International Journal of Orthopaedics

Online Submissions: http://www.ghrnet.org/index.php/ijo
doi:10.17554/j.issn.1819-6187.2016.03.172

Int. J. of Orth. 2016 August 23 3(4): 1-7
ISSN 1819-6187

ORIGINAL ARTICLE

Sagittal Plane Malalignment in Paediatric Supracondylar Fractures of the Distal Humerus: A Review of the Literature

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Received: June 1, 2016
Revised: June 22, 2016
Accepted: June 23, 2016
Published online: August 23, 2016

ABSTRACT

AIM: Sagittal plane malalignment in supracondylar fractures of the humerus is thought to remodel well and be of doubtful functional significance. Consequently it has been given little attention. Our aim was to review the contemporary literature for consensus about the optimal radiographic method to assess sagittal plane alignment, define acceptable limits of reduction in this plane and assess the functional consequences of the ensuing hyperextension deformity.

METHODS: A search of MEDLINE(Ovid), PubMed, EMBASE, CINAHL and the Cochrane & DARE databases for "supracondylar fracture*" AND "sagittal" OR "anterior humeral line" OR "humerocapitellar angle" was conducted in October 2013.

RESULTS: The search identified 42 articles. Of these, 13 papers evaluated optimal radiological parameters or patient outcomes in supracondylar fractures with reference to sagittal plane deformity.

CONCLUSIONS: Inadequate reduction of supracondylar fractures in the sagittal plane results in loss of elbow flexion, although it may not be significantly disabling. The humerocapitellar angle has better reliability and prognostic value than any other radiographic measurement, but should not be used in isolation. In children under the age of 6 a humerocapitellar angle of 42 degrees +/- 18 degrees is acceptable. In older children who have limited remodelling potential, variability of +/- 6 degrees is acceptable.

Key words: Sagittal; Supracondylar fractures; Humerus; Range of motion; Remodelling; Radiographic measurement

Rashid A, Abdul-Jabar HB, Bretherton CP, Majed A, Corner T. Sagittal Plane Malalignment in Paediatric Supracondylar Fractures of the Distal Humerus: A Review of the Literature. *International Journal of Orthopaedics* 2016; 3(4): 1-7 Available from: URL: http://www.ghrnet.org/index.php/ijo/article/view/1744

INTRODUCTION

Supracondylar fractures of the distal humerus constitute 3.3-17.9%[1,2] of all paediatric fractures and 58% of elbow fractures in children[3]. Skagg and Flynn's review of 8361 supracondylar fractures revealed a male predominance of 60%, 60% were left sided and 98% were extension type. Unlike most paediatric fractures, which increase in incidence up to the age of 12, the average age at time of fracture is 6.7 years[1,2,4]. They are classified according to Wilkins' modification of the Gartland classification[5]: Type I (undisplaced) accounting for 52%, Type IIa (displaced but with an intact posterior cortex and no rotational displacement) and Type IIb (same as Type IIa but with rotational displacement) accounting for 24% and Type III (displaced with no cortical continuity) accounting for 24%[3,6] (Figure 1). A type IV pattern has been proposed[7], which in addition to complete loss of cortical contact, describes instability in flexion and extension as assessed intra-operatively or under image guidance and may prove useful for operative decision making. Although this classification system has better reliability than other commonly used classification systems[8], several studies have highlighted its poor inter-observer reproducibility and therefore advocate examining the absolute degree of radiographic displacement when deciding how to manage these injuries[9,10]. As a consequence there has been an increase in the number of articles assessing the validity of various radiographic parameters to ensure adequate fracture reduction. This can help avoid

Figure 1 Gartland classification for the supracondylar fractures of the elbow.

elbow deformity, which may have functional consequences[11,12,13].

As the elbow functions as a hinge joint, deformities that lie outside its plane of motion may not correct[14]. Accordingly the importance of avoiding coronal plane malalignment, assessed using Baumann's angle, has been established[4]. If allowed to occur it may contribute to cubitus varus, which has both cosmetic consequences of an undesirable gunstock deformity and functional sequela including limitation of range of motion, tardy ulnar nerve palsy and an increase risk of lateral epicondyle fractures[15,16,17,18]. Conversely, sagittal plane malalignment, assessed using anterior humeral line (AHL) and humerocapitellar angle (HCA), is thought to remodel well and any malalignment that persists as a hyperextension deformity is thought to be of doubtful functional significance[19]. As a consequence it has been given relatively little attention.

