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GENERAL REVIEW

Anterior femoral notching ≥ 3 mm is associated with increased risk for supracondylar periprosthetic femoral fracture after total knee arthroplasty: a systematic review and meta-analysis

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Abstract

Purpose Anterior femoral notching (AFN) may be associated with a higher risk for supracondylar periprosthetic fracture (sPPF) after total knee arthroplasty (TKA), although studies have yielded inconclusive results. We aimed to systematically investigate and meta-analyze the best available evidence regarding the association between AFN and the risk of sPPF after TKA.

Methods A comprehensive search of PubMed, Scopus, Mendeley, Google Scholar and Cochrane databases was performed, from conception to February 29, 2020. Data were expressed as odds ratio (OR) with 95% confidence intervals (CI). I^2-index was employed for heterogeneity. Newcastle–Ottawa scale was implemented for quality assessment of the included studies.

Results Nine studies fulfilled the eligibility criteria, including a total of 3264 patients subjected to TKA. Among them, there were 150 patients who sustained a sPPF. Overall, patients exposed to AFN (AFN group) demonstrated an increased risk for sPPF compared to those not exposed (control group) (OR 3.91, 95% CI 1.22–12.58, $p = 0.02$; I^2 68.52%). Subgroup analysis based on AFN depth with a cut-off value of 3 mm further clarified this association. Patients with AFN ≥ 3mm were at higher risk for sPPF compared to patients with AFN < 3 mm and control group (OR 4.85, 95% CI 2.08–11.33, $p = 0.00$; I^2 0.0%). On the contrary, fracture risk was not significant for patients with AFN < 3 mm compared to the control group (OR 5.0, 95% CI 0.44–56.82, $p = 0.19$; I^2 42.99%).

Conclusion Patients, exposed to AFN ≥ 3 mm in depth, are at higher risk for sustaining a sPPF.

Keywords Anterior femoral notching · Supracondylar periprosthetic fracture · Total knee arthroplasty · Meta-analysis · Systematic review

Introduction

Periprosthetic fracture (PPF) is one of the most devastating complications after total knee arthroplasty (TKA). The treatment of patients with a PPF around the knee is often challenging, associated with prolonged recovery and thus resulting in poorer functional outcomes [1, 2]. Moreover, the mortality rate is also increased in this patients' group [3]. The reported incidence of PPFs varies from 0.3 to 2.5%, but it may reach up to 38% for revision cases [4]. Recognizing and delineating the factors that predispose to this dreaded complication would assist orthopedic surgeons to better assess fracture risk for their patients.

Postoperative supracondylar periprosthetic femoral fractures (sPPF) are the most common type of PPF around the

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knee [5]. The majority of them occur during the first five years from the index operation [6]. Alongside osteoporosis and advanced age, epidemiological evidence also features female gender, chronic use of corticosteroids, neurologic disorders, anterior femoral notching (AFN), osteolysis, revision TKA, constrained implants, knee ankylosis and rheumatoid arthritis as potential risk factors for sPPF after TKA [5–8].

Among the aforementioned risk factors, perhaps the most controversial is AFN [5, 6, 9–12]. AFN is an encroachment produced on the anterior surface of the femoral cortex during femoral preparation in order to achieve a closer fit of the implant, with the proper restoration of posterior condylar offset, while simultaneously avoid overstuffing of the patellofemoral joint. Since the early 1980s, there were reports of increased incidence of sPPF in patients with AFN after TKA [12–15]. Implementation of modern instrumentation during TKA has decreased the incidence of AFN in recent years [14, 16]. Even in lower rates though, AFN remains a problem possibly associated with the use of posterior reference systems, navigated TKA, femoral sizer design or limited size options of femoral components in TKA systems that would provide the surgeon with the modularity to choose the best fit implant for each patient [16–18]. Biomechanical studies have shown that AFN weakens the cortical bone close to the prosthesis, augment the local stress raiser and significantly decrease the load to failure [19–21]. However, the clinical impact of AFN has been considerably debated as several studies have failed to link AFN with an increased risk for development of a sPPF in the clinical setting [9, 10, 22].

The aim of our study was to systematically investigate and meta-analyze the best available evidence regarding the association between AFN and the risk of sPPF after TKA.

Materials and methods

Guidelines followed

This study was conducted following the guidelines of the Preferred Reporting Items for a Systematic Review and Meta-analysis (PRISMA) statement [23]. A completed PRISMA checklist has been submitted as Online Resource 1.

Study selection

The following PICO (Population, Intervention/Exposure, Comparison, Outcome) elements were applied for inclusion in this meta-analysis: (i) population: patients that underwent TKA, (ii) exposure: the presence of AFN in postoperative radiographs, (iii) control: patients without AFN in postoperative radiographs, (iv) outcome: incidence of sPPF.

