A Reduction in Body Mass Index Lowers Risk for Bilateral Slipped Capital Femoral Epiphysis

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Abstract

Background Slipped capital femoral epiphysis (SCFE) is occurring in greater numbers, at increasingly younger ages, and more frequently bilaterally (BL-SCFE). Obesity is one risk factor for SCFE. However, it is unclear whether postoperative decreases or increases in body mass index (BMI) alter the risk of subsequent contralateral SCFE.

Questions/purposes We therefore determined whether (1) BMI percentile was a risk factor for BL-SCFE; and (2) postoperative increases and/or decreases in BMI percentile influenced the risk for BL-SCFE.

Methods We retrospectively reviewed the records of 502 patients surgically treated for SCFE and identified 138 (27%) with BL-SCFE and 364 (73%) with unilateral SCFE (UL-SCFE); 173 patients, 60 (35%) with BL-SCFE and

113 (65%) with UL-SCFE met our inclusion criteria. Risk factors included sex, age, slip stability, slip chronicity, slip angle, and obesity. Percentile BMI was recorded at the time of first SCFE surgery, at the time of last followup for patients undergoing UL-SCFE, and at the time of second SCFE surgery for patients undergoing BL-SCFE.

Results Sex, age, slip stability, and slip angle were not associated with BL-SCFE. Postoperative obesity (odds ratio [OR], 3.5; 95% confidence interval [CI], 1.2–9.7) and acute slip chronicity (OR, 2.9; 95% CI, 1.3–6.7) had higher risks for sequential BL-SCFE. Obese patients who became nonobese postoperatively had a decreased risk of sequential BL-SCFE compared with those who remained obese (OR, 0.16; 95% CI, 1.2–116.5).

Conclusions Only postoperative obesity and an acute slip were risk factors for sequential BL-SCFE. BMI reduction to lower than the 95% percentile after SCFE surgery was associated with lower risk for BL-SCFE development. The data suggest early supervised therapeutic weight management programs for patients treated for UL-SCFE are important to reduce risk of subsequent SCFE.

Level of Evidence Level III, prognostic study. See Guidelines for Authors for a complete description of levels of evidence.

Each author certifies that he or she, or a member of his or her immediate family, has no funding or commercial associations (eg, consultancies, stock ownership, equity interest, patent/licensing arrangements, etc) that might pose a conflict of interest in connection with the submitted article.

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Each author certifies that his or her institution approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.

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Introduction

Slipped capital femoral epiphysis (SCFE) is a relatively common hip disorder in adolescents that usually occurs in association with a high body mass index (BMI) around the time of the pubertal growth spurt. SCFE is defined as anterosuperior displacement of the metaphysis relative to the capital femoral epiphysis through the physis [3]. The

condition generally leads to deformity of the proximal femur, which can result in an increased risk of developing osteoarthritis of the hip [46].

As the international epidemic of childhood obesity continues to grow [41], an increasing number of children are developing SCFE [36, 48]. Evidence suggests SCFE is occurring in greater overall numbers [27, 35], in children at increasingly younger ages [35], and in the form of bilateral SCFE (BL-SCFE) to a greater degree than historically reported [23, 26, 30, 43]. Risk factors such as age, sex, ethnicity, BMI, and geographic and seasonal variations have been linked to the development of SCFE in general [27]. Several studies [23, 35, 39, 42] have related obesity to BL-SCFE but these studies used a different definition of obesity than the current gold standard of age- and sex-specific BMI [6, 30, 32]. In addition, obesity being a relatively manageable condition, the effect of changes in obesity after an initial slip and its association with a subsequent slip (ie, incidence of BL-SCFE) were not assessed.

A better understanding of risk factors for BL-SCFE could help resolve the ongoing controversy surrounding the role of prophylactic pinning of the contralateral hip in patients presenting with unilateral SCFE (UL-SCFE) [22, 40, 42, 49], especially if a simple measure such as weight reduction could spare patients with UL-SCFE the risks of a second slip or the complications of prophylactic pinning.

