or superiority between these methods, but they all prove superior to Weaver-Dunn reconstruction (Breslow et al. 2002, Deshmukh et al. 2004, Salzman et al. 2010, Mardani-Kivi et al. 2013, Nuchtern et al. 2013).

Anatomic AC and CC ligament reconstruction techniques have become popular. Among the various autograft or allograft tendons used are semitendinosus, gracilis, palmaris longus, peroneus brevis, or tibialis anterior. Clinical and biomechanical studies have shown their superiority in reproducing the strength and stiffness of the native AC joint complex compared with other techniques, and also in resulting in a good outcome in shoulder function (Costic et al. 2004, Deshmukh et al. 2004, Gonzalez et al. 2007, Law et al. 2007, Yoo et al. 2010). Reconstruction of both the CC and AC ligaments has shown beneficial effects upon AC joint stability (Dawson et al. 2009, Carofino and Mazzocca 2010). The complication rate is almost 30% in anatomic CC ligament reconstruction. Typical complications include tunnel malposition, graft ruptures, clavicle fractures, and hardware failures (Cook et al. 2013, Martetschlager et al. 2013).

Arthroscopy-assisted or fully arthroscopic methods have also emerged to treat acute AC joint dislocation. They are used with various stabilizing devices and are suggested as minimizing morbidity and soft tissue damage. Thus far, studies discussing minimal invasive techniques are technical notes or retrospective case series with only small

numbers of patients. It seems that the functional results are equal to those of open surgery (Chernchujit et al. 2006, Defoort and Verborgt 2010, Ranne et al. 2012, Gille et al. 2013).

The literature provides no study discussing long-term results of surgery after acute type V dislocation. De Tullio et al. (1994), assessed the results of Kirschner wire fixation in Allman type III dislocation after a 10-year follow-up, evaluated 95% of their patients as having excellent or good results regarding pain, shoulder motion, and strength.

Sometimes the surgery is performed after a long delay (several months) following unsuccessful nonoperative or operative treatment. A few preliminary studies report that in chronic AC joint dislocation, CC ligament reconstruction with tendon graft has resulted in reasonable shoulder function (Tauber et al. 2007, 2009). A few studies have compared results of early and delayed surgery. After early surgery, these are clearly superior to results of late reconstruction. Shoulder function, pain, degree of AC joint reduction, number of complications, and patient satisfaction are inferior with the delayed surgery (Rolf et al. 2008, von Heideken et al. 2013). In both of these studies, delayed surgery was performed by the modified Weaver-Dunn procedure. The CA ligament is certainly not as strong and suitable for CC ligament reconstruction as is a tendon graft.

2.7.5. Sternoclavicular joint injuries

Nonoperative treatment of sternoclavicular joint injuries

Treatment of grade I and II sprains is nonoperative. In grade I injury, the treatment is symptomatic, with a sling only to provide support. The joint should be protected from further injury until asymptomatic. If the SC joint is anterior subluxation, it can be reduced by directing the shoulder posteriorly and medially and manually manipulating the medial end of the clavicle. However, no complete consensus exists as to effectiveness of joint reduction regarding subluxation. In grade II injury, the sling is used for 3 to 4 weeks for pain reduction and immobilization. Further injuries should be avoided for 6 to 8 weeks (Allman 1967, Groh and Wirth 2011, Maier et al. 2011).

Furthermore, in complete anterior and posterior joint dislocation, the initial treatment option can be nonoperative. In anterior dislocation, closed reduction is best performed

with the patient under general anesthesia, supine on a table with a pad between the shoulders. Pressure is then applied on the medial clavicle in the posterior direction. After reduction, the upper arm is immobilized with a sling for 4 to 6 weeks. During closed reduction of posterior dislocation, the recommendation is to have a thoracic surgeon available. Under general anesthesia, the patient is placed supine with a bolster between the shoulder blades. The ipsilateral upper arm is then extended and abducted. Gentle traction is applied to the abducted arm and is slowly increased while the arm is brought to extension. As in anterior dislocation, the arm is immobilized with a sling for 4 to 6 weeks (Nettles and Linscheid 1968, Groh and Wirth 2011, Maier et al. 2011).

Functional results after closed reduction for both anterior and posterior dislocations are mainly good (Glass et al. 2011). After closed reduction of anterior dislocation, the SC joint is typically unstable but then well tolerated. The associated recurrence rate is between 21 and 100% (Nettles and Linscheid 1968, Salvatore 1968, Eskola 1986).

Operative treatment of sternoclavicular joint injuries

In anterior dislocation, surgery should be considered if the reduced SC joint is permanently unstable and symptomatic. In posterior dislocation, acute surgery is recommended after an unsuccessful closed reduction and later on if the joint is symptomatically unstable (Maier et al. 2011). A variety of techniques introduced to stabilize the SC joint include plate, tendon grafts, tenodesis, Kirschner wires, pins, and suture anchors. Resection of the medial clavicle is also an alternative method (Eskola et al. 1989, Glass et al. 2011, Thut et al. 2011, Singer et al. 2013). Results of surgery vary widely. According to the limited number of reports, tenodesis, suture fixation, and tendon grafts appear to have positive results. Resection of the medial clavicle seems to offer poor results. Kirschner wire fixation is associated with dangerous complications and is thus inadvisable (Eskola et al. 1989, van Tongel et al. 2012).

3. AIMS OF THE STUDY

The specific aims of the study were:

- I To assess and compare outcomes of operative and nonoperative treatment modalities for acute clavicle fractures in adults by way of a systematic literature review.

- II To compare outcomes of nonoperative and operative treatment of completely displaced acute midshaft clavicle fractures on the strength of a randomized controlled trial.

- III To assess long-term functional and radiographic outcomes of surgery for acute type V acromioclavicular joint dislocations.

- IV To assess functional and radiographic outcomes of surgery for chronic acromioclavicular joint dislocations.

4. PATIENTS AND METHODS

Studies II, III, and IV were approved by the local ethics committee (Helsinki University Central Hospital, Ethics Committee, Department of Surgery: 2004-02-27, 66/E6/04) before their initiation. Principles of the Declaration of Helsinki were obeyed in all studies.

4.1. Study I: Systematic literature review of clavicle fractures

The objective was to find potential high-quality comparative studies discussing acute clavicle fractures. A skilled information specialist performed an electronic database search without language restrictions from the following databases: the Cochrane Database of Systematic Reviews (CDSR), Database of Abstracts of Reviews of Effects (DARE), the Cochrane Controlled Trials Register (CCTR), the Cumulative Index to Nursing and Allied Health Literature (CINAHL), Ovid MEDLINE In-Process & Other Non-indexed Citations, Ovid MEDLINE, Journals@Ovid, Current Controlled Trials register, and Embase. Terms for the search were: fractures, fracture fixation, fracture healing, clavicle, and collar bone. The available literature was explored from 1966 until the end of March 2011. If there was uncertainty as to study methodology in the reports included, the authors were contacted by email for more detailed information.

Prior to the literature search, inclusion criteria were defined. Studies included were randomized controlled trials (RCT) and controlled clinical trials (CCT) comparing operative to nonoperative treatment, operative to another operative treatment, and nonoperative to another nonoperative treatment. Eligible studies involved at least 30 adult patients (≥ 18 -year) and follow-up time should have been at least 6 months. Primary outcomes in this study were Constant shoulder score (CS), Disabilities of the Arm, Shoulder and Hand score (DASH), and pain (visual analogue scale, VAS); also observed were fracture union, range of motion (ROM), return to previous activity, and complications. Studies dealing with non-acute fractures (treatment after 3 weeks) and studies written in languages the authors were unable to read were excluded. Study selection and assessment of methodological quality were made by three independent investigators. Discrepancies between investigators were solved by negotiation, or when necessary, by a fourth investigator.

Data extraction from each study was conducted by use of a predetermined form comprising three sections: 1) characteristics of the studies, 2) criteria for risk of bias, and 3) effectiveness

of the studies. Complications were assessed by means of recommendations of the *Cochrane Handbook of Systematic Reviews of Interventions* (Loke et al. 2011). All complications reported were documented in order to have wide coverage of adverse effects. Assessment of risk of bias in trials was performed according to Furlan (*Appendix 1*) (Furlan et al. 2009). A trial was assessed to have a low risk of bias if at least half out of these 12 criteria were met. On the other hand, if the trial met less than 6 criteria, it was rated as having a high risk of bias.

Findings were summarized by strength of evidence. Difference in means served as a summary measure. The evidence for each outcome was evaluated by use of the Grading of Recommendations Assessment, Development and Evaluation (GRADE) approach, in which the quality of the evidence on a specific outcome was based on five domains: 1) limitations of the study design, 2) inconsistency, 3) indirectness, 4) imprecision of results, and 5) publication bias across all studies measuring that particular outcome. We determined the quality of evidence as high if at least two high-quality randomized controlled trials provided results for the outcome. The following criteria served for assessing quality of the evidence: High-quality evidence (A) = consistent findings among at least 75% of RCTs with no limitations in study design, consistency, directness, or precision and no known or suspected publication biases. Moderate-quality evidence (B) = one of the domains not met. Low-quality evidence (C) = two of the domains not met. Very low-quality evidence (D) = three of the domains not met. No evidence = no RCT identified that addressed this outcome.

4.2. Study II: Randomized clinical trial of midshaft clavicle fractures

This trial was performed in Töölö Hospital, Helsinki, and registered at ClinicalTrials.gov (NCT01199653). Patients were included in the study if the following criteria were fulfilled: 1) the fracture was in the middle third of the clavicle and was completely displaced: the vertical displacement was at least one clavicle width in an AP radiograph (no cortical contact between the main diaphyseal fragments), 2) the fracture was fresh, and treatment was started within 7 days, 3) patient age was between 18 and 70 years, and 4) the patient had provided informed consent. Fractures were classified according to the AO/OTA classification.

Exclusion criteria were: 1) fracture without displacement, 2) multiply injured patient, 3) associated neurovascular injury, 4) patient offering insufficient cooperation (mental illness or drug addiction), 5) patient with cancer or any severe illness, 6) pathological fracture, 7)

treatment beginning later than 7 days after injury, 8) open fracture, 9) patient on corticosteroid or immunosuppressive medication, 10) concomitant upper extremity fracture, 11) earlier clavicle or shoulder-region fracture, 12) pregnancy, or 13) lack of informed consent.

Nonoperative treatment was performed with a sling for 3 weeks. For the first 3 weeks only pendulum motion was allowed, from 3 to 6 weeks active abduction and flexion up to the horizontal plane, and after 6 weeks, fully active motion. Return to full activities was permitted after 3 months.

Surgery took place within 7 days after injury for all patients. The fracture was stabilized with a straight 3.5-mm AO/ASIF stainless steel reconstruction plate and 3.5-mm stainless steel cortical screws. The plate was placed on the anterior aspect of the clavicle and was bent to the contour and curvature of the clavicle. The length of the plate was determined according to the grade of comminution of the fracture. The aim was to place at least 3 bicortical screws in the medial and lateral main fragments. No bone grafting was included. Postoperatively, the arm was immobilized in a sling for 3 weeks. The postoperative protocol of exercises was similar to that in the nonoperative group. No hardware removal was scheduled.

The main outcomes, CS and DASH, were evaluated at 3 months and at one year. At the 3-month assessment, CS was performed by an independent physiotherapist instructed in standardized testing. At the 1-year appointment, CS was carried out by the main author. Secondary outcome measures were pain, fracture healing, and complications. Pain was measured with the visual analogue scale (VAS, 0-100) at the 3 and 6 weeks, at 3 months, and at one year. The primary hypothesis was that no difference would appear between the groups in function (CS) or in disability (DASH) at the 1-year follow-up.

Fracture healing was evaluated from AP and 15° vertically tilted radiographs. Radiographs were evaluated by an independent radiologist. At the time of randomization, radiographs included both clavicles, so the lengths of the injured and the uninjured clavicles could be measured correctly. Shortening was defined as the difference between the length of the uninjured and injured clavicles. Vertical displacement was assessed by using clavicle diaphyseal width as the displacement unit. Union was defined as complete periosteal and endosteal bridging between medial and lateral fragments in radiographs, and that the patient had neither pain nor instability in the fracture region.

The following incidents were considered as complications or adverse events: 1) a new operation performed for any reason, 2) primary reduction loss, 3) plate sheared off or causing irritation, or 4) antibiotics necessary for wound infection. Symptomatic malunion meant shortening of more than 20 mm, angulation, or displacement of the clavicle, and a patient's having sequelae such as pain, weakness, or easy fatigability. Delayed union was defined as no bridging callus or endosteal healing in radiographs at 3-month assessment, and the patient had pain or instability in the fracture region. Nonunion was defined as no periosteal and endosteal healing in radiographs at the 1-year visit. Symptoms of thoracic outlet syndrome (TOS) from brachial plexus compression were assessed as pain, paresthesia, numbness, or weakness in the hand, arm, or shoulder.

Randomization was carried out in the emergency room with sequentially numbered, opaque, sealed envelopes. After preliminary information, a member of the research group counseled the patient thoroughly, obtained an informed consent, and enrolled the patient in the study. The random allocation sequence was concealed from the authors. Randomization was blocked and sizes randomly varied between 4 and 10. There was no blinding of the selected treatment to health-care providers involved with those patients.

Prior to the study's beginning, a power calculation determined sufficient sample size. The basis was a difference of 10 points between the groups in CS, power of 0.80, and significance of 0.05 (comparing means with a t-test). As a result of calculation, the required sample size was 26 patients per group. The dropout rate was anticipated to be 15%, so 60 patients was the required number to randomize.

4.3. Study III: Long-term results of surgery in type V acromioclavicular joint dislocations

Patient information came from the operating room register in Töölö Hospital, Helsinki. Retrieval focused on patients who had surgery for acute AC joint dislocation. From April 1985 to December 1993, this register provided 390 patients. Preoperative radiographs of all identified patients were examined to classify the dislocations. Patients with Rockwood type V dislocation (i.e. CC interval widened 100-300% in AP radiography) were included. Multitrauma patients, patients who had surgery later than 2 weeks after injury, and patients with lower-type (I, II, III, or IV) AC joint dislocation were excluded (n=277). Of 113 patients

who had surgery for type V dislocation, 13 were deceased, 46 did not answer repeated invitations, and for 4 patients no address was available. The other 50 were examined retrospectively (*Appendix 2*). Patient gender was 42 male and 8 female. Injury mechanisms were bicycling (20), simple fall (20), sport (6), and traffic accident (4). Mean age at time of injury was 36 (range 20-57) years, and at the time of examination 54 (range 40-75). Mean follow-up time in this study was 18 (range 15-22) years.

Various methods were used to stabilize the AC joint: A Kirschner wire from the lateral edge of the acromion into the clavicle (36), a 4.5-mm screw (12) or biodegradable screw (2) through the acromion into the clavicle. Kirschner wires and screws were removed 6 to 8 weeks after surgery under local anesthesia. No biodegradable screws were removed.

Shoulder function was measured with CS, DASH, and the simple shoulder test (SST). Subacromial impingement was evaluated with the Copeland shoulder impingement test and AC joint dysfunction with the cross-arm test. Pain was measured with VAS (0-100). AC joint stability was evaluated clinically. Possible complications were determined from the patient, and explored from the patient records and from radiographs.

Alignment of the AC joint, mechanical and methodological failures, and Kirschner-wire migration were evaluated from radiographs taken after primary surgery. Radiographs taken for the long-term follow-up included both clavicles. On these radiographs were assessed AC and GH joint arthrosis, osteolysis of the lateral clavicle, CC distance, AC joint space, and alignment of the lateral clavicle with the acromion. The vertical translation of the clavicle at the AC joint was assessed in clavicle widths.

