Recurrent Dislocations and Complete Necrosis – The Role of Pelvic Support Osteotomy

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The treatment of hip instability in adolescents and young adults is often related to severe dysplastic acetabulum, proximal migration of the femur, and/or the absence of part or all of the femoral head and neck, and presents a surgical challenge. Furthermore, reconstructive procedures for this difficult problem, such as, greater trochanteric arthroplasty, hip arthrodesis, pelvic osteotomy, femoral osteotomy, and Girdlestone operation, are less than satisfactory.[1] Proximal femoral (PF) subtrochanteric osteotomy, also called 'pelvic support osteotomy (PSO)', has been described as a treatment for hip instability in adolescents and young adults (Table 1). The purpose of this presentation is to address the roles of PSO and Ilizarov hip reconstruction (IHR), a modified form of PSO, which combines distal femoral osteotomy for concomitant lengthening and varus angulation, for the management of recurrent dislocations and complete necrosis of the femoral head.[2-7] In this presentation, I will briefly review the histories of PSO and IHR, and elaborate on the outcomes and technical considerations of IHR, based upon an extensive review of the literature and personal experience.

Brief history and rationale of PSO and IHR

PSO has long history in orthopedic surgery. The technique was developed and popularized by A. Lorenz,[8] Von Bayer.[9] A. Schanz,[10] H. Milch,[11-14] and RS. Henderson,[15] but was rapidly replaced by total hip replacement arthroplasty(THRA). The basic concepts and goals of PSO are to enhance femoro-pelvic stability by PF valgus osteotomy, and to improve hip biomechanics by displacing the center of gravity medially, which results in an improvement in the mechanical efficiencies of abductor muscles.[11-13,16] Overcorrection of PF valgus osteotomy places the extremity in a fixed abduction position relative to the pelvis to eliminate hip adduction, and reduces or prevents the T-sign because the contralateral pelvis cannot drop.[11-13,17] However, the clinical application of traditional PSO is limited due to its intrinsic shortcomings. In particular, the optimal extent of angulation is difficult to achieve. If the angle is too large, excessive genu valgum, fixed pelvic obliquity, and impingement pain on adduction of the lower extremity to the neutral position may ensue. Alternatively, if the angle is too small, the result would be an insufficient improvement in hip biomechanics.[12-14] Most importantly, the issue of remaining leg-length discrepancy (LLD) cannot be addressed.[7]

To overcome the shortcomings of traditional PSO, Ilizarov designed a modified PSO, which incorporated a second distal femoral osteotomy, to realign the knee joint and to correct LLD, and PF valgus osteotomy for pelvic support. Russian literature indicate that Ilizarov and his associates started to use a modified PSO technique in the early or mid-1970s.[3-5,18,19] Ilizarov emphasized the importance of PF osteotomy extension to correct the fixed flexion deformity of the hip and to permit locking of the hip joint by stabilizing the hip in the sagittal plane during single stance.[2,6,7,17]

IHR is considered a breakthrough in terms of resolving the inherent problems of PSO, as the treatment goals for normal gait are to obtain stability by reconstructing a stable fulcrum, to improve energy efficiency by restoring abductor mechanism, and to improve cosmetic appearance by eliminating shortening/joint contracture-related problems.

Table 1. Indications of pelvic support osteotomy

1. Hip instability : severe dysplastic acetabulum
DDH : neglected, unsuccessfully treated
Traumatic hip dislocation with instability
Paralytic or spastic dislocation (post-poliomyelitis, cerebral palsy, muscular dystrophy)
2. Partial or total absence of femoral head and neck
Severe sequelae of septic arthritis (Choi type IV)
Skeletal dysplasia (SED, Morquio, etc)
Severe AVN
Post-Girdlestone resection arthroplasty

Indications of IHR

IHR is a useful surgical procedure for the salvage of damaged hips not suitable for arthrodesis or hip arthroplasty (Table 1). To date only 12 original articles and 3 case reports have been published in the English literature on the merits of IHR (Table 2). According to the literature, IHR is most suitable for skeletally mature adolescents or young adults that present with an unstable hip that is mobile and associated with a Trendelenburg gait (T-gait) and a large LLD. IHR is highly effective at eliminating T-gait, particularly when there is good abductor muscle function before surgery. The two most frequent indications are a neglected or an unsuccessfully treated developmental dislocation of the hip (DDH)[20-25,27] and severe septic hip sequelae.[1,17,24,26,27] IHR is also indicated for the treatment of hip instability related to paralytic subluxation/dislocation, post-traumatic hip subluxation/dislocation, spondylo-epiphyseal dysplasia,[28] osteonecrosis of the femoral head,[29] and post-excision arthroplasty.[30]

