Arch Orthop Trauma Surg
DOI 10.1007/s00402-015-2368-6

TRAUMA SURGERY

The relevance of neutral arm positioning for true ap-view X-ray to provide true projection of the humeral head shaft angle

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Received: 16 July 2015

Abstract
Introduction Textbooks commonly recommend using the true anterior–posterior (ap)-view with the patient's arm in a sling and therefore in internal rotation (IR) for radiologic diagnostic assessment of the proximal humerus after trauma. However, IR or external rotation (ER) may affect the projection of the head shaft angle (HSA) and therefore bias the diagnostic conclusion significantly. We hypothesized that neutral rotation (NR) of the arm is mandatory for true ap-view to provide true projection of the HSA.
Materials and methods A simplified geometrical model of the proximal humerus was used to examine the influence of different arm positions and angulations of the central ray in relation to the projection of the HSA.
Results Both ER and IR misleadingly suggested an increased valgus angle. Simulating the true ap-view with the central ray in cranio-caudal direction, IR changed the projection of the HSA substantially.
Conclusion In conclusion, standard fixation of the patient's arm in a shoulder sling in IR for true ap-view may result in an oblique projection, potentially leading to incorrect surgical implications. To prevent misdiagnosed valgus or varus angulation, NR of the arm should be obeyed when performing true ap-view X-ray. We, therefore, highly recommend to overcome the traditionally arm position, ensuring the true amount of dislocation to assure correct surgical implications and comparable follow-up examinations.

Keywords Varus · Valgus · Proximal humerus · Head shaft angle · True ap-view · X-ray

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Introduction

Based on plain radiographs, recent studies have investigated the influence of initial and postoperative varus or valgus malalignment of proximal humeral fractures [1–12]. Generally, varus malalignment is known to result in unstable fracture stability and may, therefore, be predictive for inferior outcome [1, 2, 4, 9–12].

Imaging techniques for the radiographic assessment of the proximal humerus have not been described consistently in previous clinical studies. To measure the HSA, some authors utilized true ap-view radiographs [2, 5, 6, 11, 12], others ap-view radiographs [1, 3, 8–10], best available radiographs in the anteroposterior view [13], or non-specified projections [4]. Furthermore, some published figures do not display the previously described radiographs [12]. The terms "standard ap-view" and "true ap-view (glenoid view)" have been misleadingly used for the same positioning [6].

The true ap-view is part of the so-called "trauma series" and is recommended for assessing proximal humeral fractures [14–20]. The positioning of the patient's trunk in relation to the central X-ray beam and the radiographic cassette (projection plane) has been well described for the true ap-view [21]. To assure the proper true ap-view radiograph, the affected shoulder should be rotated 30°–40° towards the X-ray plate until the scapula of the injured side appears parallel to the X-ray plate (Fig. 1). To avoid overlapping of the humerus

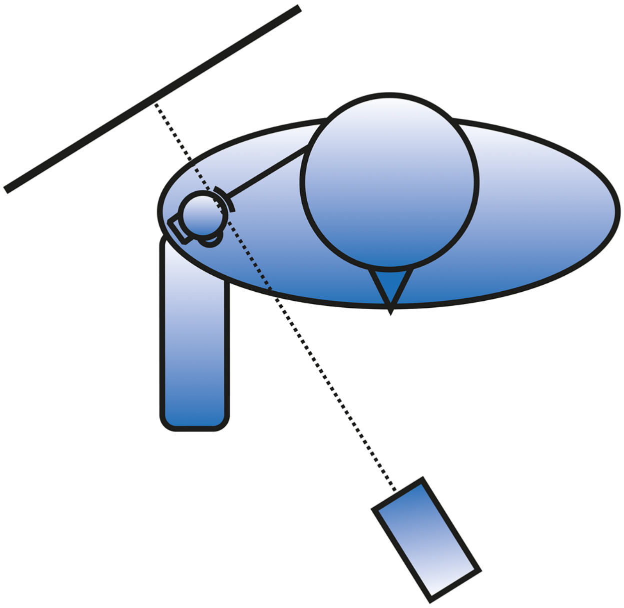

Fig. 1 Positioning for true ap-view: rotating the unaffected shoulder 30°–40° away brings the scapula of the injured side parallel to the X-ray plate. This avoids overlapping of the humerus head and the glenoid. NR of the patient's arm provides ap-projection of the proximal humerus