4.4. Study IV: Surgical treatment of chronic acromioclavicular joint dislocation

Patient information came from the operating room register in Töölö Hospital, Helsinki. In this register we searched for patients who had surgery for chronic AC joint dislocation and found 39 patients between May 2005 and April 2011. Of these 39 patients, 25 participated in a follow-up visit. The other 14 patients refused the follow-up visit or did not respond to the invitation. Indications for delayed surgery were permanent pain or discomfort in the shoulder region with the inability to do normal work or daily tasks after unsuccessful nonoperative treatment (19 patients) or after unsuccessful surgery (6 patients). The surgery and clinical examination in the follow-up visit was performed by separate individuals.

Mean delay from primary injury to reconstructive surgery was 435 (range 149-1586) days, and mean follow-up time from surgery to follow-up visit, 4.2 (range 1-7) years. Most patients (21) were male. Mean age at time of injury was 44 (range 22-59) years. Injury mechanisms in primary dislocation were bicycling (9), fall (7), sport (7), and traffic accident (2). Radiographs after the primary injury showed a spectrum of injury types. Type V injury had occurred in 15 patients, type III in 6 patients, type II in 3, and type IV in one.

All patients underwent surgery by a single surgeon. Injured CC ligaments were reconstructed by autogenous semitendinosus and gracilis tendons. Into the clavicle at the sites of CC ligament insertion were drilled 5.5-mm holes. If signs of arthrosis were visible in the AC joint, resection of the distal clavicle was performed. Prepared tendons and double FiberWire® #5 sutures were passed under the coracoid process. The AC joint was reduced manually. The tendons were pulled through the drill holes and attached to the clavicle with 5.5 x 15-mm tenodesis screws. If the tendon graft was sufficient to cover the AC joint, it was attached to the acromion to strengthen the superior AC ligament. Finally, double FiberWire® sutures were tied over the clavicle. Postoperatively, the arm was immobilized in a sling for 2 to 3 weeks.

The follow-up visit included evaluation of function of both shoulder joints by CS and DASH scores. Pain was assessed with VAS (0-10) and AC joint dysfunction with the cross-arm test. AC joint stability was assessed clinically. All possible complications relating to delayed surgery were observed. Length of sick leave was also determined and the patient's subjective satisfaction with the end-results of the delayed surgery (excellent, good, moderate, poor).

Radiographs after primary injury were examined to grade the original AC joint dislocation according to the Rockwood classification. The follow-up visit included AP and axillary radiography. From these radiographs were evaluated alignment of the AC joint, AC joint arthrosis, osteolysis of the lateral clavicle, and possible complications.

4.5. Statistical methods in Studies II, III, and IV

All statistical analyses were performed with SPSS Statistics (IBM, Chicago, IL, USA). The Kolmogorov-Smirnov test was used for normality. All studies used 2-sided tests, and p values below 0.05 were considered statistically significant.

Study II: Nominal variables were analyzed by the chi-square or Fisher's exact test. Scale, ordinal, and continuous variables were analyzed by the Mann-Whitney U-test. An intention-to-treat analysis served to compare the groups. "Last observation carried forward" was used as the imputation method. Missing 1-year values were replaced by the 3-month values.

Study III: Nominal variables were analyzed by the McNemar test. Differences between continuous variables in relation to the injured and the uninjured shoulder were assessed with the 95% confidence interval (CI) for means. Subgroup analyses comparing results between patients with or without complications and with different grade of joint positions were analyzed by Fisher's exact test.

Study IV: Nominal variables were analyzed by Fisher's exact test. CS scores between the injured and uninjured shoulder were analyzed by paired-samples t-test.

5. RESULTS

5.1. Study I: Systematic literature review of clavicle fractures

From the electronic database searches came 1072 abstracts reporting clavicle fractures. After excluding duplicates and studies not addressing clavicle fractures or not fulfilling inclusion criteria, 230 publications remained for examination. From these, 27 were evaluated as being potentially included. After thorough examination, 14 studies were qualified for the systematic review. Of these 14 studies, 6 were randomized controlled trials and 8 controlled clinical trials. Two studies originated from the same patient population, and therefore only results of the more recent study from Austria were analyzed (Smekal et al. 2009, 2011). Studies came from several other countries: Canada (Canadian Orthopaedic Trauma Society 2007), China (Shen et al. 2008), Germany (Jubel et al. 2005, Böhme et al. 2011), India (Kulshrestha et al. 2011), Netherlands (Hoofwijk and van der Werken 1988), Taiwan (Lee et al. 2007, 2008, Pai et al. 2009, Hsu et al. 2010), United Kingdom (Ferran et al. 2010), and United States (Judd et al. 2009). Only one study discussed lateral clavicle fractures (Hsu et al. 2010).

Studies analyzed for this systematic review included 1190 patients, among whom 631 were included in the six randomized controlled trials and 559 in the seven controlled clinical trials. Numbers of patients per study ranged from 32 to 157. Follow-up time was 6 to 30 months. A high risk of bias emerged in two studies (score <6 in risk-of-bias assessment). The studies produced numerous outcomes which were reported with varying accuracy. Only a minority reported outcomes that we considered important (primary outcomes). *Table 1* categorizes the studies included in the systematic review.

Treatment of middle-third fractures

Middle-third clavicle fractures were the topic of six RCTs and six CCTs. Operative and nonoperative treatment were compared in three RCTs and in three CCTs. Different operative methods were compared in two RCTs and in three CCTs. Only one RCT compared two types of nonoperative treatment.

Function, disability, and pain were considered to have critical clinical relevance. Delayed union, nonunion, and complications were classified as having important clinical relevance. No publication bias appeared in the studies included. After data processing, the following observations emerged about study evidence:

1) Operative vs. nonoperative treatment (6 studies)

Function (CS)

In favor of surgery, evidence was of moderate quality (B) with considerable effectiveness during a 6-week period, and small effectiveness after the 6-month follow-up.

Disability (DASH)

In favor of surgery, evidence was of moderate quality (B) with considerable effectiveness during the 6-week period, and small effectiveness after the 6-month follow-up.

Pain (VAS)

In favor of surgery was very limited evidence (D) with considerable effectiveness in pain relief in the 1- to 5-month period and small effectiveness in the 6- to 7-month period.

Complications, delayed union, nonunion

Evidence was of moderate quality (B) for a similar risk of relatively mild complications between patients treated operatively or nonoperatively, and was of moderate quality (B) for delayed union and nonunion being more common among patients treated nonoperatively than operatively.

2) Operative vs. operative treatment (5 studies)

Function (CS)

Limited evidence (C) existed of no difference in function at one year and later between pin and plate or locking plate and nonlocking plate among elderly patients.

Disability (DASH)

These studies provided no evidence.

Pain (VAS)

Evidence was very limited (D) for no difference in postoperative pain at 3 days between a locking plate and nonlocking plate among elderly patients.

Complications, delayed union, nonunion

Evidence was very limited (D) for a smaller need for reoperations among elderly patients initially treated with a locking plate than among those treated with a nonlocking plate. Evidence was limited (C) for no difference in complications between treatment with pin or plate, and evidence was moderate (B) for osteosynthesis method having no impact on the incidence of delayed union or nonunion.

3) Nonoperative vs. nonoperative treatment (one study)

A single study discussing two nonoperative treatment modalities revealed limited evidence (C) for no difference in pain between a rucksack bandage and mitella in the 2-week and 6-month periods. No evidence emerged as to function or disability.

Treatment of lateral-end and medial-end fractures

No controlled trials were available on medial-end fractures. Only one trial comparing the hook plate to tension band wire in lateral-end fractures fulfilled inclusion criteria. In that study, average time for union between treatment groups was similar. No major complications appeared in that study.

According to that single study, evidence was very limited (D) for no difference in function between hook plate and tension band wire at the 6-month follow-up. Very limited evidence (D) also supported the osteosynthesis method's having no impact on incidence of delayed union or nonunion, and very limited evidence (D) supported no difference in complications between patients treated with hook plate or tension band wire.

5. Results

Table 1. Risk of bias, characteristics, and outcomes of the 13 studies included in the systematic review of clavicle fractures.

STUDY	risk of bias score	number of patients	follow-up time	CS	DASH	VAS	union (%)	ROM	complication (%)
MIDDLE-THIRD FRACTURES: Operative vs. nonoperative treatment									
COTS 2007 RCT	8								
plate		67	1 y	96	5		98		37
sling		65	1 y	90	15		86		63
Judd 2009 RCT	7								
Hagie pin		29	1 y				96		76
sling		28	1 y				96		7
Smekal 2011 RCT	5								
ESIN		60	2 y		1	98	100		30
sling		60	2 y		3	95	88		39
Jubel 2005 CCT	6								
ESIN		26	6 mo	98	2	1	100	175	54
rucksack bandage		27	6 mo	90	10	14	93	165	78
Böhme 2011 CCT	3								
plate		53	8 mo	95			98		15
ESIN		20	8 mo	97			100		13
rucksack bandage		47	8 mo	90			98		15
Kulshrestha 2011 CCT	7								
plate		45	18 mo				100		27
sling		28	18 mo				71		93
MIDDLE-THIRD FRACTURES: Operative vs. operative treatment									
Shen 2008 RCT	8								
3D plate		67	1 y				94		1
superior plate		66	1 y				65		12
Ferran 2010 RCT	7								
Rockwood pin		17	1 y	92			100		24
plate		15	1 y	89			100		27
Lee 2008 CCT ^(a)	7								
Knowles pin		56	1 y	95			100		7
plate		32	1 y	93			97		47
Lee 2007 CCT ^(a)	6								
Knowles pin		32	30 mo	85			100		13
DCP		30	30 mo	84			97		53
Pai 2009 CCT ^(a)	6								
locking plate		29	1 y	92			97		41
non-locking plate		35	1 y	89			97		57
MIDDLE-THIRD FRACTURES: Nonoperative vs. nonoperative treatment									
Hoofwijk 1988 RCT	6								
rucksack bandage		78	10 mo			3	95		7
mitella		79	10 mo			2	100		1
LATERAL-THIRD FRACTURES: operative vs. operative treatment									
Hsu 2010 CCT	7								
hook plate		35	6 mo				100	165	26
tension band		30	6 mo				100	168	12

Abbreviations

CS	Constant shoulder score
DASH	Disabilities of the Arm, Shoulder and Hand score
VAS	Visual analogue scale
ROM	Range of motion
ESIN	Elastic stable intramedullary nailing
3D	Three dimensional
DCP	Dynamic compression plate
CCT	Controlled clinical trial
RCT	Randomized controlled trial
mo	month
y	year
^(a)	Studies report number of patients only at follow-up

5.2. Study II: Randomized clinical trial of midshaft clavicle fractures

Randomization took place between August 2004 and October 2007. During that period, 390 patients with clavicle fracture were treated in Töölö Hospital; 330 patients were excluded for not meeting inclusion criteria, declining to participate, or being unable to participate (nonlocal residents, foreigners). Of these, 60 patients were randomized, 32 to the nonoperative group, and 28 to the operative group. The drop-out rate was 15%, since 9 patients (nonoperative group 7, operative group 2) were lost from the 1-year visit. Of these patients, 6 did not appear for their 1-year visit despite several calls; one each had emigrated, moved to another locality, or could not participate due to a current pregnancy. Hence, 25 in the nonoperative group and 26 patients in the operative group completed the 1-year assessment.

The results verified our hypothesis, since no significant difference appeared between the nonoperative and the operative group in CS at the 3-month ($p=0.77$) or 1-year ($p=0.75$) visits. Likewise, no difference appeared in DASH at the 3-month ($p=0.81$) or 1-year visit ($p=0.89$). At the 3-week assessment, the operative group had significantly less pain than the nonoperative group ($p=0.049$), but no difference existed between the groups at 6-week ($p=0.76$), at 3-month ($p=0.65$), or at 1-year ($p=0.98$) follow-ups (*Table 2*).

All fractures in the operative group healed. In the nonoperative group, 19 fractures (76%) healed radiologically ($p=0.01$). Of the 6 patients with nonunion, 5 had their injury on the nondominant side. No patients with nonunion desired reconstructive surgery during follow-up, because their experience of disability was minor.

There were 19 complications, of which 12 occurred in the nonoperative group and 7 in the operative group ($p=0.15$). None were major, and none of the patients underwent surgery because of any complication. In the operative group, three fractures, and in the nonoperative group, one fracture healed after a delay and were consolidated at the 1-year visit ($p=0.61$). In the nonoperative group appeared two symptomatic malunions ($p=0.24$). No wound infections occurred. In one patient, the plate was slightly bent, and reduction was lost between the 6-week and 3-month visits. In one patient, the plate was broken by the 1-year radiograph, but the fracture healed without loss of reduction. In one patient, the plate caused mild irritation. In the nonoperative group, one patient underwent surgery after 4 months for brachial plexus irritation ($p=0.49$). She was followed up in the nonoperative group on the basis of the intention-to-treat principle. There were three refractures ($p=0.61$). In the nonoperative group, two patients fell down 6 months after randomization and suffered a new fracture at the bridging callus. Both of these fractures healed. In the operative group, one patient fell from a motor-bike 2 weeks prior to the 1-year appointment and had a new fracture adjacent to the medial end of the plate. Due to this recent refracture, he scored poorly in CS (39) at the 1-year assessment compared as to the mean value in the operative group (86).

A statistically significant difference appeared in vertical displacement at baseline between united and nonunited fractures ($p=0.009$). All fractures displaced by <1.5 clavicle width united, whereas half the fractures dislocated >1.5 clavicle widths failed to unite. No differences appeared in fracture classification ($p=0.06$) or in shortening ($p=0.77$). At 1-year, no differences appeared in CS ($p=0.50$) or pain ($p=0.57$) between patients with union or nonunion. However, when the disability was assessed with the DASH, a 16-point difference emerged ($p=0.047$) in favor of union.

Table 2. Characteristics of all randomized patients at baseline and outcomes of those patients, who were analyzed during follow-up.

5. Results

Characteristic	Nonoperative group (n=32)	Operative group (n=28)	p value
Gender, number of patients			0.57
male	28	24	
female	4	4	
Mean age, years	33 (12)	41 (11)	0.009
Dominant arm, number of patients			0.11
left	6	1	
right	26	27	
Fractured side, number of patients			0.43
left	18	19	
right	14	9	
Mechanism of injury, number of patients			0.14
fall	7	12	
bicycling	16	9	
sports	8	4	
motorcycle accident	1	3	
Smoking-status, number of patients			0.59
smoker	17	15	
non-smoker	15	13	
Outcome	Nonoperative group (n=25)	Operative group (n=26)	p value
CS			
3 months	80.0 (10)	78.7 (11)	0.77
1 year	86.1 (9)	86.5 (12)	0.90
1 year with imputation ^(a)	85.2 (10)	87.3 (7)	0.75
DASH			
3 months	14.3 (14)	14.2 (13)	0.81
1 year	7.1 (14)	4.3 (6)	0.81
1 year with imputation ^(a)	8.0 (13)	5.0 (6)	0.89
Pain, VAS			
3 weeks	16 (16)	10 (14)	0.049
6 weeks	13 (19)	13 (17)	0.76
3 months	5 (10)	9 (15)	0.65
1 year	7 (19)	3 (6)	0.88
1 year with imputation ^(a)	7 (17)	3 (6)	0.98
Fracture healing			
union	19/25	26/26	0.01

Standard deviation (SD) in parentheses

^(a) Imputation of the missing data = "last observation carried forward". Missing value of the 1-year outcome is replaced by the 3-month value.

