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Late screw-related complications in locking plating of proximal humerus fractures: A systematic review

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ABSTRACT

Locking plating is a common surgical treatment of proximal humeral fractures with satisfactory clinical results. Implant-related complications, especially screw-related, have been reported, however, the lack of information regarding their onset, used surgical technique, complexity of the fracture, bone quality etc., prevents from understanding the causes for them. The aim of this systematic review is to identify the potential risk factors for late screw complications by gathering information about the patient characteristics, comorbidities, fracture types, surgical approaches and implant types. A PubMed search was performed using humerus, fractures, bone and locking as keywords in clinical papers written in English. All abstracts and manuscripts on distal or humerus shaft fractures, and those on proximal humerus fractures without any or with only iatrogenic complications were excluded. One hundred studies met the inclusion criteria, resulting in 33% of the reported cases having at least one complication, with 11% of all complications being screw-related. Most of the latter were secondary screw perforations and screw cut-outs, being predominantly linked to poor bone quality, while screw loosening and retraction were found less frequently as a result of locking mechanism failure. Overall, the amount of information for complications was limited and screw perforation was the most frequent screw-related complication, mostly reported in female patients older than 50 years, following four-part or AO/OTA type C fractures and detected four weeks postoperatively. The sparse information in the literature could be an indicator that the late screw complications might have been under-reported and under-described, making the understanding of the screw-related complications even more challenging.

Introduction

Locking plates have led to important changes in bone fracture management, allowing flexible biological fracture fixation based on the principle of an internal fixator and decreasing the incidence of bone union failures, compared to conventional plates [1–4]. Following the introduction of the locking compression plate (LCP) [5] and the less invasive stabilization system (LISS) by the *Arbeitsgemeinschaft für Osteosynthesefragen* (AO) [6] with the first clinical results published in 2003 [7], the use of locking plates nowadays has resulted in development of different designs for a variety of anatomical locations and serves as a treatment option for several diseases and deformities apart from primary fractures [8].

Locking plates have revolutionized fracture fixation at the proximal humerus too [7,9]. Several studies have evaluated their biomechanical behavior [10] or reported clinical outcomes [7,11,12]. According to previous literature reviews, locking plates are considered as a more successful implant of choice, especially for fixation of proximal humeral fractures [13,14], with complication rates being less than 13% [15], compared to conventional plates, where the percentage of complications can be as high as 50% [16]. However, some articles demonstrate complication rates higher than expected, related to avascular necrosis, delayed union, malunion, non-union, and intrinsic implant failure [4,17,18].

Especially in case of screw-related mechanical complications, such as screw perforation, cut-out, retraction and/or loosening, the complication rates are not negligible. For instance, screw perforation of the articular cartilage occurs in almost 11.6% of all humerus fractures [17], often registered together with avascular necrosis of the humeral head (4.6% [18]), varus collapse (6.8% [18]) or loss of

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reduction (12.2% [17]). In the early years of locking plate applications, most screw-related complications were detected in the early postoperative period, defined as early or primary complications, and assumed to be linked to poor operating technique [4,19–21]. Later, authors started to report about a secondary onset of screw complications [22], assumed to be mainly resulting from poor bone quality. However, most of the studies provided only limited details on the secondary screw-related complications, often neglecting to describe the exact type of failure, the onset of complications and the conditions leading to failure at the bone-screw interface. This results in limited current knowledge about the risk factors for late screw-related complications, impeding us in addressing them in order to reduce the screw-related complication rates.

In order to understand the risk factors behind the late screw complications, we have performed a systematic review of the current literature focusing on the use of locking plates for proximal humerus fracture fixation, aiming to reveal the incidence of late bone-screw interface complications, such as: (a) screw perforation, (b) screw cut-out, (c) screw loosening and (d) screw retraction (pull-out). Our objectives were to determine the onset of bone-screw interface failure and identify the surgical, implant and patient related characteristics that can represent the risk factors for late onset of screw complications.

Materials and methods

A PubMed search was performed on 28th of March 2019 with humerus fracture locking as keywords, incorporating the following script: ((“humerus” [MeSH Terms] OR “humerus” [All Fields]) AND (“fractures, bone” [MeSH Terms] OR (“fractures” [All Fields] AND “bone” [All Fields]) OR “bone fractures” [All Fields] OR “fracture” [All Fields])) AND locking [All Fields].

Articles were included based on the following criteria:

(a) Proximal humerus fractures.
(b) Use of locking plates.
(c) Late screw related complications.
(d) English language for both abstract and manuscript.

The following information were collected for all publications:

- Year of publication – to identify any patterns reflecting surgeon’s experience with locking plate techniques.
- Type of study (prospective or retrospective) – to identify any correlation between screw complications and surgeons experience with locking plate techniques.
- Patients age – to find out whether advanced age is linked to increased incidence of screw related complications.
- Classification type – to understand whether the complexity of fractures is a potential risk factor.
- Type of locking plates – to identify any relations choice of plates and screw complications.
- Follow up duration – to determine postoperative time point(s) with higher risk of late screw complications.

In terms of failure mode, the focus was on:

- Screw perforation, defined as bone-screw interface failure leading to screw tip axially penetrating through the subchondral bone into the joint.
- Screw cut-out, defined as bone-screw interface failure related to movement in direction perpendicular to the screw axis and distal displacement of the humeral head fragment.
- Screw purchase failure, defined as bone-screw interface failure without macro displacement of either the bone fragment or the screw.
- Locking mechanism loosening, defined as loosening of the thread connection between plate and screw (in the plate hole).
- Screw retraction, defined by unscrewing or pulling-out of the screw from the bone and/or plate (along the screw axis).

From the cases with late screw complications, further details were collected about the bone or fracture fixation quality, comorbidities or other risk factors (e.g. smoking, alcohol abuse, obesity, and osteoporosis), details about the surgical approach and any other relevant information. Further implant-related complications, such as plate bending, plate breakage, plate-induced subacromial impingement, were excluded from the focus of the study, but were shortly reviewed instead for the completion of the work. Similarly, other non-implant related complications, including avascular necrosis without screw migration, infection, delayed union, malunion, non-union, were not within the scope of the analysis, but they were shortly described.

Results

The search resulted in 634 found articles. Out of them, 534 papers were related to distal or shaft humerus fractures, or describing either no complications or only early postoperative complications (Fig. 1). Therefore, only 100 studies were included in this work.

Year of publication

The first published work on late screw related complications was in 2005 [23], followed by seventeen articles in the early period of locking plate applications (2005–2009) [13,18–33]. Forty-six papers reported on late screw related complications in the mid-term period of locking plate applications (2010–2014) [34–79], while thirty-six – in the most recent period of applications (2015–2019) [80–115]. Until the day of literature search, only five publications were published in 2019 [116–120] (Fig. 2).

Type of study

Forty-five studies recruited patients prospectively [17,20–24,27,29,32,34–36,39,40,42,47–49,52,55,57,59,65–67,69,71,75,77,79,81,83,85,87,89,92,95,96,98,106–109,114,115] and 55 articles reviewed retrospectively the medical history of patients treated for proximal humeral fractures [13,18,19,25,26,28,30,31,33,37,38,41,43–46,50,51,53,54,56,58,60–64,68,70,72,73,74,76,78,80,82,84, 86,88,90,91,93,94,99–105,110–113]. The studies aimed to report clinical results from the use of locking plates, compare different surgical techniques (e.g. with or without the use of allografts), or compare locking plates to alternative treatment methods of proximal humerus fractures.

Number of patients and fractures

In several studies the small number of patients (less than 50) was considered as a limitation. Nine articles included less than 25 participants [24,54,65–68,74,79,88], seventy-two studies were with a participants number ranging between 26 and 100 [13,17,19,20,23–27,29–40,42–47,50–52,57–62,64,67,70,72,73–76,78,79,83–90,92,93,96–98,101,104–115] and nineteen studies included more than 100 patients [21,22,28,48,49,65,66,68,71,77,80–82,91,94,95,99,100,102]. The total number of patients included in all studies was 7182 with 7198 fractures, considering 16 patients having bilateral proximal humeral fractures.

Patients age

The age of patients included in the reviewed publications ranged from 16 to 100 years. For most of the articles the recruited participants in each study were younger and older than

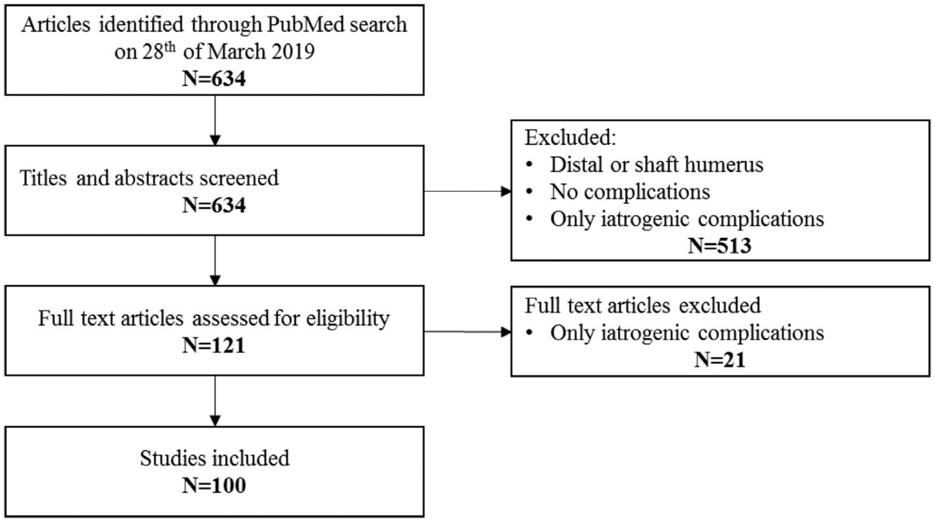

Fig. 1. Flowchart of the present systematic review.

