Temporal trends in surgical implants for *in situ* fixation of stable slipped capital femoral epiphysis

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Stable slipped capital femoral epiphysis (SCFE) is a pediatric hip disorder managed with *in situ* fixation of the proximal femoral epiphysis, otherwise known as 'pinning the hip'. The objective of this study was to characterize how the choice of implant for *in situ* fixation of stable SCFE has changed over time. A systematic review of publications concerning *in situ* fixation of stable SCFE from January 1993 to November 2021 was conducted. The change in the type, diameter, and number of implants used in publications over time and the age of their respective patient cohorts was evaluated. A total of 207 articles met inclusion criteria. There was an increase in publications using cannulated screws over time ($P = 0.0113$). As the yearly percentage of publications using threadless non-cannulated implants decreased ($P = 0.0309$), the percentage using cannulated screws increased ($P = 0.0047$). Single-implant fixation also increased ($P = 0.0409$). While there was no difference in the rate of increase of implants < 7 mm or ≥ 7 mm in diameter ($P = 0.299$), patients with larger-diameter implants were, on average, older than patients with smaller-diameter implants ($P = 0.0462$). In general, the age of patients undergoing *in situ* fixation of stable SCFE has not changed ($P = 0.595$). Irrespective of patient-specific considerations, single cannulated screws have become the implant of choice for *in situ* fixation of stable SCFE. There has not been a consensus on the optimal implant diameter; instead, patient-specific considerations are of paramount importance in this decision. *J Pediatr Orthop B* 33: 437–442 Copyright © 2023 The Author(s). Published by Wolters Kluwer Health, Inc.

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Introduction

Slipped capital femoral epiphysis (SCFE) is a condition of the hip joint that primarily affects growing adolescents and can lead to devastating outcomes if not treated properly and promptly. The injury occurs when the femoral epiphysis displaces posteroinferiorly relative to the metaphysis [1]. It is the most common hip disorder in adolescents, with an estimated 10.8 cases per 100 000 children [2]. Based on a patient's walking capacity, the Loder classification categorizes slips as stable or unstable [3]. Stable slips refer to those on which patients can bear weight with or without crutches, whereas unstable slips refer to those on which patients cannot bear weight. The risk of osteonecrosis in stable SCFE is low (<10%) compared to the risk in unstable SCFE (24–47%) [4].

Treatment of SCFE is predominantly operative. In stable SCFE, surgeons primarily opt for *in situ* fixation of the proximal femoral epiphysis without perioperative reduction to reduce the risk of avascular necrosis [5–7]. *In situ* fixation is characterized by the percutaneous insertion of an implant across the growth plate under fluoroscopic guidance to prevent further slippage of the femoral epiphysis. In the orthopedic vernacular, this procedure is referred to as 'pinning the hip'. With the prospect of gradual postoperative bone remodeling, a normal hip function is ideally restored. Several factors dictate the choice of implant for *in situ* fixation: age, achieving adequate stability, the risk of complications (e.g. avascular necrosis, chondrolysis, femoroacetabular impingement, limb-length discrepancy), and the ease of future hardware removal [8]. Moreover, surgeons' implant preferences are personal, based on their experiences with different implants.

This paper aims to characterize how the choice of implant for *in situ* fixation of stable SCFE has changed over time through a systematic review of publications from 1993 to 2021 reporting on implants used in surgery. We also begin to correlate these changes with patient demographics by evaluating implant choice in the context of patient age. The authors hypothesized that there had been a change in the type, diameter, and number of implants used for operative management. Outcomes between

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different implants have been compared, but the actual implants used in practice have not been well-characterized cross-institutionally. Identifying temporal trends in implant usage allows surgeons to compare their practice with evolving field standards. Thereupon, we may identify gaps in our knowledge and patient care. Of note, previous studies have been published regarding changes in implant choice when managing certain pediatric injuries, such as supracondylar humerus fractures, femoral shaft fractures, and forearm fractures [9]. Other studies have reviewed changes in implants in the fields of arthroplasty, spine surgery, shoulder and elbow surgery, and trauma [10–13]. To our knowledge, this is the first study to systematically review temporal changes in implant choice across the field of pediatric orthopedics.

