MEDICAL IMAGING—TECHNICAL ARTICLE

Dynamic assessment of sternoclavicular joint instability using four-dimensional computed tomography

Yin Peng Goh,[1] Ash Kamali Moaveni,[2] Gregory Hoy,[3,4] Julie Tate[1] and Andrew Rotstein[1]

1 Victoria House Medical Imaging, MIA Radiology, I-MED Radiology Network, Melbourne, Victoria, Australia
2 Department of surgery, Alfred Hospital, Monash University, Melbourne, Victoria, Australia
3 Melbourne Orthopaedic Group, Melbourne, Victoria, Australia
4 Department of Surgery, Monash University, Melbourne, Victoria, Australia

YP Goh MBBS, FRANZCR; **A Kamali Moaveni** MBChB, FRACS, FAOrthA, MPH; **G Hoy** FRACS, FAOrthA, FACSP; **J Tate** BSc (Hons), PgCert (CT); **A Rotstein** MBBS, FRANZCR.

Correspondence
Dr Yin Peng Goh, Victoria House Medical Imaging, MIA Radiology, I-MED Radiology Network, Brandon Business Park, Building 2, Level 3, 540 Springvale Road, Glen Waverley, Melbourne, Vic. 3150, Australia
Email: yinpeng.goh@gmail.com

Conflict of interest: The authors did not receive and will not receive any benefits or funding from any commercial party related directly or indirectly to the subject of this study

Submitted 8 September 2018; accepted 15 January 2019.

doi:10.1111/1754-9485.12862

Summary

Chronic post-traumatic sternoclavicular joint (SCJ) instability can be debilitating and result in restriction of normal daily activities. The diagnosis can be difficult to make clinically or with the use of static imaging modalities. Wide-volume dynamic four-dimensional computed tomography (4D CT) can confidently diagnose chronic post-traumatic SCJ instability. This can aid surgeons in pre-operative planning and help to triage patients into surgical or non-surgical candidates. We propose that 4D CT to be a routine pre-operative imaging in patients with chronic post-traumatic SCJ instability.

Key words: computed tomography; dynamic; instability; post-traumatic; sternoclavicular joint.

Introduction

Traumatic injuries to the sternoclavicular joint (SCJ) are rare, accounting for less than 3% of all traumatic joint injuries,[1] owing to the presence of strong ligamentous stabilizers.[2,3] It usually requires a high-energy vector to disrupt the ligaments to result in SCJ subluxation or dislocation. The commonest causes of traumatic SCJ injury include motor vehicle accidents and contact sports. On imaging, standard AP radiographs and 'serendipity view' are traditionally performed to confirm the diagnosis of dislocation.[4] CT angiogram may be performed in patients with suspected SCJ dislocation due to its close proximity to the adjacent vessels and the potential for mediastinal compression and fatal vascular injuries (Fig. 1).

Post-traumatic chronic SCJ instability can result in severe pain, instability and scapular dyskinesia,[3] causing restriction of normal daily, leisure and sports activities. Clinically, there may or may not be a persistent prominence over the SCJ, therefore making SCJ instability a difficult diagnosis based on clinical examination.

Wide-volume dynamic four-dimensional computed tomography (4D CT) allows us to perform functional three-dimensional (3D) evaluation of SCJ in real time. Dynamic 4D CT allows us to confidently diagnose SCJ instability, therefore guiding surgical approach. To our knowledge, this is the first case series reporting the use of 4D CT in guiding management of chronic post-traumatic SCJ instability. We propose that 4D CT to be a routine pre-operative imaging in patients with chronic post-traumatic SCJ instability.