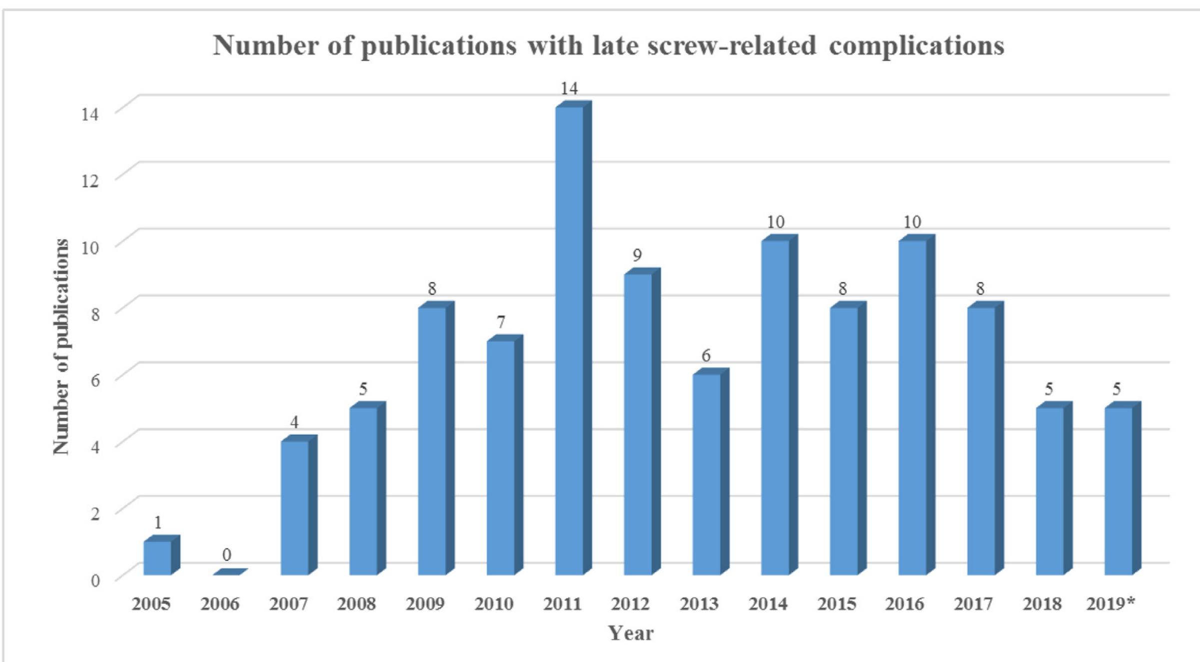

Fig. 2. Number of publications per year that included screw related complications. *Year 2019 was incomplete, because the search ended on 28th of March 2019.

50 years. In terms of mean or median age of the patients in each investigation, 3 studies had a relatively young cohort with mean or median below 50 years [82,83,98], 80 articles focused on older adults with mean or median age ranging from 50 to 70 years [13,17–31,33,34,36,37,38,40,41,43–49,51–61,63,64,66–71,74–84,86,88–90, 92–95,97,100–103,105,107,108,110,112,113,115], and 13 studies were on geriatric patients older than 70 years [35,39,42,50,62,65,87,96,98,99,106,109,114]. Three studies compared geriatric to non-geriatric patients with no reported details the whole cohort age [90,104,115] and one study compared older to younger adults [31].

Classification type

Three classifications were mostly used for categorization of the fracture type: (a) Neer [121]; (b) AO/OTA [122]; and (c) Hertel [123]. Neer classification was used in sixty-five studies [18,23,26,27,30,32–37,39–42,44,46–48,50,51,53–56,58,60–66,68,71–74,76,78,80,81,83,85–90,92,93, 96–104,105,109,110,112,113], while the AO/OTA classification was used in fifteen articles [17,19,21,24,28,43,45,49,57,59,70,77,82,108,115]. Seventeen studies used both these classifications [13,20,22,25,29,31,38,52,67,69,75,79,91,95,106,107,111]. Two studies used the newer classification by Hertel [93,97], and one used both the AO/OTA and Hertel classifications [106].

Most of the fractures treated with locking plates were either three-part according to the Neer classification, or Type B following the AO/OTA classification (Table 1). Regarding the fractures classified according to Neer, there were 1002 two-part fractures treated with locking plates, 2268 three-part fractures and 1104 four-part fractures (Fig. 3). In the articles using the AO/OTA classification, 440 fractures were type A, 1039 type B and 750 type C (Fig. 3). Seventy-one fractures were classified as Hertel 7 and 12 fractures – as Hertel 12.

Table 1
General characteristics of studies included in this review, focusing on the year of publication, type of study, number of patients, fracture classification type, type of locking plates and the follow up period.

		Number of studies
Year of publication	2005–2009	18
	2010–2014	46
	2015–2019	36
Type of study	Prospective	45
	Retrospective	55
Number of patients	<=25	9
	>25 and <=100	72
	>100	19
Mean or median age group	<50	3
	50–70	80
	>70	13
	Geriatric to non-geriatric adults	3
	Older to younger adults	1
Classification type	Neer	65
	AO	15
	Both AO and Neer	17
	Hertel	2
	Both AO and Hertel	1
Type of locking plates	PHILOS	56
	LPHP	17
	LCP	7
	NCB	9
	DiPHOS	2
	Other locking plates	30
Follow up period	Short (<6 months)	4
	Mid (>6 months and < 5 years)	94
	Long (>5 years)	2

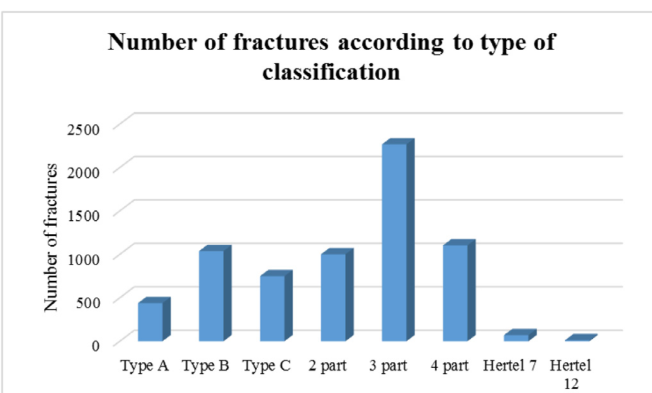

Fig. 3. Number of fractures according to the type of classification.

Type of locking plates

In the reviewed papers, the fractures were treated with the following locking plates: Proximal Humeral Internal Locking System (PHILOS, DePuy Synthes, Zuchwil, Switzerland), Locking Humerus Plate (LPHP, DePuy Synthes), Locking Compression Plate (LCP, DePuy Synthes), Non-Contact Bridging plate (NCB, Zimmer, Warsaw, USA), DiPHOS H Proximal Humeral Plate (Lima Corporate, Udine, Italy) and others (Fig. 4).

In total, 2833 fractures were treated with PHILOS plates. In some studies, PHILOS was the sole choice of implant [13,18,20,24,25,30,35,36,40,46–48,57,58,61,65,68,73,76,77,79,86,88,89,93,95,98,100, 104,106,107,109,110,112–115] while in other papers, surgeons compared PHILOS to other locking plates such as LPHP [27,49,57,60,61,89,106], LCP [71], NCB [76], and others [20,30,37,42,61,68,73, 78,88,91].

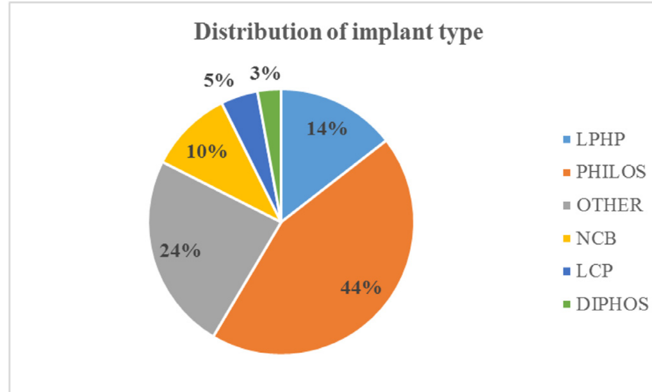

Fig. 4. Distribution of locking plate types used per number of treated patients, with PHILOS plate being the most used implant of choice for treatment of proximal humerus fractures.

LPHP were used to treat 932 fractures. Nine studies used only LPHP [9,23,28,32,36,48,56,65,74] while in seven studies the LPHP was compared to PHILOS [27,49,57,60,61,89,106], and in one study – to other locking plates (2009) [33].

Six hundred and fifty three NCBs were used to treat fractures in nine studies, either alone [37,42,46,59,67,77,87,99] or in comparison to PHILOS [76].

Two hundred and ninety LCPs were used exclusively in six studies [25,39,68,88,96,113], while in one study LCP was used alongside with PHILOS [71].

One hundred and eighty-four DiPHOS plates – the only polyetheretherketone plate of the reviewed locking plate group – were used either alone or in comparison to other implants [86,97].

The rest of used locking plates were grouped in a category called “other locking plates” and including such implants as those with no reported information about producer/commercial name, locking plates found in less than two papers, and/or with limited global circulation on the orthopaedic implant market, or used to treat less than 100 fractures. In total, 1450 “other locking plates” were included in 30 articles [19,20,25,30,37,41,42,45,52,58,61,64,68–70,73,75,78,80,82,84,88,89,91,95,96,98,105,111,113].

Follow up period

Mean follow up period ranged from 2 weeks to 7 years post-operatively. Studies were categorized in (a) short term – with mean or median follow up period being shorter than 6 months; (b) mid-term – with mean or median follow up period being from 6 months to 5 years; and (c) long-term – with mean or median follow up period being longer than 5 years. Accordingly, there were 4 short-term studies [24,27,78,98], 94 mid-term studies [13,17,19–27,29–39,41–66,68–84,86–107,109–115] and 2 long-term studies [53,119].