Methods

We performed a systematic and extensive literature review utilizing multiple databases, including Pubmed, EMBASE, MEDLINE, CINAHL Complete, and Web of Science, to identify publications from January 1993 to November 2021 comprising clinical cases using *in situ* fixation of stable SCFE. The concept of slip stability was introduced in 1993, so studies prior to this date were not included [3]. We highlight the search strategy employed for Pubmed below. The other database searches were modified based on this approach.

('slipped capital femoral epiphys*'[tiab] OR 'slipped upper femoral epiphys*'[tiab] OR 'slipped epiphys*'[tiab] OR SCFE[tiab] OR SUFE[tiab] OR epiphysiolys*[tiab] OR ('Epiphyses, Slipped'[Mesh] AND 'Femur'[Mesh]) OR 'Slipped Capital Femoral Epiphyses'[Mesh]) AND (fixation[tiab] OR pinning[tiab] OR stabilization[tiab] OR epiphysiodes*[tiab] OR 'Internal Fixators'[MESH]).

After duplicate articles were removed, two independent reviewers analyzed the article titles and abstracts, and a third reviewer was consulted when there was a lack of consensus. Relevant articles focused on treating stable SCFE pathology via *in situ* fixation, including prophylactic fixation of the contralateral hip in patients with unilateral SCFE. Given the variability in SCFE categorizations (e.g. stable or unstable; acute, chronic, or acute-on-chronic; mild or severe slip), we removed articles that exclusively reported on cases of unstable SCFE. We excluded papers on non-SCFE pathology or alternative fixation techniques, like osteotomy and preoperative reduction. We also excluded literature reviews without affiliated case reports and papers with abstracts in languages other than English. Among the remaining articles, a single author reviewed the full texts and noted the implants' features. We excluded biomechanical studies of implants using non-human materials and studies without mention of the implant used.

The included articles categorized implants based on the type, diameter, and/or number used. The type of implant was sub-categorized based on cannulation and threading, while implants with additional unique features were grouped as 'miscellaneous'. Each article was assigned a level of evidence according to the Oxford 2011 Levels of Evidence classification to assess the methodological quality of the literature cohort [14]. We examined the following trends for each type, diameter, and number of implants: the change in the number of publications using a particular implant over the publication year, the change in the number of publications using a specific implant over the actual date of surgery reported in articles (or the median date for a range of dates), and the change in the percentage of publications using a particular implant in a given publication year. Finally, we identified the mean age of the patient cohort in each publication to assess changes over time in the age of patients with stable SCFE undergoing *in situ* fixation.

Statistical analysis

Bivariate regression analyses were used to assess trends in implant usage and age over time. One-way ANOVA and Student's *t*-test were used to compare the average age between groups. We used Prism 9, version 9.5.1 (GraphPad Software, LLC) for all statistical tests. A *P*-value of less than 0.05 was considered statistically significant.

