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Original article

Growth modulation by hemi epiphysiodesis using eight-plate in Genu valgum in Paediatric population

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ABSTRACT

Introduction: Genu valgum is an angular deformity of the knee, often treated surgically by osteotomy or by growth modulation (using tension band, staples, transphyseal screws and eight-plate which require removal after correction). With this study, we attempt to evaluate the efficacy, rate of correction and complications with the use of 8-plate in the correction of genu valgum deformity in children.
Material and method: In a retrospective study of 24 patients with 11 bilateral and 13 unilateral (35 knees) genu valgum deformity which required surgical corrections were included. There were 11 males, and 13 females and all of them were treated with Steven's technique (Stevens, 2006) using eight-plate and monitored closely.
Result: Twenty-four patients with an average age of 10 years and 8 months (range: 5 yrs, 7 months–14 yrs, 2 months), with the mean preoperative & post-implant removal (Post-IR) tibiofemoral angle of 22.02° ± 5.15° (range 14°–31°) & 6.14° ± 1.92° (range 2°–10°) respectively, required an average time period of 1yr & 5m ± 5 m (range 10 months–28 months) for correction after which implants were removed. Of the 35 limbs, we achieved excellent results in 91.6%. One case (4.16%) had a partial correction of the deformity, and one case (4.16%) had reported with a superficial infection which was taken care. There were 2 cases (8.33%) of over-correction, which was gradually self-corrected during follow-up.
Conclusion: Our results reflect the efficacy of flexible titanium eight plate which corrects angular deformity by acting as a tension band on one side of the growth plate and offers the advantage of reversible Hemi epiphyseal growth modulation. Guided growth modulation is a best available alternative for the treatment of an angular deformity in the patients with open physis.
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1. Introduction

Genu Valgum is an angular deformity of the knee, found commonly in pediatric age group.[1] It is a physiologic process and usually subsides by 6yrs of age spontaneously.[2] When it does not subside with age, and the deformity continues to progress with age, then it is known to be a pathological deformity. The cause may be idiopathic or congenital syndromes like Arthrogryposis, Vitamin D resistant rickets, tyrosinemia, etc. or it may also be post-traumatic. In pathological angular deformities, due to disease progression, there is a gradual displacement of the mechanical axis which affects skeletal growth. When Valgus deformities exceed 10°, it becomes symptomatic with pain in the knee, limp, and stiff knee, which further leads to a non-functioning limb with permanent deformity along with limb length discrepancy and ultimately cause of early knee arthritis.[3]

Genu valgum can be corrected surgically either by osteotomy and internal fixation or gradual correction by external fixator or by growth modulation.[4] Growth modulation means modifying/manipulating the normal growth patterns. It facilitates correction of angular deformities by selectively reversible tethering a portion of the physis to correct limb alignment.[5] Deformities that can be treated with growth modulation include ankle valgus, genu valgum, genu varum, knee flexion contracture, and limb-length discrepancy (LLD). Growth modulation in genu valgum is done by Hemi epiphysiodesis using implants such as tension band, staples,[6,7] transphyseal screws[8] and 8-plate[9,10] but require removal after correction has been achieved. Recent advances in experimental techniques for guided growth include physeal transplantation[11] and biological modulation.[12]

We studied 24 cases of genu valgum subjected to correction of deformity using 8-plate. With this study, we attempt to evaluate

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the efficacy, rate of correction and complications with the use of 8-plate in the correction of genu valgum deformity in children.

2. Material and method

In this retrospective study, a total of 24 patients with 11 bilateral and 13 unilateral knees affected with genu valgum deformity were included. There were 11 males and 13 females in the current study. All the cases had only genu valgum deformity, and no other deformity was present. All of them were operated using 8-plate. Inclusion criteria were mainly growing physis.

Preoperatively, all limbs were evaluated for limb length discrepancy along with angular and rotational deformities. Radiographically, lower extremity scanogram/standing Knee AP roentgenogram was taken for assessment. The tibiofemoral angle was used pre-operatively as well postoperatively at every follow-up to assess the degree of deformity and degree of correction. To avoid any interobserver error, a single orthopedic surgeon recorded all measurements.