Complications

In total, 2386 complications were reported, reflecting 33% of all cases. Usually, patients had more than one complication at the same time, hence the true percentage of patients with complications should be smaller, but not possible to assess. Almost half of the complications (46%) were implant related, while the rest included delayed union, malunion, non-union, necrosis, infection etc. (Fig. 5).

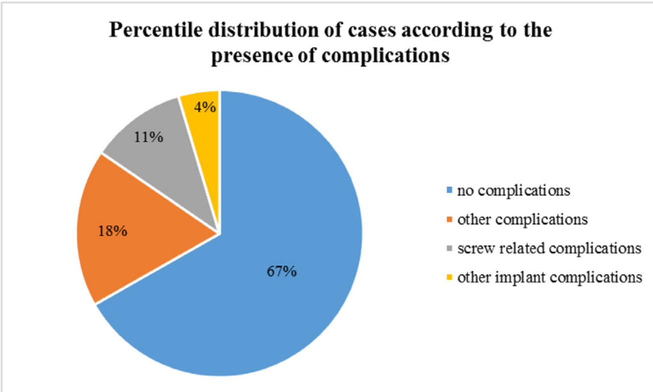

Fig. 5. Distribution of cases with and without complications.

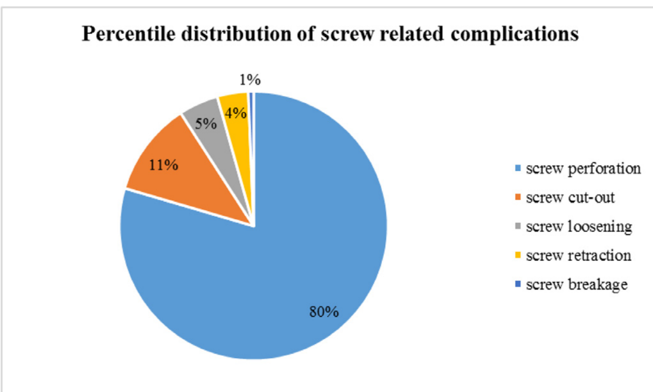

Fig. 6. Distribution of cases among different types of screw related complications (loosening, perforation, cut-out, retraction and breakage).

Table 2
Percentage of cases with screw-related complications where information about the onset, location, classification, age, gender, bone status, fixation status, surgical technique and comorbidities were provided.

	Perforation	Cut-out	Loosening	Retraction
Time	49%	12.5%	35.9%	13.3%
Location	–	–	23.1%	26.7%
Fracture classification	15.4%	65.9%	28.2%	23.3%
Age	13.1%	43.2%	10.3%	16.7%
Gender	5.7%	25.0%	5.1%	16.7%
Bone status at complication	5.2%	13.6%	5.1%	6.7%
Fixation status at complication	13.6%	12.5%	2.6%	3.3%
Surgical technique	3.4%	14.8%	10.3%	16.7%
Comorbidities	0.5%	0.0%	5.1%	10.0%

Screw related complications

Screw related complications dominated the implant-related ones and were then divided into screw perforation, cut-out, loosening, retraction and breakage (Fig. 6). A more focused look at the characteristics of complications, e.g. time, location, fracture type etc. (Table 2), revealed that the majority of them were underdescribed. Repeating the procedure for late screw-related complications only showed that the percentages were further decreased (Table 3).

Screw perforation

There were 612 cases with screw perforating the articular cartilage, but the onset or diagnosis time was provided for only 49% of the cases. Three cases with screw perforation were diagnosed within 24 h after the surgery [38], and 80 cases were detected later than 4 weeks postoperatively [25,26,59,75,77,80,81,89,91,93,94,96,30,97,115,118,35,38,40,42,49,50,53]. For the rest of the cases, the time of perforation was rather described than specifically provided; 7 cases were characterized with early perforations [44,59], in 5 cases screw perforation occurred "initially" [28], without a specific onset, and in 4 cases it was detected immediately postoperatively [99]. In six cases the perforation was seen intraoperatively [102], while in 8 cases the only comment on time was that screw perforation was not detected intra-operatively [24,95]. In six cases screw perforation was registered during the follow-up [93,102], and 12 cases were characterized with late perforations [19,44,76]. In addition, 58 cases were defined by the authors as being with primary [9,35,40,58,71,78,85,94,103,106], while 121 were classified as having secondary perforations [9,28,99,106,120,35,58,74,78,83,85–87].

Table 3
Percentage of late screw-related complications where location, fracture classification, age, gender, bone status, fixation status, surgical technique and comorbidities were provided.

	Perforation	Cut-out	Loosening	Retraction
Location	–	–	27%	100%
Fracture classification	8%	78%	27%	100%
Age	8%	11%	9%	100%
Gender	7%	11%	9%	100%
Bone status at complication	16%	22%	0%	0%
Fixation status at complication	14%	11%	9%	0%
Surgical technique	5%	11%	18%	0%
Comorbidities	1%	0%	9%	50%

Regarding the fracture type and its relation to screw perforations (Fig. 7), there were six two-part fractures [24,50,71,74], eight three-part fractures [25,26,30,50,71,79,84] and seventeen four-part fractures [48,74,75,83,116] registered with screw perforations. We also found ten cases of type A fractures [19,35,42,46], twenty of type B [19,23,35,42,46,58,79] and thirty-two of type C [19,23,35,46,58,119] with registered screw perforations (Fig. 8). There was also one patient with Hertel 12 fracture that sustained a screw perforation [93].

Screw perforations were registered in only two patients younger than 50 years with [58,83], the rest of the patients with perforations were either between 50 and 70 years old (nineteen cases) [19,24,84,97,25,26,30,35,50,58,68,74] or older than 70 years (twenty cases) [19,35,119,50,58,68,79,84,93,97,115]. Thirty-nine cases of patients with screw perforations were without direct reports on age, five cases included patients younger than 70 years [104], five cases were with patients younger than 60 years old [109] and twenty-nine cases included patients older than 60 years old [35,109]. There were twenty-six cases of screw perforations with registered female patients [19,24,79,84,93,97,115,25,26,30,32,50,58,68,74] and nine cases with registered male patients [19,32,58,68,84].

Two articles – reporting on screw perforations – provided information about the number of screws used in the humeral head: 3 cases were with screw perforation when the configuration included 5 screws in the head [19]; 3 cases were with 6 screws [19]; 1 case – with 7 screws [19]; 1 case – with 8 screws [19] and 1 case – with 9 screws [26]. In five cases the screw perforation coincided with implant malposition and/or poor pre-operative planning using longer screws than needed. The use of means for medial support did not show any changes to the occurrence of screw perforation; there were two cases with screw perforation without graft use compared to one case with grafting [50]; one case was with screw perforation and medial support compared to one case without such support [71]; one case was with screw perforation

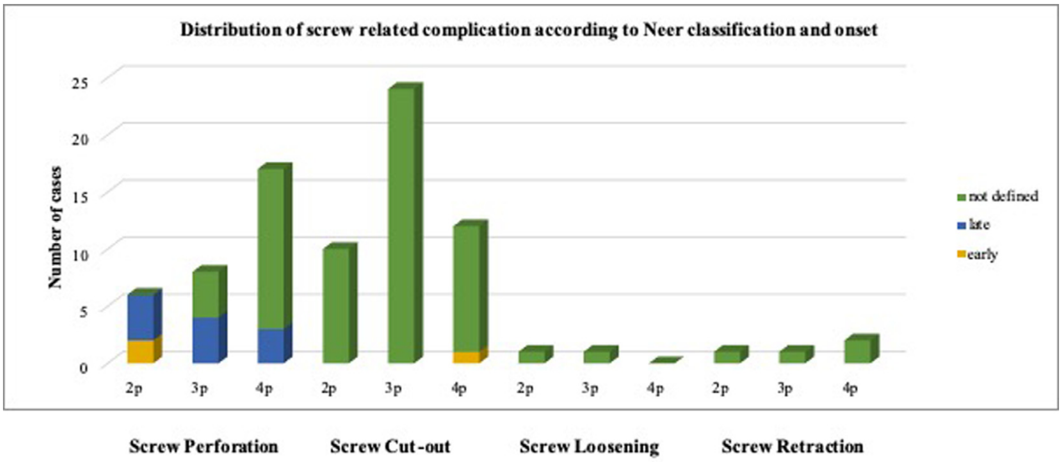

Fig. 7. Number of cases reported according to the Neer classification. Note that they deviate from the total number of cases per screw complications, as most studies do not focus on describing the complications.