We enrolled studies that met the following inclusion criteria: (i) were conducted in patients subjected to TKA, (ii) AFN was assessed using lateral knee radiographs, (iii) provided extractable data on the number of sPPF in both patients with (AFN group) or without AFN (control group), (iv) provided sufficient information to complement 2×2 contingency tables and (v) reported at least one patient with a sPPF. Case–control, cross-sectional or cohort studies were equally considered for eligibility. Articles published in English, French or German literature were considered for inclusion.

Exclusion criteria were: (i) studies having no patients with a sPPF, (ii) studies investigating patients with periprosthetic fractures other than sPPF, (iii) case series, (iv) biomechanical studies, (v) animal studies. Patients with a periprosthetic fracture other than sPPF reported among the included studies were also excluded from the final sample of subjects evaluated by our study.

Search strategy

A comprehensive search of PubMed, Scopus, Mendeley, Google Scholar and the Cochrane Central Register of Controlled Trials was performed to identify eligible studies. Our search strategy covered the period from conception until February 29, 2020.

The PubMed search string used in our study was as follows: ("Arthroplasty, Replacement, Knee"[Mesh] OR "Knee Prosthesis"[Mesh] OR "Osteoarthritis, Knee"[Mesh] OR "Knee Arthroplasty"[All Fields] OR "Knee Replacement"[All Fields] OR "TKA"[All Fields] OR "TKR"[All Fields]) AND ("Femoral Notching"[All Fields] OR "Notch*"[All Fields] OR “Anterior Femoral Notching”[tiab] OR “Anterior Femoral Cortex”[tiab]) AND ("Periprosthetic Fractures"[Mesh] OR "Femoral Fractures"[Mesh] OR "Osteoporotic Fractures"[Mesh] OR "Femoral Fractures"[tiab] OR "Osteoporotic Fractures"[tiab] OR "Periprosthetic Fracture"[All Fields] OR "Supracondylar Fracture"[All Fields]). This was modified accordingly for the other databases.

The main search was performed independently by three investigators (DS, NG and KA). Any disagreement was resolved by discussion with a fourth investigator, not involved in the initial process (EK). Furthermore, a manual search was conducted throughout reference lists of the included studies. A flowchart diagram is demonstrated in Fig. 1.

Data extraction

The following data were extracted and recorded: (i) first author; (ii) year of publication; (iii) country in which the study was conducted; (iv) study design; (v) total number