CS, DASH, VAS as in *Table 1*.

5.3. Study III: Long-term results of surgery in type V acromioclavicular joint dislocations

The mean CS was 90 (CI: 88-92) in the injured shoulder and 90 (CI: 87-93) in the uninjured shoulder. Subjective function was excellent, as the mean score was 5.1 in DASH and 11 in SST. When subacromial impingement was evaluated clinically, only four patients had signs of this manifestation, and in testing of AC joint dysfunction with the cross-arm test, only one patient mentioned symptoms. Pain at rest (VAS: 8/100) and at activity (VAS: 18/100) was mild. Clinically observable AC joint instability occurred in 8 patients.

Radiographs were taken of 49 patients, as one patient refused a radiological examination. In 27 patients AC joint arthrosis was evident, of which 11 appeared on the injured side, 11 on the uninjured side, and for 5 was bilateral ($p=1.0$). Four patients had GH arthrosis; one on the injured side and three on the uninjured side ($p=0.5$). Osteolysis of the lateral clavicle affected 10; one each had bilateral osteolysis or osteolysis in the uninjured clavicle; 8 had it in the injured clavicle ($p=0.04$). The AC joint stayed in good alignment in 38 patients. Surprisingly, of 12 patients with redislocation (≥ 1 clavicle width) of the AC joint after primary surgery, 6 had an anatomical reduction of the joint during follow-up.

Complications were classified as early (in relation to primary surgery) and late (discovered at follow-up visit). Reduction loss within 2 months postoperatively occurred in 12. Of these patients, 9 joints were stabilized initially with Kirschner wires, one with a screw, and 2 with a biodegradable screw. Two patients had a reoperation in the early phase due to a reduction loss, and only one patient, initially stabilized with a biodegradable screw, had a wound infection, which healed with oral antibiotics. Kirschner wires were broken in the line of the AC joint in three patients, in two of whom, the medial ends of the Kirschner wires remained permanently in the clavicle. Wire migration into the supraclavicular fossa occurred in one patient and was removed one year after the primary surgery. A summary of all complications are in *Table 3*.

Table 3. Early and late complications in 50 patients after stabilization of Rockwood type V acromioclavicular joint dislocation. Early complications (18 patients) appeared within a year postoperatively. Late complications (18 patients) emerged at the follow-up visit.

Early complication	Patients, n=18
Loss of reduction in radiographs ¹	12
Early mechanical failure in radiographs ²	6
Reoperation ³	3
Methodological failure ⁴	2
Kirschner wire migration	1
Wound infection	1
Late complication	Patients, n=18
AC joint arthrosis	11
Osteolysis of lateral clavicle	8
Clinical instability	8
Malalignment in the AC joint ⁵	6
Broken osteosynthesis	2

¹ Loss of reduction ≥ 1 clavicle-width in anteroposterior radiograph

² Breakage of osteosynthesis (3) or breaking through the acromion (3)

³ Reoperation due to reduction loss (2) or Kirschner wire migration (1)

⁴ Kirschner wires not positioned accurately in the acromion but above it

⁵ Superior translation of the clavicle ≥ 1 clavicle-width in anteroposterior radiograph

AC = acromioclavicular

Functional, clinical, and radiological outcomes were compared between patients with normal joint appearance and those with subluxated or permanently dislocated AC joints. The only significant difference appeared in lateral clavicle osteolysis, seeming to be most common in patients with constant AC joint dislocation ($p=0.007$). Outcomes in patients with no complications (14) versus those with early (18) or late (18) complications, showed no significant difference in CS ($p=0.7$), in DASH ($p=0.4$), in

SST ($p=0.8$), or in pain ($p=0.4$). Resection of the lateral end of the clavicle was performed in one patient 16 years after the primary AC joint dislocation. He managed well until a new fall injured the same AC joint. Another patient had a new type V acromioclavicular joint dislocation on the previously injured side, which was treated nonoperatively.

5.4. Study IV: Surgical treatment of chronic acromioclavicular joint dislocation

Function of the injured shoulder was inferior to function of the uninjured one, since in the former the mean CS was 83 (range 55-100) and in the latter 91 (range 77-100) ($p=0.002$). Mean DASH was 14 (range 0-58). Pain was minor. The cross-arm test was positive for 6 (24%) patients. For 14 (56%) patients, the AC joint was clinically stable at follow-up. Mean length of sick leave after reconstructive surgery was 109 (range 28-374) days. Of 25 patients, 21 (84%) assessed the subjective results as excellent or good.

In 11 (44%) patients, the AC joint was in anatomical alignment when observed in AP and in axillary radiographs. AC joint arthrosis occurred in only one patient. Lateral clavicle osteolysis (56%) (*Figure 20*) and tunnel widening (80%) (*Figure 21*) were common after the procedure. Osteolysis was visible in only one patient's preoperative radiographs.

Postoperatively, one patient had a superficial and one patient a deep wound infection. The former was treated with peroral antibiotics and the latter with intravenous and peroral antibiotics. The deep wound infection resulted in removal of tendon grafts and screws and healed only after a deltoid-muscle transfer. In two patients, reconstructive surgery failed, and these required another identical procedure. Fracture of the coracoid process appeared in five patients, and three had a fracture in the clavicle.



a) AP radiograph of right clavicle. Osteolysis extends to medial drill hole.



b) Axillary radiograph of right shoulder. The remaining lateral end of the clavicle (C) is positioned posterior to the acromial joint area.

Figure 20. AP a) and axillary b) radiographs of a patient with surgery for chronic AC joint dislocation with autogenous tendon grafts 4 years previously. Marked osteolysis has developed in the lateral clavicle.



a) AP radiograph of right clavicle.



b) Axillary radiograph of right shoulder. Both drill holes in lateral clavicle are dilated.

Figure 21. AP a) and axillary b) radiographs of a patient with surgery for chronic AC joint dislocation with autogenous tendon grafts 5 years previously. Notable tunnel widening has appeared in both drill holes. Slight osteolysis has also developed.

In 18 patients, the superior AC ligament was reinforced with a residual tendon graft. Despite this procedure, in 7 (39%) patients the AC joint was unstable. In comparison, of 7 patients without AC ligament reinforcement, 3 (43%) had an unstable AC joint. When clinically stable AC joints and unstable AC joints were compared, no difference appeared in CS ($p=0.7$), in DASH ($p=0.6$), or in patient satisfaction ($p=0.4$).

The influence of osteolysis, tunnel widening, and fracture of the coracoid process were assessed for function, disability, pain, and AC joint stability. Patients having lateral clavicle osteolysis seemed to have more disability (DASH 19, range 0-58) than patients without it (DASH 8, range 0-28), although the difference was not statistically significant ($p=0.2$).

6. DISCUSSION

6.1. Evidence for treatment of clavicle fracture (I)

The literature provided many studies discussing treatment modalities for clavicle fractures. Studies dealing with treatment of medial or lateral clavicle fractures were, however, in the minority. None of the studies analyzed the correlation between union or nonunion and functional results. Overall, the evidence was mainly graded as low or very low.

The moderate-quality evidence led to the following observations of midshaft clavicle fractures: 1) operative treatment has considerable effectiveness toward better function and less disability, particularly in short-term follow-up 2) risks of relatively mild complications after nonoperative or after operative treatment are similar, 3) delayed union and nonunion are more common among patients treated nonoperatively than operatively, and 4) osteosynthesis method has no impact on incidence of delayed union or nonunion. Only one study assessed lateral clavicle fractures and was graded as having very low-quality evidence. No studies concerned medial clavicle fractures. There emerged no major complications, but some complications were evidently related to a particular treatment modality. No clear conclusion can be drawn from the incidence of complications, because of the highly heterogeneous reporting.

Since 2005, papers have used a systematic approach to assessing studies of clavicle fractures. Results of these reviews mainly agree with our observations. The review by Zlowodzki et al. (2005) compared results of various treatment options in midshaft clavicle fractures, reporting a 4% nonunion rate in total. With nonoperative treatment, the nonunion rate was 6% for all fractures and 15% for displaced fractures. Fracture displacement, fracture comminution, female gender, and aging were associated with nonunion after nonoperative treatment. They found plating to be more successful in fracture consolidation than was nonoperative treatment. Their review reported only nonunion, infection, and fixation failures, leaving functional outcome measures unanalyzed.

Along with the appearance of randomized controlled trials comparing operative to nonoperative treatment for displaced midshaft fractures have arisen more and more systematic reviews and meta-analyses on the subject. McKee et al. (2012) concluded on the strength of

six studies that operative treatment provided a significantly lower rate of nonunion and symptomatic malunion and an earlier functional return than did nonoperative treatment. They found, however, only weak evidence that the long-term functional result of operative treatment is superior to that of nonoperative care. Rehn et al. (2013) noted that with operative treatment, time to union is shorter, nonunion rate is lower, and functional scores are better at early stages. They also found that with nonoperative treatment, risk for reoperation is higher. However, they stated that the effect of surgery on functional outcomes remains controversial. Results corresponding to those in previous reviews are also evident in the latest meta-analysis. Based on seven trials, Xu et al. (2014) concluded that operative treatment with a plate led to lower incidence of nonunion and fewer symptomatic malunions, fewer complications, better scores in DASH and CS, and lower patient dissatisfaction.

The Cochrane Reviews have also published on clavicle fractures. Lenza et al. (2009a) analyzed three studies comparing nonoperative treatment modalities for midshaft fractures. They found insufficient evidence to determine which methods of nonoperative treatment are the most appropriate. They also analyzed studies comparing different operative modalities of acute midshaft fractures or nonunion. This review included three studies and concluded that evidence is limited as to the relative effectiveness of different operative methods for acute fractures or nonunion (Lenza et al. 2009b). The most recent Cochrane Review reported evidence from eight randomized controlled trials. Evidence was limited concerning the relative effectiveness of operative vs. nonoperative treatment for acute midshaft fractures. This review provided some low-quality evidence that surgical interventions may not result in significant improvement in upper arm function (Lenza et al. 2013).

We made an extensive study search, but it is still possible that not all eligible trials were found for review. During the assessment, three studies were excluded because they were in a foreign language (Chinese). Thus some information was missed. The quality of the studies was remarkably variable. Major shortcomings included improper methods of randomization and concealment of allocation, analysis not based on the intention-to-treat principle, and especially unsystematic and insufficient reporting. Clinical heterogeneity was considerable in patient characteristics, interventions, outcome measures, and fracture morphology between studies, so effect sizes were impossible to pool in a meta-analysis. In addition, it was impossible to calculate number-needed-to-treat figures for these trials because of missing

data. Due to a lack of evidence, no conclusions are possible to draw as to treatment of lateral and medial clavicle fractures.

6.2. Nonoperative or operative treatment for displaced midshaft clavicle fractures (II)

Our study discovered no differences in shoulder function (CS), disability (DASH), or pain (VAS) at 1-year follow-up. All fractures in the operative group healed, but in the nonoperative group emerged a high incidence of nonunion (24%). In the nonoperative group was a clinically and statistically significant difference (15.8 points, $p=0.047$) in DASH score between patients with united fractures and those with nonunited fractures. In function, however, there existed no difference between these patients (1.8 points, $p=0.5$). Our study revealed that with nonoperative and operative treatment of displaced midshaft clavicle fractures, equal results in function, disability, and pain can be achieved with a low risk of complications, and also that nonunion barely impairs shoulder function.

One Canadian randomized controlled trial of displaced midshaft clavicle fractures concluded that at the 1-year follow-up, the operative group scored better in function (CS, $p=0.001$) and in disability (DASH, $p<0.01$), and also had lower rates of malunion and nonunion than did the nonoperative group (Canadian Orthopaedic Trauma Society 2007). Differences in CS and in DASH were statistically significant, but with any clinical significance unclear. As in our study, the nonunion rate was lower in the operative group.

Smekal et al. (2009) compared ESIN to nonoperative treatment and found no difference in disability (DASH) after a 25-week follow-up. At the 2-year follow-up, a statistical, but not a clinical difference in function (CS) emerged. All fractures in the operative group healed, whereas nonunion was observable in 10% of patients of the nonoperative group. When comparing two operative modalities, ESIN or plate, in displaced midshaft clavicle fractures, no differences appeared in functional shoulder scores (CS, Oxford Score) or in union (Ferran et al. 2010). A prospective study of a 10-year follow-up found that 46% of nonoperatively treated patients were not fully recovered, and 27% had cosmetic defects from the fracture (Nowak et al. 2004).

A recent randomized controlled trial of displaced midshaft clavicle fractures claimed that rate of nonunion was significantly reduced after open reduction and plate fixation (1%) as compared with nonoperative treatment (17%) ($p=0.007$). In addition, disability (DASH, $p=0.04$) and shoulder function (CS, $p=0.01$) were significantly better after open reduction and plate fixation than after nonoperative treatment at 1-year follow-up. When patients with nonunion were excluded from analysis, no significant differences in disability or function at any time point emerged between treatment groups. Thus, the improved outcomes appeared to result from prevention of nonunion by open reduction and plate fixation (Robinson et al. 2013).

In primary radiographs of our study, mean shortening of the injured clavicle was 10 mm in the nonoperative and 11 mm in the operative group. We compared the lengths of the injured and contralateral shoulders. In our opinion, this procedure is the most concrete method to measure shortening. Fractures of the diaphyseal clavicle are commonly oblique or comminuted. Assessing radiographs of the injured side only is challenging, because true fracture shortening is difficult to measure. The association between clavicle shortening after healing and clinical outcome is still controversial. Some studies have reported that shortening of the healed clavicle fracture causes shoulder joint disability (Hill et al. 1997, Lazarides and Zafiroopoulos 2006, Canadian Orthopaedic Trauma Society 2007), whereas some have found no association with disability (Nordqvist et al. 1997, Nowak et al. 2004, Rasmussen et al. 2011).

We found 12 complications in the nonoperative and 7 in the operative group. Compared with previous randomized controlled trials, we expected more nonunion in the nonoperative group, but still the high incidence of nonunion (24%) was surprising. An apparent connection existed between nonunion and vertical displacement. Displacement of more than 1.5 clavicle widths was associated with considerable risk of nonunion in patients with nonoperative treatment. Otherwise, the rates of adverse effects were acceptable.

Our study had some weaknesses. Probably not all eligible patients were recruited to the study, causing some selection bias in the study population. That evaluation at 1-year was done by the main author may cause some experimenter bias. These possible biases do not exclude the fact that our results are parallel to those of other similar studies and can be generalized to any

patient with an isolated, displaced midshaft clavicle fracture. Not all the patients completed the 1-year follow-up. Lost patients were distributed unequally, because seven were in the nonoperative group and two in the operative group. Based on incidence of nonunion in our study population, it could be possible that one or two nonunions occurred among these lost patients. We included no high-demand patients such as professional athletes, so we were unable to conclude what sort of difficulties or deficiencies malunion or nonunion might cause for a person with very high physical demands.

6.3. Operative treatment of acromioclavicular joint injuries (III, IV)

In Study III, the patients, after long-term follow-up of type V dislocation treatment, had good shoulder function and minor disability. We found no difference in function between injured and uninjured shoulders. It seems that permanent AC joint dislocation is associated with lateral clavicle osteolysis. Overall, sequelae were of minor importance, with no permanent insufficiency in shoulder function. In Study IV, function of the injured shoulder was poorer than in the uninjured shoulder. The mean CS of the injured shoulder failed to correspond to the estimated normative value of that score. Complications were many, such as constant instability of the AC joint, lateral clavicle osteolysis, tunnel widening, and fractures of the coracoid process and clavicle. It seems that a connection exists between lateral clavicle osteolysis and sense of disability.