It appears that IHR is not ideal for young children, because in accordance with Wolff's law, gradual straightening of the PF tends to occur at the site of valgus angulation and this results in loss of pelvic support. Although IHR is not contraindicated in young children, for example, when hip instability is associated with marked LLD due to multiple lower-limb growth disturbances secondary to neonatal sepsis, one should expect repeat IHR at or near skeletal maturity. Another alternative is to undergo femoral lengthening without a PSO, inserting half pins into the pelvis to prevent proximal migration of the femur, in the younger age, and subsequently perform IHR when the patients are near skeletal maturity.[17]

Technical considerations and complications

Careful preoperative surgical planning, based on data obtained from clinical and radiographic assessments, is essential to achieve a level pelvis and to restore the mechanical axis of the lower-limbs perpendicular to the horizontal line of the pelvis in bipedal stance.[1,17,31] The optimum level of PSO is controversial. Although some authors have recommended proximal osteotomy, in which the acetabulum rests on the lesser trochanter,[9,32] most prefer more distal osteotomy in the anticipation of abductor mechanical benefits due to displacement of the center of gravity medially. Important technical considerations are summarized as follows.[1,2,7,10,17,31]

1. To determine the optimum level of PF valgus osteotomy, the femoral shaft should be fully adducted against the lateral wall of the pelvis, which is usually situated somewhere between the infracotyloid recess and the ischial tuberosity. This renders longer proximal segment and provides better hip stabilization and an optimal location for soft tissue interposition to produce a weight-bearing surface without direct abutment between the proximal femoral osteotomy and the pelvis.
2. How much valgus angulation is desirable? This issue is highly controversial. In the era of conventional PSO, Henry Milch[12] emphasized that the post-osteotomy angle must not be permitted to exceed the angle of inclination of the outer wall. He named this angle the 'alpha angle' and insisted that it should be between 210^o and 230^o, because excessive valgus at the osteotomy site leads to PF abutment against the pelvis, and even pelvic tilt, when the patient tries to bring the involved extremity into a neutral adduction/ abduction position. However, with contemporary IHR, irrespective of the size of the overcorrection of PF valgus angulation, much of the abduction deformity caused by PF valgus angulation can be compensated, if the second DF osteotomy restores the position of knee joint inclination to parallel the horizontal line of the pelvis. The mean PF valgus angulation reported in the literature varied widely between 35^o and 60^o.[16,17,21,23,28,29]

   Paley[7,17] recommended over-correction of 15^o to 20^o during PF valgus osteotomy to eliminate hip adduction in addition to pelvic drop angle (the angle between the line perpendicular to iliac crest pelvic line and the femoral shaft in single stance or during maximum attempted adduction when supine) (Fig. 1A). Based on my experiences, I recommend at least 25^o of overcorrection,[1] and more than 30^o in preadolescents. Pafilas and Nayagam[31] proposed overcorrection of 30^o-40^o of extra-valgus in addition to the sum of maximum adduction range plus adduction contracture plus another 9^o to bring the femur parallel to the vertical axis perpendicular to the pelvic line. The remaining 21^o-31^o of abduction will take the femur away from midline. Their 30^o-40^o corresponds to 21^o-31^o of extra-valgus in addition to the pelvic drop angle. Overcorrection is entirely empirical in anticipation of remodeling at the valgus osteotomy and some atrophy of the soft tissue interposed between the femur and lateral pelvic wall.
3. The next important issue is how to determine the level of DF osteotomy. Paley[7,17] used the CORA method, which utilizes an imaginary proximal mechanical axis line (Fig. 1A). He stated that proximal mechanical axis line corresponds to a line perpendicular to the horizontal pelvic line, passing through the point of 1/3 to 1/2 the distance lateral to the medial edge of the proximal fragment. In contrast, Kadykalo and Kuftyev[18] presented a formula that took into consideration the amount of PF valgus and DF varus angulation (Fig. 1B) (Table 3). The mean DF varus

angulation reported in the literature varied in the range between 10° and 22°.[16,23,28,29]