We therefore determined whether (1) BMI percentile and clinical factors (sex, age, slip stability, slip chronicity, slip angle) were risk factors for BL-SCFE; and (2) post-operative increases and/or decreases in BMI percentile influenced the risk for BL-SCFE.

Patients and Methods

We conducted an institutional review board-approved retrospective database review of electronic medical records at an urban, tertiary care, children's hospital and identified all 502 patients who underwent a procedure for SCFE from January 1998 through December 2009. We characterized patients as either having BL-SCFE or UL-SCFE based on whether in situ screw fixation was performed on the contralateral side and further segregated them into those with concurrent BL-SCFE (single-stage bilateral surgery on radiographically confirmed SCFE) or sequential BL-SCFE (staged bilateral surgery). Of the 502 identified patients with SCFE, 138 (27%) had BL-SCFE and 364 (73%) had UL-SCFE. Inclusion criteria were ≥ 3 months' post-operative followup after the first surgery for patients with UL-SCFE and after the last SCFE surgery for patients with BL-SCFE, BMI records over the study period, and in situ percutaneous fixation. We excluded 288 patients with

Table 1. Associated pathology/comorbidity

Pathology/comorbidity	Number of patients screened	Number of patients Excluded as a result of missing data or comorbidity
Turner syndrome	1	1*
Trauma	18	10
Perthes	2	2*
Osteopenia	1	0
Marfan syndrome	1	1
Growth hormone deficiency	2	2*
Hypothyroidism	7	3
Down syndrome	5	5*
Diabetes mellitus (Type I and II)	5	2
Cerebral palsy	1	1
Blount's disease	1	0
Autism	2	0

* Patients excluded only as a result of a comorbidity.

incomplete medical records (such as preoperative or post-operative height or weight needed to determine BMI), initial SCFE treatment at an outside institution, external radiographs only, prophylactic pinning on the contralateral hip, presence of a comorbidity and/or endocrinopathy, and initial open surgical treatment for SCFE, 11 patients with prophylactic pinning performed on a contralateral healthy hip with no clinical or radiographic signs of SCFE, and 10 patients diagnosed with an endocrinopathy or other pathology or comorbidity because these patients have reported underlying causes for SCFE (Table 1); we further excluded 14 patients because they were not initially treated with in situ pinning and six because they were treated at an outside hospital (Fig. 1). These 329 exclusions left 173 patients for study. Of the 173 patients, 113 (65%) were diagnosed with UL-SCFE and 60 (35%) with BL-SCFE. Of the 60 patients with BL-SCFE, 18 patients (30%) had concurrent BL-SCFE, whereas 42 (70%) had sequential BL-SCFE with a median interval between diagnosis of 8.4 months (mean, 12 months; range, 1–46 months) (Fig. 2). The mean age at the time of presentation was 12 years (range, 8–17 years). Seventy-five (43%) of the 173 patients were females. The minimum followup was 0.25 years (mean, 3.3 years; range, 0.25–10 years). Of the 173 patients, 88 (51%) had reached skeletal maturity at last followup based on chronological age (≥ 14 years old for females and ≥ 16 years old for males); among the 113 patients with UL-SCFE, 69 (61%) were skeletally mature based on their chronological age at the time of last followup. No patients were recalled specifically for this study; all data were obtained from medical records and radiographs.

Fig. 1 A flow diagram of the study cohort detailing patient selection and exclusion reasons when applicable. Overall 173 of 502 (34%) patients were included in the study. [†]Inadequate followup was defined as time from index surgery until the last date of clinical visit less than 3 months.

Fig. 2 A diagram presenting the time in months to sequential slip among the 42 patients who progressed to sequential BL-SCFE by the end of the study period. The median interval between sequential BL-SCFE diagnoses was 8.4 months (mean, 12.4 months; range, 1.2–45.9 months).