Technique

All 4D CT scans of the SCJ were performed using 320 × 0.5 mm multi-detector computed tomography (Aquilion One Toshiba Medical Systems, Otawara-shi, Tochigi-ken, Japan) with 16 cm of z-axis coverage. The

Journal of Medical Imaging and Radiation Oncology

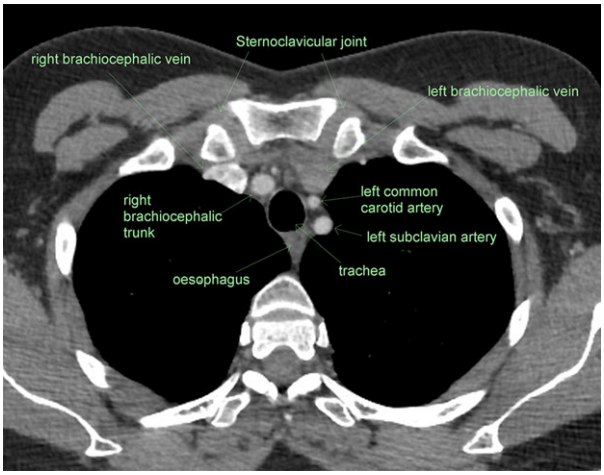

Fig. 1. Post contrast axial CT scan in a 23-year-old female demonstrating the anatomical relationship between the sternoclavicular joints and the major vessels in the mediastinum.

low-dose scan parameters used in the 4D dynamic acquisition were 120 kVp (peak), 60 mA and rotation time of 350 milliseconds (ms), yielding 2.8 volumes of data per second. No table movement was necessary. Two of our three patients had static CT performed prior to 4D CT. The static CTs were acquired using 135 kVp, automatic exposure control, 0.5 mm slice thickness, 0.5 mm slice interval over 10 cm z-axis coverage. The authors have obtained written informed consent from all the patients for print and electronic publication of the case series.

Initial radiologist consultation was performed to ascertain the joint motions (scapular retraction/protraction or shoulder elevation/depression) that reproduced the patients' symptoms, such as pain, clicking or instability. The patients were coached by the imaging technologist to perform these motions in a slow and smooth motion to minimize motion artefact. The patients were scanned in a prone position with a cushion under their chest to allow free motion of both scapulae and SCJs. Continuous gantry rotation was performed with joint movement in real time using a low-dose protocol.

2D axial and coronal images of the 4D CT of both SCJs were reconstructed and displayed over time in cine mode, showing motion at each specific point of the joint. 3D images of the SCJ were reconstructed using a volume-rendering technique and the images were displayed over time in cine mode, showing dynamic 4D joint motions.

The static CT image dataset were reconstructed into axial, coronal and sagittal planes with bone and soft tissue algorithms, followed by 3D volume rendered images.

The effective radiation dose was calculated using the dose-length product (DLP) and multiplying this with the neck conversion factor (*k)* of 0.0059. Table 1 summarizes the total scan time and radiation doses in all three patients.

Case series

Patient 1

A 58-year-old right hand dominant man presented 8 weeks after traumatic anterior dislocation to the right SCJ after falling off mountain bike. He was initially treated conservatively in a sling. However, he reported worsening pain, clicking and 'grating sensation' at the SCJ upon shoulder protraction and retraction. There were no signs of neurovascular compression or airway compromise. Clinical examination demonstrated a bony protrusion of the medial clavicle anteriorly. A diagnostic CT, followed by wide-volume dynamic 4D CT were performed to quantify the degree of instability. He was instructed to perform shoulder protraction and retraction, which normally reproduces his symptoms.

The initial diagnostic CT showed severe anterosuperior subluxation of the right medial clavicle with marked soft tissue thickening. Upon scapular protraction on dynamic 4D CT, the bony cortex of the medial clavicle contacted the clavicular notch of the manubrium at mid motion on axial (Fig. 2) and coronal (Fig. 3) reformats, corresponding to the patient's pain at the time of study. 4D reconstruction demonstrated significantly increased rotation of the right medial clavicle on scapular retraction (Fig. 4), confirming instability, which corresponded to the patient's reported symptoms of instability at the time of study. These findings were not evident on static imaging.

Based on the degree of instability and ongoing symptoms, the patient opted for surgical stabilization of the right SCJ with figure-of-eight reconstruction using Tibialis Posterior allograft. Cardiothoracic backup was organized at the operation. Three months post-operatively, he achieved complete pain relief, regained near full range of motion and reported marked improvement in instability.

Table 1. Summarizes the total scan time and radiation doses of the static CT and dynamic 4D CT in all three patients.