2.1. Operative procedure

The method included of extraperiosteal plating with two non-locking screws under fluoroscopic guidance (as described by Stevens[13]). One plate per physes was used in each deformity, and the location was distal femur medial aspect in all cases.

Under general anesthesia, the tourniquet was applied and a 2–3 cm incision taken centering over the physis located under a C-arm. A 1.2 mm K-wire was passed into the physis under fluoroscopic guidance. Due care was taken to avoid any damage to the physis. The tension band plate (2-hole 4.5 mm titanium plate) now placed extra periosteally, and 1.6 mm guidewires introduced into the metaphyseal and the epiphyseal region with care to avoid damaging the periosteum. The plate placed flush to the bone and fixed with 4.5 mm fully threaded self-tapping cannulated screws over the guide wires into the metaphysis and the epiphysis after drilling with a 3.2 mm cannulated drill bit. The final placement of the plate and the screws are confirmed under the C-arm in AP and lateral views with the plate being in the center of the lateral view to avoid any iatrogenic sagittal plane deformities. The skin was sutured with nonabsorbable sutures, and compression bandage applied.

2.2. Post-operatively

All the patients were ambulated immediately after surgery, as soon as pain subsides. There was no need for immobilization or physical therapy. Patients were followed up every three months and evaluated using standing x-rays. Close follow-up is essential to prevent overcorrection (i.e., development of an opposite deformity). Thus allowing controlled correction of the deformity.

Once the desired correction of the tibiofemoral angle was achieved, hardware was removed and the all cases were the followed-up minimum for a year after plate removal.

2.3. Implant

2.3.1. The eight-plate

It is a two-hole pre-contoured dynamic construct plate, available in three lengths (12 mm, 16 mm and 20 mm) (Fig. 1), with variable lengths of non-locking self-tapping cannulated 4.5 mm fully threaded screws (16 mm, 24 mm, and 32 mm).

All the complications were recorded as per the defined criteria (Table 1). A correction was considered to be completed only when the desired Tibio-femoral angle was achieved after hardware removal and maintained up to the skeletal maturity.

3. Result

Twenty-four patients with an average age of 10 years and 8 months (±2y and 4m) (range 5yrs 7 m–14yrs 2 m), with mean preoperative & post-implant removal tibiofemoral angle of 22.02° ± 5.15° valgus (range 14°–31°) & 6.14° ± 1.92° (range 2°–10°) respectively, required an average time period of 1yr + 5m ± 5 m (range 10 months–28 months) after which implants were removed. The mean amount of deformity corrected was found to be 15.9° ± 5.86° (range 8°–27°), and the overall rate of correction of deformity was recorded to be 0.91° ± 0.19° per month (Table 2). An algorithm has been formed to manage the paediatric population with genu valgum deformity as shown in Fig. 2 . Fig. 3 shows the clinical picture of pre and postoperative correction with a valgus knee.

Of the 35 limbs, we achieved excellent results in 91.67%. One case (4.16%) had a partial correction of the deformity, and one case (4.16%) had reported with a superficial infection which was taken

Fig. 1. Eight-plate with three different sizes.

Table 1
Criteria for Complications.

Complications	Failure to achieve desired correction or under correction Overcorrection at skeletal maturity Implant failure due to loosening/backing out or migration or breaking of screws and plate Physeal violation by the implant or early physeal closure (as compared with the opposite side) Infection Need for repeat surgery except for routine implant removal after correction

care. There were 2 cases (8.33%) of over-correction, which was gradually self-corrected during follow-up. There were no cases of implant specific complications such as a plate or screw breakage or backing out of the screws or migration of plate. No rebound deformity was observed, in any of the corrected cases (Fig. 4).

4. Discussion

In genu valgum, the mechanical axis is shifted laterally. Angular deformities of the knee lead to an abnormal loading and alteration of the knee biomechanics leading to asymmetrical stress distribution on the weight-bearing surface of the knee joint. There exists a variety of techniques to address this problem.[13] It involves correction of deformity either by osteotomy or by growth modulation through various growth inhibition techniques via a variety of implants.