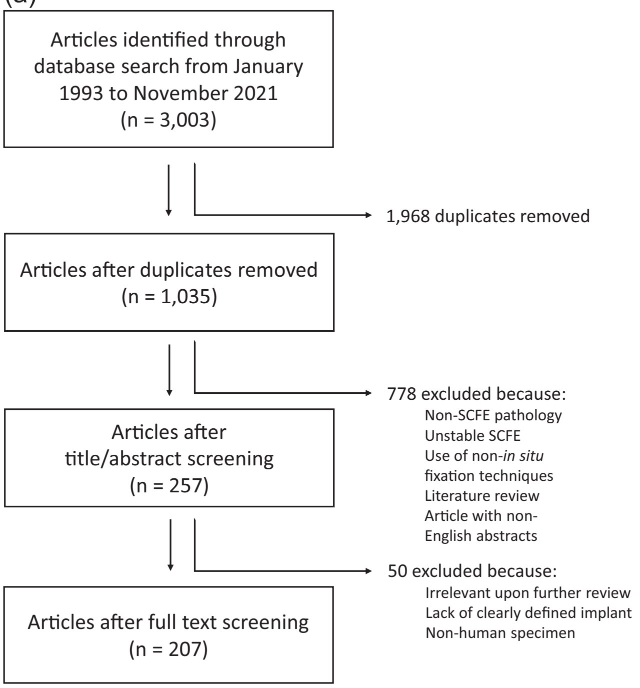
Results

A total of 3003 articles were initially identified through the databases of which 1035 articles remained after exclusion of duplicates. 257 articles met the inclusion/exclusion criteria upon review of titles and abstracts. Of these, 207 articles were included in our data analysis after review of the full texts. The process is illustrated in Fig. 1a. The majority of included articles were level of evidence 4. Our literature cohort also largely included levels of evidence 3 and 5 (Fig. 1b).

Of the 207 articles that met inclusion criteria, 188 identified the type of implant used for *in situ* fixation. Of these, 143 used a cannulated screw (95 partially-threaded and 17 fully-threaded among those reported); 17 used a threaded non-cannulated implant (e.g. solid screw, threaded Schanz-type nail, threaded Kirschner wire); 53 used a threadless non-cannulated implant (e.g. non-threaded Kirschner wire, Knowles pin, Steinman pin, Moore's pin); and 24 used a miscellaneous implant. Miscellaneous implants included a Hansson pin, bone graft, telescoping screw, free-gliding screw, von Bahr screw, Nyström nail, Smith-Peterson nail, Sven Johanssen nail, and a distally 'unthreaded' screw. Of note, these articles are not mutually exclusive, as many articles included multiple different types of implants. We found an increase in the number of publications using cannulated screws for *in situ* fixation of stable SCFE over time ($P = 0.0113$; Fig. 2a). Similarly, we found an increase in the use of cannulated screws based on the actual date of surgeries reported in 112 of these articles (P = 0.0064; Supplementary Fig. 1A, Supplemental digital content 1, *http://links.lww.com/JPOB/A92*). Given fluctuations in the total number of publications on SCFE per year, we also analyzed the percentage of publications in a year using a particular implant. We found an increase in the percentage of publications in a given year using cannulated screws (P = 0.0047) and a decrease in the percentage using threadless non-cannulated implants (P = 0.0309; Supplementary Fig. 2A, Supplemental digital content 2, *http://links.lww.com/JPOB/A93*).

Fig. 1

(a)



(b)

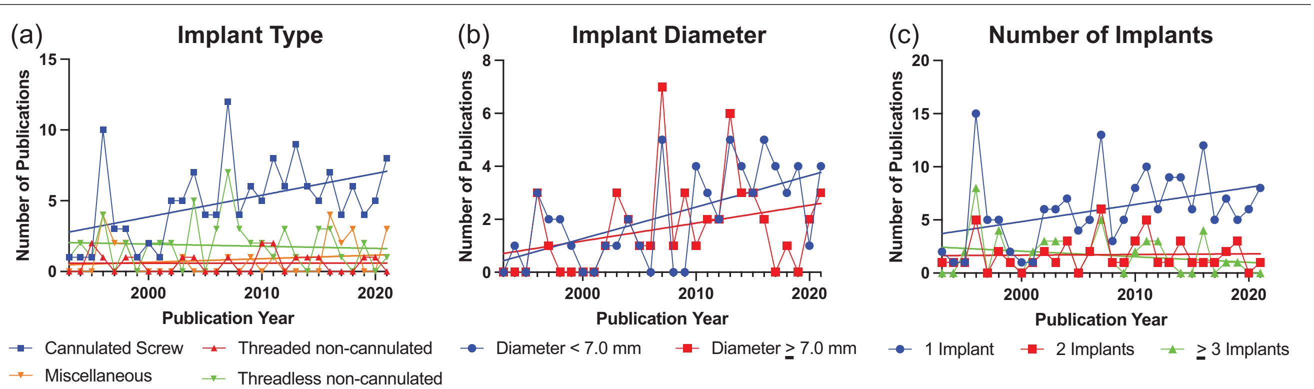
Level of Evidence	1	2	3	4	5
Number of Papers	0	6	60	94	47