Demographic data, collected from patients' medical records and analyzed, included sex, age at the time of surgery, mechanism of injury, duration of preoperative symptoms such as pain or limp, ability to bear weight on the affected extremity at the time of presentation, clinical followup in years calculated from the time of first SCFE surgery to the most recent clinical visit, height (meters) and weight (kilograms) recorded either preoperatively or ≤ 2 weeks from the first surgery (pre-BMI), and between 3 and 5 months after the last SCFE surgery for patients with BL-SCFE, and at the time of last clinical visit for patients with UL-SCFE (post-BMI). BMI was calculated from the recorded height and weight information using the well-established formula of (weight in kg)/(height in m²). We classified patients as either nonobese or obese at the time of their primary SCFE surgery and at last followup for UL-SCFE or at the time of their contralateral SCFE surgery for BL-SCFE. Obese was defined using BMI $\geq 95^{\text{th}}$ percentile

in accordance with the most recent 2011 Centers for Disease Control and Prevention guidelines for sex- and age-specific BMI growth charts [2, 12, 14, 25, 34, 37, 38].

We further classified each case as being stable or unstable SCFE based on criteria elucidated by Loder et al. [31]. Slip chronicity was categorized as chronic (time of presentation ≥ 3 weeks later than the development of symptoms) or acute (symptoms < 3 weeks) as proposed by Kallio et al. [21]. The cases were further classified into one of three grades of severity based on measurements of the slip angle on frog-leg lateral radiographs as described by Southwick [8, 29, 44] (Grade I [mild] SCFE was defined as slip angle $< 30^\circ$, Grade II [moderate] SCFE 30° – 50° , and Grade III [severe] $> 50^\circ$).

We assessed trends in BMI change by comparing pre-BMI percentile with post-BMI percentile. Patients with UL-SCFE and those with sequential BL-SCFE were divided into four different groups based on whether they remained

or moved to either the obese or the nonobese categories at followup (obese-obese, obese-nonobese, nonobese-obese, nonobese-nonobese). In the overall cohort of patients with SCFE, the mean BMI increased from 29 kg/m² (range, 14–42 kg/m²) at the time of the first surgery to 32 kg/m² (range, 16–54 kg/m²) at the time of the second SCFE surgery for BL-SCFE or at the most recent followup for patients with UL-SCFE. One hundred thirty-seven patients (79%) had a BMI $\geq$ 95th percentile at first presentation compared with 134 patients (78%) at the last followup.

We used univariate and multivariate logistic regression analysis to identify potential risk factors for sequential BL-SCFE compared with patients with UL-SCFE using the following variables with categories as described previously: age (dichotomized as $\leq$ 10 or $>$ 10 years old at the time of presentation for SCFE), sex, slip chronicity, slip stability, slip angle, clinical followup in years (to analyze whether there was a difference in followup between patients with UL-SCFE and patients with BL-SCFE because we did not collect radiographic data on patients' skeletal maturity), and obesity. We used Kaplan-Meier curves to illustrate the difference in incidence and time to sequential BL-SCFE among obese and nonobese patients at 24 months followup. Bivariate logistic regression analysis was performed to assess whether change in obesity category (obese-obese, obese-nonobese, nonobese-obese, nonobese-nonobese) had a major effect on developing sequential BL-SCFE. Data initially recorded in Microsoft Excel (Redmond, WA, USA) were imported into SPSS (SPSS Inc, Chicago, IL, USA) software for statistical analysis.

Results

Postoperative obesity (odds ratio [OR], 3.5; 95% confidence interval [CI], 1.2–9.7; $p = 0.011$) and acute slip at the first SCFE surgery (OR, 2.9; 95% CI, 1.3–6.7; $p = 0.017$) were risk factors for developing subsequent BL-SCFE. Sex, age, followup, slip stability, and slip angle were not risk factors for subsequent BL-SCFE (Table 2).