The concept of mechanical manipulation of bone growth was first introduced by Heuter in 1862, stating that the growth of epiphysis is inhibited when the pressure is increased along the axis of the epiphysis, and the growth is promoted when the pressure is decreased.[14] Seven years later, Volkmann reported that the unsymmetrical growth of a joint is due to variation in compressive forces.[15] Based on these findings, the concept of growth modulation was established. Eccentric loading of weight over the physis, exerts pressure on the mechano-transducer chondrocytes which inhibit the growth of the physis. This progresses the deformity further increasing the gait disturbance, pain, and functional disability. It mainly suggests early-stage intervention so that negative feedback correction can be harnessed.

In 1940, Haas described the flexibility of the physis using a surgical instrument – wire loop in a canine and recorded growth inhibition, substantiating the concept of guided growth for deformity correction.[16,17] Shortly following, Dr. Walter Blount introduced his surgical staple for gradual correction of deformity, which gained much recognition in the late 1940s.[18,19] Staples function by adding fulcrum within the physis, which produces compression inhibiting the growth. However, for a longer duration, it may lead to permanent damage to physis. Although popular since its introduction, its use is decreased owing to the fear of premature iatrogenic permanent physeal arrest as well as unpredictable outcomes.[20,21] Other complications like occasional breakage or migration of staples were also noted, leading to revision or prematurely abandoning this treatment.[22,23] Next advancement was in 1998 by Métaizeau, who introduced

Table 2
Details of the patients with respective tibiofemoral angles.

Sr. No.	Age (years + months)	Sex (M/F)	Tibiofemoral angle				Time taken for correction	Complications
			Right		Left			
			Pre-op	Post-IR	Pre-op	Post-IR		
1	6 + 9	M	20	5	–	–	12 m	None
2	12 + 3	F	–	–	18	6	15 m	None
3	13 + 01	M	–	–	16	8	11 m	None
4	7 + 7	F	28	2	30	3	22 m	Over correction
5	12 + 10	F	17	5	–	–	16 m	Superficial infection
6	10 + 4	F	24	8	–	–	18 m	None
7	8 + 6	F	21	7	18	6	14 m	None
8	11 + 6	M	24	8	27	9	20 m	None
9	13 + 4	F	–	–	16	7	14 m	None
10	12 + 5	F	25	6	21	5	23 m	None
11	10 + 9	M	–	–	15	7	10 m	None
12	12 + 9	F	18	9	–	–	12 m	None
13	10 + 5	M	30	8	28	6	23 m	None
14	9 + 4	F	20	4	24	5	19 m	None
15	13 + 11	M	15	7	–	–	12 m	None
16	12 + 4	F	16	6	14	4	12 m	None
17	7 + 10	M	–	–	22	2	18 m	Over correction
18	11 + 10	M	27	8	25	6	21 m	None
19	5 + 7	F	–	–	21	5	11 m	None
20	9 + 10	F	28	4	29	5	28 m	None
21	14 + 2	F	19	10	17	9	12 m	Partially corrected
22	11 + 3	M	–	–	20	8	13 m	None
23	8 + 10	M	31	6	29	5	20 m	None
24	13 + 7	M	18	6	–	–	15 m	None
Average	10yrs + 8 months ± 2years 4 months (range 5yrs 7 months–14 yrs 2 months)	11:13	22.41	6.41	21.66	5.88	17.28 m ± 5.02 m (1yr 5 mon ± 5 mon)	2 cases of over correction which got gradually corrected on follow-up, one case of under correction and one case of superficial infection which was taken care