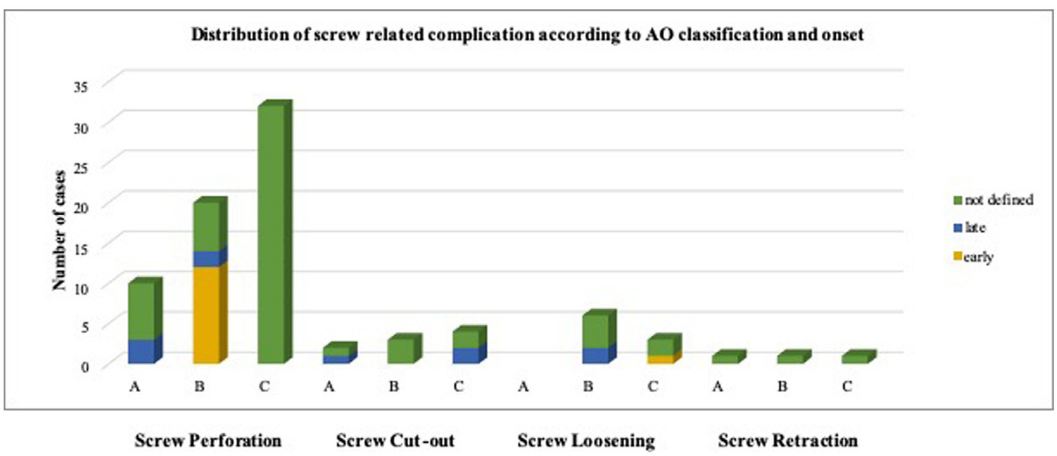

Fig. 8. Number of cases reported according to the AO/OTA classification. Note that they deviate from the total number of cases per screw complications, as most studies do not focus on describing the complications.

after fibular allografting [113] compared to one case without calcar support [74]. Twenty-five cases with screw perforations coincided with avascular necrosis [19,26,50,53,55,78,97,99,101,112], one case was classified as osteonecrosis [92] and two cases – just as necrosis [9,35]. Three perforated screws were found in fractures with non-unions [19,24,26] and one – with malunion [89]. There were 17 cases with loss of reduction [9,35,55,58,71,75,114,117] and 4 cases where the fixation failed [26,89,100]. Moreover, there were thirty-two cases with varus dislocation [23,43,74,76,91,100,111], four cases with varus malalignment [23,32] and three cases with varus subsidence [35,38]. We found four cases with head collapse [26,50] and five cases with fracture collapse without evidence of whether it was varus or valgus [48]. In six cases of screw perforation the fracture was displaced [40], and one screw perforation occurred during fracture settling [66]. Finally, there were seven cases where screw perforation coincided with humeral impaction [35,59,94]. Not enough information was given for the comorbidities in the patients with screw perforation complications, the reported cases included one obese patient, one patient with emphysema and home oxygen-dependence, one patient with steroid dependence for respiratory issues [50] and three patients with severe osteoporosis [71,96]. Screw perforation was accompanied by persistent pain in three cases [24,30,50] and stiffness in three cases [111].

With regard to late screw perforation, three cases were registered after treating type A fractures [19,42] and two cases – after type B fractures [35,42], while four cases were with two-part fractures [24,50,74], four cases – with three-part fractures [25,26,30,50] and three cases – with four-part fractures [74,75,83]. One screw perforation was detected in a Hertel 12 fracture [93]. The age of patients with late screw perforations ranged from 28 to 85 years, with only one patient being younger than 50 years [83], ten patients ranging from 50 years to 68 years old [19,24–26,30,35,50,74] and seven patients being older than 70 years [19,35,50,58,93,97,115]. There were fourteen female [19,24,115,25,26,30,50,58,74,93,97] and one male patients with late screw perforations [19]. Regarding surgical details, the number of head screws was reported in three cases [19,26] while in one case it was mentioned that an inferomedial screw was used [25]. Use of graft was noted only in one case with late screw perforation, while in two cases no graft use was reported [50]. In two cases with screw perforation no calcar support was achieved [74]. Interestingly, in one case screw perforation occurred after initially correct implant positioning [75], while in one case the implant malposition was assumed to be linked with secondary screw perforation [87]. Twenty cases of late screw perforation coincided with avascular necrosis [9,19,26,35,50,53,78,97], two cases – with non-union [24,26] and one case – with malunion [89]. In two cases there was loss of fixation [26,89] and in seventeen cases the fracture reduction was lost [9,58,75]. Secondary impaction of the humeral head was identified in six cases [35,59], and varus subsidence – in thirteen cases [35,38]. Collapse of the humeral head or the fracture was seen in eleven cases [26,50,74], fracture displacement – in fifteen cases [40,76], and in one case the greater tuberosity was dislocated [35]. Risk factors and comorbidities were only reported for four patients, namely obesity, emphysema, steroid dependence [50] and severe osteoporosis [96].

Screw cut-out

There were 88 cases of screw cut-out found, but in only 11 cases the observation time of the complication was provided. In two cases the authors described the onset of screw cut-out as early [59] without providing any other information. In three cases the screw cut-out was seen within less than 6 weeks [37], while in six cases the time ranged from 8 weeks to 37 months [45,90,98,103,105].

Regarding fracture type, there were ten two-part fractures [29,34,64], twenty-four three-part fractures [29,34,47,51,64,73] and eleven four-part fractures [29,34,45,73,88,103] with screw cut-out (Fig. 7). We also found two cases of type A fractures [37], three cases of Type B [27,37] and eight cases of Type C [27,37] (Fig. 8).

Most of the cases were diagnosed in patients older than 50 years, with only two cases in patients known to be younger than 50 years [27,29]. Eighteen cases were in the age group of patients between 50 and 70 years old [27,29,51,64,67,88], while eighteen screw cut-outs were found in patients older than 70 years [27,29,45,47,48,64,67,90]. The majority of screw cut-outs were found in female patients, with 22 cases diagnosed in twenty females [27,45,51,64,67,88,90,105], while only two male patients had this complication [64].

Screw cut-out occurred even in one case with good reduction confirmed in the post-operative radiograph [45], and even in one case with use of fibular allograft [88]. However, in 11 cases it was reported that the greater tuberosity, being not anatomically reduced, was the potential cause of screw cut-out [34]. Eight cases coincided with varus collapse [29,33,45], five – with osteonecrosis [29,51,64,90], 1 – with delayed union [29], 5 – with avascular necrosis, 1 – with varus malunion, and 3 – with fracture collapse. No comorbidities were reported for the cases with detected screw cut-out.

The level of information provided for cases classified with late screw cut-outs was low. There was one reported type A and two type C fractures with late screw cut-outs [37], and only two four-part fractures with this complication [45,103]. Regarding the age of patients with screw cut-out, one 72-year old [90] and one 76-year old patients were reported [45]. The gender of patients with screw cut-out was reported for three cases only (all females) [45,90,105]. Finally, there was information about the bone status at the time of complication for three cases, with none having avascular necrosis [37], while in one case the fracture collapsed into varus despite good post-operative reduction [45].

Screw loosening

In most of the publications referring to screw loosening it was not clear whether the latter was at the bone-screw or at the plate-screw interface, apart from four papers, where screw loosening was reported at the plate-screw interface [30,59,79,108].

Thirty-nine cases (5% of all complications) of screws loosening were found, with limited data provided. In only nine cases, one humeral head screw was reported as loose [41,42,46,59,69,79], while for rest of cases the location of the loose screw was not reported. Regarding the onset or observation time of loosening, one case was described as being with "early" loosening [37], while in two cases the loosening was detected on the immediate post-operative radiograph [59]. Two complications were defined as secondary screw loosening [9], while eight such complications were detected during a six-month follow up period [41,71,81,108]. There was even one case of screw loosening diagnosed 7 months post-operatively [42]. Twenty-five cases were neither classified as early nor late!

In terms of fracture type and its relation to screw loosening, there are reports about one two-part fracture [71] and one of three-part [79], but no case of four-part fracture (Fig. 7). In the articles using the AO/OTA classification, there were six type B [33,42,46,58,79] and three type C fractures with screw loosening (Fig. 8) [33,37,46].

Two patients aged less than 50 years had screw loosening; one was 48 years old [58] and one – 50 years old [79]. There were also two cases with geriatric patients having screw loosening; one aged 85 years [108] and one – 91 years [37]. Gender was also under-described in the literature – only one female [79] and one male patient [58] with screw loosening were clearly reported.

Similarly, not enough information about the surgical technique was delivered, but it seems that the presence of medial support did not prevent screw loosening from occurring [59,71,108]. In only four cases there was information about the bone or fracture condition at the time of loosening diagnosis. In one case the patient was osteoporotic [71], while in another case the loosening coincided with loss of fixation during fracture settling [37]. One patient developed pseudo-arthrosis [58] and in one case the fracture union was delayed [79]. No information about comorbidities was provided for the cases with screw loosening. In only one case a patient, diagnosed with dementia and proven to be non-compliant during the follow-up, had screw loosening in the early post-operative phase [37].

Among all eleven cases with reported late screw loosening [41,42,71,81,108], information about the location of the loose screw (humeral head) was delivered in only three cases [41,42]. Two of the cases were in type B fractures [42] and one after treatment of a two-part fracture [71]. One case with screw loosening was reported for an 85-year old female [108]. With regard to the fixation status, in only one case it was mentioned that screw loosening occurred without fracture dislocation [42]. Screw loosening occurred in a second case despite the presence of medial support [71], and in a third case – despite the use of collagen putty [108]. No risk factors were listed for the late screw loosening cases, apart from one case with osteoporotic patient [71].

Screw retraction

There were twenty-nine cases of screws retracted, with two of them defined as early, two – defined as late, whereas for the rest twenty-five cases the onset of retraction was not provided. Five cases were reported with screw retraction from the humeral head [19,24,27,39], while 3 cases were with screws retracted from the shaft [19,24,46].

One case with 2-part fracture [24], as well as one case with 3-part [24] and two with four-part fractures [24,116] had screw retraction as complication (Fig. 7). One distal screw retracted during the healing of a type A fracture [19], one screw retracted after type B [46] and one screw after type C fracture [27] (Fig. 8).

All cases of screw retraction with age information were for patients older than 50 years, with two of them being younger than

70 years [19,82]. Four of the patients with screw retraction were male [19,24] and one female [27], with no information about the gender of the others.

In one case the patient was diagnosed with non-union and fixation failure [19], while in one other case the fracture was malunited in varus [39]. In a 58 year old patient, despite having eight screw in the humeral head, one of the screws was retracted [19]. The patient had type II diabetes and was a smoker. In the same study, another patient had a history of alcohol abuse and one other case was diagnosed post a second injury. Aggarwal et al. [44] reported that three out of the five cases of screw retraction were related to the learning phase of the technique. One case resulted from poor locking of the screw to the plate [66], leading to intramuscular migration of the screw causing discomfort in the deltoid, while one case of screw retraction was completely asymptomatic [86].

There were only two cases of verified late screw retraction [24]; one being at the humeral head of a four-part fracture and one – at the shaft of a two-part fracture. Both cases were with male patients; one 63-year old with history of alcohol abuse and one 83 years old without any comorbidities or risk factors listed.