Other important point of consideration when determining the level of distal osteotomy concerns the equalization of distances between the midline of the body axis and the centers of the knee joints of affected and normal contralateral limbs, which was emphasized by Pafilas and Nayagam (Fig 1C).[31] This suggests that the level of DF osteotomy relies on the level of PF valgus osteotomy, that is, the higher the level of PF valgus angulation, the more proximally-located DF osteotomy should be to equalize the distances of knee joints from the midline of the body axis in bipedal stance. Furthermore, if there is no compensatory DF varus angulation, unequal knee distances from midline may cause secondary pelvic obliquity despite well-performed pelvic support. In this regard, I feel that using a retrograde intramedullary lengthening device[33] may be inappropriate for IHR, which requires fine adjustment of varus angulation and translation during lengthening.

4. The amount of extension should be adjusted to correct hip flexion contracture and pelvic tilt, and the sacrofemoral angle should be greater than 45° in lateral profile.
5. The amount of derotation should also be determined, based on foot progression angle and the amount and direction of rotation during passive maximum adduction. The amount of varization is also controversial. Although Pafilas and Nayagam[31] proposed bringing the femoral shaft parallel to the vertical midline axis, this may cause 9° of valgus inclination at the knee. I believe that knee joint should be realigned in its physiologic position even after DF varus angulation.
6. The amount of lengthening should be recalculated after IHR during lengthening using a woodblock or scanogram to obtain a level pelvis. Over-lengthening is poorly tolerated in hips that are already in full adduction after IHR.
7. Resection of the femoral head and neck remnant may be indicated, if the hip is painful and stiff, regardless of pre-existing osteoarthritis. The concept of resection-angulation osteotomy was originally proposed by Milch in 1955 for restoring hip mobility and pain relief.[13]

Reported complications (Table 2) include knee stiffness, pin tract infection, delayed consolidation, refracture, obturator nerve entrapment, straightening of proximal valgus angulation, and persistent T-gait. I think that there is possibility of ischiofemoral impingement if the PF valgus angulation site directly abuts the ischium.

Discussion

How to avoid or reduce remodeling of proximal valgus angulation?

IHR is safe to perform at an older age, preferably after peak growth spurt. Rozbruch et al[17] observed that when IHR was performed at a younger age before adolescence, the PF valgus osteotomy site completely remodeled, demonstrating no evidence of the pelvic support within one or two years after the operation. I also experienced the same phenomenon of remodelling (straightening) of the proximal femur when IHR was performed in the preadolescent age. One should consider to add extra-valgus angulation at the PF osteotomy site, when performing IHR to address marked LLD in a younger age. As mentioned previously, one should expect repeat IHR at or near skeletal maturity to obtain a level pelvis and to eliminate residual LLD. Another alternative is to perform simple femoral lengthening with extension of the external fixation to the pelvis at a younger age, and to reserve PSO for the second lengthening when the patients are near skeletal maturity.[17]

In my experience, translation of the proximal fragment medially relative to the distal fragment, helps facilitate and maintain valgization. Prebent plate-fixation may also be beneficial. Most importantly, postoperative strenuous abductor muscle exercise is essential.

Where is the weight-bearing fulcrum? I agree with others[17,31] that the weight-bearing area is not absolute, nor a true joint or false articulation. The center of rotation appears to vary with the position/direction of motion of the lower limbs, and depends on the soft-tissue interpositional weight-bearing surface between the PF osteotomy and the pelvis. To identify the center of rotation during adduction/abduction motion, I used cineradiography in a patient who underwent Shanz-type PSO, and managed to figure out that the center of rotation was located around the lesser trochanter and not around the apex of the valgus angulation adjacent to the ischial tuberosity during passive abduction and adduction.