Patient/Gender/Age	4D CT scan time (seconds)	Static CT scan time (seconds)	4D CT DLP (mGy.cm)	Static CT DLP (mGy.cm)	4D CT effective dose (mSv)	Static CT effective dose (mSv)
1/M/58	8.97	1	900	425	5.31	2.51
2/F/18	7.77	–	780	–	4.60	–
3/F/43	10.3	1.45	803	306	4.74	1.80

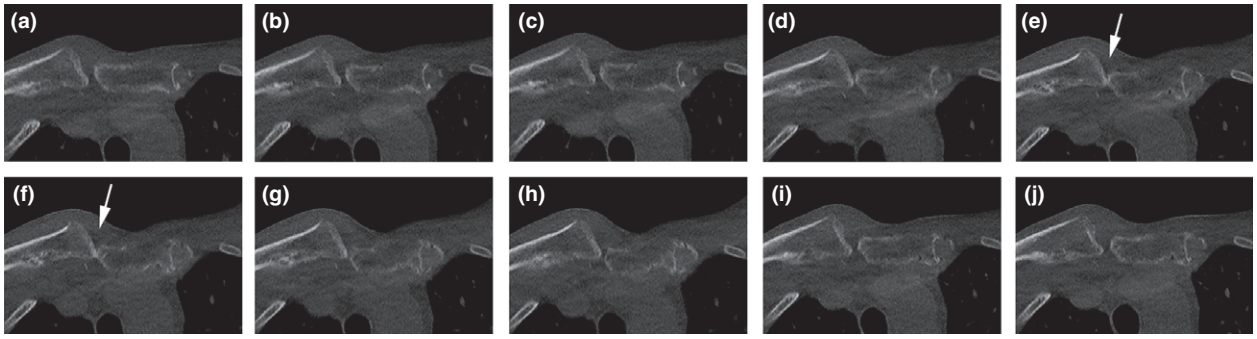

Fig. 2. Dynamic axial CT scans (with static images taken at regular time intervals shown in panels a–j) of the sternoclavicular joint in patient 1 demonstrated bony contact (white arrows in panels e and f) of the right medial clavicle and clavicular notch of the manubrium on shoulder protraction.

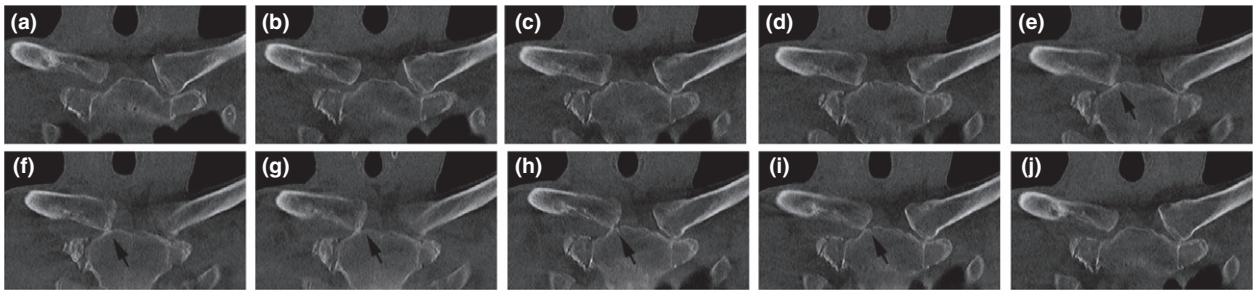

Fig. 3. Dynamic coronal CT scans (with static images taken at regular time intervals shown in panels a–j) of both sternoclavicular joints in patient 1 demonstrated bony contact (black arrows in panels e–i) of the right medial clavicle and clavicular notch of the manubrium on shoulder protraction.