Screw breakage

Screw breakages were not reported often in our cohort of papers. We only found five screws broken [19,26,35,72,78], with information about failure provided only for three of the cases. In summary, one distal screw breakage occurred in one 82-year old patient with three-part fracture [26], another distal screw broke in a 58-year old male with type A fracture despite having eight screws in the humeral head [19], and one screw breakage was reported at 6 months postoperatively after two-part fracture [35].

Other implant-related complications

Other reported implant-related complications were plate breakage, plate bending, loss of fixation or loss of reduction without any details about screw related problems etc. The number of those complications was 332, representing 14% of all complications [13,17,18,19,21,22–30,33–35,38,39,41,42,44–46,48–52,55,57,58,60,61,64–68,70,72–77,79–81,89,92–96,98–100,102,106–110,115].

Other complications

Other complications were delayed union, malunion, non-union, avascular necrosis without screw perforation and infection [13,17–63,65,66–115].

Discussion

This study revealed that 33% of the proximal humeral fractures treated with locking plates have complications, compared to older studies mentioning complication rates from 12% [15] to 35% [81]. Among the complications, almost a half were implant related, with the majority of them being screw related complications (18% from the overall complications). Perforation represented 80% of the screw related complications, most of them detected 4 weeks postoperatively or described as late or secondary perforations, predominantly in four-part or AO/OTA type C fractures, in female patients older than 50 years. No information about certain surgical techniques or comorbidities and their relation to screw perforations was provided. Screw cut-out was detected at different time points, but usually in three-part and four-part fractures and AO/OTA type B and C fractures in older female patients, mostly related to poor reduction of the greater tuberosity. Loosening was found mostly in the humeral head screws, usually in the late postoperative phase, regardless the type of fracture, age or gender of the patients. Screw retraction occurred mostly in the humeral head screws, regardless the fracture type or gender, in patients older than 50 years old, without information about surgical details or comorbidities.

The primary focus of this review was the reporting of the exact onset of late screw-related complications, but this was provided only in the 35.9% of the cases with screw loosening, in 49% of the cases with perforation, in 12.5% of the cases with screw cut-out and 13.3% of the ones with retracted screws. In some studies, the onset was qualitatively descripted, as primary, secondary, early or late, rather than providing the exact time point, making the distinction between early and late complications even more difficult. The ongoing presence of screw related complications (Table 1 and Fig. 2) cannot be simply a result of inexperience of surgeons with the new implants and techniques [15,120], but some of these can be attributed to implant and/or bone risk factors. In this review, non-screw related complications were also listed, ranging from subacromial impingement often linked with plate mal-positioning to plate bending and breakage, according to the definition of implant complications [46]. There were also other complications, described as usual complications due to surgical fracture treatment (infection, nerve injuries), or bone union failures (malunion, delayed union, and non-union).

The majority of screw related complications were screw perforation and screw cut-out. Based on the biomechanics of locking plates [124], screw loosening (failure of screw purchase to bone or locking mechanism failure) and screw retraction should not appear often with these fixations, since those complications are rather associated with conventional plates [125,126]. In fact, locking plates were introduced to provide angular stability [127,128], and the secure screw-plate connection should not allow failures at the screw-plate interface. Therefore, screw loosening and retraction, whether manifested early or late, are assumed as failures of the locking mechanism, indicating poor or insufficient intraoperative locking of screws in the plate holes.

Earlier reviews hypothesized that late screw migration is related to poor bone quality [12,17,21]. In the current literature review, information about bone quality, type of fracture or reduction quality was given for a relatively small number of cases (Table 2), impeding findings about the relation between bone factors and screw complications. This can be related to the conclusion by Kralinger et al., where despite a large cohort of patients, they failed to identify a link between poor bone mineral density and increased incidence of complications [81]. They also identified the problem of insufficient information regarding the risk factors leading to complications in proximal humerus fracture treatment with locking plates. In addition, the current study reviewed any indirect measures of poor bone quality, trying to identify the age of patients with complications. However, the reported data was limited, therefore a safe conclusion on the effect of age on the increased rates of complications could not be derived. This result was supported by the study by Hinds et al. [90] who found no difference in clinical outcomes when comparing geriatric to non-geriatric patients. In addition, most studies included only mid-term clinical outcomes (see Table 1), which might have underestimated the complication rates.

However, based on the fact that most screw failures were seen in the humeral head (see Table 4), bone type (trabecular in the humeral head versus cortical in the shaft) seems to have an impact on the screw-related failure. Even so, the significant number of cases with no information about the location of screw complication could have led to a potential underestimation of the number of complications in the humerus shaft. In addition, there was a significant number of cases without any information about the onset of complications, impeding the separation of surgical-related from

Table 4
Complications as described in the reviewed articles, with focus on screw loosening, screw perforation, screw cut-out and screw retraction, but also including incidence of screw breakage, other implant related complications and other complications. NWD* denotes the not-well-defined screw complications, in terms of time or location or both.

	Early	Late	No time	Total
Screw perforation				
Head	72	228	312	612
Screw cut-out				
Head	2	9	77	88
Screw loosening				
Head	2	3	4	9
NWD*	1	8	21	30
Screw retraction				
Head	2		3	5
Shaft		2	2	4
NWD*			21	21
Screw breakage		1	4	5
Other implant complications				332
Other complications				1277

non-surgical related complications, thus adding to the underestimation of the actual size of the problem.

This study has some limitations, especially in calculating the exact number of screw related complications, describing the onset of screw complications, their locations, the underlying risk factors, such as bone mineral density, age, anatomic reduction and restoration of medial cortical support as described by Krappinger et al. [12]. However, these limitations are a result of not well-defined complications in the current literature. Although the present work is neither the first to identify the inconsistency in the reports of complications [129] nor to propose that a consensus for complications is vital in orthopaedics in general, this review is the first to focus on the reporting of screw-related complications in order to understand the risk factors of these complications. This review identified the under-reporting of these complications, which impedes to identify the link between individual risk factors and screw-related complications.

Despite the fact that locking plates are considered as a successful technique in the treatment of proximal humerus fractures [130–139], recent clinical papers still report relatively high rate of screw-related complications. However, exact information regarding the occurrence and circumstances of these compilations remain sparse. This literature review revealed lack of standardization and grey areas in the documentation of complications, mainly regarding the description of the time point (given for only a fraction of cases, ranging from 12.5% to 49%), the location of screw related complications (from 23.1% to 26.7%), and the risk factors that have led to failure. These underly the need for detailed description of complications and for a consensus in the reporting [140]. Besides specifying surgical errors leading to primary complications, such as intraoperative screw perforation of the glenohumeral joints, the authors propose to divide the screw related complications into two groups; (a) failure of locking mechanism with the examples of locking mechanism loosening and screw retraction and (b) bone-screw interface failure with the examples of screw perforation, screw cut-out and screw purchase failure. Clinical study reports should present the complications with clearly defined timeline, location and underlying risk factors, in order to re-evaluate the success of locking plate applications. These are expected to lead to better understanding on the incidence and causes, advancing towards avoidance of surgical errors, decrease of complication rates, improved locking plate designs and appropriately selection of patients for treatment with these implants.

Declaration of Competing Interest

All authors report no conflict of interest in relation to the content of this study.

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Appendix

Tables 5–9.

Table 5
Papers included in the retrospective analysis, in order of publication, focusing on type of study (P: prospective or R: retrospective), number of patients, age group, fracture classification used, type of implant, duration of follow up (mean or median follow up, short <6 months, long >5 years), number of cases with screw loosening, screw perforation, screw cut-out, screw retraction, screw breakage, other implant complications and other complications. *denotes cases where there was no distinction between different types of screw complications and ** denotes reduction failure with or without screw cut-out.

Paper	Prospective (P) or Retrospective (R)	Number of pts	Number of Fx	Mean or Median age	Classification	Type of implants	Follow up	Screw loosening	Screw perforation	Screw cut-out	Screw retraction	Screw breakage	Other implant related complications	Other complications
Fankhauser et el. [23]	P	28	29	64.2	AO	LPHP	Mid		1	2			4	4
Charalambous et al. [24]	R	23	25	63	Neer	PHILOS	Short		4		4		1	7
Gardner et al. [25]	R	35	35	62	Neer	LCP	Mid	2	6		1		1	12
Moonot et al. [26]	P	32	32	59.9	Neer	PHILOS	Mid					1	3	8
Agudelo et al. [27]	R	153	153	62.3	AO	PHILOS, LPHP	Short			6	1		3	47
Hepp et al. [28]	P	83	83	65	AO, Neer	LPHP	Mid		12				4	9
Owsley and Gorczyca [29]	R	52	53	52	Neer	PHILOS, Other	Mid			12			1	16
Klitscher et al. [30]	R	30	30	59	AO, Neer	PHILOS	Mid	1	3					25
Egol et al. [19]	R	51	51	61	AO, Neer	PHILOS	Mid		8		1	1	1	6
Shahid et al. [31]	P	41	41	Mix	Neer	PHILOS	Mid		2					2
Lee and Shin [32]	R	44	45	64.4	Neer	LPHP	Mid		2				1	13
Thalhammer et al. [33]	R	42	42	57.8	AO	LPHP, Other	Mid	2*		2*			6	23
Helwig et al. [34]	P	87	87	64	AO, Neer	PHILOS, Other	Mid			11				33
Südkamp et al. [9]	P	187	187	62.9	AO	LPHP	Mid	2	32				9	30
Brunner et al. [35]	P	157	158	65	AO, Neer	PHILOS	Mid	1	35		2	1	13	57
Gradl et al. [36]	P	76	76	63	Neer	LPHP	Mid		2	4			5	25
Erhardt et al. [37]	P	50	50	61	AO	NCB	Mid	1		7			4	1
Solberg et al. [38]	R	38	38	66.5	AO, Neer	Other	Mid		6				4	13
Ricchetti et al. [39]	P	52	54	66.5	Neer	LCP	Mid				1		2	9
Olerud et al. [40]	P	50	50	75	Neer	PHILOS	Mid		7				1	5
Geiger et al. [41]	R	28	28	60.7	Neer	PHILOS	Mid	1					6	4
Röderer et al. [42]	P	54	54	70	AO	NCB-PH	Mid	2	3				4	7
Aksu et al. [43]	R	103	103	62	Neer	PHILOS, Other	Mid		5				2	11
Aggarwal et al. [44]	P	47	47	58.5	AO, Neer	Other	Mid		6		5		5	13
Gaheer and Hawkins [45]	R	56	56	68.7	Neer	PHILOS	Mid		1	1			1	5
Röderer et al. [46]	P	107	107	66.1	AO	NCB	Mid	2	19		1		2	26
Shi et al. [47]	R	76	76	68.8	Neer	PHILOS, Other	Mid			1				5
Yang et al. [48]	P	64	64	61/65	AO, Neer	LPHP	Mid		5				6	8
Zhu et al. [49]	P	26	26	50.5	Neer	PHILOS, LPHP	Mid		5					3
Badman et al. [50]	R	81	81	60	Neer	PHILOS, Other	Mid		3					14
Ong et al. [51]	R	51	51	62.8	AO, Neer	PHILOS	Mid			4			1	4
Olerud et al. [52]	P	30	30	72.9	Neer	PHILOS	Mid		8				2	14
Hirschmann et al. [53]	P	57	57	65	Neer	PHILOS	Long		1					2