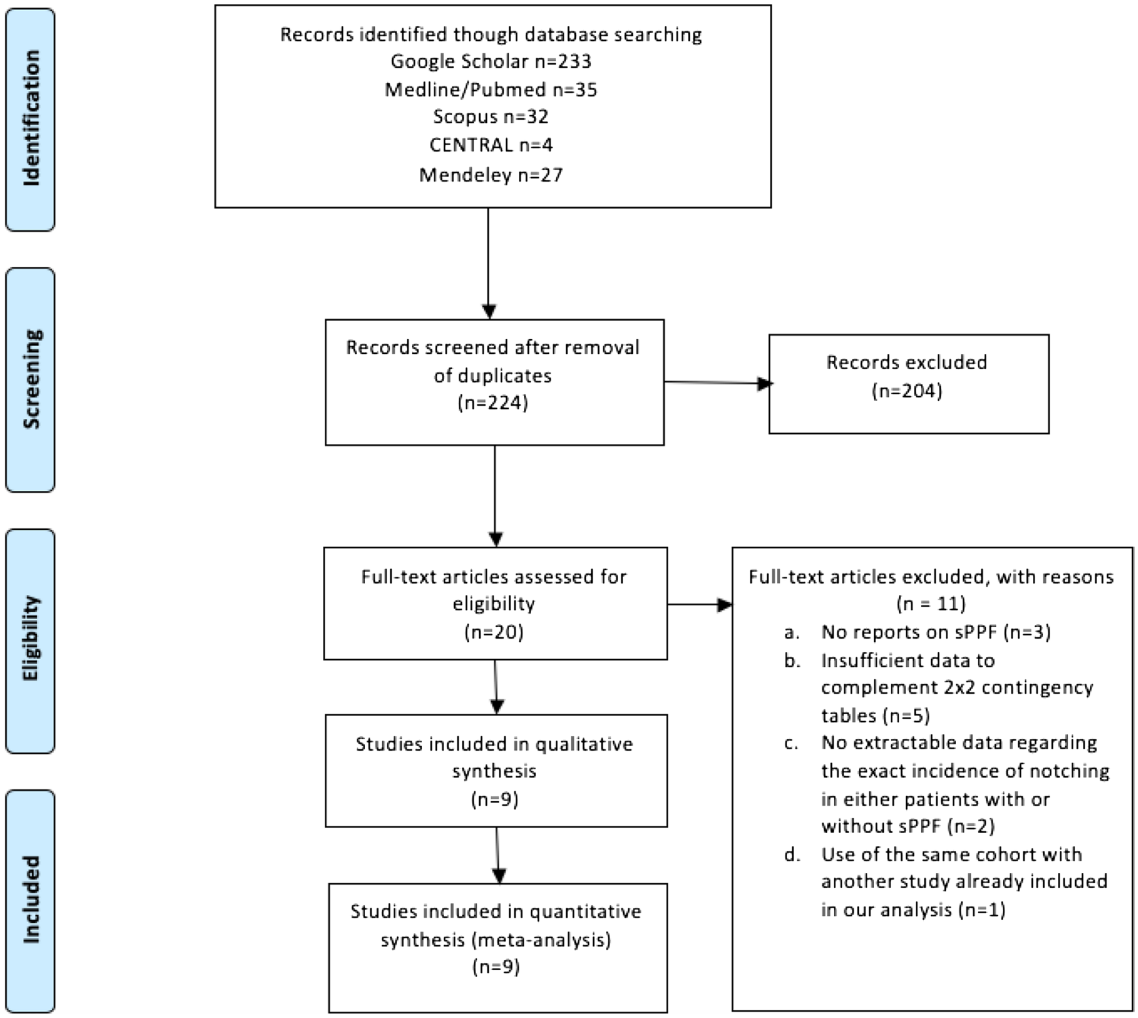

Fig. 1 Flowchart diagram

of participants, with their demographics and other comorbidities; (vi) the number of sPPF in both AFN and control groups; (vii) AFN classification used in each study; (viii) time from the index TKA to sPPF.

Risk of bias and study quality assessment

Quality assessment of the included studies was performed independently by the first three authors, using the Newcastle–Ottawa Scale (NOS) [24]. NOS is a tool designed to evaluate the quality of non-randomized studies. For that purpose, it uses a star awarding system. Each study may be awarded a maximum of nine stars; specifically, up to four stars in the selection category, two stars in the comparability category and three stars in the exposure/outcome category. A higher number of stars per category corresponds to a higher quality study design and execution [24].

Statistical analysis

Random-effects model was used for data synthesis (Mantel/Haenszel model) in cases of moderate to high heterogeneity or fixed effects model in cases of low heterogeneity. Heterogeneity was tested by the Cochrane Chi-square test. The degree of heterogeneity was evaluated with the I^2 statistics; heterogeneity was defined as low ($I^2 < 30\%$), moderate ($I^2 = 30–60\%$) or high ($I^2 > 60\%$). The association between AFN and sPPF was reported as odds ratios (OR) with 95% confidence intervals (CI). A p value of < 0.05 was considered statistically significant. To further explain the heterogeneity among studies, sensitivity analysis and subgroup analysis were conducted. Subgroup analysis was performed for categorical variables, such as the classification system for AFN used in each study and the magnitude of notching (subdivided in two distinct categories), as it was anticipated that these could have a significant effect on the main outcome. Sensitivity analysis (using random-effects model) was implemented to locate outliers, defined as studies that had large residuals (|z| > 2), lower methodological quality or those adding substantial heterogeneity. Publication bias was assessed using Funnel plot, and the Egger's test *(p* values > 0.1 indicated the absence of publication bias). All analyses were performed with the *Comprehensive MetaAnalysis V2* software.

Results

Study characteristics

Our search strategy identified 331 potentially relevant studies. Following removal of duplicates (n = 107), 224 records were screened based on title and abstract. Full-text assessment was conducted in 20 studies, 11 of which were excluded due to the following reasons: (i) three studies did not report any patient with a sPPF, (ii) five did not report sufficient data to complement 2 × 2 contingency tables, (iii) two did not report extractable data on the incidence of notching in either patients with or without a sPPF and (iv) one evaluated the same cohort with another study already included in our analysis [6].

Nine studies were eventually included for qualitative and quantitative analysis, based on our pre-established criteria. They were published between 1987 and 2019. The countries in which they were conducted were: France (n = 1), Korea (n = 1), Singapore (n = 1), Spain (n=2), UK (n = 1) and USA (n = 3). Five studies were retrospective [9, 12, 18, 25, 26], while four studies prospectively enrolled patients [2, 6, 10, 27]. Regarding study design, three of them were case–control studies [2, 6, 9], while six were cohort studies [10, 12, 18, 25–27].

Sample size ranged from 55 to 1089 patients, providing a total number of 3264 patients subjected to TKA for various indications. Among the included patients, a total of 150 sPPF and 663 cases with AFN were reported. Three studies graded AFN based on Tayside classification [6, 9, 25], five studies [2, 10, 18, 26, 27] evaluated AFN using its depth in millimeters, while one study [12] did not use any classification system.