When assessing trends in BMI change, BMI percentile change, and prevalence of obesity among patients with UL-SCFE ($n = 113$) and those with sequential BL-SCFE ($n = 42$), BMI increased in patients with UL-SCFE an average of 2.92 kg/m² (range, -9.8 to $+16.8$ kg/m²). Among patients with sequential BL-SCFE, BMI increased an average of 3 kg/m² (range, -5 to $+12.52$ kg/m²). When analyzing the effect of postoperative BMI percentile changes for the included 155 patients (113 UL-SCFE + 42 BL-SCFE), Kaplan-Meier curves illustrated that a higher percentage of obese patients with UL-SCFE develop BL-SCFE and have these events earlier than patients with UL-SCFE of normal BMI. At 24 months of followup, the Kaplan-Meier estimate was 91% free from transitioning to BL-SCFE for children with normal BMI (95% CI, 83%–99%) while lower ($p = 0.018$) in obese children (70%; 95% CI, 62%–78%) (Fig. 3). In the subset of 16 patients who decreased their BMI from $\geq$ 95th percentile to $<$ 95th percentile, 15 (94%) of them remained UL-SCFE, whereas only one (6%) developed BL-SCFE. Patients whose BMI decreased to less than the 95th percentile were less ($p = 0.026$) likely to progress to BL-SCFE than patients

Table 2. Presentation of patients with UL-SCFE compared with patients with sequential BL-SCFE

Variable	Variable subcategory	Unilateral SCFE (n = 113)	Sequential BL-SCFE (n = 42)	Univariate p value	Logistic regression; multivariate p value
Sex, number (%)	Male	59 (52.0)	26 (62)	0.364	0.229
	Female	54 (48.0)	16 (38)		
Age at first SCFE, number (%)	Age $\leq$ 10 years	13 (12)	9 (22)	0.126	0.208
	Age $>$ 10 years	100 (88)	33 (78)		
Slip chronicity [16], number (%)	Acute ($<$ 3 weeks)	18 (16)	14 (33)	0.026*	0.017*
	Chronic ($>$ 3 weeks)	94 (84)	28 (67)		
Slip stability [42], number (%)	Stable	94 (83)	34 (81)	0.812	0.841
	Unstable	19 (17)	08 (19)		
Severity of slip [43], number (%)	Grade I	73 (64)	25 (59)	0.381	0.328
	Grade II	16 (14)	10 (24)		
	Grade III	22 (20)	07 (17)		
Postoperative BMI $\geq$ 95 th percentile, number (%)		80 (71)	37 (88)	0.035*	0.011*
Followup (years), mean $\pm$ SD (range)		3.3 $\pm$ 2.5 (0.25–10.2)	3.2 $\pm$ 1.8 (0.75–7.3)	0.724	0.619

* Significant risk factor associated with the incidence of sequential BL-SCFE based on a 95% confidence interval; UL = unilateral; SCFE = slipped capital femoral epiphysis; BL = bilateral; BMI = body mass index.

Fig. 3 A Kaplan-Meier freedom from sequential BL-SCFE survivorship curve. The log-rank test indicated that conversion to sequential BL-SCFE occurs more often and sooner in patients with high BMI. At 24 months followup, 9% of patients with postoperative BMI < 95% developed sequential BL-SCFE compared with 30% of those with BMI > 95%. Error bars denote 95% CI as determined with Greenwood's formula.

Fig. 4 A chart showing patients progressing to BL-SCFE per categorical BMI change. The trends in BMI change were assessed by comparing pre-BMI percentile with post-BMI percentile. Patients with UL-SCFE and those with sequential BL-SCFE were divided into four different groups based on whether they remained or moved to

either the obese or the nonobese categories during the study period. Obesity was defined as having an age-/sex-specific BMI > 95th percentile. Obese patients whose BMI decreased to less than the 95th percentile were less ($p = 0.026$) likely to progress to BL-SCFE than patients who remained obese.

who remained obese (OR, 0.16; 95% CI, 1.2–116.5) (Fig. 4).