Why does T-gait persist after PSO in some patients? The literature suggests that an average of 30.3% (range, 0 to 62.5%) of patients have a persistent positive T-sign after IHR, although it is reduced in severity in most patients (Table 2). This persistence may be due to abductor insufficiency related to atrophied abductor muscles before surgery, or loss of fulcrum during follow-up due to remodeling of PF valgus angulation. Age at the time of PSO may also be an important factor for the retention of hip function.[13] Inan et al[34] concluded that T-gait is correlated with gluteus medius volume, and that T-gait disappeared with the restoration of gluteus muscle volume. In their series, four of five patients with a persistently positive T-gait were at least 31 years of age.

Based on these results, they speculated that atrophied muscle might not be restored by PSO in older patients.

Is it possible to convert to total hip replacement arthroplasty (THRA) later on? IHR does not burn the bridge in terms of preservation of bone stock around the proximal femur, and thus, THRA after PSO is still possible, although it is a technically demanding procedure due to proximal femur deformation. Careful attention to surgical detail is essential for successful THRA, otherwise, the distal end of femoral stem can penetrate the cortex.[35] Shiltenwolf et al[36] found that THRA could be performed without difficulty by straightening the proximal femur by osteotomy and using a long-stem prosthesis.

Conclusion

IHR effectively improves hip abductor biomechanics by PF valgus osteotomy for pelvic support, and thus, eliminates or reduces Trendelenburg gait, and at the same time, corrects LLD and knee joint malalignment by DF osteotomy. In this regard, IHR is an excellent option for the treatment of unstable, irreducible hips associated with either severe dysplastic acetabulum or partial or total absence of the femoral head and neck in adolescents and young adults. If IHR is performed at a younger age to correct marked LLD, remodelling of PF valgus angulation is inevitable with resultant loss of pelvic support. In this situation, second IHR should be contemplated near or at skeletal maturity to obtain a level pelvis and to eliminate residual LLD. Another alternative is to perform simple femoral lengthening with extension of the external fixation to the pelvis at a younger age, and to reserve PSO for the second lengthening. Future studies should be directed toward determining the precise location of the newly reconstructed weight-bearing fulcrum, and to develop an effective means of normalizing abductor muscle function.

References

1. Choi IH, Shin YW, Chung CY, et al. Surgical treatment of the severe sequelae of infantile septic arthritis of the hip. *Clin Orthop Relat Res.* 2005;434:102-109.
2. Catagni MA, Malzev V, Kirienko A. Treatment of Disorders of Hip Joint. In: Maiocchi AB, eds. *Advances in Ilizarov Apparatus Assembly.* Milan: Il Quadratino; 1994:119-134.
3. Ilizarov GA, Kaplunov AG, Tereschenko VA. Modified pelvic support osteotomy for restoration of the pelvic support and simultaneous femoral lengthening. Published in Russian; 1978.
4. Ilizarov GA, Samchukov ML, Kurtov VM. Ilizarov restorative reconstruction surgery in the treatment of hip osteoarthritis, congenital and pathological hip dislocation in children and adults. In: Materials of Second International Symposium. Experimental, Theoretical, and Clinical Aspects of Transosseous osteosynthesis developed in kurgan Scientific Research Institute. Kurgan, USSR; 1986:100-102.
5. Ilizarov GA, Samchukov ML. Ilizarov reconstructive surgery in the treatment of hip osteoarthritis. *Ortop Travmatol Protez.* 1988:10-13.
6. Ilizarov GA. Treatment of Disorders of the Hip. In: Green SA, eds. *Transosseous Osteosynthesis.* Berlin: Springer Verlag; 1992:668-696.
7. Paley D. Hip joint considerations In: *Principles of deformity correction.* Heidelberg: Springer-Verlag; 2002:647-694.
8. Lorenz A. Uber die Behandlung der irreponiblen angeborenen Huftluxation und der Schenkelhals Peudarthrosen mittels Gabelung (Bifurkation des oberen Femurendes). *Wien Klin Wochenschr.* 1919;32:997-999.
9. V. Baeyer H. Operative Behandlung von nicht reponierbaren angeborenen Huftverrenkungen. *Munster Med Wochenschrift.* 1918;165:1216-1217.
10. Schanz A. Zur Behandlung der veralteten angeborenen Huftverrenkung. *Munich Med Wochenschr.* 1922;69: 930-931.
11. Milch H. The pelvic support osteotomy. *J Bone Joint Surg.* 1941;23:581-595.
12. Milch H. The post-osteotomy angle. *J Bone Joint Surg.* 1943;25:394-400.
13. Milch H. The resection-angulation operation for hip-joint disabilities. *J Bone Joint Surg Am.* 1955;37-A:699-717.
14. Peltier LF. The Classic. The “pelvic support” osteotomy. *Clin Orthop Relat Res.* 1989;249:4-11.
15. Henderson RS. Osteotomy for unreduced congenital dislocation of the hip in adults. *J Bone Joint Surg Br.* 1970;52:468-473.
16. Samchukov ML, Birch JG. Pelvic support femoral reconstruction using the method of Ilizarov: a case report. *Bull Hosp Jt Dis.* 1992;52:7-11.
17. Rozbruch SR, Paley D, Bhave A, et al. Ilizarov hip reconstruction for the late sequelae of infantile hip infection. *J Bone Joint Surg Am.* 2005;87-A:1007-1018.
18. Kadykalo OA, Kuftyev LM. Some biomechanical principles of the hip reconstruction with defect on head and neck of the femur by Ilizarov method. In: *The value of general biological patterns in regeneration tissue opened by G. A. Ilizarov. Scientific works*