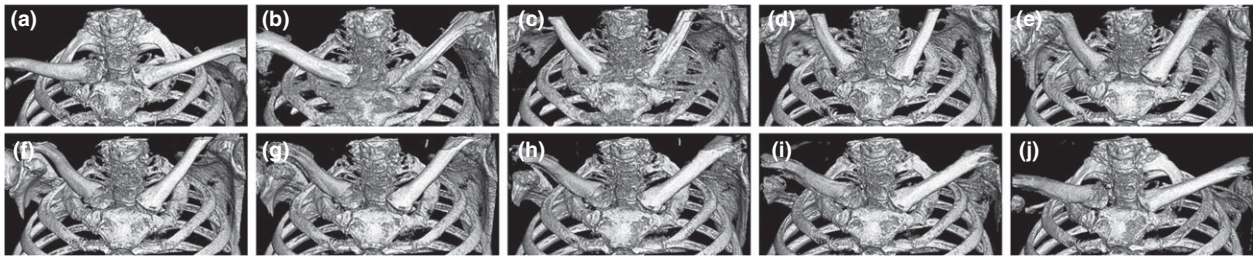

Fig. 4. Dynamic 4D CT scans (with 3D reconstructed images taken at regular time intervals shown in panels a–j) of both sternoclavicular joints in patient 1 demonstrated significantly increased rotation of the right medial clavicle from neutral position to shoulder retraction, confirming instability. The asymptomatic left sternoclavicular joint showed minimal rotation of the medial clavicle.

Patient 2

An 18-year-old right hand dominant female presented with chronic pain and instability in her right SCJ following a motor vehicle accident 5 years ago. At the time of initial injury, no imaging was performed and she was treated conservatively with a figure-of-eight sling for immobilization. She reported gradual worsening of instability and pain in her right SCJ, most severe on scapular retraction while the shoulder was externally rotated. Despite ongoing physiotherapy, her symptoms worsened and she was unable to play netball or compete in a 10-pin bowling tournament.

On clinical examination, she had significant ligamentous laxity and moderate right SCJ anterior subluxation. Based on clinical history and examination findings, there was a high suspicion of previous medial clavicular epiphyseal fracture and possible fibro-cartilaginous disc injury, resulting in chronic post-traumatic anterior instability of the SCJ. Pre-operative 4D CT was not performed as SCJ instability was diagnosed based on clinical examination findings. The patient opted for reconstructive surgery of the right SCJ with figure-of-eight reconstruction using Palmaris Longus tendon autograft.

Four months post-operatively, she reported improvement but with persistent low-grade residual pain and

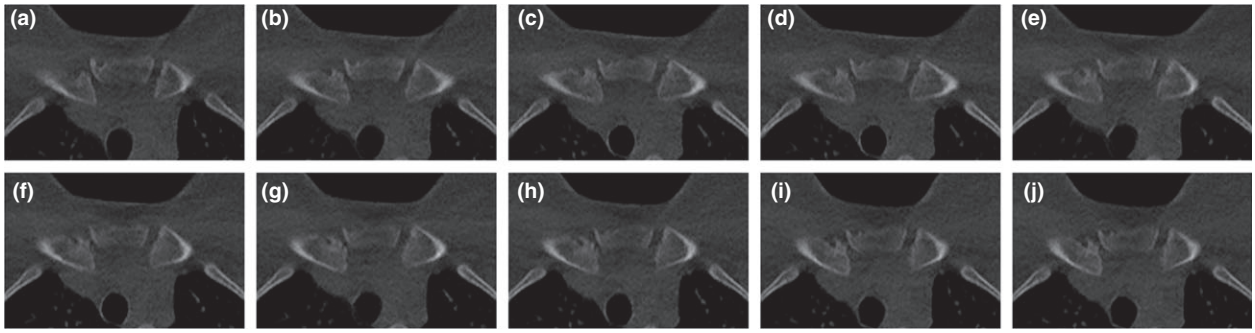

Fig. 5. Post-operative dynamic axial CT scans (with static images taken at regular time intervals shown in panels a–j) of both sternoclavicular joints in patient 2 demonstrated bilateral stable SCJ 4-month post right SCJ reconstructive surgery.

instability. A 4D CT was organized and it demonstrated bilateral stable SCJs on dynamic motion (Fig. 5), with a mildly reduced range of motion on the right SCJ, which was an expected post-operative finding. A static CT was not performed in this young patient to minimize radiation dose.

Based on findings on 4D CT, she was advised to continue physiotherapy and achieved full range of motion with no residual pain or instability 12 months after reconstructive surgery.