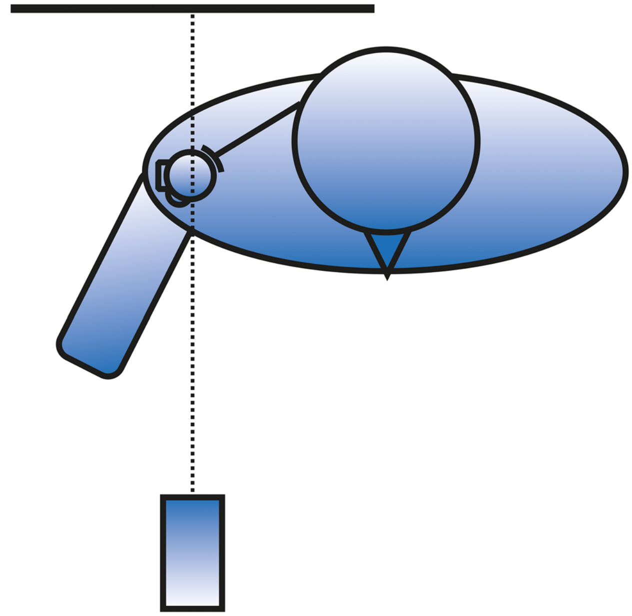

Fig. 2 Standard ap-projection causes overlap of the humerus head and the glenoid. Because of the steric position of the scapula and the shoulder joint, ER of the humerus provides ap-projection of the proximal humerus

head and the acromion, the central X-ray beam should be directed 20° cranio-caudally [20, 23].

Although the position of the patient's trunk has been described consistently, variability exists on the description of the positioning of the patient's arm. Placing the patient's arm in ER has been generally recommended for the standard ap-view [1, 9, 10, 22] (Fig. 2). However, few authors have recommended keeping the patient's arm in neutral position for true ap-view [22, 23]. Furthermore, in case of trauma or fracture, most authors have recommended immobilizing the arm in a sling [14–18, 24] in order to minimize pain. For this purpose, the arm is usually placed in 60° of IR and slight flexion.

The HSA has commonly been used in fracture diagnostics to determine the amount of varus or valgus fracture displacement. However, there are various techniques described in the literature to measure the HSA (Fig. 3) in the true ap-projection, potentially leading to heterogeneous results: Hertel [25] uses a line perpendicular to the anatomic neck that intersects a line parallel to the proximal humeral shaft to measure the HSA (α_1), Poeze [6] defines the HSA as the angle at the intersection of a line through the anatomic neck and a line parallel to the proximal humeral shaft (α_2), whereas Court-Brown [3] defines the HSA with a line from the tip of the greater tuberosity to the calcar region and the axis of the humerus shaft (α_3).

So far, little attention has been drawn to the importance of correct patient positioning and reproducible conditions between primary and follow-up X-rays in case of proximal humeral fractures. We, therefore, hypothesized that variations in arm positioning and beam orientation would significantly change the projection of the HSA. We aimed to define the ideal patient's arm positioning to achieve correct projection of the HSA in true ap-view X-ray.

Methods

Geometrical model

In order to study influences on the visualization of HSA on two-dimensional X-ray films, we reduced the complex three-dimensional structure of the proximal humerus to a simplified model. In the model used for this study, the axis of the humerus shaft intersects with the axis of the humerus head [25, 26]. These axes define a plane, as it is mathematically defined by three points or by two straight lines that intersect. As previously described, we defined an angle of 135° as an average value [25]. According to orthographic projection, this defined area projects a plane in the front view, whereas in the top view, it displays as a line (Fig. 4). For further simplification, we defined the humerus shaft axis, representing the rotational axis for ER and IR. A reconstructed CT scan of a macerated humerus (Impax EE R20, Agfa HealthCare N.V., Mortsel, Belgium) was used to develop the model and to demonstrate that it equates a correct ap-projection (Fig. 4).