Our aim was to review the contemporary literature for consensus as to the optimal radiographic method to assess sagittal plane alignment, define acceptable limits of reduction in this plane with relation to age and time for potential remodelling and assess the functional consequences of the ensuing hyperextension deformity.

METHODS AND MATERIALS

A search of MEDLINE (Ovid), PubMed, EMBASE, CINAHL and the Cochrane & DARE databases for "supracondylar fracture*" AND "sagittal" OR "anterior humeral line" OR "humerocapitellar angle" was conducted in October 2013, which identified 85 articles. After removal of duplicates, 42 articles remained. Each of the 42 abstracts was screened using our exclusion / inclusion criteria specified in Table 1. Of these, 13 papers evaluated optimal radiological parameters or patient outcomes in supracondylar fractures with reference to sagittal plane deformity. The excluded papers were:

- Not related to the humerus (6)
- Not available in English Language (4)
- Conference abstracts (4)
- No long-term follow up (3)
- Patient outcome not primary focus of study (2)
- Surgical technique or protocol comparison (4)
- Not related to sagittal deformity (2)
- Anatomical studies (3)
- Biomechanical studies (1)

Table 1 Inclusion/ Exclusion Criteria

Inclusion criteria	Exclusion criteria
• Sagittal plane deformity • Clinical outcome • Bone remodelling • Radiological assessment at follow up • English Language	• Case reports, editorials, comments, letters, guidelines, protocols, abstracts, review papers, unpublished studies • Not related to humerus/elbow • Detailed operative technique comparisons • Purely anatomical or biomechanical studies

RESULTS

Table 2: Table 2 lists the articles included in the literature review and discusses their study design, parameters and outcomes.

DISCUSSION

Rogers et al[30] first described the AHL in 1978 as a line drawn on the lateral radiograph along the anterior humeral cortex which distally bisects the middle third of the capitellar ossification centre (Figure 2). Passage of the AHL anterior to the middle third of the capitellar ossification centre indicates the presence of posterior displacement of the distal fragment. However as the capitellar ossification centre, which normally appears between six months and two years, progressively increases in size until it reaches its adult configuration between ten and twelve years, the AHL may bisect it at different points depending on the age of the child making its use somewhat difficult. Herman et al[20] performed a radiographic study of inter and intra-observer variability of the AHL in different age groups and found that the capitellar bisection was more variable in children under the age of four years, passing almost equally through either the middle third or the anterior third of the capitellum. Although the AHL is useful for diagnosis of minimally displaced fractures, it is a poor predictor of functional outcome as it cannot differentiate between translation, which remodels well, and angulation, which does not[13].

The HCA quantifies the compliment of the angular relationship between the humeral shaft and the capitellum on the lateral radiograph (Figure 3). Unlike the AHL, it can differentiate between angular and translational deformity, which is of prognostic value[13]. Simanovsky et al[22] measured the HCA in 142 normal children, finding a mean of 41.6 ± 5.6 degrees with no statistically significant variation with age, sex, or side. This angle decreases with posterior angulation of the distal fragment and increases with anterior angulation of the distal fragment. Difficulty determining the capitellar ossification centre in younger children sometimes makes measurements difficult. Moraleda et al[24] assessed the intra-observer reliability of the HCA in 10 patients. The intraclass correlation coefficient at the time of fracture, at time of last follow up and for the uninjured elbow was 0.95, 0.84 and 0.76 respectively.

Table 2 Results.