Patient 3

A 43-year-old right hand dominant female presented with ongoing instability, crepitus and pain in the right SCJ radiating to the right shoulder 16 months after a motor vehicle accident. At the time of injury, she sustained a right greater tuberosity fracture and sternoclavicular joint dislocation. She was treated conservatively with physiotherapy and optimal pain relief, but only achieved minimal symptomatic improvement.

Clinical examination was difficult given both apprehension and pain, however, there was a suspicion of a post-traumatic SCJ instability resulting in ongoing pain. The patient was keen to undergo surgical debridement and stabilization of the SCJ. Given that a definitive diagnosis of SCJ instability was difficult clinically in this case, a 4D CT was organized to assess the degree of instability.

4D CT demonstrated symmetrical movement in both SCJs on dynamic motion and there was no evidence of subluxation (Fig. 6). There was, however, subchondral sclerosis and cystic change in the right SCJ on axial (Fig. 7a) and coronal (Fig. 7b) CT, consistent with post-traumatic arthritis. Based on these imaging findings, conservative management was opted, and a cortisone injection into the right SCJ was performed on the same day. Three weeks later, the patient reported some pain improvement, however, the residual pain continued to affect her daily activities. An SCJ debridement was performed, based on findings on 4D CT, for post-traumatic arthritis rather than SCJ stabilization surgery in the case of instability. Intraoperative examination findings confirmed a stable right SCJ, confirming findings on 4D CT. This is an example of a modified surgical approach following 4D CT imaging findings, which optimizes the patient's outcome.

Discussion

This is the first case series demonstrating the use of 4D CT in the dynamic functional assessment of post-traumatic SCJ instability. We have demonstrated the use of 4D CT to provide anatomical and functional information in real-time joint movement that provides extra information cannot be seen in conventional static imaging.

Sternoclavicular joint is a diarthrodial saddle-type synovial joint with <50% of the clavicular head contacting the clavicular notch of the manubrium, rendering this an inherently unstable joint.[3,5] In 25% of the population, there is articulation between the manubrium and upper medial surface of the first costal cartilage.[3] The SCJ is stabilized by the strong capsular ligaments (anterior and posterior sternoclavicular ligaments), extracapsular interclavicular ligaments and costoclavicular ligaments.[2,3]

Sternoclavicular joint instability is defined by an abnormal increase in joint mobility. The causative factors of SCJ instability may be traumatic or atraumatic.[3] Traumatic instability or dislocation is defined by the direction of displacement of the clavicular head, namely anterior (commonest and fortunately less dangerous), posterior or superior. Atraumatic instability is usually anterior and seen in people who are prone to capsular or ligamentous laxity (e.g. Ehlers-Danlos Syndrome) or secondary to arthritis.[6]

Diagnosing SCJ instability on clinical examination can be difficult. Allman classified instability of the SCJ based on the degree of ligamentous disruption.[7] Type 1 describes a simple sprain of the sternoclavicular ligaments; Type 2 describes disruption of the sternoclavicular ligaments and capsule resulting in subluxation but not dislocation; Type 3 describes rupture of all supporting

