Balloon osteoplasty—a new technique for minimally invasive reduction and stabilisation of Hill–Sachs lesions of the humeral head: a cadaver study

Gunther H. Sandmann · Philipp Ahrens ·
Christoph Schaeffeler · Jan S. Bauer ·
Chlodwig Kirchhoff · Frank Martetschläger ·
Dirk Müller · Sebastian Siebenlist · Peter Biberthaler ·
Ulrich Stöckle · Thomas Freude

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Abstract

Purpose Traumatic shoulder dislocation may be complicated by concomitant bony injury of the glenoid rim or the humeral head. In Hill–Sachs lesions, reconstruction techniques vary widely and range from open reduction to tendon transposition or humeral head derotation. These operations are extensive and have questionable outcomes. With the expertise from vertebral compression fracture reduction by kyphoplasty, we examined in a cadaver feasibility study whether reduction of the Hill–Sachs lesion via hydraulic lift might be an anatomical and minimally invasive treatment option. We postulated that the use of a balloon-assisted kyphoplasty reduction could achieve almost anatomical correction of the defect.

Methods We created Hill–Sachs lesions in six humeral specimens and performed a computed tomography (CT)

scan before and after reduction with the kyphoplasty system. The entry point at the greater tuberosity and balloon positioning was visualised by fluoroscopy. The size of the Hill–Sachs lesion before and after reduction was measured using CT scans in the axial orientation.

Results Using the balloon kyphoplasty system, we achieved a statistically significant reduction (80 %) of the Hill–Sachs lesion.

Conclusion In a preliminary cadaver study we show that using a balloon kyphoplasty system might be an alternative treatment option for Hill–Sachs lesions, with reduced collateral damage that can occur with other minimally invasive techniques. Future work is needed to evaluate the technique under arthroscopic conditions.

Introduction

Due its anatomy, the shoulder is one of the most mobile and least constrained joints in the body, and its range of motion in several planes may be accompanied by pathological instability. After a traumatic shoulder dislocation, neurological deficits, rotator cuff tears or fractures of the greater tuberosity or glenoid can appear [1, 2]. Numerous factors have been identified as potential risk factors for recurrent instability, including short postoperative immobilisation, younger age, contact sports, poor glenohumeral ligament quality, bony Bankart lesions and Hill–Sachs defects [3]. Hill–Sachs lesions are cortical impression fractures of the humeral head that involve 10–30 % of the articular surface [4]. These lesions result from high-energy impact of the humeral head against the antero-inferior or posterior glenoid rim and occur typically in shoulder dislocations. Incidence

Gunther H. Sandmann and Philipp Ahrens contributed equally

G. H. Sandmann (✉) · P. Ahrens · C. Kirchhoff ·
F. Martetschläger · D. Müller · S. Siebenlist · P. Biberthaler
Department of Traumatology, Klinikum rechts der Isar,
Technische Universität München,
Ismaninger Strasse 22,
81675 Munich, Germany
e-mail: Gunther.Sandmann@mri.tum.de

C. Schaeffeler · J. S. Bauer
Department of Radiology, Klinikum rechts der Isar,
Technische Universität München,
Ismaninger Strasse 22,
81675 Munich, Germany

U. Stöckle · T. Freude
BG Klinik Tübingen, Eberhard-Karls University,
Schnarrenbergstrasse 95,
72076 Tübingen, Germany

varies between 47 % and 80 % for anterior and up to 100 % in posterior dislocation events [5]. The Hill–Sachs defect is usually centred at a mean of 209° along the axial axis of the articular surface, with an average defect arc of 52° [6]. It is well known that recurrent dislocations increase the defect zone [7]. Whereas the concomitant Bankart lesion must be addressed in most cases, the Hill–Sachs lesion is rather often disregarded unless it engages at the anteroinferior rim of the glenoid and causes recurrent dislocations [8]. Nevertheless, the Hill–Sachs lesion—graded by defect depth by Calandra et al. [9]—and the inverted-pear glenoid were found to be the main reasons for failed arthroscopic shoulder stabilisations [8]. Itoi et al. and Yamamoto et al. evaluated the importance of the bony defect in anterior shoulder instability and outlined a therapeutic treatment method [10]. Whereas there is consensus that bony glenoid defects >21 % of the glenoid surface must be addressed by anatomical (e.g. J-bone graft [11]) or extra-anatomical reconstructions, such as the Latarjet procedure [12, 13], surgical interventions for Hill–Sachs lesions are diverse. For lesions comprising 20–40 %, several approaches have been described ranging from percutaneous correction [14] evaluated in the cadaver model to clinical interventions such as arthroscopic interference screw insertion, remplissage manoeuvres [15], osteochondral allograft transplantations [16] and rotational osteotomies [17]. Shenoy et al. [18] described the use of the lateral clavicle as an autograft to repair reverse Hill–Sachs defects, and the use of allografts has also been described [13]. Defects involving >40 % of the articular surface often require arthroplasty [19].