In acute surgery, the main effort is to create an optimal environment for healing of the AC ligaments, CC ligaments, and muscle attachments, thus achieving a stable clavicle, an asymptomatic AC joint, and normal shoulder joint function. In delayed surgery, aims are basically the same. The major challenge, however, is to eliminate chronic pain and sense of disability. Insufficiency of stabilizing structures, altered anatomical relations, chronic clavicle dislocation, and high torsion forces in the lateral clavicle make this surgery much more challenging.

Although the nature of AC joint dislocation is simple, the choice of an optimal treatment method and moment, and attainment of a good functional result are somewhat difficult. Sometimes the clinician finds it hard to realize why the patient has sequelae or is dissatisfied with the end result. It is certain that we are not familiar with all circumstances influencing a good result. The surgery is problematic, since the incomparable treatment method has as yet

to be invented. The variety of treatment methods is astonishing, so surgeons cannot be blamed for lack of imagination. The literature has reports discussing Kirschner wires, screws, plates, hook plates, anchors, bands, sutures, and tendons by way of open surgery, minimal invasive techniques, or arthroscopy (Lin et al. 2006, Leidel et al. 2009, Salem and Schmelz 2009, Basyoni et al. 2010, DeBerardino et al. 2010, Petersen et al. 2010, Salzmann et al. 2010, Yoo et al. 2010, El Shewy and El Azizi 2011, Liu et al. 2012).

In Study III, all patients had a Rockwood type V injury, whereas Study IV included lower-type injuries, as well. Possibly, lower-type AC joint injuries also fail to heal properly under nonoperative management and require later surgery. The amount of soft-tissue injury evidently increases from type III to type V. In type V dislocations, stability of the AC joint may also depend on the healing of muscle attachments (Lizaur et al. 1994). Thus far, research has not clarified the character of CC and AC ligament rupture nor their intrinsic healing ability and schedule. No one knows whether healing capability differs between ligament avulsion and midsubstance rupture. Urist found in 1946 that an intact AC ligament could prevent joint dislocation even if CC ligaments were cut. He also found that the gradual sectioning of AC ligaments, CC ligaments, and muscle attachments led to complete disarticulation, and that the AC ligament acted as the primary structure preventing posterior displacement of the clavicle (Urist 1946). Because of the fundamental importance of the AC ligament in clavicular stability, this lesion should always be repaired in acute surgery and reconstructed in delayed surgery.

The literature seems to provide no study discussing long-term results of surgery in acute type V dislocation. De Tullio et al. (1994) assessed the long-term results of Allman grade III dislocation and found good results for pain, ROM of the shoulder joint, and strength. Allman grade III injuries included at least Rockwood type III and V injuries, thus their patient population was heterogeneous. Moreover, their outcomes were approximate and limited. A Swedish study comparing acute surgery with delayed surgery in type V injuries showed better results in shoulder function, in disability, in pain, and in satisfaction resulting from acute-phase treatment (von Heideken et al. 2013).

If, for some reason, the nonoperative treatment ends undesirably, or results of acute surgery are poor, the consequences may be persistent pain and insufficiency in the shoulder region,

inability to perform overhead activities, and a frequent sense of instability or weakness. In such a situation, the surgeon is obliged to consider methods to remedy a chronic AC joint dislocation. Weaver and Dunn published a method to treat chronic AC joint dislocation. They made a resection to the lateral end of the clavicle and stabilized the AC joint by placing the acromial end of the shortened CA ligament into the medullary canal of the lateral clavicle (Weaver and Dunn 1972). Since then, various modifications have developed from this Weaver-Dunn method (Hosseini et al. 2009, Boileau et al. 2010, Bostrom Windhamre et al. 2010, Kim et al. 2012b). The first report of CC ligament reconstruction with tendon grafts in chronic AC joint dislocation appeared 13 years ago (Jones et al. 2001). It seems that CC ligament reconstruction with an autogenous tendon graft yields better results than does modified Weaver-Dunn or synthetic ligament. The CA ligament appears too weak to restore the stability of the AC joint (Tauber et al. 2007, 2009, Yoo et al. 2010, Fauci et al. 2013).

Against temporary Kirschner wire fixation criticism has arisen for its failing to stabilize the AC joint sufficiently and also for the risk of wire migration. At present, this method is generally out of favor, because contemporary methods have appeared. On the other hand, even reconstructive surgery seems not always to ensure AC joint stability. Study IV showed that after reconstructive surgery, 44% of patients suffered AC joint instability. One reason for this failure may be tunnel widening that ruins stability by preventing tendon-to-bone healing.

Several complications developed in both of our studies. In Study III we found reduction loss in the early phase. It seems that in long-term follow-up, the permanent AC joint dislocation had no influence upon shoulder function or its sequelae. Lateral clavicle osteolysis appeared commonly in patients who had constant AC joint dislocation. A stable AC joint seems to enable possible revascularization of the lateral end of the clavicle. In Study IV, the surgical method results in the characteristic complication profile. Tunnel widening and lateral clavicle osteolysis were extremely common. Failure in AC joint stabilization may be a consequence of unsatisfactory tendon-bone integration and graft incorporation. The frequency and extent of osteolysis was surprising. In some patients, osteolysis affected the lateral clavicle as far as to the drill holes and thus caused graft loosening and instability. Moreover, this osteolysis seemed to be surgery-induced. Due to long-term clavicle dislocation and the substantial quantity of scar tissue, clavicle mobilization and surgical dissection must be thorough. During this detachment, the arterial supply may undergo damage, resulting in dissolution of bone

mineral. In addition, clavicle drilling and tenodesis screws may disturb blood perfusion in bone, leading to significant osteolysis. The basis for lateral clavicle osteolysis is unclear (Gordon and Chew 2004). One cause may be a local bone-circulation disturbance, but AC ligaments and muscle aponeurosis may also prove crucial to lateral clavicle circulation (Knudsen et al. 1989). Fractures of the coracoid process and clavicle were also common. The reason for coracoid process fractures may be the ability of nonabsorbable sutures to stress the bone or to cut into the bone gradually.

Both studies were retrospective, presenting only low-level evidence of the topic. The precise level of preoperative function or disability remains in doubt, making the actual change in outcomes unclear. Eligible patients were not all able to attend the follow-up visit, and thus selection bias is possible. The main author examined the patients at the follow-up visit, making possible observer bias. Study III had three treatment modalities, making the study cohort heterogeneous. In Study IV, some modifications in surgical technique occurred over the course of time, but these had hardly any major impact on results. In Study IV, the range in follow-up times was 1 to 7 years, which may have influenced results.

6.4. Future prospects

To strengthen the evidence regarding clavicle fracture treatment, we need more high-quality randomized controlled trials comparing operative treatment modalities and nonoperative treatment. It would be desirable to see published the very first randomized study comparing operative to nonoperative treatment on unstable Neer II lateral clavicle fractures. Future studies should also assess the effect of malunion and nonunion on functional outcomes and thus help determine whether to treat patients with symptomatic malunion or nonunion surgically only. A deficiency also exists in data on the best treatment for high-demand patients. It is, however, promising to notice that new randomized studies are in progress or beginning, even on lateral clavicle fractures. In ClinicalTrials.gov are eleven randomized studies on diaphyseal fractures and two studies on Neer II lateral fractures.

Knowledge as to the best treatment for types III, IV, and V acromioclavicular joint dislocation is also deficient. Comparative studies assessing operative and nonoperative treatment are essential at least for type III and V dislocations. At the moment, ClinicalTrials.gov has three randomized studies comparing the sling to the hook plate. Most challenging in these studies

will be the low incidence of these injuries and the long follow-up required. Because many of the sequelae manifest later than during the first years, follow-up should be longer, at least 5 years. It would be worthwhile to compare the results of nonoperative and operative treatment in chronic AC joint dislocation. Another issue left unsolved is why some patients suffer sequelae after nonoperative treatment, even in lower-type injuries, and how to prevent osteolysis in operative treatment of chronic AC joint dislocation.

7. CONCLUSIONS

- I The quality of evidence in the literature is generally low or very low. Due to a lack of evidence, no conclusions can be drawn on medial- or lateral-third fracture treatment. Moderate-quality evidence regarding acute midshaft clavicle fractures demonstrates these likely conclusions:
- After short-term follow-up, operative treatment leads to slightly better function and lesser disability than does nonoperative treatment.
 - After 6 months, the advantages of operative treatment are small, because most nonoperatively treated patients also recover.
 - Union is better secured with surgery.
 - Nonoperative treatment usually leads to adequate function, pain relief, and union rates.
 - The osteosynthesis method has no effect on the incidence of delayed union or nonunion.
- II With both nonoperative and operative treatment of acute displaced midshaft clavicle fractures, an equal functional outcome is achieved at 1-year follow-up. Regardless of treatment method, the sense of disability is low. Nonoperative treatment is associated with a high nonunion rate (24%). Risk of nonunion is significant if initial fracture displacement is >1.5 clavicle widths. Plate fixation secures the union at a low complication rate.
- III Operative treatment of acute type V acromioclavicular joint dislocation leads to good functional outcome in long-term follow-up. Sequelae after surgery are minor and cause no permanent disability.
- IV Operative treatment of chronic AC joint dislocation is demanding. Surgery may not necessarily stabilize the AC joint or restore shoulder function. The complication rate is high, and especially tunnel widening and lateral clavicle osteolysis may ruin the results.

APPENDIX

Appendix 1.

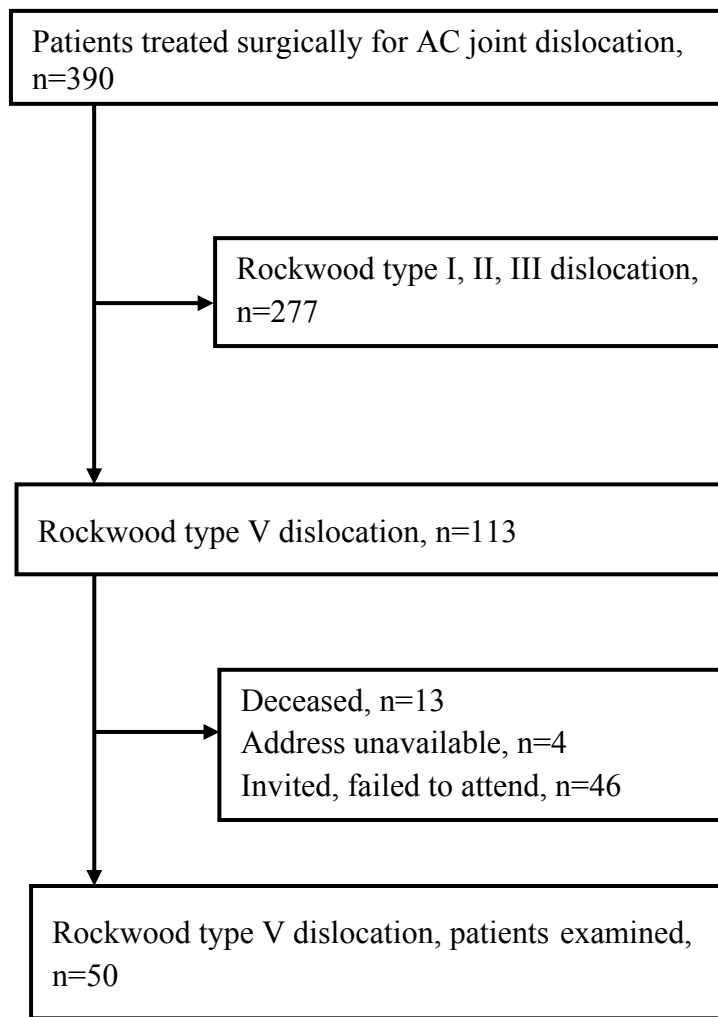
Criteria for risk of bias assessment in Study I.

If ≥ 6 of 12 criteria were fulfilled (i.e. with the answer “yes”) the trial had a low risk of bias.

Criteria	Answer
1. Was the method of randomization adequate?	Yes/No/Unsure
2. Was the treatment allocation concealed?	Yes/No/Unsure
3. Was the patient blinded to the intervention?	Yes/No/Unsure
4. Was the care provider blinded to the intervention?	Yes/No/Unsure
5. Was the outcome assessor blinded to the intervention?	Yes/No/Unsure
6. Was the drop-out rate described and acceptable?	Yes/No/Unsure
7. Were all randomized/allocated participants analyzed in the group to which they were allocated?	Yes/No/Unsure
8. Are reports of the study free of suggestion of selective outcome reporting?	Yes/No/Unsure
9. Were the groups similar at baseline regarding the most important prognostic indicators?	Yes/No/Unsure
10. Were co-interventions avoided or similar?	Yes/No/Unsure
11. Was the compliance acceptable in all groups?	Yes/No/Unsure
12. Was the timing of the outcome assessment similar in all groups?	Yes/No/Unsure

Appendix 2.

Flow of patients in Study III. Patients were treated for acute type V AC joint dislocation between April 1985 and December 1993.



ACKNOWLEDGEMENTS

This study was carried out at the Department of Orthopaedics and Traumatology, Helsinki University Central Hospital.

My warmest gratitude goes to my supervisors Mika Paavola and Ville Remes for their expert guidance and supportive attitude. This entire project began when Ville suggested the topic of this study and encouraged me to jump on it. With Mika I have had dozens of discussions and always received answers, even to the trickiest questions. His knowledge of methods of scientific research is invaluable.

I am most indebted to the official reviewers of this thesis, Tapio Flinkkilä from the Department of Surgery, Oulu University Hospital, and Heikki Mäenpää from the Department of Musculoskeletal Diseases, Tampere University Hospital. Their valuable comments and suggestions markedly improved the final thesis.

I offer my sincere thanks to my co-authors on the original publications. Jarkko Pajarinen, Head of the Department of Orthopaedics and Traumatology, also for providing the possibility to carry this thesis to the goal (touchdown!). Jan-Magnus Björkenheim, the grand old man of shoulder surgery, who always offers his help and has admirable positive insights into everything. Vesa Savolainen, whose enthusiasm for research and for improving knowledge and skills are enviable. Antti Malmivaara, whose helpful attitude toward and encouragement in research is admirable; without his wide expertise, the first article would never have seen the light of day. Ville Haapamäki, also for his excellent radiographical analyses.

I want to warmly thank Professor Ilkka Kiviranta for his supportive and encouraging attitude, warm conversations and advice. My sincere thanks also go to Eero Hirvensalo, Chairman of the Musculoskeletal Division of Surgery, for the opportunity to perform this study.

I am very grateful to Marja-Liisa Alsio, Eija Pöyry, Sanna Hokkanen, and Leena Caravitis for their indispensable help with patients and documents. I also have to thank Anna-Liisa Nieminen for providing the facilities in the outpatient clinic for examining the patients.

I am very grateful to Carolyn Brimley Norris for reviewing the language of all my articles and thesis. Her useful English courses are memorable. Her never-ending enthusiasm for author-editing and bettering Finnish to English is admirable.

I wish to thank Reijo Sund for help with statistical problems.

I would like to express my gratitude to the staff of Töölö Hospital: in the emergency department (tapis), radiological department, surgical department, all wards, and the outpatient clinic for helping me and taking care of the patients in the clinical series. I am deeply touched by your expertise. Special thanks also to the registry of patient records in Töölö Hospital for kind help with the slew of papers.