(*continued on next page*)

Table 5 (*continued*)

Paper	Prospective (P) or Retrospective (R)	Number of pts	Number of Fx	Mean or Median age	Classification	Type of implants	Follow up	Screw loosening	Screw perforation	Screw cut-out	Screw retraction	Screw breakage	Other implant related complications	Other complications
Sanders et al. [54]	R	17	18	58	Neer	Other	Mid		2				6	3
Voigt et al. [55]	P	56	56	75.5/72	Neer	PHILOS, Other	Mid		13				1	23
Wu et al. [56]	R	60	60	57.7/58.6	AO	LPHP	Mid		3					24
Faraj et al. [57]	R	92	92	66.2	Neer	PHILOS, LPHP	Mid			6			17	12
Königshausen et al. [58]	R	52	52	69.9	AO	Other	Mid	2	5				1	9
Ruchholtz et al. [59]	P	79	80	65.5	Neer	NCB	Mid	2	7	2				4
Konrad et al. [61]	P	153	153	64/67	AO	PHILOS, LPHP	Mid		36		2		10	33
Konrad et al. [60]	P	318	318	60.8/67	Neer	PHILOS, LPHP	Mid		68				5	34
Schliemann et al. [62]	R	27	27	71	Neer	PHILOS	Mid		6				6	23
Martetschläger et al. [63]	R	70	70	58	Neer	PHILOS	Mid	3		1			2	7
Ong et al. [64]	P	63	63	62	AO, Neer	Other	Mid			7			2	6
Grawe et al. [65]	R	17	17	57	Neer	LPHP	Mid			3				9
Urda et al. [66]	R	15	15	70	Neer	PHILOS	Mid		1		1			4
Barco et al. [67]	P	23	23	62	Neer	NCB	Mid			3			1	11
Lekic et al. [68]	R	12	12	59	Neer	LCP	Mid		3					1
Sun et al. [69]	R	68	68	64.2	Neer	Other	Mid	2	1				1	5
Acklin et al. [70]	P	97	97	62	AO	PHILOS	Mid		7					12
Jung et al. [71]	R	62	63	62.2	Neer	PHILOS, LCP	Mid	1	3				2	9
Ye et al. [72]	R	89	89	67.2	Neer	PHILOS, Other	Mid			3		1	8	6
Matejčić et al. [73]	R	59	59	70.5	Neer	PHILOS	Mid			7				9
Pak et al. [74]	R	21	21	63.5	Neer	LPHP	Mid		2					7
Verdano et al. [75]	R	70	70	63	Neer	Other	Mid		1				4	
Ockert et al. [76]	P	124	124	70.9	Neer	PHILOS, NCB	Mid		9				6	15
Buecking et al. [77]	P	120	120	62/67	Neer	NCB	Mid		3				10	1
Freude et al. [78]	P	56	56	60	AO, Neer	PHILOS	Short		5			1	2	9
Park and Jeong [79]	P	21	21	61	AO, Neer	Other	Mid	1	1					2
Lin et al. [80]	R	86	86	63/61	AO	Other	Mid		1				3	4
Kralinger et al. [81]	P	150	150	69	Neer	PHILOS	Mid	6	34					49
Kumar et al. [82]	R	51	51	38	Neer	PHILOS	Mid		1				2	5
Boudard et al. [83]	R	34	35	49.6	Neer	PHILOS, Other	Mid		1				14	25
Erasmo et al. [84]	R	81	82	56	Neer	PHILOS	Mid		3				3	17

(*continued on next page*)

Table 5 (*continued*)

Paper	Prospective (P) or Retrospective (R)	Number of pts	Number of Fx	Mean or Median age	Classification	Type of implants	Follow up	Screw loosening	Screw perforation	Screw cut-out	Screw retraction	Screw breakage	Other implant related complications	Other complications
Zhang et al. [85]	R	144	144	58/63	Neer	Other	Mid		11				5	20
Rotini et al. [86]	P	160	160	64	Neer	DiPhos	Mid		8		2		23	43
Bockmann et al. [87]	P	71	71	67	Neer	NCB	Mid	2	7				5	4
Chen et al. [88]	R	22	22	67.2	Neer	LCP	Mid			1				2
Koljonen et al. [89]	R	40	40	63	Neer	PHILOS, LPHP	Mid		1				2	2
Hinds et al. [90]	R	71	71	Mix	AO, Neer	Other	Mid			1				1
Ortmaier et al. [91]	R	30	30	61.3	Neer	PHILOS	Mid		5					9
Broder et al. [92]	R	49	49	60.7	Neer	Other	Mid		1					5
Carbone and Papalia [93]	P	31	31	73.3	Hertel	PHILOS	Mid		5					15
Falez et al. [94]	P	76	76	68.5	AO	PHILOS	Mid		3				12	11
Capriccioso et al. [95]	R	101	101	59.3/62.4	AO	Other	Mid		7					33
Chen et al. [96]	P	30	30	68	Neer	LCP	Mid		1					2
Gumina et al. [97]	R	52	52	68.9/63	Hertel	DiPhos, Other	Mid		2					4
Vijayvargiya et al. [98]	P	26	26	46	Neer	PHILOS	Short			1				3
Aguado et al. [99]	R	90	90	67.4	Neer	NCB	Mid		6					3
Gavaskar et al. [100]	P	26	26	79	Neer	PHILOS	Mid		2					3
Gadea et al. [101]	R	29	29	57	Neer	PHILOS, Other	Mid		1					34
Jin et al. [102]	P	40	40	64.9	Neer	Other	Mid	3	8				1	1
Gönç et al. [103]	R	31	31	58.4	Neer	PHILOS	Mid		1	2				6
Goch et al. [104]	R	125	125	Mix	AO, Neer	PHILOS, Other	Mid		9					14
Jia et al. [105]	R	65	65	60	Neer	PHILOS	Mid			1			1	8
Beeres et al. [106]	R	282	285	64	AO, Hertel	PHILOS, LPHP	Mid		65				15	11
Fisher et al. [107]	P	164	164	60	AO, Neer	Other	Mid		16				3	25
Peng et al. [108]	P	80	80	74.3	Neer	Other	Mid	1					6	4
Chen et al. [109]	R	42	42	58.3	Neer	PHILOS	Mid		12					5
Ge et al. [110]	P	69	69	75.1	Neer	Other	Mid		8				3	7
Kim et al. [111]	R	164	164	70/72	Neer	PHILOS	Mid		3				3	21
Zeng et al. [112]	R	181	181	57.4	Neer	PHILOS	Mid		5				12	18
Chen et al. [113]	R	97	97	69.1/68.6	Neer	LCP	Mid		7					18
Wang et al. [114]	R	122	122	61.1	Neer	PHILOS	Mid		2				2	38
Yang et al. [115]	R	70	70	Mix	Neer	PHILOS	Mid		1					5
Cai et al. [116]	R	31	31	70	Neer	Other	Mid		8		8			8
Plath et al. [117]	P	32	32	77.1	AO, Neer	PHILOS	Mid		8				2	16
Borer et al. [118]	P	62	62	64	AO, Neer	PHILOS	Mid		8				25	15
Falez et al. [119]	P	76	76	68.5	AO	PHILOS	Long		1				12	11
Hengg et al. [120]	P	67	67	76.8	Neer	PHILOS	Mid		4				2	13

Table 6
Characteristics of screw loosening cases per publication, focusing in time of observation or perforation onset (hrs: hours, wks: weeks, mo: months, yr: year, 1ry: primary, 2ry: secondary, op: operative, Int: initial, FU: follow-up), type of fracture (A: AO/OTA Type A, B: AO/OTA Type B, C: AO/OTA Type C, 2p: two part Neer, 3p: three part Neer, 4p: four part Neer), age of patient (in years), gender (M: male and F: female), type of implants, surgical information, bone or fracture information (AVN: avascular necrosis, MU: malunion, NU: non-union, GT: greater tuberosity, Fx: fracture, ON: osteonecrosis), comorbidities and any other relevant information (FU: follow up). Note that w/t denotes with and w/o denotes without.