Generally, most of these techniques are surgically extensive and their outcomes often questionable. In particular, operations using tendon transpositions, as described by McLaughlin [20] or Hawkins [21] or humeral head derotation [22] often used in the past, are associated with a reduced range of motion. Therefore the aim of this feasibility study was to develop a minimally invasive procedure to restore the anatomical humeral head geometry as an innovative treatment option.

Methods

Six formalin-fixed cadaveric shoulders were used (mean age, 77 years) for biomechanical testing. Before testing, all humeral heads were scanned using 256-row multidetector computed tomography (MDCT) (Philips, Best, The Netherlands), using a high spatial resolution protocol (in-plane resolution 0.25 mm, slice thickness 0.6 mm, edge enhancing bone reconstruction kernel) to assess original geometry (Figs. 1 and 2). The specimens were attached to a clamp and an impression fracture was created using a metal punch. Using this setup, we always achieved a Calandra type III lesion [9, 23]. Afterwards, we examined the impression fracture for size in an MDCT scan, as

Fig. 1 **a** Different types of fenestrated custom-made cannulas with the KyphX Xpander® balloon catheter. **b** Extended balloon through fenestrated cannula (detail)

described above, and measured fracture dimension in 15 consecutive 2-mm-thick slices, reformatted perpendicular to the humeral shaft axis. These prepared humeri were potted into metal cylinders and positioned under the C arm so that the fractured circumference could be seen in an axial view (Fig. 3). The approach through the greater tuberosity (Fig. 2) was chosen to benefit from the most stable osseous region of the humeral head during the osteoplasty. We modified the standard kyphoplasty cannula for our purpose so that the cannula was fenestrated and balloon positioning was easy to handle (Fig. 1). After cannula placement, the balloon was inserted under C-arm control and softly inflated (Fig. 3). We used the KyphX Xpander® (Kyphon/Medtronic, Memphis, TN, USA) balloon catheter and inflated the device to a maximum of 120 psi with amidotrizoic acid (Gastrografin, Schering, Berlin, Germany) (Fig. 4). After smooth reduction, beginning from the centre, the balloon was deflated and rotated to reach the lower and later the upper parts of the fracture. We inflated/deflated repeatedly per position because we have found that in reducing tibial plateau fractures, fracture reduction needed time for the impacted bone to find its way back to its anatomical position. After reduction, we evaluated results using another MDCT scan and calculated the remaining Hill–Sachs lesion in cubic millimetres using IntelliSpace Portal™, Philips Healthcare®, Best, The Netherlands.

Statistical analysis

Statistical analysis was performed using the software package SPSS (version 19, IBM, Somers, NY, USA). All data

Fig. 2 **a** Clinical image of the Hill–Sachs lesion. **b** Cannula insertion via the greater tubercle. “*”Hill–Sachs lesion

Fig. 3 **a–c** Axial view during fluoroscopy showing reduction with the balloon. **d–f** Anteroposterior view with Hill–Sachs lesion reduction

were tested for normal distribution and compared using *t* tests. The level of significance was set at $P < 0.05$.

Results

Humeral head volume (formalin-fixed samples, $n=6$) was calculated using a CT scan with a mean of $39,130 \pm 6,577 \text{ mm}^3$.