Regarding the mechanism of fracture, five studies reported extractable data; among 75 patients with a sPPF, 70 patients sustained a low-energy fracture (93.3%), whereas five patients had a high-energy injury. Patients sustained a sPPF had a mean age ranging from 61 to 78 years, whereas those without a sPPF had a mean age ranging from 75 to 76.6 years. Three studies [2, 12, 18] reported the incidence of osteoporosis in their fracture group. In detail among 33 patients with a sPPF, 17 had osteoporosis. In three studies, patients with a sPPF were age and sex-matched to those without a fracture [2, 6, 9]. The mean time from index TKA to sPPF was 4.75 years (range 0.1−7.3).

Limited data concerning patients' other comorbidities, the indication for the initial TKA as well as the type of implants used were provided in the studies. The descriptive characteristics of the included studies are presented in Table 1.

Risk of bias assessment

Three [6, 9, 18] studies were allocated eight stars and considered as low risk of bias ("good" quality), lacking serious methodological weaknesses. Five studies [2, 10, 25–27] obtained seven stars due to minor weaknesses in study design and were considered of "fair" quality. More specifically, one study [2] included two patients who underwent revision TKA, possibly introducing selection bias. Two studies [10, 25] reported lost to follow-up for a considerable amount of patients, whereas the remaining two studies [26, 27] did not report adequate follow-up in their cohorts, introducing moderate bias. Finally, one study [12] was considered of "poor" quality, rated with 5/9 stars because the AFN and control groups were not matched for any important parameter (age, sex, type of implant), thus introducing comparability bias. The quality assessment of the included studies using the NOS is depicted in Online Resource 2.

Comparison between AFN and the control group

Overall, the AFN group demonstrated a higher risk for sustaining a sPPF compared with the control group (n = 9 studies, OR 3.91, 95% CI 1.22–12.58, $p = 0.02$; I^2 68.52%) (Fig. 2). A complete summary of comparative characteristics between AFN and the control group is demonstrated in Table 2.

Moreover, evaluation of AFN incidence reported in the included studies based on the time of initial operation (index TKA) revealed a noticeable overall decrease in the incidence of AFN observed over time, especially after the year 2000 (Table 3). More specifically, the overall incidence of AFN reported for surgeries performed before the year 2000 was 21.99%, whereas for surgeries performed after the year 2000 was 10.42% (study by Lizaur-Utrilla et al. was excluded from this analysis since they reported on patients operated before and after 2000).

Subgroup analysis

Subgroup analysis was performed analyzing the fracture risk in accordance with the magnitude of encroachment produced on the anterior femoral cortex. We also performed a subgroup analysis based on the classification scheme used in each study for evaluation of AFN.

Table 1 Descriptive characteristics of the studies included in the analysis

ID	First author	Study design	Country	Notching classification	Population (knees)	Mean age (years)	Male / females (n)	AFN	sPPF	Time between TKA and sPPF (years)
1	Zainul-Abidin [6]	Case–control	Singapore	Tayside	124	68.9	15/109	13	40	1.9
2	Minarro [9]	Case–control	Spain	Tayside	150	NR	10/140	14	50	5.8
3	Lee [18]	Cohort	Korea	Depth in mm	148	70.1	0/148	17	2	0.1
4	Lizaur-Utrilla [2]	Case–control	Spain	Depth in mm	55	75	NR	6	27	7.3[a]
5	Gujarathi [25]	Cohort	UK	Tayside	174	69	57/98	72	3	3.4
6	Hernigou [27]	Cohort	France	Depth in mm	605	NR	NR	25	20	6
7	Ritter [10]	Cohort	USA	Depth in mm	1089	69.4	436/653	325	2	3.3
8	Ritter [14]	Cohort	USA	Depth in mm	670	69.7	236/434	180	2	1.4
9	Aaron [12]	Cohort	USA	NR	249	NR	NR	11	4	NR

AFN anterior femoral notching; *NR* not reporting; *sPPF* supracondylar periprosthetic fracture; *TKA* total knee arthroplasty

[a] 7.3 years for primary TKA and 2.8 years for revision TKA

Concerning the group of studies which classified AFN based on its depth, we separated the patients exposed to AFN in two subgroups as follows: (i) those with AFN $\geq$ 3 mm in depth and (ii) those with AFN < 3 mm in depth. Consequently, we compared (i) the subgroup of patients with AFN $\geq$ 3 mm to the rest of the patients (patients not exposed to AFN and those with AFN < 3 mm) and (ii) the subgroup of patients with AFN < 3 mm to those not exposed to AFN. Data for this subgroup analysis were available from five studies [2, 10, 18, 26, 27]. Regarding the first comparison, the risk of fracture was increased in patients with AFN $\geq$ 3 mm, also demonstrating zero heterogeneity (OR 4.85, 95% CI 2.08–11.33, $p = 0.00$; I^2 0.0%), whereas it was not significant for patients with AFN < 3 mm (OR 5.0, 95% CI 0.44–56.82, $p = 0.194$; I^2 42.99%) [10, 18, 26] (Fig. 3 and Fig. 4, respectively).