Systematic review workflow. (a) Flowchart of study selection. (b) Levels of evidence of articles in literature cohort.

Furthermore, 98 articles identified the diameter of the implant, which ranged from 2 mm to 10 mm. 61 articles used an implant less than 7 mm in diameter, and 48 articles used an implant greater than or equal to 7 mm in diameter with a subset using implants of both sizes. There was not a statistically significant difference between the change in the use of <7 mm and ≥7 mm-diameter implants (P = 0.299). Rather, there was an increase in the number of publications using both diameter groupings over time (pooled slope = 0.0934, P = 0.0004; Fig. 2b). Similar results were found when trended over the actual surgery dates reported in 62 articles (Supplementary Fig. 1B, Supplemental digital content 1, *http://links.lww.com/JPOB/A92*). There was also no change over time in the percentage of publications each year using <7 or ≥7 mm-diameter implants (P = 0.798; Supplementary Fig. 2B, Supplemental digital content 2, *http://links.lww.com/JPOB/A93*).

A total of 186 articles identified the number of implants used for hip fixation. Of these, 173 used a single implant, 50 used two implants, and 49 used more than two implants. These articles were not mutually exclusive. We found an increase in single-implant fixation among publications (P = 0.0409; Fig. 2c), a change that was also seen when trended over the actual surgery dates reported in 110 of these publications (P = 0.0445; Supplementary Fig. 1C, Supplemental digital content 1,

Fig. 2



Temporal trends in the type, size, and number of implants for *in situ* fixation of stable SCFE among publications from 1993 to 2021 (regression lines shown). (a) Type of implants reported among publications over time. (b) Diameter of implants reported among publications over time. (c) Number of implants reported among publications over time.

http://links.lww.com/JPOB/A92). The percentage of publications in a given year using a single implant increased as well (P = 0.0260; Supplementary Fig. 2C, Supplemental digital content 2, *http://links.lww.com/JPOB/A93*).

The coefficient of determination, slope, standard error, P-value, and 95% confidence intervals for all bivariate regression analyses of the number of publications using a particular implant over time are shown in Table 1. These statistical measures are also shown in Supplementary Tables 1 and 2, Supplemental digital content 3, *http://links.lww.com/JPOB/A94* for bivariate regression analyses of the number of articles using an implant according to the actual date of surgery and the percentage of articles using a specific implant in a publication year, respectively.

Finally, we found that the age of patients undergoing *in situ* fixation of stable SCFE did not change among publications from 1993 to 2021 (P = 0.595; Supplementary Fig. 3A, Supplemental digital content 4, *http://links.lww.com/JPOB/A95*). When stratified by implant type, diameter, and number, there was no change in the mean patient age in any of these subgroups (P > 0.05; Supplementary Fig. 3B–D, Supplemental digital content 4, *http://links.lww.com/JPOB/A95*). While there was no difference in the mean age of patients between implant types (F(3204) = 2.161, P = 0.0937) or number (F(2242) = 0.295, P = 0.745), publications using ≥7.0 mm-diameter implants had, on average, older patient cohorts than publications using <7.0 mm-diameter implants (12.6 years versus 11.7 years, P = 0.0462).