We created Hill–Sachs defects by blunt trauma. Mean lesion size was $1,420 \text{ mm}^3 \pm 482$ (range $566\text{--}1,912 \text{ mm}^3$). Impression fracture size was a mean of 3.6% of total humeral head volume, ranging from 1.6% to 5.4% . All lesions could be graded according to Calandra et al. [9] as grade III lesions. After lesion reduction using the balloon kyphoplasty system, mean lesion size was $282 \text{ mm}^3 \pm 191$ (range $40\text{--}560 \text{ mm}^3$); thus an average of 80% of the defect size was restored. Of note, the original

Fig. 4 **a, b** Hill–Sachs lesion before and after balloon reduction. **c** Three-dimensional image of the humeral head with Hill–Sachs lesion. **d** Axial view after balloon reduction. “*”Hill–Sachs defect

contour of the humeral head was not extended in any of the cases. Using the *t* test for paired samples, we found a *P* value of 0.0007, which was highly statistically significant. Values of the sample pairs are reported in Table 1.

Discussion

The Hill–Sachs lesion is associated with shoulder instability and recurrent dislocations [6, 7, 24], which affect shoulder function and even the outcome after arthroscopic Bankart repairs [8]. If the lesion occupies a specific size and position on the humeral head, shoulder destabilisation occurs [25–27]. Sekiya et al. showed in their biomechanical work that even Hill–Sachs lesions affecting 12.5 % of the humeral head lead to glenohumeral-joint destabilisation [23]. Many Hill–Sachs lesions are overlooked or misinterpreted and their size underestimated—in part because treatment options are generally extensive and often technically demanding. Nevertheless, lesions comprising 20–40 %, or even more, of the articular surface require surgical intervention. Surgical options are many, and making the right choice is often difficult. Many techniques have been described to reduce the impression fracture, and the most popular surgical options are remplissage—i.e. capsulotenodesis to the humeral bony defect, which can be done arthroscopically [28–30]. Generally, the redislocation rate using the remplissage technique is low and ranges between 2 % and 6 % [30], whereas a slight restriction in external rotation of approximately 10° appears. Boileau et al. [29] showed that this limited range of motion did not affect sports activity and that 90 % of patients were able to return to sports, although only 68 % at a preinjury level. Alternatively, defect filling with allografts as an osteochondral transplantation [31] is described in the literature, but larger case series evaluating this technique have not been published. We show in a preliminary cadaver feasibility study successful use of the kyphoplasty balloon system for reducing humeral head fractures. The kyphoplasty system has been used for many years in fracture treatment of vertebral bodies, and as its use

has increased [32], it is also increasingly popular to reduce other impression fractures [33]. Its extravertebral application is thus spreading and the technique has been described for reducing tibial plateau [33], distal radius [34], displaced calcaneus and even acetabular fractures [35].

To our knowledge, we are the first to describe the use of kyphoplasty balloons for reducing humeral head impression fractures in a pilot cadaver study that shows an almost anatomical reduction can be achieved. The technique is easy to learn and instruments simple to handle, so that the reduction of Hill–Sachs lesions may become easier, with better outcomes.

We admit that this was only a laboratory study and that work is yet to be done in terms of clinical application. There are still several questions that must be answered, especially concerning the feasibility of the new technique under arthroscopic conditions and the matter of defect filling. It might be that the reduction itself is sufficient, as long as range of motion is limited to leave the defect unaffected for six weeks. Alternatively, defect filling with cancellous bone or bone substitutes might be superior to cement filling of the defect, particularly considering the generally young age of affected patients. The method does not restore cartilage damage but might help avoid future damage to the humeral head and recurrent shoulder dislocations. Though the lesions in our setting were relatively small, we have no doubt that larger lesions can be successfully treated using this new technique.

Conclusion

Fracture reduction, especially in mobile joints such as the shoulder, is always a challenge and demands highly trained and ambitious surgeons. With the minimally invasive surgical technique described here, reduction with less collateral damage and reduced patient convalescence is possible. Results of our laboratory study are promising and show an anatomical reduction of the impression fracture in all cases.