I am most indebted to my nearest colleagues in Töölö Hospital: Lauri Handolin, Mikko Heinänen, Tim Söderlund, Tuomas Brinck, Tuomo Pyhältö, and Vincent van Iterson. Without their understanding and sympathy, my thesis would have been impossible. Warm thanks go also to all my colleagues in Töölö Hospital, whose commitment to their admirable work is unique.

My sincere thanks to Mia Kalervo (äitee) and Terttu Rantanen for essential advice and help in all arrangements related to this dissertation.

This study would have been impossible without all the volunteer participants. Their self-sacrificing, unselfish, and positive attitude towards research deserves high respect.

I wish to thank my friends and colleagues Laura Jartti and Katri Louhi. Our memorable journeys already started in medical school. I will never forget our running in full flight a couple of years ago when “a bear” was chasing us.

My deepest gratitude goes to my loving parents Maija and Kari. I would not be here without their heartfelt support and help. I have to admire their enthusiasm for taking care of their grandchildren and maintaining the heritage of our respected war veterans; their constant help to veterans is remarkably noble. I am also thankful to my sister Elina and her family, Tomi, Siiri, Inkeri, Frans, Lyyti, Omppu, and Tikru. I enviously watch their joy of life and happiness.

Acknowledgements

Finally, I owe my warmest gratitude to my husband Ilkka for his love and faith. He pushed me through this project and helped at every turn. His interest in and knowledge of medicine is deeply admirable. There is no question about medicine he cannot answer. I am most indebted to him for many surgical skills that cannot be learned from books.

This study has been financially supported by the Helsinki University Central Hospital Research Foundation, the Finnish Research Foundation for Orthopaedics and Traumatology, the Finnish Office for Health Technology Assessment at the National Institute for Health and Welfare, and the Research Foundation of Orion Corporation to whom I am sincerely grateful.

Espoo, April 2014

Kaisa Virtanen

REFERENCES

- Abdel Fatah EE, Shirley NR, Mahfouz MR, Auerbach BM.** A three-dimensional analysis of bilateral directional asymmetry in the human clavicle. *Am J Phys Anthropol.* 2012; 149: 547-559.
- Adams JM, Bilaniuk JW, Difazio LT, Siegel BK, Durling-Grover R, McCarthy D, Grob P, Bobbin MD, Skerker RS, Nemeth ZH.** Standard computed tomography of the chest, abdomen, and pelvis is sensitive and cost-effective for the detection of fractures of the shoulder girdle. *Am Surg.* 2011; 77: 1183-1187.
- Allman FL, Jr.** Fractures and ligamentous injuries of the clavicle and its articulation. *J Bone Joint Surg Am.* 1967; 49: 774-784.
- Andermahr J, Jubel A, Elsner A, Prokop A, Tsikaras P, Jupiter J, Koebke J.** Malunion of the clavicle causes significant glenoid malposition: a quantitative anatomic investigation. *Surg Radiol Anat.* 2006; 28: 447-456.
- Andermahr J, Jubel A, Elsner A, Johann J, Prokop A, Rehm KE, Koebke J.** Anatomy of the clavicle and the intramedullary nailing of midclavicular fractures. *Clin Anat.* 2007; 20: 48-56.
- Andersen K, Jensen PO, Lauritzen J.** Treatment of clavicular fractures. Figure-of-eight bandage versus a simple sling. *Acta Orthop Scand.* 1987; 58: 71-74.
- Annandale T.** Simple Comminuted Fracture of the Clavicle treated by the Removal of a Sharp Fragment. *Br Med J.* 1873; 2: 82.
- Antonio GE, Cho JH, Chung CB, Trudell DJ, Resnick D.** Pictorial essay. MR imaging appearance and classification of acromioclavicular joint injury. *AJR Am J Roentgenol.* 2003; 180: 1103-1110.
- Assobhi JE.** Reconstruction plate versus minimal invasive retrograde titanium elastic nail fixation for displaced midclavicular fractures. *J Orthop Traumatol.* 2011; 12: 185-192.
- Austin LS, O'Brien MJ, Zmistowski B, Ricchetti ET, Kraeutler MJ, Joshi A, Fenlin JM, Jr.** Additional x-ray views increase decision to treat clavicular fractures surgically. *J Shoulder Elbow Surg.* 2012; 21: 1263-1268.
- Banerjee R, Waterman B, Padalecki J, Robertson W.** Management of distal clavicle fractures. *J Am Acad Orthop Surg.* 2011; 19: 392-401.

- Bannister GC, Wallace WA, Stableforth PG, Hutson MA.** The management of acute acromioclavicular dislocation. A randomised prospective controlled trial. *J Bone Joint Surg Br.* 1989; 71: 848-850.
- Barbaix E, Lapierre M, Van Roy P, Clarijs JP.** The sternoclavicular joint: variants of the discus articularis. *Clin Biomech (Bristol, Avon).* 2000; 15 Suppl 1: S3-7.
- Bartonicek J, Fric V, Pacovsky V.** Displaced fractures of the medial end of the clavicle: report of five cases. *J Orthop Trauma.* 2010; 24: e31-35.
- Basyoni Y, El-Ganainy AE, Aboul-Saad M.** Acromioclavicular joint reconstruction using anchor sutures: surgical technique and preliminary results. *Acta Orthop Belg.* 2010; 76: 307-311.
- Bathis H, Tingart M, Bouillon B, Tiling T.** Conservative or surgical therapy of acromioclavicular joint injury - what is reliable? A systematic analysis of the literature using "evidence-based medicine" criteria. *Chirurg.* 2000; 71: 1082-1089.
- Bathis H, Tingart M, Bouillon B, Tiling T.** The status of therapy of acromioclavicular joint injury. Results of a survey of trauma surgery clinics in Germany. *Unfallchirurg.* 2001; 104: 955-960.
- Beim GM, Warner JJ.** Clinical and radiographic evaluation of the acromioclavicular joint. *Oper Tech Sports Med.* 1997; 5: 65-71.
- Bendell JL.** VI. Bone Plating in Irreducible Fracture of the Clavicle. *Ann Surg.* 1912; 56: 867-868.
- Bhatia DN, Page RS.** Surgical treatment of lateral clavicle fractures associated with complete coracoclavicular ligament disruption: Clinico-radiological outcomes of acromioclavicular joint sparing and spanning implants. *Int J Shoulder Surg.* 2012; 6: 116-120.
- Black S, Scheuer L.** Age changes in the clavicle: from the early neonatal period to skeletal maturity. *Int J Osteoarchaeol.* 1996; 6: 425-434.
- Blakeley CJ, Harrison HL, Siow S, Hashemi K.** The use of bedside ultrasound to diagnose posterior sterno-clavicular dislocation. *Emerg Med J.* 2011; 28: 542.
- Boileau P, Old J, Gastaud O, Brassart N, Roussanne Y.** All-arthroscopic Weaver-Dunn-Chuinard procedure with double-button fixation for chronic acromioclavicular joint dislocation. *Arthroscopy.* 2010; 26: 149-160.
- Bontempo NA, Mazzocca AD.** Biomechanics and treatment of acromioclavicular and sternoclavicular joint injuries. *Br J Sports Med.* 2010; 44: 361-369.

- Bossart PJ, Joyce SM, Manaster BJ, Packer SM.** Lack of efficacy of 'weighted' radiographs in diagnosing acute acromioclavicular separation. *Ann Emerg Med.* 1988; 17: 20-24.
- Bostrom Windhamre HA, von Heideken JP, Une-Larsson VE, Ekelund AL.** Surgical treatment of chronic acromioclavicular dislocations: a comparative study of Weaver-Dunn augmented with PDS-braid or hook plate. *J Shoulder Elbow Surg.* 2010; 19: 1040-1048.
- Bosworth BM.** Acromioclavicular separation: New method of repair. *Surg Gynecol Obstet.* 1941; 73: 866-871.
- Brandt W.** Das Schlüsselbein des menschlichen Fetus. *Z Anat Entwicklungsgesch.* 1934: 653-669.
- Breslow MJ, Jazrawi LM, Bernstein AD, Kummer FJ, Rokito AS.** Treatment of acromioclavicular joint separation: suture or suture anchors? *J Shoulder Elbow Surg.* 2002; 11: 225-229.
- Brossmann J, Stabler A, Preidler KW, Trudell D, Resnick D.** Sternoclavicular joint: MR imaging - anatomic correlation. *Radiology.* 1996; 198: 193-198.
- Brunner U, Habermeyer P, Schweiberer L.** Special status of lateral clavicular fracture. *Orthopade.* 1992; 21: 163-171.
- Böhme J, Bonk A, Bacher GO, Wilharm A, Hoffmann R, Josten C.** Current treatment concepts for mid-shaft fractures of the clavicle - results of a prospective multicentre study. *Z Orthop Unfall.* 2011; 149: 68-76.
- Camargo PR, Phadke V, Braman JP, Ludewig PM.** Three-dimensional shoulder kinematics after total claviclectomy: A biomechanical investigation of a single case. *Man Ther.* 2013; 18: 620-623.
- Canadian Orthopaedic Trauma Society.** Nonoperative treatment compared with plate fixation of displaced midshaft clavicular fractures. A multicenter, randomized clinical trial. *J Bone Joint Surg Am.* 2007; 89: 1-10.
- Carofino BC, Mazzocca AD.** The anatomic coracoclavicular ligament reconstruction: surgical technique and indications. *J Shoulder Elbow Surg.* 2010; 19: 37-46.
- Chan KY, Jupiter JB, Leffert RD, Marti R.** Clavicle malunion. *J Shoulder Elbow Surg.* 1999; 8: 287-290.
- Checchia SL, Doneux PS, Miyazaki AN, Fregoneze M, Silva LA.** Treatment of distal clavicle fractures using an arthroscopic technique. *J Shoulder Elbow Surg.* 2008; 17: 395-398.

- Chen YF, Wei HF, Zhang C, Zeng BF, Zhang CQ, Xue JF, Xie XT, Lu Y.** Retrospective comparison of titanium elastic nail (TEN) and reconstruction plate repair of displaced midshaft clavicular fractures. *J Shoulder Elbow Surg.* 2012; 21: 495-501.
- Chernchujit B, Tischer T, Imhoff AB.** Arthroscopic reconstruction of the acromioclavicular joint disruption: surgical technique and preliminary results. *Arch Orthop Trauma Surg.* 2006; 126: 575-581.
- Chien M, Bulloch B, Garcia-Filion P, Youssfi M, Shrader MW, Segal LS.** Bedside ultrasound in the diagnosis of pediatric clavicle fractures. *Pediatr Emerg Care.* 2011; 27: 1038-1041.
- Chillemi C, Franceschini V, Dei Giudici L, Alibardi A, Salate Santone F, Ramos Alday LJ, Osimani M.** Epidemiology of isolated acromioclavicular joint dislocation. *Journal* [serial online]. 2013 Date 3568861]; 2013: [171609 screens]. Available from: URL:<http://www.ncbi.nlm.nih.gov/pubmed/23431452>.
- Collins HD.** VII. A Dressing for Fracture of the Clavicle. *Ann Surg.* 1912; 55: 88-91.
- Cook JB, Shaha JS, Rowles DJ, Bottoni CR, Shaha SH, Tokish JM.** Clavicular bone tunnel malposition leads to early failures in coracoclavicular ligament reconstructions. *Am J Sports Med.* 2013; 41: 142-148.
- Costic RS, Labriola JE, Rodosky MW, Debski RE.** Biomechanical rationale for development of anatomical reconstructions of coracoclavicular ligaments after complete acromioclavicular joint dislocations. *Am J Sports Med.* 2004; 32: 1929-1936.
- Cross KP, Warkentine FH, Kim IK, Gracely E, Paul RI.** Bedside ultrasound diagnosis of clavicle fractures in the pediatric emergency department. *Acad Emerg Med.* 2010; 17: 687-693.
- Daruwalla ZJ, Curtis P, Fitzpatrick C, Fitzpatrick D, Mullett H.** Anatomic variation of the clavicle: A novel three-dimensional study. *Clin Anat.* 2010; 23: 199-209.
- Davis GG.** The Treatment of Fractures of the Clavicle. *Ann Surg.* 1890; 11: 44-48.
- Davis GG.** IV. Injuries to Nerves in Fractures: Report of Two Operative Cases in Fractures of the Humerus and Clavicle. *Ann Surg.* 1896; 23: 147-152.
- Dawson PA, Adamson GJ, Pink MM, Kornswiet M, Lin S, Shankwiler JA, Lee TQ.** Relative contribution of acromioclavicular joint capsule and coracoclavicular ligaments to acromioclavicular stability. *J Shoulder Elbow Surg.* 2009; 18: 237-244.

- De Tullio V, Orsi R, Celenza M.** Surgical treatment of Allman type III acromio-clavicular dislocation. A long-term follow-up study. *Acta Orthop Belg.* 1994; 60: 300-302.
- Deafenbaugh MK, Dugdale TW, Staeheli JW, Nielsen R.** Nonoperative treatment of Neer type II distal clavicle fractures: a prospective study. *Contemp Orthop.* 1990; 20: 405-413.
- DeBerardino TM, Pensak MJ, Ferreira J, Mazzocca AD.** Arthroscopic stabilization of acromioclavicular joint dislocation using the AC graftrope system. *J Shoulder Elbow Surg.* 2010; 19: 47-52.
- Defoort S, Verborgt O.** Functional and radiological outcome after arthroscopic and open acromioclavicular stabilization using a double-button fixation system. *Acta Orthop Belg.* 2010; 76: 585-591.
- DePalma AF.** Surgical Anatomy of Acromioclavicular and Sternoclavicular Joints. *Surg Clin North Am.* 1963; 43: 1541-1550.
- Deshmukh AV, Wilson DR, Zilberfarb JL, Perlmutter GS.** Stability of acromioclavicular joint reconstruction: biomechanical testing of various surgical techniques in a cadaveric model. *Am J Sports Med.* 2004; 32: 1492-1498.
- Deunk J, Dekker HM, Brink M, van Vugt R, Edwards MJ, van Vugt AB.** The value of indicated computed tomography scan of the chest and abdomen in addition to the conventional radiologic work-up for blunt trauma patients. *J Trauma.* 2007; 63: 757-763.
- Di Francesco A, Zoccali C, Colafarina O, Pizzoferrato R, Flamini S.** The use of hook plate in type III and V acromio-clavicular Rockwood dislocations: clinical and radiological midterm results and MRI evaluation in 42 patients. *Injury.* 2012; 43: 147-152.
- Dias JJ, Steingold RF, Richardson RA, Tesfayohannes B, Gregg PJ.** The conservative treatment of acromioclavicular dislocation. Review after five years. *J Bone Joint Surg Br.* 1987; 69: 719-722.
- Drosdowech DS, Manwell SE, Ferreira LM, Goel DP, Faber KJ, Johnson JA.** Biomechanical analysis of fixation of middle third fractures of the clavicle. *J Orthop Trauma.* 2011; 25: 39-43.
- El Mekkaoui MJ, Sekkach N, Bazeli A, Faustin JM.** Proximal clavicle physeal fracture-separation mimicking an anterior sterno-clavicular dislocation. *Orthop Traumatol Surg Res.* 2011; 97: 349-352.
- El Shewy MT, El Azizi H.** Suture repair using loop technique in cases of acute complete acromioclavicular joint dislocation. *J Orthop Traumatol.* 2011; 12: 29-35.