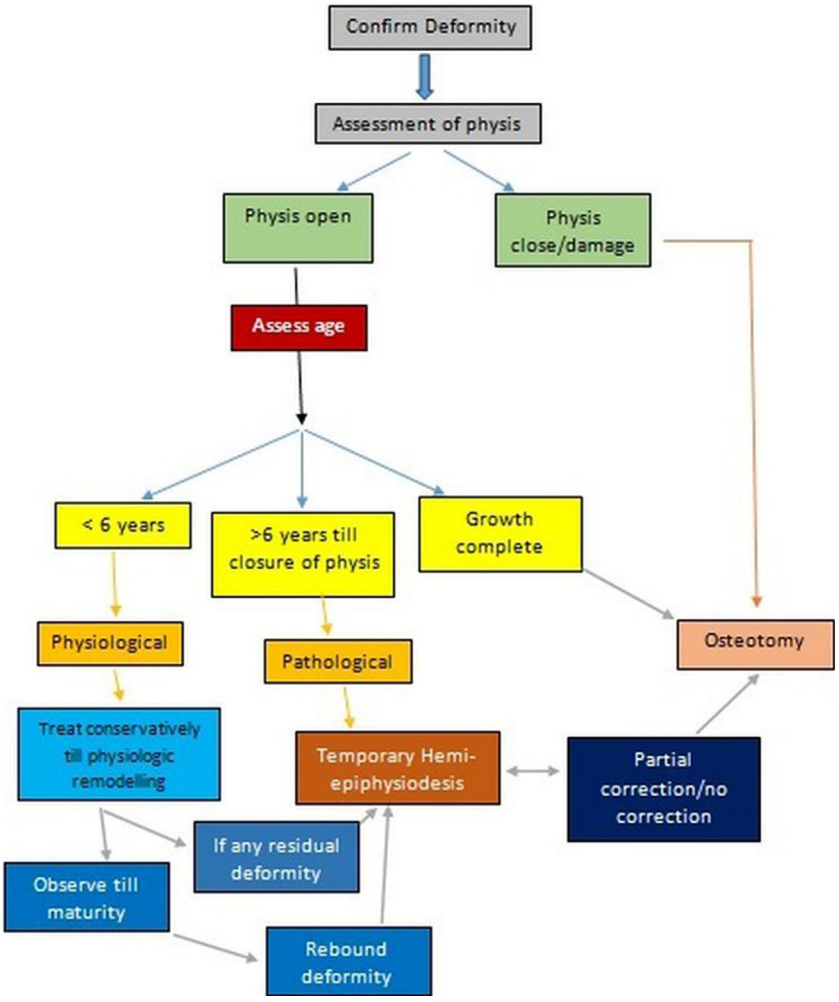

Fig. 2. Algorithm showing the management of Genu Valgum in Paediatric patients.

transphyseal screws for percutaneous epiphysiodesis in the correction of angular deformity.[8] However, there was a concern whether epiphysiodesis was reversible as the screw traverse through physis.[24]

In 2007, Stevens introduced a technique of temporary hemi epiphysiodesis, using a different construct then staples, but based on Blount principles.[25] It comprised of a non-locking extraperiosteal tension plates with two screws for angular correction. It is technically simple and highly efficient, allowing gradual correction with minimal complications and removable.[9,10,13] The eight-plate acts as a focal hinge at the perimeter of the physis with a longer lever arm, so as the physis grows, the screws toggle in the plate and pivot in the bone bringing about gradual correction and does not produce compression at the physis, thus preserving the growth potential.[25,26] These tension plates are predominantly used for various deformities like angular corrections as well as for other indications like knee flexion contractures and correction of leg-length discrepancies in young patients.[27] In 2008 Stevens and Klatt, suggested that temporary Hemi epiphysiodesis performed at an early age in pathological physis yielded much faster improvement in limb alignment as well as the pathological state of the physis by eliminating eccentric loading of physis.[28] The much-followed tradition of advocating delay in the corrective surgery (temporary Hemi epiphysiodesis) up to the age of 8–10 years due to fear of permanent physeal damage was discontinued.