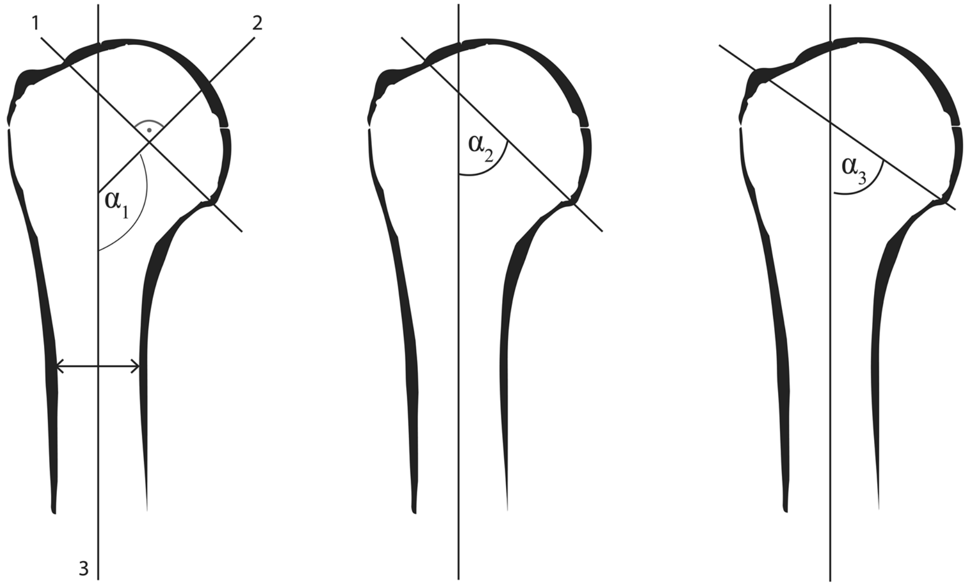

Fig. 3 Measurement techniques according to Hertel [25], Poeze [6] and Court-Brown [3]

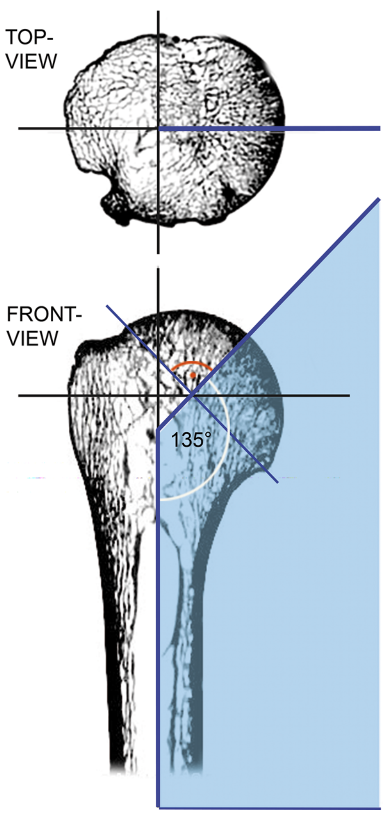

Fig. 4 The model and its relation to the proximal humerus in NR are shown in the front view and in the top view

Orthographic projection

To evaluate the resulting projection of our model in orthographic projection, trigonometric functions and the rules of descriptive geometry were applied by rotating the model virtually along the shaft axis (Fig. 5). The intersection point of the axes was called A in the front view and A′ in the top view (Fig. 5). The constructional approach required the definition of an additional point on the neck/head axis. This point was named B in the front view and B′ in the top view and may describe the intersection of the neck/shaft axis with the articular surface of the humerus head (Fig. 5). In orthographic projection, the projection lines were perpendicular to the projection plane. In the starting position, our model of the HSA (α) and its plane were orientated parallel to the projection plane in neutral position (Fig. 5).

While rotating the model around the shaft axis (rotation angle β), its projection accordingly changed in the front view (Fig. 5). To calculate the amount of these changes, the rotation can be drafted in the front view and in the top view for better understanding (Fig. 6). The top view point B′ described a part of a circle while rotating the model around the shaft axis (Fig. 6). The projection of the rotation angle β around the shaft axis was not affected in the top view, whereas the HSA changed in the front view (α and α''). The amount of rotation of B′ defined the length of the auxiliary line x in the top view and in the front view. The auxiliary line x referred by trigonometric function to both the rotation angle (β) and the projected HSA (α''). By this means, the projection of the model was constructed and calculated for ER (45°, 30°, 15°), NR and IR (15°, 30°, 45°, 60°, 70°), according to the orthographic projection.

Central projection

Radiography is known to be equivalent to central projection. For the central projection, only the central ray is perpendicular to the projection plane (X-ray film). The