Study	Design	Patients	Parameter	Comparator	Follow-up	Primary outcome	Secondary outcomes: Functional scores & Complications
Herman et al 2009[20]	Retrospective single centre analysis of variability of AHL in uninjured elbows with age.	N=30 (4 months to 4 years)	AHL	Measurement of each elbow on two separate occasions by three observers: paediatric orthopaedic surgeon, senior orthopaedic resident, medical student.	n/a	In children under 4 the AHL passes through the anterior third of the capitellum almost as commonly as it passes through the middle third. In older children it passes more consistently through the middle third. The measurement of AHL had moderate/substantial intra and inter-rater reliability.	n/a
Turhan et al 2008[21]	Retrospective multi-centre analysis of radiological outcome of open vs. closed reduction of Supracondylar humeral fractures (SCHX) in the sagittal plane.	N=76 MUA & K-wiring (2-12 years) N=68 ORIF (2-13 years)	AHL, HCA, ACL	Score based on achievement of normal AHL, HCA or ACL: 0 criteria=poor 1 criteria=fair 2 criteria=good 3 criteria=excellent Excellent & good = acceptable.	n/a	There was no difference in sagittal plane reduction between open (74.9% acceptable) and closed techniques (75.0% acceptable).	n/a
Simanovsky et al 2007[13]	Retrospective single centre analysis of sagittal plane reduction in SCHX.	30/223 of SCHX under-corrected in sagittal plane at time of study. Mean age at fracture =5.4 N=22 available for follow up.	HCA	Elbow range of movement. Flynn criteria	Until skeletal maturity Mean= 8.2 years	77% of patients had >5° difference in HCA compared to uninjured side. 50% had limited elbow flexion of which 31% were aware of this. 45% had unsatisfactory results by Flynn criteria although only 3 patients (14%) felt subjectively disabled.	n/a
Simanovsky et al 2008[22]	Retrospective single centre analysis of variability of HCA in uninjured elbows in relation to age and sex.	N=142	HCA		n/a	Mean HCA + SD in uninjured elbow = 41.6 +-5/6°. No statistically significant influence on HCA by age, sex, or side. A few extreme variations despite normal elbow range of motion (HCA 30-70°)	
Fitzgibbons et al 2011[23]	Retrospective single centre case-control study looking at predictors of failure of closed reduction and casting of Gartland type II SCHX.	N=61	AHL		Mean=41 days	20% failure of non-operative treatment (requiring delayed pinning). The degree of extension at time of injury will predict likelihood of failure of conservative treatment.	Width of soft tissue shadow is of borderline significance
Persiani et al 2012[19]	Retrospective single centre analysis of remodelling in SCHX.	N=62	HCA, BA, Lateral rotation percentage.	Flynn Criteria, MEPS, POSNI	Mean= 4 years 3 months	More lateral remodelling than coronal remodelling. Mean 8° of sagittal remodelling at 9 years in Gartland type III fractures. All patients had satisfactory elbow function by Flynn Criteria and excellent by MEPS& POSNI.	n/a
France & Strong 1992[11]	Retrospective single centre analysis of deformity and function in patients with SCHX treated by closed reduction and splinting (CRS), traction, and percutaneous pinning. (CRPP)	Total N=137 Deformity and function assessed =84 (mean age 6.9 years) Repeat radiograph 12 – 36 months post fracture N = 18	HCA BA	Flynn Criteria Excellent or good = satisfactory Fair or poor = unsatisfactory	Mean = 2.7 years	78% satisfactory by Flynn criteria but good function in all patients regardless of treatment method. Relationship between HCA and residual flexion (better with CRPP). Limited sagittal remodelling within 12- 36 months – mean 2°.	n/a
Moraleda et al 2013[24]	Retrospective single centre analysis of clinical and radiographic outcome of Gartland type II SCHX treated with splint immobilisation (without reduction).	N=46 (Mean age 5.5 +/- 2.6 years)	BA, HCA, Radiographic carrying angle	MEPS, Flynn Criteria, QuickDASHquestionnaire (an abbreviated form of the Disabilities of the Arm, Shoulder and Hand questionnaire to measure disability).	Mean = 6.6 +/- 2.8 years	Mean HCA at time of fracture = 12.8° vs 30.5° at final f/u (Mean degree of sagittal remodelling 17.7°) Mean degree of change compared to uninjured arm: flexion= -6.9°, extension= +5.8°, HCA + SD = -11.4° (30.5° +- 11° vs 41.9° +- 9.9°) The intraclass correlation coefficient for HCA at the time of fracture, at time of last follow up and for the uninjured elbow was 0.95, 0.84 and 0.76 respectively. Mild increase in elbow extension, excellent functional results in the majority.	80.4% had satisfactory results according to Flynn criteria. The mean score was 10 points for the QuickDASH questionnaire, .7 points for the QuickDASH-sports questionnaire.

Table 2 Results.