Discussion

In this study, we hoped to comment on temporal trends in surgeons' implant preferences for *in situ* fixation of stable SCFE by analyzing the popularity of implants over nearly three decades of orthopedic literature. In doing so, we may identify where the field is headed and possible unanswered questions. Our results revealed an increase in the reported use of cannulated screws among articles published from 1993 to 2021. A secondary analysis of the percentage of articles using an implant each year confirmed a movement away from the use of threadless non-cannulated implants and towards the use of cannulated screws. There has also been an upward trend in single-implant fixation. Additionally, there was no difference in the change in usage between different implant diameters. The reported use of <7 mm and ≥7 mm-diameter implants both increased over time with no significant preference for one or the other. However, when stratified by patient age, we found that older patients' slips were more commonly fixated with larger-diameter implants.

The rising trend of single-cannulated screws is not surprising in the context of prior literature. Most surgeons today agree that the minor benefit of stabilization with multiple implants does not offset the increased risk of complications. Comparative studies have shown that a single screw provides sufficient fixation with minimal rates of joint penetration, chondrolysis, and avascular necrosis compared to using two or more implants [15–17]. A better understanding of optimal screw positioning and the earlier detection of slips where a single screw suffices may explain this growing trend [18,19]. The higher complication rates associated with multi-implant stabilization are likely related to the difficulty of conceptualizing the three-dimensional anatomy of the proximal femur and its blood supply with two-dimensional fluoroscopy [20]. Furthermore, the threading of cannulated screws prevents slip progression and implant migration, which likely explains the relative minimal use of threadless non-cannulated implants in the literature [21,22]. Among publications reporting screws for *in situ* fixation, partially-threaded screws have been predominantly used. Despite an overwhelming majority of articles citing the use of partially-threaded over fully-threaded screws, there is mixed evidence on the advantages of one construct over the other [23–25]. Regardless of the length of threading along the screw, the implant trajectory so as to maximize the number of threads engaging both the epiphysis and metaphysis is likely the most important prognostic factor [21,26]. Still, threaded screws have their downside. Most notably, they arrest growth at the physis, increasing the risk of limb-length discrepancy and femoroacetabular impingement [27–29]. Implants like Kirschner wires, Hansson hook pins, and telescopic screws permit continued femoral growth and therefore, have historically been used in younger patients [30–32]. Interestingly, our analysis did not identify a difference or change in the age

Table 1 Bivariate regression analysis results for implant usage among publications from 1993 to 2021

		Coefficient of determination	Slope	Standard error	P-value	95% confidence interval
Type of implant						
	Cannulated	0.215	0.153	0.0564	0.0113	0.0375 to 0.269
	Threaded non-cannulated	0.0000378	0.000493	0.0154	0.975	–0.0312 to 0.0321
	Threadless non-cannulated	0.00622	–0.0153	0.0372	0.684	–0.0915 to 0.0610
	Miscellaneous	0.0278	0.0251	0.0286	0.388	–0.0336 to 0.0838
Implant diameter	Less than 7 mm	0.341	0.119	0.0319	0.0009	0.0537 to 0.185
	Greater than or equal to 7 mm	0.107	0.0675	0.0376	0.0835	–0.00957 to 0.145
Number of implants	One	0.146	0.161	0.0750	0.0409	0.00720 to 0.315
	Two	0.00108	0.00591	0.0346	0.866	–0.06514 to 0.0770
	Greater than or equal to three	0.0541	–0.0527	0.0424	0.225	–0.140 to 0.0343

of patients undergoing fixation with different implant types. Nonetheless, our findings suggest that irrespective of patient-specific considerations, single cannulated screws have increasingly become the implant of choice for *in situ* fixation of stable SCFE.