Discussion

The association between obesity and the development of SFCE in adolescents is well established. Increased body mass can cause the phenomenon of repetitive microtrauma through the proximal femoral physis to occur with increasingly greater forces. This mechanism, combined with relative femoral retroversion seen in overweight adolescents and the resulting elevated shear stresses, causes physeal chondrocyte apoptosis, biomechanical instability

of the physis, and subsequent anterosuperior displacement of the proximal femoral metaphysis relative to the capital epiphysis, which remains contained in the acetabulum [1, 19, 20, 50]. BL-SCFE can occur at the initial presentation, which we labeled concurrent SCFE in the current study, or over time in the contralateral hip, which we labeled sequential SCFE. The prevalence of sequential BL-SCFE is approximately 20% [22]. Obesity is a highly modifiable risk factor that can be managed through lifestyle changes and supervised weight reduction [33]. Such simple alterations in lifestyle along with clinical weight reduction supervision could lead to a decrease in percentile BMI and subsequently a decrease in the relative risk for BL-SCFE among patients presenting with UL-SCFE. This treatment

option would introduce a midline approach, avoid the surgical prophylactic pinning of the contralateral hip in willing patients with UL-SCFE, and its possible iatrogenic risks yet closely monitoring patients and actively reducing the risks for potential sequelae of a SCFE, particularly an unstable or severe SCFE that might occur in an unpinned contralateral hip [9, 42, 47]. Hence, the present study aimed first to evaluate obesity and other clinical features as potential risk factors for BL-SCFE and then to investigate the association between sufficient increase or decrease in BMI percentile to move from being obese to nonobese or vice versa in the postoperative period after surgical treatment of UL-SCFE and the impact this change could have on the relative risk for BL-SCFE.

Limitations of the current study include the following. First, the study was retrospective and we excluded many patients lacking BMI information (Fig. 1). However, we presume these patients were just subject to random inconsistency in nursing measurement practices rather than some form of selection bias. Second, we lacked followup in all patients to skeletal maturity. Given this limitation, it is possible that some patients with UL-SCFE could still progress to BL-SCFE; however, among patients who finished the study with UL-SCFE, 61% reached their sex-specific skeletal maturity chronological age; the mean age of patients with UL-SCFE at the time of the second BMI reading was 15.6 years (range, 10–24 years) for females and 15.5 years (range, 11–25 years) for males. Furthermore, the median followup in patients with UL-SCFE was 2.6 years, whereas the median time to second slip among patients with BL-SCFE was 8.2 months (mean, 12 months; range, 1–46 months); thus, we believe a small number of patients could have been lost to followup with an unrecorded progress to BL-SCFE affecting our results. Third, we excluded 11 patients who had prophylactic pinning. This decreased the number of patients < 10 years old at the time of first SCFE in this study. This limitation could have altered the identification of young age among other variables as a risk factor for BL-SCFE in the present study. Last, our designation of UL-SCFE versus BL-SCFE, whether concurrent or sequential, relied on surgical records rather than an independent review of patients' radiographs to identify asymptomatic mild slips. This limitation could have decreased the actual number of patients with BL-SCFE. However, in accordance with most studies published on SCFE, the described incidence relied on symptomatic SCFE that required treatment rather than radiographic assessment. In addition, there exists some controversy on whether mild SCFE diagnosis can be made solely based on radiographs. For these reasons, we believe our results are not affected by the bias this limitation might impose.

We identified obesity and acute slip chronicity as risk factors for the development of sequential BL-SCFE. Other