Screw perforation	No	Timing	Fracture type	Age	Gender	Implant type	Surgical info	Bone or fracture	Comorbidities	Other info
[19]	1	–	C	69	F	PHILOS	5 head screws	–	–	–
	1	–	C	71	F		5 head screws	–	–	–
	1	–	B	74	F		6 head screws	–	–	–
	1	Late	A	83	F		8 head screws	AVN	–	At the last FU
	1		A	55	M		6 head screws	AVN	–	
	1	–	A	61	M		7 head screws	–	–	–
	1	–	A	61	M		6 head screws	NU	–	–
	1	–	C	80	M		5 head screws	–	–	–
[23]	1	–	C	–	–	LPHP	Plate too caudally Use of too long screws	Varus dislocation, Varus malalignment	–	No info which is perforated or which cut-out
	1	–	C	–	–				–	
	1	–	B	–	–				–	
[24]	1	No intra op	2 p.	57	F	PHILOS	–	NU	–	Persistent pain
	3	–	–	–	–		–	–	–	–
[25]	1	3 mo	3 p.	61	F	LCP	W/t inferomedial screw	–	–	–
	5	–	–	–	–		–	–	–	–
[26]	1	6 wks	3 p.	68	F	PHILOS	9 head locking screws	Loss of fixation, Head collapse, NU, AVN		shaft bicortical self-tapping screws
[28]	5	Int	–	–	–	LPHP	–	–	–	–
	7	2ry	–	–	–		–	–	–	–
[30]	2	–	–	–	–	PHILOS	–	–	–	–
	1	9 mo	3 p.	58	F		–	–	–	Pain
[31]	2	–	–	–	–	PHILOS	–	–	–	–
[32]	1	–	–	–	M	LPHP	–	–	–	No progression
	1	–	–	–	F		–	Varus malalignment	–	Revision surgery
[9]	21	1ry	–	–	–	LPHP	–	–	–	–
	5	2ry	–	–	–		–	Reduction loss	–	–
	6		–	–	–		–	Head necrosis	–	–
[35]	11	1ry	B	>60	–	PHILOS	–	–	–	–
	10		C		–		–	–	–	–
	1		A		–		–	–	–	–
	1	7 wks	B	–	–		–	2ry impaction	–	–
	1	3 mo	–	62			–	Necrosis	–	Proximal plate pulled out
	1	6 mo	–	74	–		–	Impaction, GT dislocation	–	
	10	2ry	–	–	–		–	2ry head subsidence, Loss of reduction	–	
[36]	2	–	–	–	–	LPHP	–	–	–	–
[38]	3	<24 hrs	–	–	–	Other	–	–	–	–
	3	4.5 mo	–	–	–		–	Varus subsidence	–	–
[40]	1	1ry	–	–	–	PHILOS	Suboptimal position	–	–	–
	6	4 mo	–	–	–		–	Changed Fx position	–	–
[42]	1	6 mo	–	–	–	NCB	–	–	–	–
	1	8 mo	B	–	–		–	–	–	–
	1	10 mo	A	–	–		–	–	–	–
[43]	3	–	3/4 p.	–	–	PHILOS or Other	–	Varus inclination	–	–
	2	–	2/4 p.	–	–		–	Varus displacement	–	1 case was intra op
[44]	5	Early	–	–	–	Other	–	–	–	–
	1	Late	–	–	–		–	–	–	–
[45]	1	–	–	–	–	PHILOS	–	–	–	–
[46]	4	–	A	–	–	NCB	–	–	–	–
	3	–	B	–	–		–	–	–	–
	12	–	C	–	–		–	–	–	–
[48]	5	–	4 p.	–	–	LPHP		Fx collapse	–	–

(*continued on next page*)

Table 6 (*continued*)

Screw perforation	No	Timing	Fracture type	Age	Gender	Implant type	Surgical info	Bone or fracture	Comorbidities	Other info
[49]	5	<3 mo	–	–	–	PHILOS or LPHP	–	–	–	–
[50]	1	6 mo	2 p.	71	F	PHILOS or Other	W/o graft	head collapse, AVN	Obesity	Painful
	1	6 mo	3 p.	51	F		W/t graft		Emphysema	–
	1	12 mo	2 p.	50	F		W/o graft		Steroid dependence	–
[52]	8	–	–	–	–	PHILOS	–	–	–	–
[53]	1	>1 year	–	–	–	PHILOS	–	Partial AVN	–	–
[54]	2	–	–	–	–	Other	–	–	–	–
[55]	1	–	–	–	–	PHILOS or Other	–	2ry loss of reduction, varus deformity, partial AVN	–	–
	12	–	–	–	–		–	–	–	–
[56]	3	–	–	–	–	LPHP	–	–	–	–
[58]	1	1ry	B	74	F	Other	–	–	–	–
	1	–	C	76	F		–	–	–	–
	1	2ry		85	F		–	Loss of reduction	–	–
	1	–		53	M		–	–	–	–
	1	–		49	F		–	–	–	–
[59]	2	Early	–	–	–	NCB	–	–	–	–
	4	6 wks	–	–	–			2ry humeral impaction	–	–
	1	–	–	–	–		–	–	–	–
[60]	68	–	–	–	–	PHILOS or LPHP	–	–	–	–
[61]	36	–	–	–	–	PHILOS or LPHP	–	–	–	–
[62]	6	–	–	–	–	PHILOS	–	–	–	–
[66]	1	–	–	–	–	PHILOS	–	Fx settling	–	–
[68]	1	–	–	61	M	LCP	–	–	–	–
	1	–	–	86	M		–	–	–	–
	1	–	–	68	F		–	–	–	–
[69]	1	–	–	–	–	Other	–	–	–	–
[70]	7	–	–	–	–	PHILOS	–	–	–	–
[71]	2	1ry	2 p.	–	–	PHILOS or LCP	W/t medial support		Osteoporosis	
	1	–	3 p.	–	–		W/o medial support	Reduction loss	Osteoporosis	–
[74]	1	2ry	2 p.	63	F	LPHP	W/o calcar support	Varus collapse	–	–
	1	2ry	4 p.	55	F				–	–
[75]	1	7 mo	4 p.	–	–	Other	Int correct position	Reduction loss	–	–
[76]	9	Late	–	–	–	PHILOS or NCB	–	Varus displacement	–	–
[77]	2	6 wks	–	–	–	NCB	–	–	–	–
	1	8 wks	–	–	–		–	–	–	–
[78]	1	1ry	–	–	–	PHILOS	–	–	–	–
	3	2ry	–	–	–		–	Partial AVN	–	–
	1	2ry	–	–	–		–	–	–	–
[79]	1	–	3 p./ B	72	F	Other	–	–	–	–
[80]	1	3 mo	–	–	–	Other	–	–	–	–
[81]	12	< 6 wks	–	–	–	PHILOS	–	–	–	–
	9	< 3 mo	–	–	–		–	–	–	–
	2	< 6 mo	–	–	–		–	–	–	–
	2	< 1 yr	–	–	–		–	–	–	–
	9	–	–	–	–		–	–	–	–
[82]	1	–	–	–	–	PHILOS	–	–	–	–
[83]	1	2ry	4 p.	28		PHILOS or Other	–	–	–	–
[84]	1	–	3 p.	72	F	PHILOS	–	–	–	–
	1	–	4 p.	51	M		–	–	–	–
	1	–	3 p.	64	F		–	–	–	–
[85]	5	1ry	–	–	–	Other	–	–	–	–
	6	2ry	–	–	–		–	–	–	–
[86]	8	2ry	–	–	–	DiPhos	–	–	–	–
[87]	1	2ry	–	–	–	NCB	Implant malposition	–	–	–
	6		–	–	–		–	–	–	–
[89]	1	6 wks	–	–	–	PHILOS or LPHP	–	MU, Loss of fixation	–	–
[91]	1	6 wks	–	–	–	PHILOS	–	Varus collapse	–	–
	1	8 wks	–	–	–		–		–	–
	1	10 wks	–	–	–		–		–	–
	1	11 wks	–	–	–		–		–	–
	1	12 wks	–	–	–		–		–	–
[92]	1	–	–	–	–	Other	–	ON	–	–
[93]	1	3 mo	Hrtl 12	77	F	PHILOS	–	–	–	–
	4	FU	–	–	–		–	–	–	–

(*continued on next page*)

Table 6 (*continued*)

Screw perforation	No	Timing	Fracture type	Age	Gender	Implant type	Surgical info	Bone or fracture	Comorbidities	Other info
[94]	2	1ry	–	–	–	PHILOS	–	–	–	–
	1	6 wks	–	–	–		–	–	–	2ry due to cut-out
[95]	7	No intra op	–	–	–	Other	–	–	–	–
[96]	1	9 mo	–			LCP	–	–	Severe osteoporosis	–
[97]	1	4 mo	–	76	F	DiPhos or Other	–	AVN	–	–
	1	–	–	65	F		–	–	–	–
[99]	4	Post op	–	–	–	NCB	–	–	–	–
	2	2ry	–	–	–		–	AVN	–	–
[100]	2	–	–	–	–	PHILOS	–	Fixation loss, Varus collapse	–	–
[101]	1	–	–	–	–	PHILOS or Other	–	AVN	–	–
[102]	6	Intra-op	–	–	–	Other	–	–	–	–
	2	FU	–	–	–		–	–	–	–
[103]	1	1ry	–	–	–	PHILOS	–	–	–	–
[104]	4	–	–	>70	–	PHILOS or Other	–	–	–	–
	5	–	–	<70	–		–	–	–	–
[106]	2	1ry	–	–	–	PHILOS or LPHP	–	–	–	–
	63	2ry	–	–	–		–	–	–	–
[107]	16	–	–	–	–	Other	–	–	–	–
[109]	5	–	–	<60	–	PHILOS	–	–	–	–
	7	–	–	>60	–		–	–	–	–
[110]	8	–	–	–	–	Other	–	–	–	–
[111]	3	–	–	–	–	PHILOS	–	Varus malreduction	–	Stiffness
[112]	5	–	–	–	–	PHILOS	–	AVN	–	–
[113]	1	–	–	–	–	LCP	Fibular allograft	–	–	–
[114]	2	–	–	–	–	PHILOS	–	Reduction loss	–	–
[115]	1	6 mo	–	80	F	PHILOS	–	–	–	–
[116]	8*	–	4 p.	–	–	Other	–	–	–	Loosening or cut-out
[117]	8	–	–	–	–	PHILOS	–	Loss of reduction	–	Cut-out
[118]	4	6 wks	–	–	–	PHILOS	–	–	–	–
	4	>6 mo	–	–	–		–	–	–	–
[119]	1	–	C	85	–	PHILOS	–	Impaction	–	Cut-out
[120]	5	2ry	–	–	–	PHILOS	–	–	–	–

Table 7
Characteristics of screw cut-out cases per publication, focusing in time of observation or cut-out onset (wks: weeks, mo: months, Post op: post-operative), type of fracture (A: AO/OTA Type A, B: AO/OTA Type B, C: AO/OTA Type C, 2p: two part Neer, 3p: three part Neer, 4p: four part Neer), age of patient (in years), gender (M: male, F: female), type of implants, surgical information, bone or fracture information (AVN: avascular necrosis, MU: malunion, DU: delayed union, GT: greater tuberosity, Fx: fracture, ON: osteonecrosis), comorbidities and any other relevant information. Note that w/t denotes with and w/o denotes without.