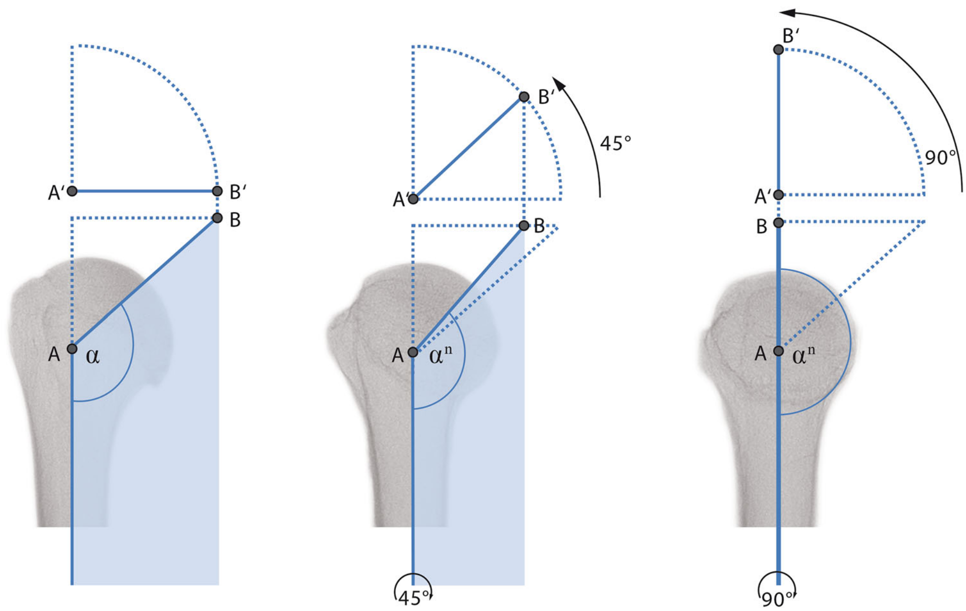

Fig. 5 Constructional approach in orthographic projection based on Fig. 4 illustrates NR, 45° and 90° of rotation

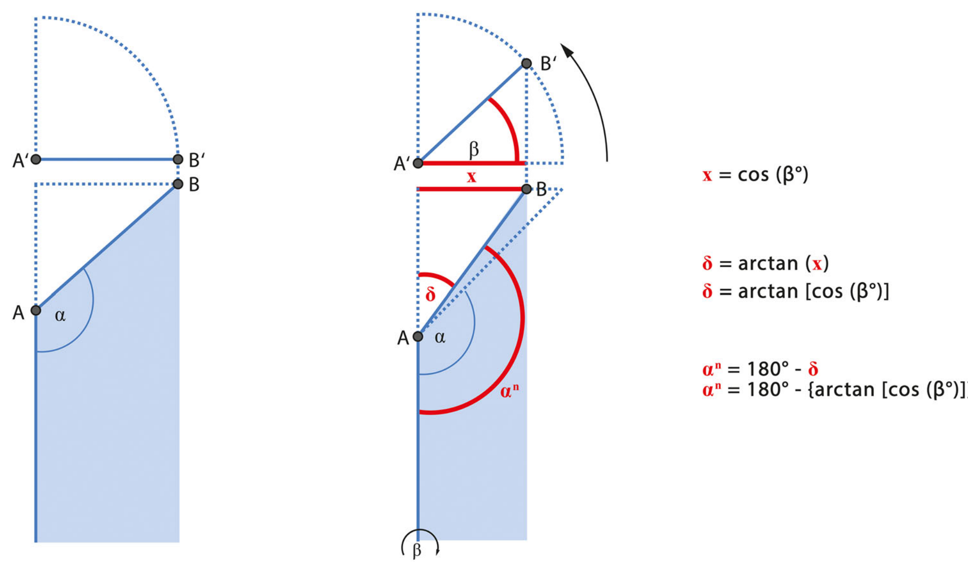

Fig. 6 Mathematical approach: The rotation angle β leads via cosine to the auxiliary line x, which allows to calculate the angle δ, that is the supplementary angle to the projected head shaft angle α^n

other rays are divergent [21]. Evaluating our model in central projection is incomparably more difficult than it is in orthographic projection. Therefore, we examined the projection of the model in central projection using Rhinoceros-Software (McNeel, Seattle, North America). In detail, we calculated the projection of the HSA in ER (45°, 30°, 15°), NR and in IR (15°, 30°, 45°, 60°, 70°), according to central projection implicating a central beam perpendicular to the projection plane and a central beam with a cranio-caudal tilt of 20° towards the projection plane.

Placing the patient's arm in a sling [14–18, 24] inevitably causes IR and flexion of the arm (Figs. 7, 8). Therefore, the projection of the HSA in case of IR and concomitant flexion was calculated for an average patient (flexion 30°, IR 60° and 70°, cranio-caudal tilt of central ray 20°), as well as for an obese patient as an extreme (flexion 50°, IR 60° and 70°, cranio-caudal tilt of central ray 0° and 20°).

Results

In orthographic projection, the calculated HSA changed by the same amount, no matter if the model was rotated internally or externally (Table 1 presents the resulting projected angle, Table 2 presents the resulting difference of the projected angle towards the original HSA of 135°). Both ER and IR misleadingly suggested the projection of the HSA to appear in valgus.