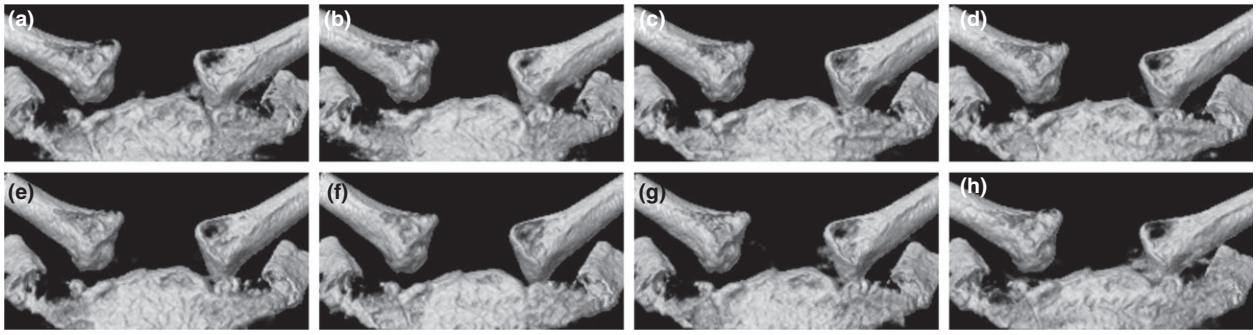

Fig. 6. Dynamic 4D CT scans (with 3D reconstructed images taken at regular time intervals shown in panels (a–j) of both sternoclavicular joints in patient 3 demonstrated bilateral stable SCJ with symmetrical movement on dynamic examination. There was no subluxation or asymmetric increased range of motion of the symptomatic right SCJ.

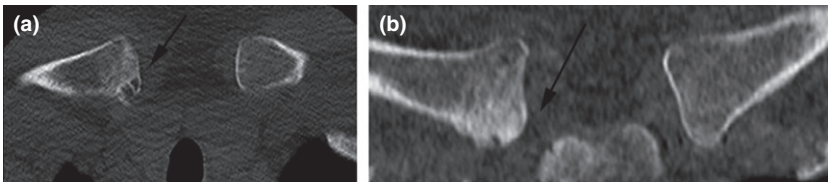

Fig. 7. Axial (a) and coronal (b) CT in patient 3 demonstrated asymmetric subchondral sclerosis and cystic change of the right SCJ (black arrows), consistent with post-traumatic degenerative arthritis. The asymptomatic left SCJ demonstrates normal joint space with no evidence of degenerative change.

ligaments with complete dislocation. The primary treatment for SCJ injuries is non-operative, as surgical intervention may require extensive exposure with potential fatal complications owing to the close relationship between the SCJ and the major vasculatures as shown in Figure 1.[8,9]

Patients with recurrent SCJ instability after traumatic dislocation are often treated conservatively to attempt to restore joint motions and scapular kinematics[8,10,11] because of the perceived risks of surgery near major vessels. When conservative treatments fail, surgery may be considered for relief of pain by surgical debridement of the joint as in Case 3, or instability (that may be anterior or posterior) by reconstruction. Reconstruction uses soft tissue transfers such as Palmaris autografts or Tibialis allografts with suture material supplementation as in cases 1 and 2. Metal fixation is usually avoided around the SCJ due to the risk of iatrogenic damage.[12]

Conventional imaging techniques of the SCJ including plain radiography (standard anteroposterior, Hobbs, Heinig and 'serendipity' views),[4] CT and MRI are useful in the diagnosis of SCJ dislocation.[3] However, these static imaging techniques do not allow functional assessment of the joint, particularly in the clinical context of instability.

4D CT using 320 multi-detector CT provides a new dimension to musculoskeletal imaging that allows dynamic kinematic visualization of joint motions over 16 cm in z-axis without table movement. The use of 4D CT in functional joint assessment has been described in the literature to diagnose several conditions (including mid carpal instability, trigger lunate syndrome, snapping scapula syndrome and post-traumatic elbow impingement) in which conventional imaging failed to demonstrate the causative factor to account for the patient's symptoms.[13–16] In one case report, 4D CT successfully identified the causative factor of an atraumatic SCJ instability causing tracheal compression on dynamic motion in a patient who presented with a choking sensation.[17]

This is the first case series demonstrating the use of 4D CT in the functional assessment of post-traumatic SCJ instability. In our experience, 4D CT can be used pre-operatively to confidently diagnose SCJ instability, therefore guiding surgical approach. 4D CT can also serve as an objective pre-operative baseline assessment for future follow up in the event of unsatisfactory symptomatic improvement or slow recovery.

There are several limitations in our study. The effective radiation dose of the 4D CT is between 2.1 and 2.6 times that of the static 3D CT performed on the same patient on the same day. The difference in radiation dose in different patient is due to the variation in patient's body habitus and the number of motions required to reproduce their symptoms. Combining all motions into one single motion can minimize scan time, hence minimizing radiation dose. A reduction in the z-axis range on both static and dynamic scans in future imaging of the SCJ

can further reduce the radiation dose. Reconstructing 3D static CT from the dynamic volumetric 4D dataset can eliminate the need to acquire normal dose static CT, which can further reduce the radiation dose. The second limitation in our study is that our 4D CT was performed in prone position and the SCJs were examined without the normal gravitational influence from the weight of the upper limb. A standing CT will be helpful to simulate the patient's symptoms in true functional standing position. However, all standing multi-slice CT scanners are only capable of dynamic volume acquisitions up to 4 cm, which will not provide adequate z-axis coverage for 4D CT of the SCJ.