Table 1 Results from pre- and postreduction computed tomography scans

Sample	Volume humeral head (mm ³)	Volume Hill–Sachs lesion (mm ³)	Percent total volume	Volume Hill–Sachs lesion after osteoplasty (mm ³)	Percent total volume after osteoplasty
1	47.906	1,510	3.15	560	1.17
2	47.164	1,676	3.55	350	0.74
3	36.440	566	1.55	40	0.11
4	34.370	1,186	3.45	88	0.26
5	35.162	1,912	5.44	330	0.94
6	33.736	1,670	4.95	326	0.97

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References

1. Bahk M, Keyurapan E, Tasaki A, Sauers EL, McFarland EG (2007) Laxity testing of the shoulder: a review. *Am J Sports Med* 35:131–144
2. Robinson CM, Shur N, Sharpe T, Ray A, Murray IR (2012) Injuries associated with traumatic anterior glenohumeral dislocations. *J Bone Joint Surg Am* 94:18–26
3. Grana WA, Buckley PD, Yates CK (1993) Arthroscopic Bankart suture repair. *Am J Sports Med* 21:348–353
4. Krackhardt T, Schewe B, Albrecht D, Weise K (2005) Arthroscopic fixation of the subscapularis tendon in the reverse Hill–Sachs lesion for traumatic unidirectional posterior dislocation of the shoulder. *Arthroscopy* 227.e1–227.e6
5. Chen AL, Hunt SA, Hawkins RJ, Zuckerman JD (2005) Management of bone loss associated with recurrent anterior glenohumeral instability. *Am J Sports Med* 33:912–925. doi:10.1177/0363546505277074
6. Calandra JJ, Baker CL, Uribe J (1989) The incidence of Hill–Sachs lesions in initial anterior shoulder dislocations. *Arthroscopy* 5:254–257
7. Cetik O, Uslu M, Ozsar BK (2007) The relationship between Hill–Sachs lesion and recurrent anterior shoulder dislocation. *Acta Orthop Belg* 73:175–178
8. Burkhart SS, De Beer JF (2000) Traumatic glenohumeral bone defects and their relationship to failure of arthroscopic Bankart repairs: significance of the inverted-pear glenoid and the humeral engaging Hill–Sachs lesion. *Arthroscopy* 16:677–694
9. Calandra JJ, Baker CL, Uribe J (1989) The incidence of Hill–Sachs lesions in initial anterior shoulder dislocations. *Arthroscopy* 5:254–257
10. Yamamoto N, Itoi E, Abe H, Kikuchi K, Seki N, Minagawa H, Tuoheti Y (2009) Effect of an anterior glenoid defect on anterior shoulder stability: a cadaveric study. *Am J Sports Med* 37:949–954. doi:10.1177/0363546508330139
11. Auffarth A, Kralinger F, Resch H (2011) Anatomical glenoid reconstruction via a J-bone graft for recurrent posttraumatic anterior shoulder dislocation. *Oper Orthop Traumatol* 23:453–461. doi:10.1007/s00064-011-0055-5
12. Latarjet M (1954) Treatment of recurrent dislocation of the shoulder. *Lyon Chir* 49:994–997
13. Allain J, Goutallier D, Glorion C (1998) Long-term results of the Latarjet procedure for the treatment of anterior instability of the shoulder. *J Bone Joint Surg Am* 80:841–852
14. Kazel MD, Sekiya JK, Greene JA, Bruker CT (2005) Percutaneous correction (humeroplasty) of humeral head defects (Hill–Sachs) associated with anterior shoulder instability: a cadaveric study. *Arthroscopy* 21:1473–1478. doi:10.1016/j.arthro.2005.09.004
15. Park MJ, Tjoumakaris FP, Garcia G, Patel A, Kelly JDt Arthroscopic remplissage with bankart repair for the treatment of glenohumeral instability with Hill–Sachs defects. *Arthroscopy* 27:1187–1194. DOI S0749-8063(11)00522-6 [pii]10.1016/j.arthro.2011.05.010
16. Engel T, Hepp P, Osterhoff G, Josten C (2009) Arthroscopic reduction and subchondral support of reverse Hill–Sachs lesions with a bioabsorbable interference screw. *Arch Orthop Trauma Surg* 129:1103–1107. doi:10.1007/s00402-009-0840-x
17. Keppler P, Holz U, Thielemann FW, Meinig R (1994) Locked posterior dislocation of the shoulder: treatment using rotational osteotomy of the humerus. *J Orthop Trauma* 8:286–292