Fig. 7 Wearing a shoulder sling brings the patients arm in internal rotation and flexion, the amount of rotation depends on the patient's constitution

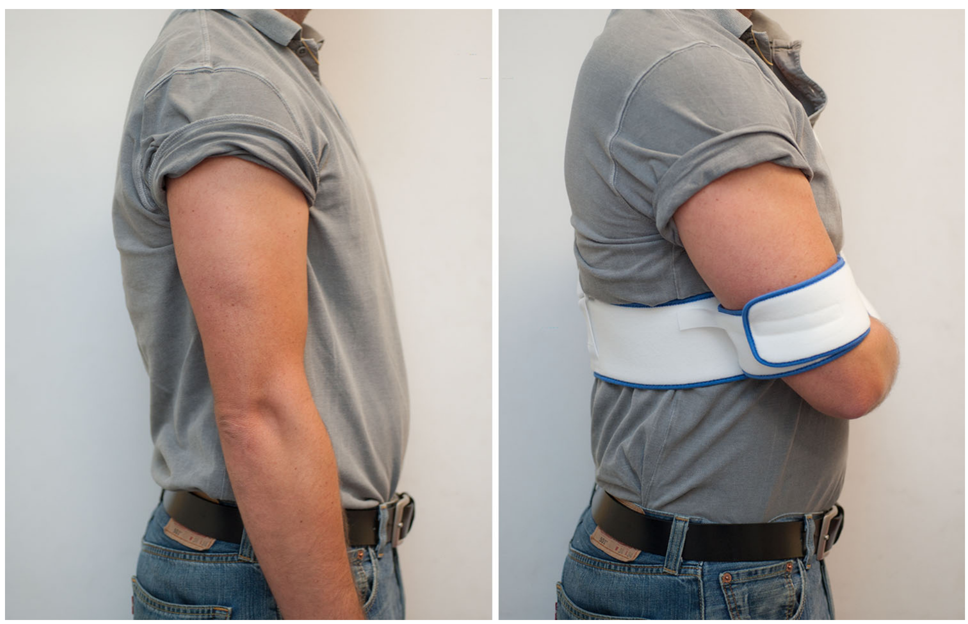

Fig. 8 Wearing a shoulder sling brings the patients arm in internal rotation and flexion, the amount of flexion depends on the patient's constitution

The amount of rotation of the model was not directly proportional to the change of the resulting projection. A change from 0° to 30° of ER or IR resulted in a difference of Δ 4° for the projected HSA, whereas a change from 60° to 70° of ER or IR caused a difference of Δ 8° (161°–153°) (Tables 1, 2).

Similar results were found for the central projection, as long as the rotational axis of our model was kept parallel and the central beam was perpendicular to the projection plane. Deviations of the central beam caused different amounts of distortion in IR and ER as well as a change of the position of the rotational axis in relation to the projection plane (i.e. flexion of the patient's arm as a consequence of a shoulder sling) (Tables 1, 2).

With the central beam set perpendicular to the projection plane and in 45° ER or IR, the projection of the 135° HSA changed to 145° (Δ +10°). With the central ray tilted by 20° in cranio-caudal direction, the projection changed to 150° (Δ +15°) in 45° of IR and to 136° (Δ +1°) in 45° of ER, respectively (Tables 1, 2).

Table 1 Resulting projection of the model simulating different arm positions in orthographic and central projection (central ray 0°) and in true ap-view (central projection, central ray 20° craniocaudal)

	Orthographic projection	Central projection	True ap-view
ER 45°	145°	145°	136°
ER 30°	139°	139°	133°
ER 15°	136°	136°	133°
NR	135°	135°	135°
IR 15°	136°	136°	139°
IR 30°	139°	139°	144°
IR 45°	145°	145°	150°
IR 60°	153°	153°	159°
IR 70°	161°	161°	165°

Table 2 Difference of the projected HSA towards the original HSA of 135° in orthographic and central projection (central ray 0°) and in true ap-view (central projection, central ray 20° craniocaudal)

	Orthographic projection	Central projection	True ap-view
ER 45°	10°	10°	1°
ER 30°	4°	4°	−2°
ER 15°	1°	1°	−2°
NR	0°	0°	0°
IR 15°	1°	1°	4°
IR 30°	4°	4°	9°
IR 45°	10°	10°	15°
IR 60°	18°	18°	24°
IR 70°	26°	26°	30°

Simulation of an average constitutional patient with shoulder sling

Flexion of the humerus is known to change the position of the rotational axis towards the projection plane and the central beam. In a simulated patient with normal weight and the arm in a sling (anteflexion 30°, IR 70°, central ray cranio-caudal 20°), the projection of our model changed from 135° to 158° (Δ +23°).