Concerning the group of three studies [6, 9, 25] that used Tayside classification, we aimed to separate patients in two subgroups based on the grade of notching (grade I or II and grade III or IV). Regarding patients with grade III and IV AFN, no separate analysis could be performed as there was only one study reporting results on these patients. However, based on two studies [9, 25], the risk of sPPF for patients with AFN grade I or II was not significantly increased compared with patients without AFN (OR 0.56, 95% CI 0.17–1.80, $p = 0.334$; I^2 0.0%) (Fig. 5).

Disintegrate analysis, based on the classification scheme applied in each study for evaluation of AFN, demonstrated different results. For those studies which classified AFN using depth, the risk for sPPF was significantly increased for the AFN compared to control group ($n = 5$ studies, fixed effect model, OR 4.15, 95% CI 1.41–12.20, $p = 0.01$; I^2 24.5%) [2, 10, 18, 26, 27]. On the other hand, for those studies which employed Tayside classification to evaluate AFN, the risk for sPPF was nonsignificantly higher for the AFN compared to control group (OR 1.58, 95% CI 0.20–12.13, $p = 0.65$; I^2 78.72%) [6, 9, 25].

Sensitivity analysis

One study was considered to be of "poor quality" by our risk of bias assessment [12]. Sensitivity analysis with exclusion of this study revealed a nonsignificant association between AFN and the risk of sPPF (OR 2.69, 95% CI 0.95–7.56, $p = 0.06$; I^2 58.40%).

Two studies [2, 12] included cases of sPPF following revision TKA (a potentially confounding factor for sPPF). Sensitivity analysis with the removal of these studies showed that the risk for sPPF albeit being higher for patients exposed to AFN, it was not statistically significant (OR 2.75, 95% CI 0.82–9.19, $p = 0.099$; I^2 64.16%).

Furthermore, two studies [12, 26] included patients operated before 1980, using older implants and possibly

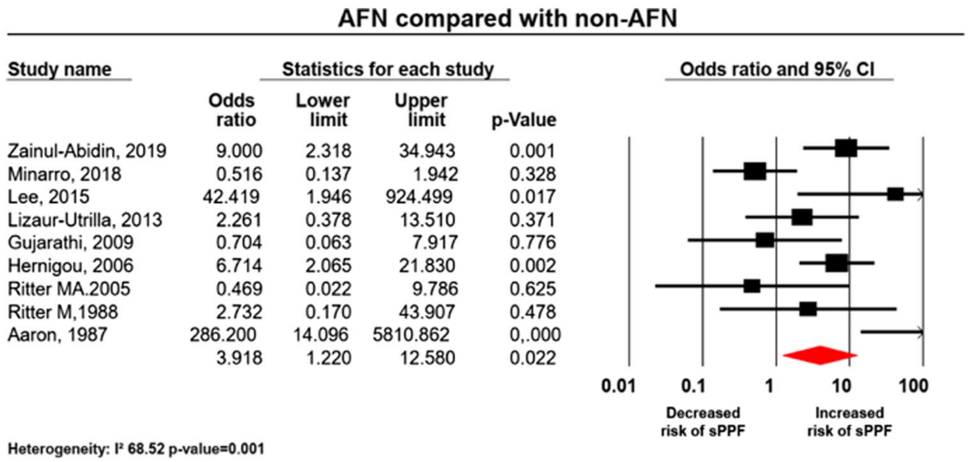

Fig. 2 Forest plot of the comparison between AFN and control group with regard to sPPF risk

Table 2 Comparative characteristics between notched and non-notched groups of the studies included in the analysis

ID	First author	AFN				Odds Ratio	*P*-value	AFN (sPPF/No fracture)					
		Exposed		Not exposed				Tayside				Depth	
		Total	sPPF	Total	sPPF			Grade I	Grade II	Grade III	Grade IV	< 3 mm	≧ 3 mm
1	Zainul-Abidin [6]	13	10	111	30	9.0	0.001	4/–	3/–	3/–	0/–	NR	NR
2	Minarro [9]	14	3	136	47	0.51	0.328	3/11		0/0	0/0	NR	NR
3	Lee [18]	17	2	131	0	42.41	0.017	NR		NR		1/7	1/8
4	Lizaur-Utrilla [2]	6	4	49	23	2.26	0.371	NR		NR		0/0	4/2
5	Gujarathi [25]	72	1	102	2	0.7	0.776	0/39	1/27	0/5	0/0	NR	NR
6	Hernigou [27]	25	4	580	16	6.71	0.002	NR		NR		0/0	4/21
7	Ritter [10]	325	0	764	2	0.46	0.625	NR		NR		0/205	0/120
8	Ritter [14]	180	1	490	1	2.73	0.478	NR		NR		0/42	1/137
9	Aaron [12]	11	4	238	0	286.2	0.000	NR					

sPPF supracondylar periprosthetic femoral fracture; *AFN* anterior femoral notching; *NR* not reporting