variables including age, sex, symptom duration, slip stability, slip chronicity, slip angle, and clinical followup were not predictive for the development of sequential BL-SCFE. Previous literature has demonstrated inconsistent findings in terms of risk factors for the development of sequential BL-SCFE. Riad et al. [39] followed 90 patients with SCFE to skeletal maturity, 20 of whom presented with concurrent BL-SCFE and 16 with UL-SCFE but later developed BL-SCFE. In their series, chronologic age was the only major predictive factor for BL-SCFE with subanalysis prompting a recommendation for strong consideration toward prophylactic pinning of the contralateral hip in females < 10 years old and males < 12 years old at presentation [39]. Koczowski [23] found boys were at a higher risk than females for developing secondary, asymptomatic SCFE on the contralateral side [23]. Bidwell and Stott [7] reported that neither slip stability nor sex was predictive of contralateral SCFE in a series of 171 patients with patients with UL-SCFE followed for ≥ 3 years, 56 (31%) of whom developed BL-SCFE [7]. However, these authors did find age < 12 years to be a major risk factor. Although three other investigations supported this finding of younger age as a risk factor for BL-SCFE [28, 30, 45], Koenig et al. [24] reported that age, sex, slip stability, slip chronicity, modified Oxford bone age, physeal slope angle, and slip angle were not associated with the development of BL-SCFE in a series of 71 patients with UL-SCFE [24]. We found patients presenting with an acute slip are at risk for sequential BL-SCFE and have a 2.5 chance of developing BL-SCFE compared with those who present with a chronic slip. Although almost all unstable slips are acute, not all stable slips are chronic and many are acute, thus increasing the number of acute slips among patients with sequential BL-SCFE and resulting in finding acute slips as a potential risk factor for BL-SCFE. We found age < 10 years at the time of first SCFE surgery tended toward significance, so a larger sample size may have clarified this as a risk factor. Most patients in the overall denominator of patients studied who were < 10 years old at the time of presentation had the contralateral hip pinned prophylactically and were therefore excluded from this study.

Relatively few studies [6, 30, 39] have examined obesity in detail as a risk factor for BL-SCFE. We demonstrated that those patients with UL-SCFE whose age- and sex-specific BMI was $\geq 95^{\text{th}}$ percentile postoperatively had a 3.5 times greater chance of developing a contralateral slip, independent of any other variable, when compared with those whose BMI decreased or remained < 95th percentile. Furthermore, survivorship analysis revealed a substantially higher percentage of obese patients with UL-SCFE develops BL-SCFE and has these events earlier than patients with UL-SCFE of normal BMI. Loder et al. [30] studied 82 children who developed BL-SCFE; 41 had sequential slips.

They found obesity and age were major risk factors when compared with a similar cohort of patients with UL-SCFE. Likewise, Bhatia et al. [6] found the BMI in 16 patients with BL-SCFE, six of which were sequential slips, was higher than that of patients with UL-SCFE. Although our observations concur with those of both Loder et al. and Bhathia et al. for obesity as a risk for BL-SCFE, direct comparison of the three studies is confounded somewhat by differing definitions of obesity, which were markedly different at the time of the previous two studies. Loder et al. defined obesity using exclusively patients' weight per Centers for Disease Control and Prevention standards. BMI has since been recognized as a more sensitive and reliable tool in determining obesity [4, 5, 10, 11, 15, 37]. Bhatia et al. did use BMI to define obesity. However, as elucidated in a subsequently published letter to the editor [32], average BMI, rather than percentile analysis, was used to draw the study conclusions without taking into account either patient age or sex [32, 33]. The vast majority of patients in our series were obese (80%) in the preoperative period and in the postoperative period (78%). However, patients who decreased their BMI sufficiently to fall out of the obesity range were substantially less likely (OR, 0.16) to have a sequential contralateral slip than those who remained obese.

In summary, in our series, acute slip chronicity and obesity were identified risk factors for development of BL-SCFE. These data speak to the importance of continued efforts in patient education and the need for more proactive referrals to specialists in nutrition and obesity management. Much like the emerging role of the orthopaedic surgeon in the early management of osteoporosis and metabolic bone disorders in postfracture care in older populations [13, 16–18], we believe SCFE presents a unique and perhaps the most important opportunity for the orthopaedic surgeon to be proactive in education and clinical intervention regarding obesity, which can greatly improve the prognosis for SCFE as well as the overall health of the pediatric patient. We also suggest that prophylactic pinning might be considered for morbidly obese patients. Such patients are above the obesity threshold for their respective age and sex and may not respond well to weight management programs or are unlikely to lose sufficient weight within the short period of time at which contralateral SCFE typically occurs. The importance of early supervised therapeutic weight management programs for patients treated for UL-SCFE remains paramount and greater study into enhancing the effectiveness of such early educational and clinical efforts is warranted.

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