Osteotomies have traditionally been considered to be the gold standard for correction of angular deformities, but it had its complications and limitations.[29,30] Revision osteotomies are required if growth continues resulting in recurrent deformities.[31] Gradual, controlled correction of deformity can also be achieved using external fixator. Others have opted for the less invasive and cost-effective method of Hemi epiphysiodesis to restore alignment with fewest complications. The latest technique involves guided growth with an eight-plate with distinct advantages. The only setback is permanent damage to physis. Pediplate (OrthoPediatrics, Warsaw, Indiana) is newly introduced implant based on the similar principle of eight-plate.[31]

Our study of guided growth with hemi epiphysiodesis using 8-plate included 35 affected knees, out of which 11 were bilateral. There were 11 males with an average age of 10 years 8 months $\pm$ 2 years 4 months which was similar to Ballal et al.,[4] Boero et al.[32] and Aslani et al. (Table 3).[33] However, Boero et al.[32] had much younger age group with the minimum being two years 3 months, whereas Aslani et al.[33] had much older age group with the maximum being 16 years. At the age of 16 years, the correction seems to be tough with growth manipulation as there is already a fusion of physis, so we recommend osteotomy in such cases. There was a female predominance in our study with a male to female ratio of 11:13, which is similar to Kulkarni et al.,[1] but other studies had male predominance. The gender determination in growth

Fig. 3. A 10 yrs. The old boy presented with left knee genu valgum deformity, where a) pre-operative radiograph, b) immediate postoperative radiograph with eight plates, and c) final postoperative radiograph after correction of deformity and implant removal.

modulation is necessary because physes fuse earlier in females than in males. Thus, age along with gender play a significant role in the management of deformity.

All the patients in our study were with idiopathic genu valgum, as that with Volpon et al.[34] and Ballal et al.,[4] whereas other studies had pathological cases like DDH, Arthrogryposis, Vitamin D resistant rickets, tyrosinemia, post-traumatic valgus and chronic osteomyelitis (Table 3). In idiopathic and post-traumatic genu valgum the rate of correction is usually faster as compared to pathological physis.

The pre-operative deformity was recorded to be the tibiofemoral angle of 22.02° ± 5.15°, which was similar to Kulkarni et al.,[1] who also had a case with the highest valgus among others with 40° tibiofemoral angles pre-operatively. We recorded post-operative correction with tibiofemoral angle after implant removal, once the desired correction was achieved and all patients have monitored atleast for a year to check for any rebound deformity. The mean post-implant removal tibiofemoral angle was observed to be 6.14°, which is acceptable apart from one case which was partially corrected and two cases overcorrected. The tibiofemoral angle after correction was found to be similar to all other studies (Table 3). The overall average deformity corrected was noted to be 15.9°. The rate of correction of deformity was found to be similar to Boreo et al.[32] and Ballal et al.[4] The average rate of correction of deformity by growth modulation depends upon the age of the patient as well as diagnosis. Younger the age faster would be the rate of correction, and idiopathic/traumatic physis are corrected at a faster rate than other pathological physis. The average duration required for correction of deformity was recorded to be 1 year 5months, which was similar to other studies except for Volpon J B[34] with 11 months. This variation may also be due to the technique used or implantation as he used Blount's staples for correction of the deformity.

Fig. 4. Clinical picture showing a 12-year-old girl with a) pre-operative valgus deformity of left knee b) Post-operative correction of the deformity.

All the cases in our study were managed by growth modulation by hemi epiphysiodesis using eight-plate with two cannulated screws, and we got excellent results with 91.67% success. We did not face any implant-related complications like the loosening of screw or plate or migration as reported by Ballal et al.[4] as well as Kulkarni et al.[1] We had one case (4.16%) of under correction, which was due to age and gender-related issues, as the patient is female reported late with deformity. We had two cases (8.33%) of over-correction, which got gradually corrected over the follow-up period, as these cases were too young. We encountered with one case of superficial infection which was taken care by antibiotics. No rebound phenomenon was observed in any of our cases. Similar studies with reported excellent results using eight plates for hemi epiphysiodesis (Table 3). Other studies like Volpon J B[34] got 82% success using Blount's staples, and Aslani et al.[33] got 84.3% success using two holes 3.5 mm reconstruction plate with 4 mm solid cancellous screws, which was lesser than compared to all eight-plate studies. Thus, eight plate has minimum complications as compared to staples/reconstruction plates.

5. Conclusion

Our results reflect the efficacy of flexible titanium eight-plate which corrects angular deformity by acting as a tension band on

Table 3
Analysis of various studies.