Table 3 Overall incidence of AFN reported over time

ID	First author	Time of operation	Total sample (knees)	AFN	Incidence
1	Zainul-Abidin [6]	2000–2015	124	13	10.4%
2	Minarro [9]	2010–2013	150	14	9.3%
3	Lee [18]	2005–2007	148	17	11.4%
4	Lizaur-Utrilla [2]	1990–2006 (sPPF) / 2000–2007 (no–sPPF)	55	6[a]	10.9%
5	Gujarathi [25]	1984–1993	174	72	41.3%
6	Hernigou [27]	1990–2000	605	25[a]	4.1%
7	Ritter [10]	1997–1998	1089	325	29.8%
8	Ritter [14]	1975–1983	670	180	26.8%
9	Aaron [12]	1975–1976	249	11	4.4%

AFN anterior femoral notching; *sPPF* supracondylar periprosthetic femoral fracture

[a] Both studies by Lizaur-Utrilla and Hernigou defined AFN only as encroachment of > 3 mm

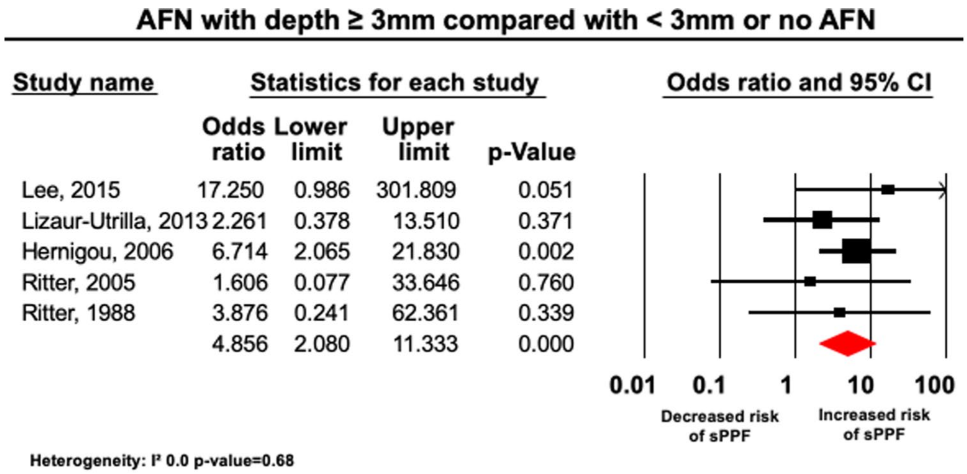

Fig. 3 Forest plot comparing the risk for sPPF between patients with AFN ≥ 3 mm compared to patients with AFN < 3 mm or not exposed to AFN

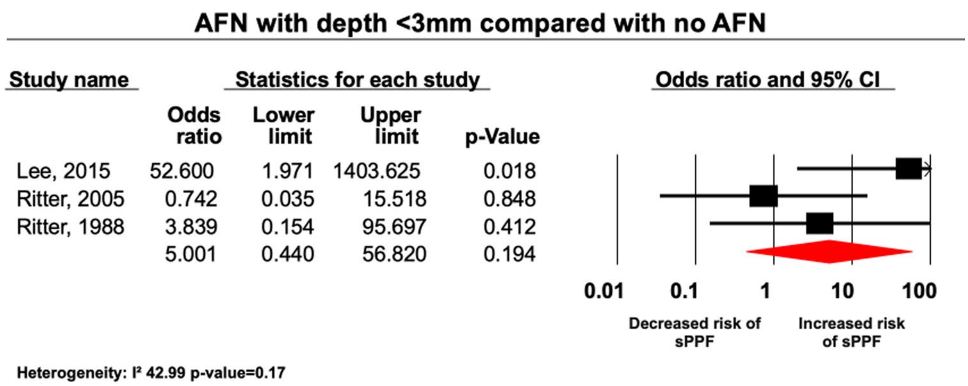

Fig. 4 Forest plot comparing the risk for sPPF between patients with AFN < 3 mm compared with patients not exposed to AFN