collection 13th Edition, The Ministry of Health, The RSFSR (The Russian Soviet Federative Socialist Republic) Kurgan All-union scientific center. Rehabilitation Traumatology and Orthopaedics; 1988:124-129.

19. Samchukov ML, Ivanova IV, DolganovDV. Analysis of pelvo-trochanteric muscles and weight-bearing after Ilizarov femoral reconstruction in patients with hip osteoarthritis. In*:* the congress of Scientific and Technical Advances of the Young Scientists of the Urals. USSR; 1986:86-87.
20. El-Mowafi H. Outcome of pelvic support osteotomy with the Ilizarov method in the treatment of the unstable hip joint. *Acta Orthop Belg.* 2005;71:686-691.
21. Gursu S, Demir B, Yildirim T, et al. The influence of aetiology of hip instability on the results of pelvic support osteotomy. *Hip Int.* 2010;20:518-523.
22. Inan M, Bowen RJ. A pelvic support osteotomy and femoral lengthening with monolateral fixator. *Clin Orthop Relat Res.* 2005;440:192-198.
23. Kocaoglu M, Eralp L, Sen C, et al. The Ilizarov hip reconstruction osteotomy for hip dislocation: outcome after 4-7 years in 14 young patients. *Acta Orthop Scand.* 2002;73:432-438.
24. Mahran MA, Elgebeily MA, Ghaly NA, et al. Pelvic support osteotomy by Ilizarov's concept: Is it a valuable option in managing neglected hip problems in adolescents and young adults? *Strategies Trauma Limb Reconstr.* 2011;6:13-20.
25. Inan M, Bomar JD, Kucukkaya M, et al. A comparison between the use of a monolateral external fixator and the Ilizarov technique for pelvic support osteotomies. *Acta Orthop Traumatol Turc.* 2004;38:252-260.
26. Manzotti A, Rovetta L, Pullen C, et al. Treatment of the late sequelae of septic arthritis of the hip. *Clin Orthop Relat Res.* 2003:410:203-212.
27. Marimuthu K, Joshi N, Sharma CS, et al. Ilizarov hip reconstruction in skeletally mature young patients with chronic unstable hip joints. *Arch Orthop Trauma Surg.* 2011;131:1631-1637.
28. Shetty GM, Song HR, Lee SH, et al. Bilateral valgus-extension osteotomy of hip using hybrid external fixator in spondyloepiphyseal dysplasia: early results of a salvage procedure. *J Pediatr Orthop B.*2008;17:21-25.
29. Sabharwal S, Macleod R. Ilizarov hip reconstruction for the management of advanced osteonecrosis in an adolescent with leukemia. *J Pediatr Orthop B.* 2011 Jul 14. [Epub ahead of print]
30. Emara KM. Pelvic support osteotomy in the treatment of patients with excision arthroplasty. *Clin Orthop Relat Res.* 2008;466:708-713.
31. Pafilas D, Nayagam S. The pelvic support osteotomy: indications and preoperative planning. *Strategies Trauma Limb Reconstr.* 2008;3:83-92.
32. Hass J. A subtrochanteric osteotomy for pelvic support. *J Bone Joint Surg.* 1943;25-A:281-291.
33. Krieg AH, Lenze U, Hasler CC. Ilizarov hip reconstruction without external fixation: a new technique. *J Child Orthop.* 2010;4:259-266.
34. Inan M, Alkan A, Harma A. Gluteal muscle after pelvic osteotomy to treat congenital dislocation of the hip. *J Bone Joint Surg.* 2005;87-A:2246-2252.
35. Thabet AM, Catagni MA, Guerreschi F. Total hip replacement fifteen years after pelvic support osteotomy (PSO): a case report and review of the literature. *Musculoskelet Surg.* 2012 Jan 12. [Epub ahead of print]
36. Schiltenwolf M, Carstens C, Bernd L, et al. Late results after subtrochanteric angulation osteotomy in young patients. *J Pediatr Orthop B.* 1996;5:259-267.