Screw cut-out	No of patients	Timing	Fracture type	Age	Gender	Implant type	Surgical info	Bone or fracture	Comorbidities	Other info
[23]	2	–	–	–	–	LPHP	–	–	–	–
[27]	1	–	B	72	F	PHILOS	–	Loss of fixation	–	–
	1	–	C	62	F		–		–	–
	1	–	C	73	F		–		–	–
	1	–	C	63	F		–		–	–
	1	–	B	82	F		–		–	–
	1	–	C	40	F		–		–	–
[29]	1	–	2 p.	71	–	PHILOS or Other	–	–	–	–
	1	–	2 p.	43	–		–	–	–	–
	1	–	2 p.	65	–		–	–	–	–
	1	–	2 p.	81	–		–	Varus collapse	–	–
	1	–	2 p.	68	–		–	Varus collapse	–	–
	1	–	3 p.	62	–		–	–	–	–
	1	–	3 p.	86	–		–	–	–	–
	1	–	3 p.	61	–		–	–	–	–
	1	–	3 p.	59	–		–	ON	–	–
	1	–	3 p.	62	–		–	Varus collapse, ON, DU	–	–
	1	–	4 p.	59	–		–	Varus collapse	–	–
	1	–	4 p.	72	–		–	Varus collapse	–	–

(*continued on next page*)

Table 7
(*continued*)

Screw cut-out	No of patients	Timing	Fracture type	Age	Gender	Implant type	Surgical info	Bone or fracture	Comorbidities	Other info
[33]	2	–	–	–	–	LPHP or Other	–	Varus collapse	–	Loosening or cut-out
[34]	2	–	2 p.	–	–	PHILOS or Other	Non-anatomically reduced GT	–	–	Considerable axial or rotational deformities
	7	–	3 p.	–	–			–	–	
	2	–	4 p.	–	–			–	–	
[36]	4	–	–	–	–	LPHP	–	–	–	–
[37]	2	< 6 wks	C	–	–	NCB	–	W/o AVN	–	–
	1	< 6 wks	A	–	–		–		–	–
	2	–	C	–	–		–	W/t Partial AVN	–	–
	1	–	B	–	–		–		–	–
	1	–	A	–	–		–		–	–
[45]	1	3 mo	4 p.	76	F	PHILOS	Post op good reduction	Varus collapse	–	Screw disengaged from the plate
[47]	1	–	3 p.	73	–	Other	–	Varus MU	–	–
[51]	1	–	3 p.	83	F	PHILOS	–	ON	–	–
	1	–	3 p.	71	F		–	–	–	–
	1	–	3 p.	69	F		–	–	–	–
	1	–	3 p.	74	F		–	–	–	–
[57]	3	–	–	–	–	PHILOS	–	–	–	–
	3	–	–	–	–	LPHP	–	–	–	–
[59]	2	Early	–	–	–	NCB	–	–	–	–
[63]	1	–	–	–	–	PHILOS	–	–	–	–
[64]	1	–	3 p.	83	F	Other	–	ON	–	–
	1	–	3 p.	71	F		–	–	–	–
	1	–	3 p.	69	F		–	–	–	–
	1	–	3 p.	74	F		–	–	–	–
	1	–	2 p.	61	M		–	–	–	–
	1	–	2 p.	80	M		–	–	–	–
	1	–	2 p.	68	F		–	–	–	–
[65]	3	–	–			LPHP	–	–	–	–
[67]	1	–	–	67	F	NCB	–	Fx collapse	–	–
	1	–	–	86	F		–		–	–
	1	–	–	56	F		–		–	–
[72]	3	–	–	–	–	PHILOS or other	–	–	–	–
[73]	3	–	3 p.	–	–	PHILOS	–	–	–	–
	4	–	4 p.				–	–	–	–
[88]	1	–	4 p.	59	F	LCP	Fibular shaft allograft	AVN	–	–
[90]	1	37 mo	–	72	F	Other	–	ON	–	–
[98]	1	8 wks		–	–	PHILOS	–	–	–	–
[103]	1	3 mo	4 p.	–	–	PHILOS	–	–	–	Cut-out of all head screws
	1	4 mo		–	–		–	–	–	
[105]	1	3 mo	–	–	F	PHILOS	–	–	–	–

Table 8
Characteristics of screw loosening cases per publication, focusing in location (H: head), time of observation or loosening onset (wks: weeks, mo: months, 2ry: secondary, Post op: post-operative), type of fracture (B: AO/OTA Type B, C: AO/OTA Type C, 2p: two part Neer, 3p: three part Neer), age of patient (in years), gender (M: male and F: female), type of implants, surgical information, bone or fracture information (Fx: fracture), comorbidities and any other relevant information. Not that w/t denotes with and w/o denotes without.

Screw loosening	Number of cases	Location	Time	Fracture	Age	Gender	Implant type	Surgical info	Bone or fracture	Comorbidities	Other info
[25]	2	–	–	–	–	–	LCP	–	–	–	–
[30]	1	–	–	–	–	–	PHILOS	–	–	–	–
[33]	1	–	–	B	–	–	LPHP or Other	–	Varus collapse	–	Loosening or cut out
	1	–	–	C	–	–		–		–	
[9]	2	–	2ry	–	–	–	LPHP	–	–	–	
[35]	1	–	–	–	–	–	PHILOS	–	–	–	–
[37]	1	–	Early	C	91	–	NCB	–	Fixation loss	Dementia	Non-compliance
[41]	1	H	4 mo	–	–	–	PHILOS	–	–	–	–
[42]	1	H	3 mo	B	–	–	NCB	–	W/o Fx dislocation	–	–
	1	H	7 mo		–	–		–	–	–	–
[46]	1	H	–	B	–	–	NCB	–	–	–	–
	1		–	C	–	–		–	–	–	–
[58]	1	–	–	B	48	M	Other	–	Pseudo-arthrosis	–	–
	1	–	–	–	–	–		–	–	–	–
[59]	2	H	Post op	–	–	–	NCB	Additional two screws	–	–	Retrograde
[63]	3	–	–	–	–	–	PHILOS		–	–	–
[69]	2	H	–	–	–	–	Other	–	–	–	–
[71]	1	–	12 wks	2p	–	–	PHILOS or LCP	W/t medial support		Osteoporosis	–
[79]	1	H	–	3p/B	50	F	Other	–	DU	–	–
[81]	3	–	<6 wks	–	–	–	PHILOS	–	–	–	–
	1		<6 mo	–	–	–		–	–	–	–
	2		–	–	–	–		–	–	–	–
[87]	2	–	–	–	–	–	NCB	–	–	–	Single screw
[102]	3	–	–	–	–	–	Other	–	–	–	–
[108]	1	–	3 mo	–	85	F	Other	W/t collagen putty	–	–	–

Table 9
Characteristics of screw retraction cases per publication, focusing in location (H: head, S: Shaft), time of observation or retraction onset (d: days, op: operative), type of fracture (A: AO/OTA Type A, B: AO/OTA Type B, C: AO/OTA Type C, 2p: two part Neer, 3p: three part Neer, 4p: four part Neer), age of patient (in years), gender (M: male, F: female), type of implants, surgical information, bone or fracture information (MU: malunion, NU: non-union), comorbidities and any other relevant information (Fx: fracture).

Screw retraction	No	Location	Timing	Fracture type	Age	Gender	Implant type	Surgical info	Bone or fracture	Comorbidities	Other info
[19]	1	S	–	A	58	M	PHILOS	8 screw in the head	NU, fixation failure	Type II diabetes, smoker	–
[24]	1	H	–				PHILOS	–	–	–	Further injury
	1	H	26 d	4 p.	83	M		–	–	–	–
	1	S	2 mo	2 p.	63	M		–	–	History of alcohol abuse	–
	1	H	–	3 p.	77	M		–	–	–	–
[25]	1	–	–	–	–	–	LCP	–	–	–	–
[27]	1	H	–	C	51	F	PHILOS	–	Loss of fixation	–	Screw-plate disengage
[35]	2	–	–	–	–	–	PHILOS	–	–	–	–
[39]	1	H	Early p.o.	–	–	–	LCP	–	Varus MU	–	Fx displacement
[44]	5	–	–	–	–	–	Other	–	–	–	3 cases prior Dec. 2007
[46]	1	S	–	B	–	–	NCB	–	–	–	–
[61]	2	–	–	–	–	–	PHILOS or LPHP	–	–	–	–
[66]	1	–	–	–	–	–	PHILOS	–	–	–	Not properly locked Deltoid discomfort
[86]	2	–	–		–	–	DiPhos	–	–	–	asymptomatic
[116]	8	–	–	4 p.	–	–	Other	–	–	–	Cut-out or pull-out

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