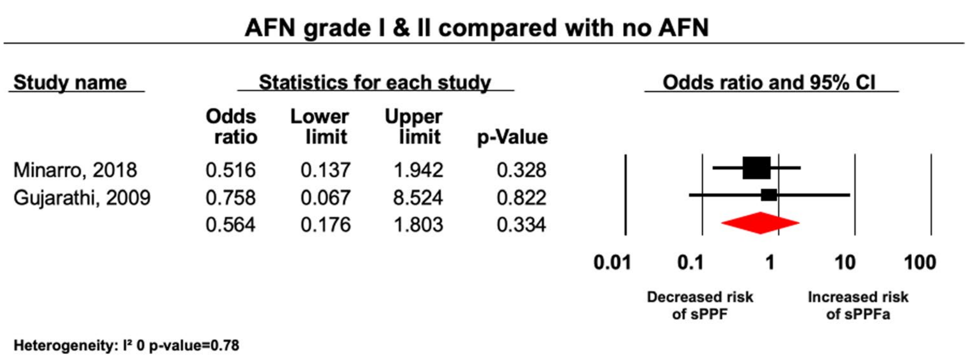

Fig. 5 Forest plot comparing the risk for sPPF between patients with AFN grade I and II compared with patients not exposed to AFN

unprecise operative techniques, which could predispose to a higher risk of periprosthetic fracture. After removal of these two studies, the risk of sPPF for the AFN group was not significant (OR 2.68, 95% CI 0.85–8.38, $p = 0.09$; I^2 64.34%).

Interestingly, when we performed the same sensitivity analyses for the subgroup of patients with AFN ≥ 3mm in depth with the removal of the aforementioned studies, the risk of fracture remained significantly increased for patients exposed to AFN ≥ 3mm. In particular, removing only the study of "poor quality" by Aaron et al., the analysis demonstrated that the subgroup of patients with AFN ≥ 3mm in depth still had a significantly higher risk for sPPF (OR 4.85, 95% CI 2.08–11.33, $p = 0.00$; I^2 0.0%). Likewise, removal of the two studies [2, 12] which included cases of sPPF following revision TKA, also marginally changed the outcomes (OR 4.96, 95% CI 2.04–12.10, $p = 0.00$; I^2 0.0%). Finally, removing both studies [12, 26] including patients operated before 1980, also resulted in minor changes (OR 6.06, 95% CI 2.31–15.87, $p = 0.00$; I^2 0.0%).

Publication bias assessment

Visual inspection of the funnel plot did not show an increased risk for publication bias. Moreover, Egger's test

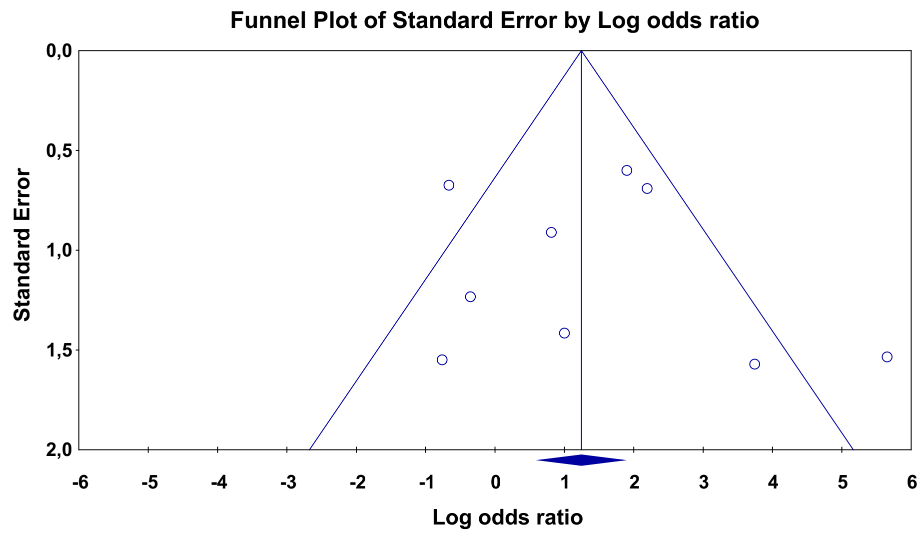

Fig. 6 Funnel plot of the included studies

revealed no statistically significant asymmetry (Y-intercept: 0.76, 95% CI −3.35–4.88, $p = 0.67$) (Fig. 6).

Discussion

This is the first systematic review and meta-analysis evaluating the association between AFN and the risk of sPPF. The most important finding of this study is that patients exposed to AFN ≥ 3 mm were at a higher risk for a sPPF compared with those exposed to AFN < 3mm and those not exposed to AFN after TKA. This robust association was invariable among studies.

PPF following TKA is a dreadful complication. Management is dictated by patient's age and comorbidities, fracture displacement, bone quality and implant stability [28]. Treatment options for sPPF include brace, internal fixation with plates or intramedullary nails, external fixation and revision arthroplasty [29]. Nonetheless, the treatment of patients with sPPF is associated with increased complication rates and decreased functional outcomes [28]. Identification of possible predisposing factors for sPPF will effectively assist in the prevention of this complication.