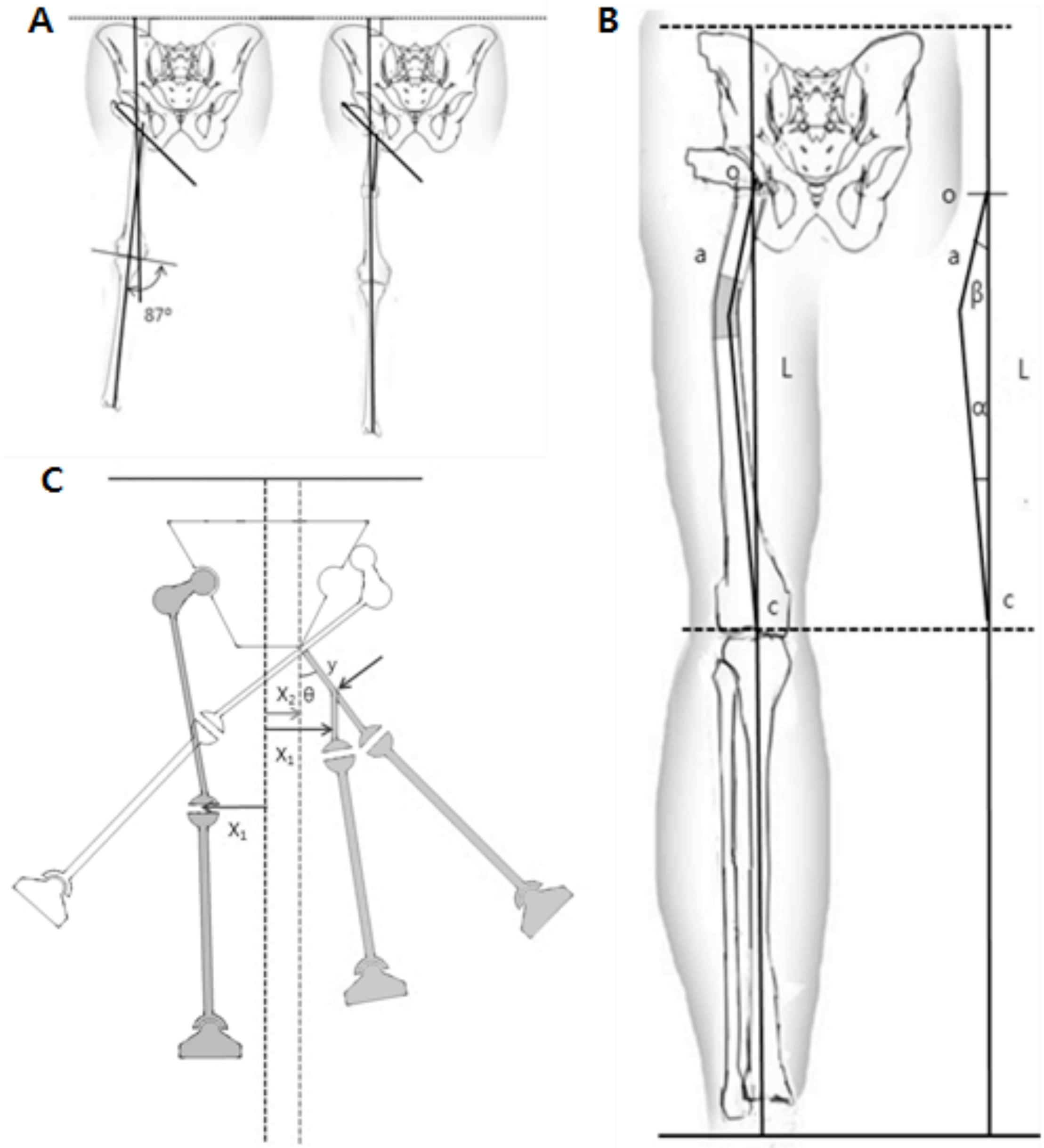

Fig. 1. Determination of varus angulation of the distal femur for Ilizarov hip reconstruction.
A. The CORA method recommended by Paley,[7,17] which utilizes an imaginary proximal mechanical axis line. The proximal mechanical axis line corresponds to a line perpendicular to the horizontal pelvic line, passing through the point of 1/3 to 1/2 the distance lateral to the medial edge of the proximal fragment. B. Preoperative simulation of the IHR, which utilizes a trigonometric equation, recommended by Kadykalo and Kuftyev,[18] taking into consideration of proximal femoral valgus angulation and distal femoral varus angulation as well as the biomechanical limb axis after reconstruction (refer to Table 3). C. When determining the level of distal osteotomy, the equalization of distances between the midline of the body axis and the centers of the knee joints of affected and normal contralateral limbs should be considered, which was emphasized by Pafilas and Nayagam.[31] The level of DF osteotomy relies on the level of PF valgus osteotomy, that is, the higher the level of PF valgus angulation, the more proximally-located DF osteotomy should be to equalize the distances of knee joints from the midline of the body axis in bipedal stance.

Table 2. Summary of the English literature on Ilizarov hip reconstruction

Author (publication year)	Etiology (no. of patient)	Age at op (yrs)	Type of support (no. of patient)	Hip function * Preop	Hip function * Postop	Postop T-sign (no. of patient)	Follow-up	Complications & Comments