Simulation of an obese patient wearing a shoulder sling

Simulating the extreme of an obese patient's arm in a sling (60°/70° IR) with a 20° cranio-caudal tilt (anteflexion 50°) led to 141° (Δ +6°, IR 60°), and 131° (Δ −4°, IR 70°), respectively. Having the central beam set perpendicular led to 89° (Δ −46°, IR 60°), and 79° (Δ −56°, IR 70°), respectively (Table 3).

Discussion

The most important finding of this study was that there is a substantial difference in diagnostic findings between different positions of the arm while taking true ap-view X-rays of the proximal humerus.

The true ap-view as part of the trauma series has been recommended for the diagnostic assessment of proximal humerus fractures [14–20]. Strict true ap-projection has been described to determine the humeral HSA [25]. Furthermore, true ap-projection projection allows determining the potential amount of varus or valgus displacement.

Positioning of the patient's arm for true ap-view has never been standardized. Heterogeneously, ER [19, 20], NR [22, 23], and IR [14–18, 24] have been proposed. Textbooks have suggested X-ray fracture diagnostics with the patient wearing a shoulder sling [15, 16, 18], inevitably imposing IR and therefore causing an oblique projection of the proximal humerus. Resulting oblique projections may be confounding [14].

For follow-up studies, the arm may be positioned in NR or ER, because the patient may have less or no pain and does not use a sling anymore. The lack of standardization in arm positioning is obvious on imaging of proximal humeral fractures treated with angular stable implants in published serial X-rays [5, 12]. Angles between angular stable screws and plates or nails remain constant over time. Different projections of the implants in follow-up examinations may therefore clearly indicate different arm positions and/or directions of the central X-ray beam. Any statement concerning change of the HSA may be misleading in this setting. In Fig. 9, failure of osteosynthesis may be suspected. However, projection of the angular

Table 3 Simulation of an average patient wearing a sling with correct central ray and an obese patient wearing a shoulder sling with and without correct inclined central ray for true ap-view

	Average patient Humeral anteflexion 30°, central ray 20° craniocaudal	Obese patient Humeral anteflexion 50°, central ray 20° craniocaudal	Obese patient Humeral anteflexion 50°, central ray perpendicular
Projection			
IR 60°	151°	141°	89°
IR 70°	158°	133°	79°
Difference			
IR 60°	16°	6°	−46°
IR 70°	23°	−2°	−56°

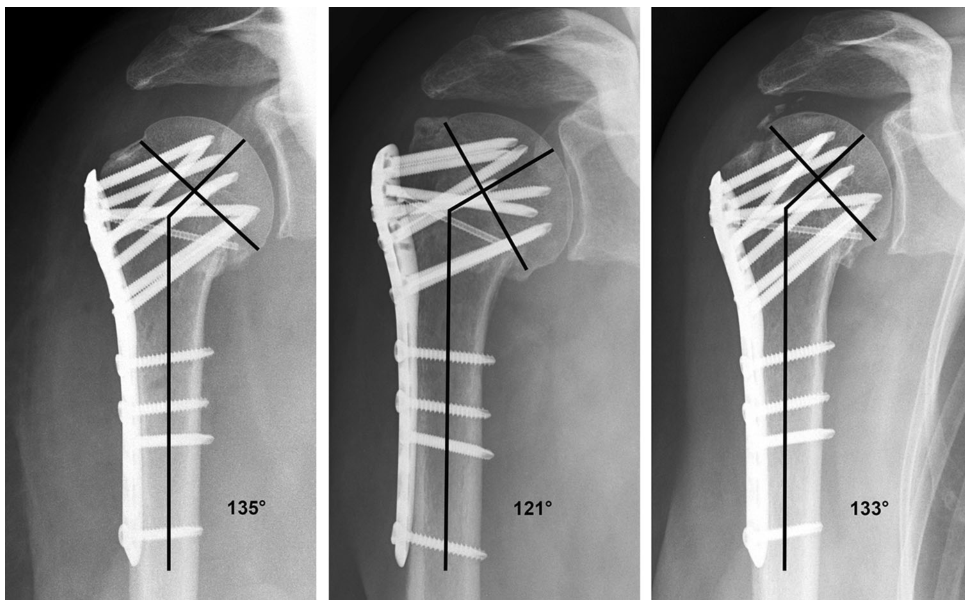

Fig. 9 Change in rotation simulates loss of reduction in this sequence of follow-up examinations (*left* post-operatively, *middle* control after 1 month, *right* final X-ray)

stable implant demonstrates that only patient positioning was changed rather than the relationship between implant and humerus.