Several factors have been associated with the risk of sPPF after TKA; however, none of them has been proved to be an independent risk factor for sPPF. A possible explanation is that the etiology of sPPF after TKA is multifactorial and differs among patients. AFN is one of the most debatable risk factors for sPPF [30]. Although the majority of surgeons believe that AFN is closely related to a sPPF, the currently available evidence does not sufficiently support an etiologic association. The relevant existing studies demonstrate that only a small proportion of patients exposed to AFN will eventually sustain a sPPF. Geometrical characteristics of the AFN, as depth and width, the method of AFN assessment, patient comorbidities and intraoperative events may further clarify this relationship.

Our results support that the depth of 3mm of AFN is associated with an increased risk for sPPF. Several biomechanical studies have supported this finding too. Culp et al. [15], using a biomechanical analysis, were the first to set the threshold of 3 mm, as the critical depth leading to a significant reduction in torsional strength of the femur. Subsequent biomechanical studies [19, 20] on human cadaveric femora also demonstrated a substantial reduction in both bending and torsional strength, together with a considerable decrease in distal femoral load to failure in notched compared with non-notched specimens. Finite element model analysis by Zalzal et al. [21] supported that AFN of ≥ 3 mm, with sharp corners, located at the proximal aspect of the femoral prosthesis, produces high-stress concentration and may predispose to a sPPF. Furthermore, it was also supported that in cases where an intraoperative AFN of ≥ 5 mm occurs, the surgeon should consider implantation of a stemmed femoral component to support the weakened distal part of the femur [31]. It is also noteworthy that a recent biomechanical study found that the effect of AFN was independent of the type of prostheses used (cruciate-retaining or posterior stabilized) [32]. However, other geometric AFN characteristics such as the width, the distance from the implant and sharpness of the corners of AFN have never been evaluated in clinical studies so far.

The method of assessment, as well as the type of radiographs used to evaluate the AFN, is also of great importance. In our study, subgroup analysis demonstrated different results for studies in which the AFN was evaluated using depth in mm or by the Tayside classification [6, 9, 25]. It should be noted, though, that there is no established correlation between notch grade as defined by Tayside classification and notch depth. In addition, the evaluation of AFN in all the included studies was based on lateral knee radiographs alone, thus underestimating the width and the edges of the AFN. Technical errors during either image intensification process or measurement of the actual notching depth in radiographs could influence the final results. Interestingly, one of the included studies in our systematic review [25] reported a total of 13% of radiographs to be of inadequate quality for AFN measurement. Similarly, only one study [10] reported radiographic magnification that was used during AFN measurement to surpass the latter problem.

Aging, osteoporosis and poor bone quality are well-recognized risk factors for periprosthetic fractures following TKA [30, 33]. Biomechanical studies have shown an increased risk for fracture when both osteoporosis and AFN are present after TKA [20]. Our findings also suggest a higher risk of sPPF for osteoporotic patients, even though they were based on data from only three studies [2, 12, 18]. However, this observation may only be the "tip of the iceberg" as there is evidence supporting that the prevalence of osteoporosis after TKA is underscored [34, 35]. Several antiosteoporosis agents to enhance periprosthetic bone mass around the knee have been reported, though none has been yet proved efficient in the long term [36].

Another interesting finding of our study is a trend toward a decrease in the incidence of AFN in the included studies over time. This observation may be attributed to the utilization of more sophisticated instrumentation during femoral preparation, the modern implant designs, alongside the higher availability of implant sizes [16], patient-specific and gender-specific implants [37]. In addition, improved surgeons' skills and arthroplasty fellowship education worldwide may have contributed to the reduction of AFN incidence [38]. The still high reported incidence of AFN in some studies [22], could be attributed to the racial and geometric morphology of the knee, the femoral bowing [39] and the surgeons' effort to avoid overstaffing the patellofemoral joint and balance the flexion and extension gaps [40].

Inherent limitations could be recognized in our analysis: first, the relatively limited number and low level of evidence of the existing studies and second, the mean follow-up in some studies was quite short to draw safe and reproducible conclusions for sPPF occurrence. Third, the heterogeneity of defining and reporting the AFN between studies should also be taken into consideration. Another limitation of our study is the lack of data, namely patients' comorbidities, indication for the index TKA, surgeons experience and the type of implants used. Subsequently, further analysis using matched groups, with respect to other possible risk factors for sPPF beyond AFN, could not be performed. Yet, the major strength of our study is the systematic and comprehensive search of the available literature to identify studies exploring the association between AFN and sPPF being the first in the literature.

Conclusions

The present meta-analysis supports that patients exposed to AFN ≥3mm in depth are at higher risk for sustaining a sPPF. However, interpretation of the results should be with caution as these originate from studies with a moderate level of evidence. Future prospective studies on patients matched for other risk factors and further biomechanical studies evaluating other geometric characteristics of AFN are warranted to further elucidate the risk for sPPF in patients with AFN following TKA.

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Availability of data and material Data can be provided upon request.

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