- ElMaraghy AW, Devereaux MW, Ravichandiran K, Agur AM.** Subacromial morphometric assessment of the clavicle hook plate. *Injury*. 2010; 41: 613-619.
- Emura K, Arakawa T, Terashima T, Miki A.** Macroscopic and histological observations on the human sternoclavicular joint disc. *Anat Sci Int*. 2009; 84: 182-188.
- Ernberg LA, Potter HG.** Radiographic evaluation of the acromioclavicular and sternoclavicular joints. *Clin Sports Med*. 2003; 22: 255-275.
- Eschler A, Gradl G, Gierer P, Mittlmeier T, Beck M.** Hook plate fixation for acromioclavicular joint separations restores coracoclavicular distance more accurately than PDS augmentation, however presents with a high rate of acromial osteolysis. *Arch Orthop Trauma Surg*. 2012; 132: 33-39.
- Eskola A.** Sternoclavicular dislocation. A plea for open treatment. *Acta Orthop Scand*. 1986; 57: 227-228.
- Eskola A, Vainionpaa S, Vastamaki M, Slati P, Rokkanen P.** Operation for old sternoclavicular dislocation. Results in 12 cases. *J Bone Joint Surg Br*. 1989; 71: 63-65.
- Fauci F, Merolla G, Paladini P, Campi F, Porcellini G.** Surgical treatment of chronic acromioclavicular dislocation with biologic graft vs synthetic ligament: a prospective randomized comparative study. *J Orthop Traumatol*. 2013; 14: 283-290.
- Ferran NA, Hodgson P, Vannet N, Williams R, Evans RO.** Locked intramedullary fixation vs plating for displaced and shortened mid-shaft clavicle fractures: a randomized clinical trial. *J Shoulder Elbow Surg*. 2010; 19: 783-789.
- Figueiredo EA, Neves EJ, Yoshizawa Júnior H, Dall'Ara Neto A, Nascimento LFC, Faria GHM, Corrêa WM.** Prospective randomized study comparing surgical treatment using anterior plate to non-surgical treatment of midshaft clavicle fractures. *Rev Bras Ortop*. 2008; 43: 419-425.
- Fischer LP, Carret JP.** Arterial vascularization of human bones. *Bull Assoc Anat (Nancy)*. 1978; 62: 419-452.
- Flinkkila T, Ristiniemi J, Lakovaara M, Hyvonen P, Leppilahti J.** Hook-plate fixation of unstable lateral clavicle fractures: a report on 63 patients. *Acta Orthop*. 2006; 77: 644-649.
- Fowler AW.** Treatment of fractured clavicle. *Lancet*. 1968; 1: 46-47.
- Fu TH, Tan BL, Liu HC, Wang JW.** Anatomical reduction for treatment of displaced midshaft clavicular fractures: Knowles pinning vs. reconstruction plating. *Orthopedics*. 2012; 35: e23-30.

- Fujita K, Matsuda K, Sakai Y, Sakai H, Mizuno K.** Late thoracic outlet syndrome secondary to malunion of the fractured clavicle: case report and review of the literature. *J Trauma*. 2001; 50: 332-335.
- Fukuda K, Craig EV, An KN, Cofield RH, Chao EY.** Biomechanical study of the ligamentous system of the acromioclavicular joint. *J Bone Joint Surg Am*. 1986; 68: 434-440.
- Fung M, Kato S, Barrance PJ, Elias JJ, McFarland EG, Nobuhara K, Chao EY.** Scapular and clavicular kinematics during humeral elevation: a study with cadavers. *J Shoulder Elbow Surg*. 2001; 10: 278-285.
- Furlan AD, Pennick V, Bombardier C, van Tulder M.** 2009 updated method guidelines for systematic reviews in the Cochrane Back Review Group. *Spine (Phila Pa 1976)*. 2009; 34: 1929-1941.
- Gale DW, Dunn ID, McPherson S, Oni OO.** Retrosternal dislocation of the clavicle: the 'stealth' dislocation. *Injury*. 1992; 23: 563-564.
- Gardner E.** The embryology of the clavicle. *Clin Orthop Relat Res*. 1968; 58: 9-16.
- Gardner MA, Bidstrup BP.** Intrathoracic great vessel injury resulting from blunt chest trauma associated with posterior dislocation of the sternoclavicular joint. *Aust N Z J Surg*. 1983; 53: 427-430.
- Gebo DL.** Climbing, brachiation, and terrestrial quadrupedalism: historical precursors of hominid bipedalism. *Am J Phys Anthropol*. 1996; 101: 55-92.
- Gille J, Heinrichs G, Unger A, Riepenhof H, Herzog J, Kienast B, Oheim R.** Arthroscopic-assisted hook plate fixation for acromioclavicular joint dislocation. *Int Orthop*. 2013; 37: 77-82.
- Glass ER, Thompson JD, Cole PA, Gause TM, 2nd, Altman GT.** Treatment of sternoclavicular joint dislocations: a systematic review of 251 dislocations in 24 case series. *J Trauma*. 2011; 70: 1294-1298.
- Golish SR, Oliviero JA, Francke EI, Miller MD.** A biomechanical study of plate versus intramedullary devices for midshaft clavicle fixation. *J Orthop Surg Res*. 2008; 3: 28.
- Gonzalez R, Damacen H, Nyland J, Caborn D.** Acromioclavicular joint reconstruction using peroneus brevis tendon allograft. *Arthroscopy*. 2007; 23: 788 e781-784.
- Gordon BH, Chew FS.** Isolated acromioclavicular joint pathology in the symptomatic shoulder on magnetic resonance imaging: a pictorial essay. *J Comput Assist Tomogr*. 2004; 28: 215-222.

- Grant JCB.** *Method of anatomy.* Williams & Wilkins, Baltimore; 1971. p. 92-105.
- Groh GI, Wirth MA.** Management of traumatic sternoclavicular joint injuries. *J Am Acad Orthop Surg.* 2011; 19: 1-7.
- Grutter PW, Petersen SA.** Anatomical acromioclavicular ligament reconstruction: a biomechanical comparison of reconstructive techniques of the acromioclavicular joint. *Am J Sports Med.* 2005; 33: 1723-1728.
- Gullo J, Singletary EM, Larese S.** Emergency bedside sonographic diagnosis of subclavian artery pseudoaneurysm with brachial plexopathy after clavicle fracture. *Ann Emerg Med.* 2013; 61: 204-206.
- Haidar SG, Krishnan KM, Deshmukh SC.** Hook plate fixation for type II fractures of the lateral end of the clavicle. *J Shoulder Elbow Surg.* 2006; 15: 419-423.
- Hall BK.** Development of the clavicles in birds and mammals. *J Exp Zool.* 2001; 289: 153-161.
- Harrington MA, Jr., Keller TS, Seiler JG, 3rd, Weikert DR, Moeljanto E, Schwartz HS.** Geometric properties and the predicted mechanical behavior of adult human clavicles. *J Biomech.* 1993; 26: 417-426.
- Havet E, Duparc F, Tobenas-Dujardin AC, Muller JM, Delas B, Freger P.** Vascular anatomical basis of clavicular non-union. *Surg Radiol Anat.* 2008; 30: 23-28.
- Heers G, Hedtmann A.** Correlation of ultrasonographic findings to Tossy's and Rockwood's classification of acromioclavicular joint injuries. *Ultrasound Med Biol.* 2005; 31: 725-732.
- Hegemann S, Kleining R, Schindler HG, Holthusen H.** Kirschner wire migration in the contralateral lung after osteosynthesis of a clavicular fracture. *Unfallchirurg.* 2005; 108: 991-993.
- Hill JM, McGuire MH, Crosby LA.** Closed treatment of displaced middle-third fractures of the clavicle gives poor results. *J Bone Joint Surg Br.* 1997; 79: 537-539.
- Hillen RJ, Burger BJ, Poll RG, de Gast A, Robinson CM.** Malunion after midshaft clavicle fractures in adults. *Acta Orthop.* 2010; 81: 273-279.
- Hillen RJ, Burger BJ, Poll RG, van Dijk CN, Veeger DH.** The effect of experimental shortening of the clavicle on shoulder kinematics. *Clin Biomech (Bristol, Avon).* 2012; 27: 777-781.

- Hohmann E, Hansen T, Tetsworth K.** Treatment of Neer type II fractures of the lateral clavicle using distal radius locking plates combined with TightRope augmentation of the coraco-clavicular ligaments. *Arch Orthop Trauma Surg.* 2012; 132: 1415-1421.
- Hoofwijk AG, van der Werken C.** Conservative treatment of clavicular fractures. *Z Unfallchir Versicherungsmed Berufskr.* 1988; 81: 151-156.
- Hosseini H, Friedmann S, Troger M, Lobenhoffer P, Agneskirchner JD.** Arthroscopic reconstruction of chronic AC joint dislocations by transposition of the coracoacromial ligament augmented by the Tight Rope device: a technical note. *Knee Surg Sports Traumatol Arthrosc.* 2009; 17: 92-97.
- Howard FM, Shafer SJ.** Injuries to the clavicle with neurovascular complications. A study of fourteen cases. *J Bone Joint Surg Am.* 1965; 47(7): 1335-1346.
- Hsu TL, Hsu SK, Chen HM, Wang ST.** Comparison of hook plate and tension band wire in the treatment of distal clavicle fractures. *Orthopedics.* 2010; 33: 879.
- Huang JI, Toogood P, Chen MR, Wilber JH, Cooperman DR.** Clavicular anatomy and the applicability of precontoured plates. *J Bone Joint Surg Am.* 2007; 89: 2260-2265.
- Huttunen TT, Kannus P, Lepola V, Pihlajamaki H, Mattila VM.** Surgical treatment of clavicular fractures in Finland - A register based study between 1987 and 2010. *Injury.* 2013; 44: 1899-1903.
- Imatani RJ, Hanlon JJ, Cady GW.** Acute, complete acromioclavicular separation. *J Bone Joint Surg Am.* 1975; 57(3): 328-332.
- Inman VT, Saunders JB.** Observations on the Function of the Clavicle. *Calif Med.* 1946; 65: 158-166.
- Izadpanah K, Weitzel E, Honal M, Winterer J, Vicari M, Maier D, Jaeger M, Kotter E, Hennig J, Weigel M, Sudkamp NP.** In vivo analysis of coracoclavicular ligament kinematics during shoulder abduction. *Am J Sports Med.* 2012; 40: 185-192.
- Jeray KJ.** Acute midshaft clavicular fracture. *J Am Acad Orthop Surg.* 2007; 15: 239-248.
- Jit I, Kulkarni M.** Times of appearance and fusion of epiphysis at the medial end of the clavicle. *Indian J Med Res.* 1976; 64: 773-782.
- Johansen JA, Grutter PW, McFarland EG, Petersen SA.** Acromioclavicular joint injuries: indications for treatment and treatment options. *J Shoulder Elbow Surg.* 2011; 20: S70-82.

- Jones HP, Lemos MJ, Schepsis AA.** Salvage of failed acromioclavicular joint reconstruction using autogenous semitendinosus tendon from the knee. Surgical technique and case report. *Am J Sports Med.* 2001; 29: 234-237.
- Jubel A, Andermahr J, Prokop A, Lee JI, Schiffer G, Rehm KE.** Treatment of mid-clavicular fractures in adults. Early results after rucksack bandage or elastic stable intramedullary nailing. *Unfallchirurg.* 2005; 108: 707-714.
- Judd DB, Pallis MP, Smith E, Bottoni CR.** Acute operative stabilization versus nonoperative management of clavicle fractures. *Am J Orthop (Belle Mead NJ).* 2009; 38: 341-345.
- Kagaya M, Ogihara N, Nakatsukasa M.** Is the clavicle of apes long? An investigation of clavicular length in relation to body mass and upper thoracic width. *Int J Primatol.* 2010; 31: 209-217.
- Kardong K.** *Vertebrates Comparative Anatomy, Function, Evolution.* New York: McGraw-Hill; 2012. p. 184.
- Kennell LA.** Simple Bandage for Fracture of the Clavicle. *Ann Surg.* 1919; 70: 506-508.
- Khan LA, Bradnock TJ, Scott C, Robinson CM.** Fractures of the clavicle. *J Bone Joint Surg Am.* 2009; 91: 447-460.
- Kim AC, Matcuk G, Patel D, Itamura J, Forrester D, White E, Gottsegen CJ.** Acromioclavicular joint injuries and reconstructions: a review of expected imaging findings and potential complications. *Emerg Radiol.* 2012a; 19: 399-413.
- Kim KC, Shin HD, Cha SM.** Surgical treatment of displaced medial clavicle fractures using a small T-shaped plate and tension band sutures. *Arch Orthop Trauma Surg.* 2011; 131: 1673-1676.
- Kim SH, Lee YH, Shin SH, Baek GH.** Outcome of conjoined tendon and coracoacromial ligament transfer for the treatment of chronic type V acromioclavicular joint separation. *Injury.* 2012b; 43: 213-218.
- Klimkiewicz JJ, Williams GR, Sher JS, Karduna A, Des Jardins J, Iannotti JP.** The acromioclavicular capsule as a restraint to posterior translation of the clavicle: a biomechanical analysis. *J Shoulder Elbow Surg.* 1999; 8: 119-124.
- Knudsen FW, Andersen M, Krag C.** The arterial supply of the clavicle. *Surg Radiol Anat.* 1989; 11: 211-214.

- Koch HJ, Raschka C, Tonus C, Witzel K.** The intramedullary osteosynthesis of the diaphyseal fracture of the clavicle compared to conservative treatment. *Dtsch Z Sportmed.* 2008; 59: 91-94.
- Koch MJ, Wells L.** Proximal clavicle physeal fracture with posterior displacement: diagnosis, treatment, and prevention. *Orthopedics.* 2012; 35: e108-111.
- Krishnan SG, Schiffen SC, Pennington SD, Rimlawi M, Burkhead WZ, Jr.** Functional outcomes after total claviclectomy as a salvage procedure. A series of six cases. *J Bone Joint Surg Am.* 2007; 89: 1215-1219.
- Kulshrestha V, Roy T, Audige L.** Operative versus nonoperative management of displaced midshaft clavicle fractures: a prospective cohort study. *J Orthop Trauma.* 2011; 25: 31-38.
- Larsen E, Hede A.** Treatment of acute acromioclavicular dislocation. Three different methods of treatment prospectively studied. *Acta Orthop Belg.* 1987; 53: 480-484.
- Larsen E, Bjerg-Nielsen A, Christensen P.** Conservative or surgical treatment of acromioclavicular dislocation. A prospective, controlled, randomized study. *J Bone Joint Surg Am.* 1986; 68(4): 552-555.
- Larson SG.** Parallel evolution in the Hominoid trunk and forelimb. *Evol Anthropol.* 1998; 6: 87-99.
- Law KY, Yung SH, Ho PY, Chang HT, Chan KM.** Coracoclavicular ligament reconstruction using a gracilis tendon graft for acute type-III acromioclavicular dislocation. *J Orthop Surg (Hong Kong).* 2007; 15: 315-318.
- Lazarides S, Zafiropoulos G.** Conservative treatment of fractures at the middle third of the clavicle: the relevance of shortening and clinical outcome. *J Shoulder Elbow Surg.* 2006; 15: 191-194.
- Ledger M, Leeks N, Ackland T, Wang A.** Short malunions of the clavicle: an anatomic and functional study. *J Shoulder Elbow Surg.* 2005; 14: 349-354.
- Lee KW, Lee SK, Kim KJ, Kim YI, Kwon WC, Choy WS.** Arthroscopic-assisted locking compression plate clavicular hook fixation for unstable fractures of the lateral end of the clavicle: a prospective study. *Int Orthop.* 2010; 34: 839-845.
- Lee SK, Lee JW, Song DG, Choy WS.** Precontoured locking plate fixation for displaced lateral clavicle fractures. *Orthopedics.* 2013; 36: 801-807.
- Lee YS, Lin CC, Huang CR, Chen CN, Liao WY.** Operative treatment of midclavicular fractures in 62 elderly patients: knowles pin versus plate. *Orthopedics.* 2007; 30: 959-964.