Given the oblique anatomical position of the scapula between the coronal and sagittal plane, patient positioning for true ap-view and for standard ap-view results in NR of the patient's arm in a true ap-view (Fig. 1), and in ER in the standard ap-view, respectively (Fig. 2). Our results confirm this anatomical assumption. With our model of the proximal humerus in NR, we did not find any distortion in the projection of the HSA; neither in orthographic projection, nor in central projection with a perpendicular or cranio-caudal tilted central ray.

Our results further demonstrate that ER and IR of the patients arm for the projection of the HSA in orthographic and central projection may misleadingly result in misdiagnosed valgus displacement. Applying a perpendicular central beam, the distortion appeared similar in IR and ER. With the central beam in 20° cranio-caudal direction according to the true ap-view procedure, the distortion of projection seems to be more influenced by IR.

Our simulation of an average constitutional patient with shoulder sling in case of a correct true ap-view changed the projection to 151° ($\Delta +16°$), pretending greater valgus than it really is. This seems to be of great importance, since varus displacement has commonly been described to be associated with poor outcome [1, 2, 4, 9, 10, 12] and impaired biomechanical conditions. Varus malalignment is known to change the pretension of the rotator cuff and to result in significantly decreased supraspinatus efficiency and higher arm elevation forces [11].

Interindividual retrotorsion should not cause relevant bias, because ER or IR from 0° to 30° only led to a change of HSA of 4° or less.

Therefore, neutral arm positioning as described by Cave and Roberts [27, 28] according to the neutral zero method with the palm of hand on the lateral thigh may be practical and reproducible for initial and follow-up examination.

Of course, a CT scan can help to evaluate the initial fracture situation or a specific question, but it is not adequate for longitudinal follow-up examination because of the inherent radiation exposure.

This study has several limitations. In relation to the complex and non-geometrical surface of the humeral head, the simplified two-dimensional model might be a weakness of this study. However, it sufficiently reveals the importance of standardized patient positioning. Furthermore, we only argue geometrically and not clinically.

In conclusion, standard fixation of the patient's arm in a shoulder sling in IR for true ap-view may result in an oblique projection, potentially leading to incorrect surgical implications. To prevent misdiagnosed valgus or varus angulation, NR of the arm should be obeyed when performing true ap-view X-ray. We, therefore, highly recommend to overcome the traditionally arm position, ensuring the true amount of dislocation to assure correct surgical implications and comparable follow-up examinations.

Acknowledgments The first author wants to thank Mag. Manfred Dopler for sharing his geometrical knowledge and for the discussion that led to this manuscript.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