Wide-volume dynamic 4D CT can accurately diagnose chronic post-traumatic SCJ instability, which can aid surgeons in pre-operative planning, and help to triage patients into surgical or non-surgical candidates. We propose that 4D CT to be a routine pre-operative imaging in patients with chronic post-traumatic SCJ instability.

References

1. Groh GI, Wirth MA. Management of traumatic sternoclavicular joint injuries. *J Am Acad Orthop Surg* 2011; **19**: 1–7.
2. Robinson CM, Jenkins PJ, Markham PE, Beggs I. Disorders of the sternoclavicular joint. *J Bone Joint Surg Br* 2008; **90**: 685–96.
3. Sewell MD, Al-Hadithy N, Le Leu A, Lambert SM. Instability of the sternoclavicular joint: current concepts in classification, treatment and outcomes. *Bone Joint J* 2013; **95-B**: 721–31.
4. Martetschlager F, Warth RJ, Millett PJ. Instability and degenerative arthritis of the sternoclavicular joint: a current concepts review. *Am J Sports Med* 2014; **42**: 999–1007.
5. Cope R, Riddervold HO, Shore JL, Sistrom CL. Dislocations of the sternoclavicular joint: anatomic basis, etiologies, and radiologic diagnosis. *J Orthop Trauma* 1991; **5**: 379–84.
6. Williams GR, Ramsey ML, Wiesel SW. *Operative Techniques in Shoulder and Elbow Surgery*, 2nd edn. Wolters Kluwer Health/Lippincott WIlliams & Wilkins, Philadephia, 2011; 252–3.
7. Allman FL. Fractures and ligamentous injuries of the clavicle and its articulation. *J Bone Joint Surg Am* 1967; **49**: 774–84.
8. Bicos J, Nicholson GP. Treatment and results of sternoclavicular joint injuries. *Clin Sports Med* 2003; **22**: 359–70.
9. Kirby JC, Edwards E, Kamali Moaveni A. Management and functional outcomes following sternoclavicular joint dislocation. *Injury* 2015; **46**: 1906–13.
10. De Jong KP, Sukul DM. Anterior sternoclavicular dislocation: a long-term follow-up study. *J Orthop Trauma* 1990; **4**: 420–3.
11. Van Tongel A, De Wilde L. Sternoclavicular joint injuries: a literature review. *Muscles Ligaments Tendons J* 2012; **1**: 100–5.
12. Lyons FA, Rockwood CA. Migration of pins used in operations on the shoulder. *J Bone Joint Surg Am* 1990; **72**: 1262–7.
13. Bell SN, Troupis JM, Miller D, Alta TD, Coghlan JA, Wijeratna MD. Four-dimensional computed tomography scans facilitate preoperative planning in snapping scapula syndrome. *J Shoulder Elbow Surg* 2015; **24**: e83–90.
14. Goh YP, Lau KK. Using the 320-multidetector computed tomography scanner for four-dimensional functional assessment of the elbow joint. *Am J Orthop* 2012; **41**: E20–4.
15. Repse SE, Amis B, Troupis JM. Four-dimensional computed tomography and detection of dynamic capitate subluxation. *J Med Imaging Radiat Oncol* 2015; **59**: 331–5.
16. Troupis JM, Amis B. Four-dimensional computed tomography and trigger lunate syndrome. *J Comput Assist Tomogr* 2013; **37**: 639–43.
17. Hislop-Jambrich JL, Troupis JM, Moaveni AK. The use of a dynamic 4-dimensional computed tomography scan in the diagnosis of atraumatic posterior sternoclavicular joint instability. *J Comput Assist Tomogr* 2016; **40**: 576–7.