Study	Design	Patients	Parameter	Comparator	Follow-up	Primary outcome	Secondary outcomes: Functional scores & Complications
Camus et al 2011[25]	Retrospective single centre analysis of clinical and radiographic outcome of Gartland type II SCHX treated with closed reduction and immobilisation.	N=155 (mean age 5.3 years)	AHL, HCA, BA, Gordon index and Griffet index (as marker of rotational instability of fracture).		5.3 months	In 80% of patients, the AHL remained anterior to the mid-third segment of the capitellum. The mean HCA = 23.77°, BA = 79.40°, Gordon index = 4.59%, and 44% of patients had a Griffet index between 1 and 3. Not all fractures treated with closed reduction and cast immobilization achieved anatomic position and alignment at final follow-up.	n/a
Gadgil et al 2005[26]	Prospective single centre analysis of clinical and radiographic outcome of displaced SCHX managed with elevated, straight-arm traction for a mean of 22 days.	N=112 (mean age 6.2 years)	Clinical carrying angle and rotational deformity, Flexion-Extension arc, HCA, metaphyseal-diaphyseal angle.	Outcome score equal to lowest grade achieved from all 5 criteria adjacent.	24 months	Excellent results were achieved in 71 (63%) patients, 33 (29%) had good results, 5 (4.4%) fair, and 3 (2.6%) poor. All patients with fair or poor outcomes were older than ten years of age. All patients over 10 had terminal restriction of flexion at final f/u (10-20°) – HCA less than10°.	Children under 6 achieved active flexion in traction earlier (mean = 26 days) than older patients (53 days).
Zatti et al 2001[27]	Prospective single centre analysis of clinical and radiological outcome in SCHX treated with reduction and percutaneous synthesis using Kirschner wires	N=16 (Mean age = 6.5 years).	BA, sagittal parameter not specified Flynn criteria		Mean = 57.9	3 cases had deficit in reduction in the sagittal plane, these remodelled and no clinical deformity or joint deficit persisted. Final functional results were satisfactory in 94%	n/a
Fleuriau-Chateau et al 1998[28]	Single centre chart review of clinical and radiographic outcome of open reduction of irreducible SCHX	N=34 (Mean Age = 7 years).	BA,HCA	Flynn Criteria	months Mean = 7 months	BA and HCA differed by an average of 2° and 5.3° respectively compared with the unaffected arm. Range of motion was satisfactory in 94%	n/a
Shank et al 2011[29]	Retrospective single centre analysis of variability of LCHA in uninjured elbows	N=71 6 male and 6 female in each age group	LCHA,BA	Measurement of each elbow on three separate occasions by five observers. Observers: 1 paediatric orthopaedic surgeon, 2 orthopaedic residents, 2 consultant orthopaedic surgeons.	n/a	Mean LCHA + 1SD = 50.8° +- 6.2° and did not vary significantly with age, sex or side. Good intra-observer (0.67) but only fair inter-observer reliability (0.37) improving with age.	

Supracondylar fracture of the humerus(SCHX,), Anterior humeral line (AHL), Humerocapitellar angle (HCA), Lateral Capitellohumeral angle (LCHA), Anterior coronoid line (ACL), Baumans angle (BA), Mayo Elbow Performance Score (MEPS), Pediatric Orthopaedic Society of North America Pediatric Outcomes Data Collection Instrument questionnaire (POSNI), Standard Deviation (SD).

The lateral capitellohumerangle (LCHA) is a complement of the HCA. It measures the angle between the AHL and the capitellar physis and is perpendicular to the axis of HCA (Figure 4). Shank et al[29] measured the LCHA in 71 normal children, finding an mean value of 50.8 ± 6.2 degrees. They found good intra-observer (0.67) but only fair inter-observer reliability (0.37) for LCHA measurements. However intra-observer reliability is more relevant to the clinical utility of this measurement, as the surgeon will likely make treatment decisions based on his or her own measurements rather than those of others. Interestingly, LCHA intra-observer reliability was only moderate in 0-2 year age group and improved to excellent in the 8-10 and 10-12 year age groups. Thus, the measurement may be more reliable in patients approaching maturity, when remodelling of angular deformity is least predictable. The LCHA has not yet been studied in patients with supracondylar fractures of the humerus.

Any sagittal plane deformity that fails to remodel usually results in a hyperextension deformity, which may or may not be clinically apparent. Until now these deformities have been deemed to be functionally inconsequential and have therefore been largely ignored. However there are several studies correlating sagittal plane deformity to loss of function[11,13]. In their retrospective review of 84 patients treated with a variety of methods over a 9-year period, France and Strong[11] found that HCA strongly correlated with a loss of flexion after supracondylar fracture and did not remodel reliably with growth. This resulted in unsatisfactory motion by the Flynn criteria (whereby 10 degrees or more of restricted motion is defined as an unsatisfactory result) in 22% of their patients although this was not considered functionally disabling. Likewise, Simanovsky et al[13] in

Figure 2 Anterior humeral line (AHL) drawn on the lateral radiograph along the anterior humeral cortex which distally bisects the middle third of the capitellar ossification centre.

Figure 4 The lateral capitellohumerangle (LCHA) measures the angle between the anterior humeral line and the capitellar physis and is perpendicular to the axis of humerocapitellar angle.