- Lee YS, Huang HL, Lo TY, Hsieh YF, Huang CR.** Surgical treatment of midclavicular fractures: a prospective comparison of Knowles pinning and plate fixation. *Int Orthop.* 2008; 32: 541-545.
- Leidel BA, Braunstein V, Kirchoff C, Pilotto S, Mutschler W, Biberthaler P.** Consistency of long-term outcome of acute Rockwood grade III acromioclavicular joint separations after K-wire transfixation. *J Trauma.* 2009; 66: 1666-1671.
- Lemos MJ.** The evaluation and treatment of the injured acromioclavicular joint in athletes. *Am J Sports Med.* 1998; 26: 137-144.
- Lenza M, Belloti JC, Andriolo RB, Gomes Dos Santos JB, Faloppa F.** Conservative interventions for treating middle third clavicle fractures in adolescents and adults. *Cochrane Database Syst Rev.* 2009a: CD007121.
- Lenza M, Belloti JC, Gomes Dos Santos JB, Matsumoto MH, Faloppa F.** Surgical interventions for treating acute fractures or non-union of the middle third of the clavicle. *Cochrane Database Syst Rev.* 2009b: CD007428.
- Lenza M, Buchbinder R, Johnston RV, Belloti JC, Faloppa F.** Surgical versus conservative interventions for treating fractures of the middle third of the clavicle. *Cochrane Database Syst Rev.* 2013; 6: CD009363.
- Leppilahti J, Jalovaara P.** Migration of Kirschner wires following fixation of the clavicle--a report of 2 cases. *Acta Orthop Scand.* 1999; 70: 517-519.
- Lester CW.** The Treatment of Fractures of the Clavicle: A Study of 422 Cases Observed in the out-Patient Department of the Roosevelt Hospital of the City of New York. *Ann Surg.* 1929; 89: 600-606.
- Li J, Wang Z, Fu J, Shi L, Pei G, Guo Z.** Surgical treatment of clavicular malignancies. *J Shoulder Elbow Surg.* 2011; 20: 295-300.
- Li M, Wang B, Zhang Q, Chen W, Li ZY, Qin SJ, Zhang YZ.** Imageological measurement of the sternoclavicular joint and its clinical application. *Chin Med J (Engl).* 2012; 125: 230-235.
- Lin WC, Wu CC, Su CY, Fan KF, Tseng IC, Chiu YL.** Surgical treatment of acute complete acromioclavicular dislocation: comparison of coracoclavicular screw fixation supplemented with tension band wiring or ligament transfer. *Chang Gung Med J.* 2006; 29: 182-189.

- Liu HH, Chang CH, Chia WT, Chen CH, Tarng YW, Wong CY.** Comparison of plates versus intramedullary nails for fixation of displaced midshaft clavicular fractures. *J Trauma*. 2010a; 69: E82-87.
- Liu PC, Chien SH, Chen JC, Hsieh CH, Chou PH, Lu CC.** Minimally invasive fixation of displaced midclavicular fractures with titanium elastic nails. *J Orthop Trauma*. 2010b; 24: 217-223.
- Liu Q, Miao J, Lin B, Guo Z.** Clinical effect of acute complete acromioclavicular joint dislocation treated with micro-movable and anatomical acromioclavicular plate. *Int J Med Sci*. 2012; 9: 725-729.
- Lizaur A, Marco L, Cebrian R.** Acute dislocation of the acromioclavicular joint. Traumatic anatomy and the importance of deltoid and trapezius. *J Bone Joint Surg Br*. 1994; 76: 602-606.
- Lizaur A, Sanz-Reig J, Gonzalez-Parreno S.** Long-term results of the surgical treatment of type III acromioclavicular dislocations: an update of a previous report. *J Bone Joint Surg Br*. 2011; 93: 1088-1092.
- Ljunggren AE.** Clavicular function. *Acta Orthop Scand*. 1979; 50: 261-268.
- Loke YK, Price D, Herxheimer A.** Chapter 14: Adverse effects. In: *Cochrane Handbook for Systematic Reviews of Interventions Version 5.1.0. [updated March 2011]. The Cochrane Collaboration.* (Ed Higgins JPT, Green S); 2011.
- Low AK, Duckworth DG, Bokor DJ.** Operative outcome of displaced medial-end clavicle fractures in adults. *J Shoulder Elbow Surg*. 2008; 17: 751-754.
- Ludewig PM, Phadke V, Braman JP, Hassett DR, Cieminski CJ, LaPrade RF.** Motion of the shoulder complex during multiplanar humeral elevation. *J Bone Joint Surg Am*. 2009; 91: 378-389.
- Lyons FA, Rockwood CA, Jr.** Migration of pins used in operations on the shoulder. *J Bone Joint Surg Am*. 1990; 72(8): 1262-1267.
- Maier D, Jaeger M, Izadpanah K, Bornebusch L, Sudkamp NP.** Traumatic injuries of the sternoclavicular joint. *Unfallchirurg*. 2011; 114: 611-621; quiz 622-613.
- Mall FP.** On ossification centers in human embryos less than one hundred days old. *Am J Anat*. 1906; 5: 433-458.
- Marchi E, Reis MP, Carvalho MV.** Transmediastinal migration of Kirschner wire. *Interact Cardiovasc Thorac Surg*. 2008; 7: 869-870.

- Mardani-Kivi M, Mirbolook A, Salariyeh M, Hashemi-Motlagh K, Saheb-Ekhtiari K.** The comparison of Ethibond sutures and semitendinosus autograft in the surgical treatment of acromioclavicular dislocation. *Acta Orthop Traumatol Turc.* 2013; 47: 307-310.
- Martetschlager F, Horan MP, Warth RJ, Millett PJ.** Complications after anatomic fixation and reconstruction of the coracoclavicular ligaments. *Am J Sports Med.* 2013; 41: 2896-2903.
- Mazzocca AD, Arciero RA, Bicos J.** Evaluation and treatment of acromioclavicular joint injuries. *Am J Sports Med.* 2007; 35: 316-329.
- McConnell AJ, Yoo DJ, Zdero R, Schemitsch EH, McKee MD.** Methods of operative fixation of the acromio-clavicular joint: a biomechanical comparison. *J Orthop Trauma.* 2007; 21: 248-253.
- McKee MD, Wild LM, Schemitsch EH.** Midshaft malunions of the clavicle. *J Bone Joint Surg Am.* 2003; 85-A: 790-797.
- McKee RC, Whelan DB, Schemitsch EH, McKee MD.** Operative versus nonoperative care of displaced midshaft clavicular fractures: a meta-analysis of randomized clinical trials. *J Bone Joint Surg Am.* 2012; 94: 675-684.
- Meda PV, Machani B, Sinopidis C, Braithwaite I, Brownson P, Frostick SP.** Clavicular hook plate for lateral end fractures:- a prospective study. *Injury.* 2006; 37: 277-283.
- Melenevsky Y, Yablon CM, Ramappa A, Hochman MG.** Clavicle and acromioclavicular joint injuries: a review of imaging, treatment, and complications. *Skeletal Radiol.* 2011; 40: 831-842.
- Millett PJ, Hurst JM, Horan MP, Hawkins RJ.** Complications of clavicle fractures treated with intramedullary fixation. *J Shoulder Elbow Surg.* 2011; 20: 86-91.
- Mirzatlooei F.** Comparison between operative and nonoperative treatment methods in the management of comminuted fractures of the clavicle. *Acta Orthop Traumatol Turc.* 2011; 45: 34-40.
- Mouhsine E, Garofalo R, Crevoisier X, Farron A.** Grade I and II acromioclavicular dislocations: results of conservative treatment. *J Shoulder Elbow Surg.* 2003; 12: 599-602.
- Mulier T, Stuyck J, Fabry G.** Conservative treatment of acromioclavicular dislocation. Evaluation of functional and radiological results after six years follow-up. *Acta Orthop Belg.* 1993; 59: 255-262.

- Murlimanju BV, Prabhu LV, Pai MM, Yadav A, Dhananjaya KV, Prashanth KU.** Neurovascular foramina of the human clavicle and their clinical significance. *Surg Radiol Anat.* 2011; 33: 679-682.
- Murray IR, Foster CJ, Eros A, Robinson CM.** Risk factors for nonunion after nonoperative treatment of displaced midshaft fractures of the clavicle. *J Bone Joint Surg Am.* 2013; 95: 1153-1158.
- Nadarajah R, Mahaluxmivala J, Amin A, Goodier DW.** Clavicular hook-plate: complications of retaining the implant. *Injury.* 2005; 36: 681-683.
- Nakayama E, Tanaka T, Noguchi T, Yasuda J, Terada Y.** Tracheal stenosis caused by retrosternal dislocation of the right clavicle. *Ann Thorac Surg.* 2007; 83: 685-687.
- Neer CS, 2nd.** Fracture of the distal clavicle with detachment of the coracoclavicular ligaments in adults. *J Trauma.* 1963; 3: 99-110.
- Neer CS, 2nd.** Fractures of the distal third of the clavicle. *Clin Orthop Relat Res.* 1968; 58: 43-50.
- Nettles JL, Linscheid RL.** Sternoclavicular dislocations. *J Trauma.* 1968; 8: 158-164.
- Nicoll EA.** Miners and mannequins. *J Bone Joint Surg Br.* 1954; 36-B: 171-172.
- Nordqvist A, Petersson C.** The incidence of fractures of the clavicle. *Clin Orthop Relat Res.* 1994: 127-132.
- Nordqvist A, Petersson CJ.** Incidence and causes of shoulder girdle injuries in an urban population. *J Shoulder Elbow Surg.* 1995; 4: 107-112.
- Nordqvist A, Petersson C, Redlund-Johnell I.** The natural course of lateral clavicle fracture. 15 (11-21) year follow-up of 110 cases. *Acta Orthop Scand.* 1993; 64: 87-91.
- Nordqvist A, Redlund-Johnell I, von Scheele A, Petersson CJ.** Shortening of clavicle after fracture. Incidence and clinical significance, a 5-year follow-up of 85 patients. *Acta Orthop Scand.* 1997; 68: 349-351.
- Norrell H, Jr., Llewellyn RC.** Migration of a Threaded Steinmann Pin from an Acromioclavicular Joint into the Spinal Canal. A Case Report. *J Bone Joint Surg Am.* 1965; 47(5): 1024-1026.
- Nourissat G, Kakuda C, Dumontier C, Sautet A, Doursounian L.** Arthroscopic stabilization of Neer type 2 fracture of the distal part of the clavicle. *Arthroscopy.* 2007; 23: 674, e671-674.

- Nowak J, Mallmin H, Larsson S.** The aetiology and epidemiology of clavicular fractures. A prospective study during a two-year period in Uppsala, Sweden. *Injury*. 2000; 31: 353-358.
- Nowak J, Holgersson M, Larsson S.** Can we predict long-term sequelae after fractures of the clavicle based on initial findings? A prospective study with nine to ten years of follow-up. *J Shoulder Elbow Surg*. 2004; 13: 479-486.
- Nuber GW, Bowen MK.** Acromioclavicular Joint Injuries and Distal Clavicle Fractures. *J Am Acad Orthop Surg*. 1997; 5: 11-18.
- Nuchtern JV, Sellenschloh K, Bishop N, Jauch S, Briem D, Hoffmann M, Lehmann W, Pueschel K, Morlock MM, Rueger JM, Grossterlinden LG.** Biomechanical evaluation of 3 stabilization methods on acromioclavicular joint dislocations. *Am J Sports Med*. 2013; 41: 1387-1394.
- Ogden JA, Conlogue GJ, Bronson ML.** Radiology of postnatal skeletal development. III. The clavicle. *Skeletal Radiol*. 1979; 4: 196-203.
- Oh JH, Kim SH, Lee JH, Shin SH, Gong HS.** Treatment of distal clavicle fracture: a systematic review of treatment modalities in 425 fractures. *Arch Orthop Trauma Surg*. 2011; 131: 525-533.
- Oheim R, Schulz AP, Schoop R, Grimme CH, Gille J, Gerlach UJ.** Medium-term results after total clavicle resection in cases of osteitis: a consecutive case series of five patients. *Int Orthop*. 2012; 36: 775-781.
- Orsini B, Amabile P, Bal L, Piquet P.** Management of an aorto-esophageal fistula caused by Kirschner wire migration in a patient with arteria lusoria. *J Thorac Cardiovasc Surg*. 2012; 144: e25-27.
- Pai HT, Lee YS, Cheng CY.** Surgical treatment of midclavicular fractures in the elderly: a comparison of locking and nonlocking plates. *Orthopedics*. 2009; 32.
- Parsons FG.** On the Proportions and Characteristics of the Modern English Clavicle. *J Anat*. 1916; 51: 71-93.
- Partal G, Meyers KN, Sama N, Pagenkopf E, Lewis PB, Goldman A, Wright TM, Helfet DL.** Superior versus anteroinferior plating of the clavicle revisited: a mechanical study. *J Orthop Trauma*. 2010; 24: 420-425.
- Patel B, Gustafson PA, Jastifer J.** The effect of clavicle malunion on shoulder biomechanics; a computational study. *Clin Biomech (Bristol, Avon)*. 2012; 27: 436-442.

- Penn I.** The Vascular Complications of Fractures of the Clavicle. *J Trauma*. 1964; 4: 819-831.
- Petersen W, Wellmann M, Rosslenbroich S, Zantop T.** [Minimally Invasive Acromioclavicular Joint Reconstruction (MINAR)]. *Oper Orthop Traumatol*. 2010; 22: 52-61.
- Pollock RC, Bankes MJ, Emery RJ.** Diagnosis of retrosternal dislocation of the clavicle with ultrasound. *Injury*. 1996; 27: 670-671.
- Postacchini F, Gumina S, De Santis P, Albo F.** Epidemiology of clavicle fractures. *J Shoulder Elbow Surg*. 2002; 11: 452-456.
- Postacchini R, Gumina S, Farsetti P, Postacchini F.** Long-term results of conservative management of midshaft clavicle fracture. *Int Orthop*. 2010; 34: 731-736.
- Preuschhoff H, Schmidt M, Hayama S, Okada M.** The influence of three-dimensional movements of the forelimb on the shape of the thorax and its importance for erect body posture. *Courier Forschungsinstitut Senckenberg*. 2003; 243: 9-24.
- Preuschhoff H, Hohn B, Scherf H, Schmidt M, Krause C, Witzel U.** Functional Analysis of the Primate Shoulder. *Int J Primatol*. 2010; 31: 301-320.
- Ranne JO, Sarimo JJ, Rawlins MI, Heinonen OJ, Orava SY.** All-arthroscopic double-bundle coracoclavicular ligament reconstruction using autogenous semitendinosus graft: a new technique. *Arthrosc Tech*. 2012; 1: e11-14.
- Rasmussen JV, Jensen SL, Petersen JB, Falstie-Jensen T, Lausten G, Olsen BS.** A retrospective study of the association between shortening of the clavicle after fracture and the clinical outcome in 136 patients. *Injury*. 2011; 42: 414-417.
- Rawes ML, Dias JJ.** Long-term results of conservative treatment for acromioclavicular dislocation. *J Bone Joint Surg Br*. 1996; 78: 410-412.
- Rehn CH, Kirkegaard M, Viberg B, Larsen MS.** Operative versus nonoperative treatment of displaced midshaft clavicle fractures in adults: a systematic review. *Eur J Orthop Surg Traumatol*. 2013.
- Renfree KJ, Riley MK, Wheeler D, Hentz JG, Wright TW.** Ligamentous anatomy of the distal clavicle. *J Shoulder Elbow Surg*. 2003; 12: 355-359.
- Restrepo CS, Martinez S, Lemos DF, Washington L, McAdams HP, Vargas D, Lemos JA, Carrillo JA, Diethelm L.** Imaging appearances of the sternum and sternoclavicular joints. *Radiographics*. 2009; 29: 839-859.