References

1. Benegas E, Zoppifilho A, Ferreirafilho A, Ferreiraneto A, Negri J, Prada F et al (2007) Surgical treatment of varus malunion of the proximal humerus with valgus osteotomy. J Shoulder Elbow Surg 16(1):55–59. doi:10.1016/j.jse.2006.04.011
2. Blonna D, Rossi R, Fantino G, Maiello A, Assom M, Castoldi F (2009) The impacted varus (A2.2) proximal humeral fracture in elderly patients: is minimal fixation justified? A case control study. J Shoulder Elbow Surg 18(4):545–552. doi:10.1016/j.jse.2009.02.004
3. Court-Brown CM, McQueen MM (2004) The impacted varus (A2.2) proximal humeral fracture: prediction of outcome and results of nonoperative treatment in 99 patients. Acta Orthop Scand 75(6):736–740. doi:10.1080/00016470410004111
4. Hardeman F, Bollars P, Donnelly M, Bellemans J, Nijs S (2012) Predictive factors for functional outcome and failure in angular stable osteosynthesis of the proximal humerus. Injury 43(2):153–158. doi:10.1016/j.injury.2011.04.003
5. Nolan BM, Kippe MA, Wiater JM, Nowinski GP (2011) Surgical treatment of displaced proximal humerus fractures with a short intramedullary nail. J Shoulder Elbow Surg 20(8):1241–1247. doi:10.1016/j.jse.2010.12.010
6. Poeze M, Lenssen AF, Van Empel JM, Verbruggen JP (2010) Conservative management of proximal humeral fractures: can poor functional outcome be related to standard transscapular radiographic evaluation? J Shoulder Elbow Surg 19(2):273–281. doi:10.1016/j.jse.2009.07.066
7. Resch H (2003) Fractures of the humeral head. Unfallchirurg 106(8):602–617. doi:10.1007/s00113-003-0661-2
8. Robinson CM, Wylie JR, Ray AG, Dempster NJ, Olabi B, Seah KTM et al (2010) Proximal humeral fractures with a severe varus deformity treated by fixation with a locking plate. J Bone Joint Surg Br 92(5):672–678. doi:10.1302/0301-620X.92B5.22849
9. Solberg BD, Moon CN, Franco DP, Paiement GD (2009) Surgical treatment of three and four-part proximal humeral fractures. J Bone Joint Surg Am 91(7):1689–1697. doi:10.2106/JBJS.H.00133
10. Solberg BD, Moon CN, Franco DP, Paiement GD (2009) Locked plating of 3- and 4-part proximal humerus fractures in older patients: the effect of initial fracture pattern on outcome. J Orthop Trauma 23(2):113–119. doi:10.1097/BOT.0b013e31819344bf
11. Voigt C, Kreienborg S, Megatli O, Schulz AP, Lill H, Hurschler C (2011) How does a varus deformity of the humeral head affect elevation forces and shoulder function? A biomechanical study with human shoulder specimens. J Orthop Trauma 25(7):399–405. doi:10.1097/BOT.0b013e31820beb80
12. Agudelo J, Schürmann M, Stahel P, Helwig P, Morgan S, Zechel W et al (2007) Analysis of efficacy and failure in proximal humerus fractures treated with locking plates. J Orthop Trauma 21(10):676–681. doi:10.1097/BOT.0b013e31815bb09d
13. Agel J, Jones C, Sanzone A, Camuso M, Henley M (2004) Treatment of proximal humeral fractures with Polarus nail fixation. J Shoulder Elbow Surg 13(2):191–195. doi:10.1016/j.jse.2003.12.005
14. Neer CS II (1970) Displaced proximal humeral fractures: part I. classification and evaluation. J Bone Joint Surg Am 23(52):1077–1089
15. Bohsali KI, Wirth MA (2009) Fractures of the proximal humerus. In: Rockwood CA (ed) The shoulder. Saunders Elsevier, Philadelphia, pp 297–298
16. Guy P (2007) Humerus, proximal. In: Rüedi TP, Buckley RE, Moran CG (eds) AO principles of fracture management, 2nd edn. AO Publishing, Davos Platz, pp 573–574
17. Sidor ML, Zuckerman JD, Lyon T, Koval K, Cuomo F, Schoenberg N (1993) The Neer classification system for proximal humeral fractures. An assessment of interobserver reliability and intraobserver reproducibility. J Bone Joint Surg Am 75(12):1745–1750
18. Leibman MI, Zuckerman JD (2005) Proximal humeral fractures: clinical evaluation and classification. In: Zuckerman JD, Koval KJ (eds) Shoulder Fractures. Thieme Medical Publishers Inc., New York, pp 34–49
19. Zeiler C, Wiedemann E, Brunner U, Mutschler W (2003) Schulterdiagnostik. Trauma und Berufskrankheit. doi:10.1007/s10039-002-0694-8
20. Jensen KL, Rockwood CA (2009) Radiographic evaluation of shoulder problems. In: Rockwood CA (ed) The shoulder. Saunders Elsevier, Philadelphia, pp 177–178
21. Grashey R (1939) Atlas typischer Röntgenbilder vom normalen Menschen. 6. Auflage ed. J. F. Lehmanns Verlag, München-Berlin
22. Swallow RA, Naylor E, Roebuck EJ, Whitley AS (1991) The shoulder. Clark's positioning in radiography, 11th edn. Butterworth-Heinemann Ltd, Oxford, p 74
23. Wambacher M, Oberladstaetter J, Rieger M (2010) Konventionelle Radiologie und Computertomographie der Schulter. In: Habermeyer P (ed) Schulterchirurgie, 4th edn. Elsevier Gmbh, Munich, pp 99–144
24. Siebenrock K, Gerber C (1993) The reproducibility of classification of fractures of the proximal end of the humerus. J Bone Joint Surg Am 75(12):1751–1755

25. Hertel R, Knothe U, Ballmer F (2002) Geometry of the proximal humerus and implications for prosthetic design. J Shoulder Elbow Surg 11(4):331–338. doi:10.1067/mse.2002.124429
26. Boileau P, Walch G (1997) The three-dimensional geometry of the proximal humerus. Implications for surgical technique and prosthetic design. J Bone Joint Surg Br 79(5):857–865
27. Cave E, Roberts S (1936) A method for measuring and recording joint function. J Bone Joint Surg 18(2):455–465
28. Ryf C, Weymann A (1995) The neutral zero method: a principle of measuring joint function. Injury 26:1–11