Figure 3 The humerocapitellar angle (HCA) quantifies the compliment of the angular relationship between the humeral shaft and the capitellum on the lateral radiograph.

Figure 5 The anterior coronoid line (ACL) is a curved line drawn on the lateral radiograph along the superior aspect of the ulna, through the coronoid and onto the anterior aspect of distal humeral shaft.

their retrospective review of 223 patients treated over a 4 year period found the HCA at reduction strongly correlated with loss of flexion at skeletal maturity. They deemed that this occurred secondary to inconsistent remodelling, resulting in unsatisfactory motion by Flynn criteria in 45% of their patients. In fact 22/223 patients had a persistent sagittal plane deformity at skeletal maturity, 17 patients did not achieve radiographic remodelling at the last follow-up and 10 had limited elbow flexion of 10 degrees or more, although the majority were not subjectively aware of this and therefore did not consider it functionally disabling.

In their critical analysis of bone remodelling in malunited fractures in children, Gasco and De Pablos[31] reported poor remodelling capacity around the elbow, especially compared to the proximal humerus and distal radius. Theoretically any remodelling that does take place is generally better in the plane of motion of the joint[19] meaning that sagittal plane deformities remodel better than coronal plane deformities[32]. However 65% of the length of humerus is achieved by the age of 6 years and only 7% of the remainder of the growth of the humerus occurs at the distal humeral physis[4], meaning that even remodelling of sagittal plane deformities is unpredictable in children over the age of 6 years. France and Strong[11] in their series of supracondylar fractures treated by closed reduction and splinting, traction, and percutaneous pinning reported an average of 2 degrees of remodelling in the sagittal plane and no remodelling in the frontal plane[11]. However this group of fractures were heterogenous and treated in a variety of different ways. Moraleda et al[24] in their series of Gartland type II fractures all treated with splint immobilisation reported that the mean HCA at time of fracture was 12.8 degrees and at final follow-up was 30.5 degrees implying that the mean degree remodelling in the sagittal plane was 17.7 degrees. Although there are no studies quantifying the degree of sagittal plane deformity that can be accepted before ensuing functional limitation, Shank suggested that sagittal plane deformity beyond 3 Standard Deviations (18 degrees) of normal should not be accepted, particularly in older patients in whom the remodelling is less predictable[29].

As HCA measures angular deformity in one plane only, it is conceivable that the HCA may be normal with a coronal plane deformity. These measurements should therefore not be used in isolation. Another radiographic parameters that is less frequently used is the anterior coronoid line (ACL), although there are no validated studies looking at its prognostic value, variation with age or sex and reproducibility. The ACL is a curved line drawn on the lateral radiograph along the superior aspect of the ulna, through the coronoid and onto the anterior aspect of distal humeral shaft (Figure 5). Its passage through anterior part of the capitellum signifies normal anatomy. Although it provides information on anterior-posterior translation of the distal fragment, it does not allude to distal fragment rotation33. The accuracy of radiographic measurements depends, in part, on the reliability with which they can be obtained. If they cannot be measured reproducibly, changes may represent measurement error rather than clinical reality. High quality radiographs are therefore crucial in obtaining accurate and reproducible measurements of these angles.

This review has the typical limitations of most review articles. Notably that only 2 of these studies included were prospective in nature and that some of the anatomic studies which did not meet the inclusion criteria and were therefore excluded, may have contained some important information about inter- and intra- observer reliability.

CONCLUSION

Inadequate reduction of supracondylar fractures in the sagittal plane results in hyperextension deformity. Although the deformity is in the plane of motion of the joint, the remodelling capacity of the distal humerus is generally limited and is especially unpredictable after the age of 6 years. The consequent loss of flexion may lead to prolonged utilization of physical therapy or repeated clinic visits, although it may not be significantly disabling.

Special care should therefore be taken when assessing sagittal plane alignment. Although the HCA has better reliability and prognostic value than any other radiographic measurement, there may be significant individual variations due to the size of the capitellar ossification centre and arm position during radiographs. Based on this systematic review we suggest a combination of two radiographic parameters, including the HCA. In children under the age of 6 years who have the capacity to achieve some remodelling an HCA of 42 degrees +/- 18 degrees (3 standard deviations) is acceptable whereas in children over the age of 6 years with limited and unpredictable remodelling capacity an HCA of 42 degrees +/- 6 degrees (1 standard deviation) is acceptable.

CONFLICT OF INTEREST

The Authors declare that there is no conflict of interest.

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