Author & Year	No. of cases	Age at the time of surgery; Mean (Range)	Sex (M/F)	Diagnosis (Vit. D Deficiency, idiopoathic, others)	Pre-op degree of deformity; Mean (Range)	Average Time taken for achieving correction	Degree of correction achieved	Method used	Complications
Volpon, J. B., 1997	46 physis (23 pts)	13 boys with a median age of 14 years and 3 months (12–15 years and 8 months), and 10 girls with a median age of 12 years (11–12 years and 9 months)	13:10	Idiopathic & congenital	14°	11 months	6° in boys and 4° in girls	Blounts stapling- all distal femur + 5 cases proximal tibia also	-In 2 cases the deformity recurred as staples were removed too early
M S Ballal et al., 2010	37 knees (25 pts)	11.6(5.5–14.9)	15:10	Symptomatic Genu valgum	8.4^0 (3°–25°)	16.1 months(7–37.3)	Tibiofemoral angle of 6°	Flexible Two hole titanium 8-plate	1. Plate and screw migration 2. Deep infection 3. Rebound deformity
Boero et al., 2011	Out of 58, 45 pts of genu valgum	10 years 10 months (range 2 years 3 months to 14 years 11 months	48% females	Idiopathic −30 B/L and pathologic-15	Idiopathic – 14° (10–20) Pathological – 22° (14–30)	11 months (idiopathic −11 Pathological −18) [Rate of correction = mean ± sd = 0.93° ± 0.82° (0–6)]	Idiopathic – 5° (4–8) Pathological −9° (5–25)	Single 8 plate per physis	1 patient with Undercorrected deformity and 2 patients with rebound deformity
H.Aslani et al., 2014	14 out of 21 B/L valgus	10yrs 3 months [±2yrs 10 months] [6–16yrs]	15:6	Idiopathic-]15, rickets −2, MPS-2, ROD −1 & tyrosinemia −1	14.9°(9–22)	17 ± 8 months	Complete correction of deformity	2-hole 3.5 mm reconstruction plates and 4 mm solid cancellous screws.	Of the 32 valgus knees, 2 had femoral screw breakage, 3 had failure for correction 2 mucopolysaccharidosis and 1- 16 yr old.
Kulkarni et al., 2015	24 pts 13 genu valgum (1 B/L)	5 yrs 3 months (2–9 years 1 month)	11:13	– Vit. D resistant rickets – Nutritional rickets – chronic Osteomyelitis – Idiopathic genu valgum – Posttraumatic tibia valga – Arthrogryposis with B/L genu valgum – Congenital short femur syndrome – Left hip DDH with left genu valgu	19.89° valgus (range 10°–40° valgus)	15.625 months (range 7–29 months)	5.72° valgus (range 2°–10° valgus)	2 hole 4.5 mm titanium plate with 4.5 mm cannulated screws	– 1 case of Loosening of the meta-physeal screw and another case with Loosening of metaphyseal screw and backing out of plate and was re-operated One case B/L knee of partial correction and one case of overcorrection in B/L knee due to late follow-up of 6 months – 2 cases had rebound deformity and were re-operated
Our study 2017	24 pts 13 unilateral and 11 B/L	10yrs + 8 months ± 2years 4 months (range 5yrs 7 months–14 yrs 2 months)	11:13	Idiopathic	22.02° ± 5.15° (range 14°–31°)	17.28m ± 5.02 m or 1yr + 5m ± 5m (range 10 m–28 m)	6.14° ± 1.92° (range 2°–10°)	Flexible Two hole titanium 8-plate with 4.5 mm cannulated screws	2 cases of over correction which got gradually corrected on follow-up, 1 cases of under correction and one case of superficial infection

one side of the growth plate and offers the advantage of reversible Hemi epiphyseal growth modulation. Guided growth modulation is best available option for the treatment of angular deformities in the skeletally immature patient. For the correction of Genu valgum, our recommendation is for the eight-plate due to its versatility, simplicity to use and cost-effectiveness. Although there is a minor risk of rebound growth after Hemi epiphysiodesis in younger patients, it continues to be a success at an early stage of deformity and is promising.

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