18. Shenoy R, Kamineni S (2011) Lateral clavicular autograft for repair of reverse hilllysachs defect. *Open Orthop J* 5:49–51. doi:10.2174/1874325001105010049
19. Gavrilidis I, Magosch P, Lichtenberg S, Habermeyer P, Kircher J (2010) Chronic locked posterior shoulder dislocation with severe head involvement. *Int Orthop* 34:79–84
20. McLaughlin HL (1963) Dislocation of the shoulder with tuberosity fracture. *Surg Clin North Am* 43:1615–1620
21. Hawkins RJ, Neer CSI, Pianta RM, Mendoza FX (1987) Locked posterior dislocation of the shoulder. *J Bone Joint Surg* 69:9–18
22. Weber BG, Simpson LA, Hardegger F (1984) Rotational humeral osteotomy for recurrent anterior dislocations of the shoulder associated with a large Hill–Sachs lesion. *J Bone Joint Surg* 66:1443–1450
23. Sekiya JK, Wickwire AC, Stehle J, Debski RE (2009) Hill–Sachs defects and repair using osteoarticular allograft transplantation. *Am J Sports Med* 37:2459–2466
24. Saito H, Itoi E, Minagawa H, Yamamoto N, Tuoheti Y, Seki N (2009) Location of the Hill–Sachs lesion in shoulders with recurrent anterior dislocation. *Arch Orthop Trauma Surg* 129:1327–1334. doi:10.1007/s00402-009-0854-4
25. Burkhart SS, De Beer JF (2000) Traumatic glenohumeral bone defects and their relationship to failure of arthroscopic Bankart repairs: significance of the inverted-pear glenoid and the humeral engaging Hill–Sachs lesion. *Arthroscopy* 16:677–694
26. Palmer I, Widen A (1948) The bone block method for recurrent dislocation of the shoulder joint. *J Bone Joint Surg Br* 30B:53–58
27. Weber BG, Simpson LA, Hardegger F (1984) Rotational humeral osteotomy for recurrent anterior dislocation of the shoulder associated with a large Hill–Sachs lesion. *J Bone Joint Surg Am* 66:1443–1450
28. Purchase RJ, Wolf EM, Hobgood ER, Pollock ME, Smalley CC (2008) Hillysachs “remplissage”: an arthroscopic solution for the engaging hilllysachs lesion. *Arthroscopy* 24:723–726. doi:10.1016/j.arthro.2008.03.015
29. Boileau P, O’Shea K, Vargas P, Pinedo M, Old J, Zumstein M (2012) Anatomical and functional results after arthroscopic hilllysachs remplissage. *J Bone Joint Surg Am* 94:618–626
30. Zhu YM, Lu Y, Zhang J, Shen JW, Jiang CY (2011) Arthroscopic Bankart repair combined with remplissage technique for the treatment of anterior shoulder instability with engaging Hill–Sachs lesion: a report of 49 cases with a minimum 2-year follow-up. *Am J Sports Med* 39:1640–1647
31. Chapovsky F, Kelly JD IV (2005) Osteochondral allograft transplantation for treatment of glenohumeral instability. *Arthroscopy* 21:1007. doi:10.1016/j.arthro.2005.04.005
32. Boonen S, Wahl DA, Nauroy L, Brandi ML, Bouxsein ML, Goldhahn J, Lewiecki EM, Lyritis GP, Marsh D, Obrant K, Silverman S, Siris E, Akesson K (2011) Balloon kyphoplasty and vertebroplasty in the management of vertebral compression fractures. *Osteoporos Int* 22:2915–2934. doi:10.1007/s00198-011-1639-5
33. Ahrens P, Sandmann G, Bauer J, Konig B, Martetschlager F, Muller D, Siebenlist S, Kirchhoff C, Neumaier M, Biberthaler P, Stockle U, Freude T (2012) Balloon osteoplasty—a new technique for reduction and stabilisation of impression fractures in the tibial plateau: a cadaver study and first clinical application. *Int Orthop*. Jun 24. [Epub ahead of print] DOI 10.1007/s00264-012-1592-8
34. Broome B, Mauffrey C, Statton J, Voor M, Seligson D (2012) Inflation osteoplasty: in vitro evaluation of a new technique for reducing depressed intra-articular fractures of the tibial plateau and distal radius. *J Orthop Traumatol*. doi:10.1007/s10195-012-0185-z
35. Gupta AK, Gluck GS, Parekh SG (2011) Balloon reduction of displaced calcaneus fractures: surgical technique and case series. *Foot Ankle Int* 32:205–210. doi:10.3113/FAI.2011.0205