- Robinson CM.** Fractures of the clavicle in the adult. Epidemiology and classification. *J Bone Joint Surg Br.* 1998; 80: 476-484.
- Robinson CM, Court-Brown CM, McQueen MM, Wakefield AE.** Estimating the risk of nonunion following nonoperative treatment of a clavicular fracture. *J Bone Joint Surg Am.* 2004; 86-A: 1359-1365.
- Robinson CM, Goudie EB, Murray IR, Jenkins PJ, Ahktar MA, Read EO, Foster CJ, Clark K, Brooksbank AJ, Arthur A, Crowther MA, Packham I, Chesser TJ.** Open reduction and plate fixation versus nonoperative treatment for displaced midshaft clavicular fractures: a multicenter, randomized, controlled trial. *J Bone Joint Surg Am.* 2013; 95: 1576-1584.
- Rockwood CA.** Dislocations of the sternoclavicular joint. *In: American Academy of Orthopaedic Surgeons Instructional Course Lectures.* (Ed Evans E). St Louis; 1975. p. 144-159.
- Rockwood CA, Jr.** Injuries to the AC joint. *In: Fractures in Adults.* Philadelphia, PA: JB Lippincott; 1984. p. 860-910.
- Rockwood CA, Jr., Green DP.** Fractures. Philadelphia: J.B. Lippincott Company; 1975. p. 611.
- Rokito AS, Zuckerman JD, Shaari JM, Eisenberg DP, Cuomo F, Gallagher MA.** A comparison of nonoperative and operative treatment of type II distal clavicle fractures. *Bull Hosp Jt Dis.* 2002; 61: 32-39.
- Rolf O, Hann von Weyhern A, Ewers A, Boehm TD, Gohlke F.** Acromioclavicular dislocation Rockwood III-V: results of early versus delayed surgical treatment. *Arch Orthop Trauma Surg.* 2008; 128: 1153-1157.
- Royster HA.** The Barrel-Staff Splint in Fracture of the Clavicle. *Ann Surg.* 1919; 70: 474-475.
- Sahara W, Sugamoto K, Murai M, Yoshikawa H.** Three-dimensional clavicular and acromioclavicular rotations during arm abduction using vertically open MRI. *J Orthop Res.* 2007; 25: 1243-1249.
- Salem KH, Schmelz A.** Treatment of Tossy III acromioclavicular joint injuries using hook plates and ligament suture. *J Orthop Trauma.* 2009; 23: 565-569.
- Salgado RA, Ghysen D.** Post-traumatic posterior sternoclavicular dislocation: case report and review of the literature. *Emerg Radiol.* 2002; 9: 323-325.

- Salvatore JE.** Sternoclavicular joint dislocation. *Clin Orthop Relat Res.* 1968; 58: 51-55.
- Salzmann GM, Paul J, Sandmann GH, Imhoff AB, Schottle PB.** The coracoidal insertion of the coracoclavicular ligaments: an anatomic study. *Am J Sports Med.* 2008; 36: 2392-2397.
- Salzmann GM, Walz L, Buchmann S, Glabgly P, Venjakob A, Imhoff AB.** Arthroscopically assisted 2-bundle anatomical reduction of acute acromioclavicular joint separations. *Am J Sports Med.* 2010; 38: 1179-1187.
- Schaefer FK, Schaefer PJ, Brossmann J, Hilgert RE, Heller M, Jahnke T.** Experimental and clinical evaluation of acromioclavicular joint structures with new scan orientations in MRI. *Eur Radiol.* 2006; 16: 1488-1493.
- Schlegel TF, Burks RT, Marcus RL, Dunn HK.** A prospective evaluation of untreated acute grade III acromioclavicular separations. *Am J Sports Med.* 2001; 29: 699-703.
- Schliemann B, Rosslenbroich SB, Schneider KN, Petersen W, Raschke MJ, Weimann A.** Surgical treatment of vertically unstable lateral clavicle fractures (Neer 2b) with locked plate fixation and coracoclavicular ligament reconstruction. *Arch Orthop Trauma Surg.* 2013; 133: 935-939.
- Schultz AH.** Skeleton of the trunk and limbs of the higher primates. *Hum Biol.* 1930; 2: 303-438.
- Sethi GK, Scott SM.** Subclavian artery laceration due to migration of a Hagie pin. *Surgery.* 1976; 80: 644-646.
- Sharr JR, Mohammed KD.** Optimizing the radiographic technique in clavicular fractures. *J Shoulder Elbow Surg.* 2003; 12: 170-172.
- Shen JW, Tong PJ, Qu HB.** A three-dimensional reconstruction plate for displaced midshaft fractures of the clavicle. *J Bone Joint Surg Br.* 2008; 90: 1495-1498.
- Singer G, Ferlic P, Kraus T, Eberl R.** Reconstruction of the sternoclavicular joint in active patients with the figure-of-eight technique using hamstrings. *J Shoulder Elbow Surg.* 2013; 22: 64-69.
- Smekal V, Irenberger A, Struve P, Wambacher M, Krappinger D, Kralinger FS.** Elastic stable intramedullary nailing versus nonoperative treatment of displaced midshaft clavicular fractures-a randomized, controlled, clinical trial. *J Orthop Trauma.* 2009; 23: 106-112.
- Smekal V, Irenberger A, El Attal R, Oberladstaetter J, Krappinger D, Kralinger F.** Elastic stable intramedullary nailing is best for mid-shaft clavicular fractures without comminution: results in 60 patients. *Injury.* 2011; 42: 324-329.

- Sood A, Wallwork N, Bain GI.** Clinical results of coracoacromial ligament transfer in acromioclavicular dislocations: A review of published literature. *Int J Shoulder Surg.* 2008; 2: 13-21.
- Spencer EE, Kuhn JE, Huston LJ, Carpenter JE, Hughes RE.** Ligamentous restraints to anterior and posterior translation of the sternoclavicular joint. *J Shoulder Elbow Surg.* 2002; 11: 43-47.
- Stegeman SA, Nacak H, Huvenaars KH, Stijnen T, Krijnen P, Schipper IB.** Surgical treatment of Neer type-II fractures of the distal clavicle: a meta-analysis. *Acta Orthop.* 2013; 84: 184-190.
- Stevenson PH.** Age order of epiphyseal union in man. *Am J Phys Anthropol.* 1924; 7: 53-93.
- Takase K.** The coracoclavicular ligaments: an anatomic study. *Surg Radiol Anat.* 2010; 32: 683-688.
- Takase K, Kono R, Yamamoto K.** Arthroscopic stabilization for Neer type 2 fracture of the distal clavicle fracture. *Arch Orthop Trauma Surg.* 2012; 132: 399-403.
- Tarng YW, Yang SW, Fang YP, Hsu CJ.** Surgical management of uncomplicated midshaft clavicle fractures: a comparison between titanium elastic nails and small reconstruction plates. *J Shoulder Elbow Surg.* 2012; 21: 732-740.
- Tauber M, Eppel M, Resch H.** Acromioclavicular reconstruction using autogenous semitendinosus tendon graft: results of revision surgery in chronic cases. *J Shoulder Elbow Surg.* 2007; 16: 429-433.
- Tauber M, Gordon K, Koller H, Fox M, Resch H.** Semitendinosus tendon graft versus a modified Weaver-Dunn procedure for acromioclavicular joint reconstruction in chronic cases: a prospective comparative study. *Am J Sports Med.* 2009; 37: 181-190.
- Taylor HN.** Operative Interference in Fractured Clavicle. *Br Med J.* 1905; 2: 1327.
- Terry GC, Chopp TM.** Functional anatomy of the shoulder. *J Athl Train.* 2000; 35(3): 248-255.
- Terry RJ.** The clavicle of the American Negro. *Am J Phys Anthropol.* 1932; 16: 351-377.
- Throckmorton T, Kuhn JE.** Fractures of the medial end of the clavicle. *J Shoulder Elbow Surg.* 2007; 16: 49-54.
- Thut D, Hergan D, Dukas A, Day M, Sherman OH.** Sternoclavicular joint reconstruction--a systematic review. *Bull NYU Hosp Jt Dis.* 2011; 69: 128-135.

- Tillmann B.** Anatomie des Menschen: Mediales schlüsselbeingelenk, Articulatio sternoclavicularis. 3rd ed. Thieme: Stuttgart 2003: 338-339.
- Tiren D, Vroemen JP.** Superior clavicle plate with lateral extension for displaced lateral clavicle fractures: a prospective study. *J Orthop Traumatol.* 2013; 14: 115-120.
- Todd TW, D'Errico JJ.** The clavicular epiphyses. *Am J Anat.* 1928; 41: 25-50.
- Tossy JD, Mead NC, Sigmond HM.** Acromioclavicular separations: useful and practical classification for treatment. *Clin Orthop Relat Res.* 1963; 28: 111-119.
- Tran de QH, Tiyaprasertkul W, Gonzalez AP.** Analgesia for clavicular fracture and surgery: a call for evidence. *Reg Anesth Pain Med.* 2013; 38: 539-543.
- Trotter S.** The significance of the "collar bone" in the Mammalia. *Am Nat.* 1885; 19 (12): 1172-1177.
- Tubbs RS, Loukas M, Slappey JB, McEvoy WC, Linganna S, Shoja MM, Oakes WJ.** Surgical and clinical anatomy of the interclavicular ligament. *Surg Radiol Anat.* 2007; 29: 357-360.
- Urist MR.** Complete dislocations of the acromioclavicular joint; the nature of the traumatic lesion and effective methods of treatment with an analysis of forty-one cases. *J Bone Joint Surg Am.* 1946; 28: 813-837.
- van der Meijden OA, Gaskill TR, Millett PJ.** Treatment of clavicle fractures: current concepts review. *J Shoulder Elbow Surg.* 2012; 21: 423-429.
- van Tongel A, MacDonald P, Leiter J, Pouliart N, Peeler J.** A cadaveric study of the structural anatomy of the sternoclavicular joint. *Clin Anat.* 2012; 25: 903-910.
- Wang J, Huang X, Lai C, Jiang K.** Clinical spectrum of cleidocranial dysplasia in a family with twins. *Pediatr Int.* 2013; 55: 392-395.
- Warren-Smith CD, Ward MW.** Operation for acromioclavicular dislocation. A review of 29 cases treated by one method. *J Bone Joint Surg Br.* 1987; 69: 715-718.
- Waskowitz W.** Disruption of the sternoclavicular joint: an analysis and review. *Am J Orthop.* 1961; 3: 176-179.
- Weaver JK, Dunn HK.** Treatment of acromioclavicular injuries, especially complete acromioclavicular separation. *J Bone Joint Surg Am.* 1972; 54(6): 1187-1194.
- Weinstein DM, McCann PD, McIlveen SJ, Flatow EL, Bigliani LU.** Surgical treatment of complete acromioclavicular dislocations. *Am J Sports Med.* 1995; 23: 324-331.

- Wenninger JJ, Jr., Dannenbaum JH, Branstetter JG, Arrington ED.** Comparison of complication rates of intramedullary pin fixation versus plating of midshaft clavicle fractures in an active duty military population. *J Surg Orthop Adv.* 2013; 22: 77-81.
- Wessel RN, Schaap GR.** Outcome of total claviclectomy in six cases. *J Shoulder Elbow Surg.* 2007; 16: 312-315.
- Wheater PR, Burkitt H. G., Daniels, V.G.** *Functional Histology.* New York: Churchill Livingstone; 1987. p. 152-153.
- Wick M, Muller EJ, Kollig E, Muhr G.** Midshaft fractures of the clavicle with a shortening of more than 2 cm predispose to nonunion. *Arch Orthop Trauma Surg.* 2001; 121: 207-211.
- Wijeratna MD, Turmezei TD, Tytherleigh-Strong G.** Novel assessment of the sternoclavicular joint with computed tomography for planning interventional approach. *Skeletal Radiol.* 2013; 42: 473-478.
- Wirth MA, Rockwood CA, Jr.** Acute and Chronic Traumatic Injuries of the Sternoclavicular Joint. *J Am Acad Orthop Surg.* 1996; 4: 268-278.
- von Heideken J, Bostrom Windhamre H, Une-Larsson V, Ekelund A.** Acute surgical treatment of acromioclavicular dislocation type V with a hook plate: superiority to late reconstruction. *J Shoulder Elbow Surg.* 2013; 22: 9-17.
- Xu J, Xu L, Xu W, Gu Y.** Operative versus nonoperative treatment in the management of midshaft clavicular fractures: a meta-analysis of randomized controlled trials. *J Shoulder Elbow Surg.* 2014; 23: 173-181.
- Yap JJ, Curl LA, Kvitne RS, McFarland EG.** The value of weighted views of the acromioclavicular joint. Results of a survey. *Am J Sports Med.* 1999; 27: 806-809.
- Yoo JC, Ahn JH, Yoon JR, Yang JH.** Clinical results of single-tunnel coracoclavicular ligament reconstruction using autogenous semitendinosus tendon. *Am J Sports Med.* 2010; 38: 950-957.
- Zanca P.** Shoulder pain: involvement of the acromioclavicular joint. (Analysis of 1,000 cases). *Am J Roentgenol Radium Ther Nucl Med.* 1971; 112: 493-506.
- Zlowodzki M, Zelle BA, Cole PA, Jeray K, McKee MD.** Treatment of acute midshaft clavicle fractures: systematic review of 2144 fractures: on behalf of the Evidence-Based Orthopaedic Trauma Working Group. *J Orthop Trauma.* 2005; 19: 504-507.

ORIGINAL PUBLICATIONS

- I Virtanen KJ, Malmivaara AO, Remes VM, Paavola MP. Operative and nonoperative treatment of clavicle fractures in adults. A systematic review of 1 190 patients from the literature. *Acta Orthop*. 2012 Feb; 83(1):65-73.
- II Virtanen KJ, Remes V, Pajarinen J, Savolainen V, Björkenheim JM, Paavola M. Sling compared with plate osteosynthesis for treatment of displaced midshaft clavicular fractures: a randomized clinical trial. *J Bone Joint Surg Am*. 2012 Sep 5; 94(17):1546-1553.
- III Virtanen KJ, Remes VM, Tulikoura IT, Pajarinen JT, Savolainen VT, Björkenheim JM, Paavola MP. Surgical treatment of Rockwood grade-V acromioclavicular joint dislocations. 50 patients followed for 15-22 years. *Acta Orthop*. 2013 April; 84(2): 191-195.
- IV Virtanen KJ, Savolainen V, Tulikoura I, Remes V, Haapamäki V, Pajarinen J, Björkenheim JM, Paavola M. Surgical treatment of chronic acromioclavicular joint dislocation with autogenous tendon grafts. *Submitted*.