A paucity of studies has considered the role of the implant diameter on surgical outcomes following *in situ* fixation. The strength of epiphyseal stabilization increases with the diameter of the implant, hence the added stability of multi-implant fixation [33,34]. Neither <7 mm nor ≥7 mm-diameter implants appear to predominate. Rather, we suspect that the paramount consideration in implant diameter may be patient-specific factors, like age, BMI, and femoral neck diameter, instead of inherent advantages with different diameter constructs. We found that patients of older chronological age were managed with larger diameter screws: understandably, bigger femurs require larger implants for adequate fixation. Additionally, the increase in larger-diameter implants in our analysis may be related to the rise in childhood obesity over the past two decades [35]. Correlating implant choice with evolving patient characteristics, like BMI, sex, and endocrinologic comorbidities, represents an interesting future research avenue. It would also be interesting to see whether there is a threshold implant diameter-to-femoral neck diameter ratio at which outcomes change.

Finally, there have been few recent studies assessing the changing age demographic of patients with SCFE. More than a decade ago, Loder and Skopelja showed that the age of patients diagnosed with SCFE was decreasing, reflecting the earlier maturation of children [36]. Our study, however, found a statistically insignificant downward trend from 1993 to 2021 in patient age. Of note, our study excluded patients with unstable SCFE and those who were not managed with *in situ* fixation. As such, the age trend is not representative of all patients with SCFE. Moreover, the analysis may be distorted, as patient cohorts of different sizes were averaged into single data points, increasing the 'weight' of patients in case reports.

We acknowledge several other limitations in our study as well. One of these limitations is the reductive nature of our analysis. Assessing the type, diameter, and number of implants as mutually exclusive is likely oversimplified. For example, Kirschner wires tend to be smaller in diameter and therefore require multiple to achieve adequate stability [37]. In addition, grouping 'miscellaneous' implants and setting arbitrary size cut-points for implant diameter distort heterogeneous groups. One future direction would be to analyze trends more granularly by combining various implant features. It also remains to be seen whether other implant features, like length and material, have changed over time. Unfortunately, these types of analyses were limited in our study by inconsistent reporting of implant features among articles.

Another limitation of our study is using publications as a proxy for field trends. Given the academic bias to publish novel findings, our literature cohort likely over-represents the use of miscellaneous implants with unique features and under-reports common-use implants, like screws. After all, we excluded a subset of papers from our analysis because no implants were specified. Additionally, the year of publication rarely reflects the actual surgery date, especially in extensive retrospective studies. Consequently, the authors trended the rates of implant usage according to the exact surgery dates. While a smaller sample of the literature reported the dates that surgeries were performed, these findings nonetheless substantiate the increasing use of single cannulated screws and the upward trend among different implant diameters. The authors also considered that our results reflect the growth in literature on SCFE over recent years as opposed to actual changes in implant preference. Therefore, the change in the percentage of publications in a given year using a particular implant was assessed. As expected, the relative use of single cannulated screws increased. Interestingly, the percentage use of threadless non-cannulated implants decreased, which was not reflected in our primary analysis. Furthermore, the percentage use of <7 mm and ≥7 mm-diameter implants did not change over time. This suggests that while reporting on implant diameters increased over time, there was no change in overall preference between different diameters. Given the limitations of publications, it may be informative to measure trends in implant usage using primary data at large academic institutions to substantiate these results.

Moreover, the methodological quality of our literature cohort, based on the levels of evidence, was moderate to low. It suggests that the conclusions we may draw on the role of different implants in stable SCFE outcomes remain limited. The field requires randomized controlled trials and prospective studies to identify the ideal implant for *in situ* fixation.

Finally, our study was limited by inconsistencies in implant nomenclature. The term 'pin', a reference to the phrase 'pinning the hip' used in the orthopedic vernacular to describe *in situ* fixation, is frequently used interchangeably with 'screw', 'nail', and 'wire'. This indiscriminate choice of language often hindered our ability to ascertain what particular implant was used by authors. Our study brings up the need for future authors to carefully characterize their implant choice to facilitate comparisons across the literature.

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Conflicts of interest

There are no conflicts of interest.

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