Samchukov & Birch[16] (1992)	DDH (1)	15	subacetab.	NA	NA	none	5 m	NA
Kocaoglu et al[23] (2002)	DDH(11); PFFD(1); MMC(1); Paralytic dislocat(1)	20 (12-33)	subacetab.	64 (42-72)	84 (68-92)	none (17); P (3)	68 m (55-81)	3 PTI 3; 1 hypocorrection
Manzotti et al[26] (2003)	septic hip(15)	21.1 (14-36)	acetabular (9); subacetab. (5); pubic ramus (1)	NA	1.94(W)	none (9); P(6)	108m (38-178)	3 knee sublux.; 2 loss of support; 2 pin substitute; 1 peroneal n. palsy; 1 regenerate fx; 1 foot ER;
Inan et al[25] (2004)	DDH(17)	24.8 (17-39)	subacetab.	NA	NA	none (12); P(5)	36.3 m (21-65)	many PTI; 2 fx,;
Rozbruch et al[17] (2005)	septic hip(8)	11.2 (7.8-14.2)	subacetab.	51 (21-67)	73 (64-79)	none (6); P (2)	5 y (1.9-9.8)	3 PTI; 2 knee stiffness ; 1 knee sublux.; 1 premature consolidation; 1 prox. migration of femur
Inan & Bowen[22] (2005)	DDH(12) septic hip(3); traumatic lux(1)	25.3 (17-39)	subacetab.	50 (32-73)	87.6 (67-98)	none (12); P (4)	52.5m (26-84)	2 PTI; 2 delayed consolidation; 1 fracture; 1knee stiffness; 1 obturator n. entrapment
Inan et al[34] (2005)	DDH(11)	25.2 (13-39)	subacetab.	52 (32-73)	92 (77-98)	none (6); P(5)	36m (23-59)	NA many PTI
El-Mowafi[20] (2005)	DDH(12); septic hip (5); AVN (5);RP(4)	22.4 (19-35)	subacetab.	55 (40-78)	81 (65-90)	none (20); P (5)	4.5y (2-7)	4 of 5patients with persistent T-sign was RP
Emara[30] (2008)	Excision arthroplasty after infected hip arthroplasty (11)	51.9 (45-61)	subacetab.	43.5 (31-50)	70.9 (65-80)	none (11)	minimum 2 y	7 PTI; 2 knee stiffness ; 2 residual knee valgus; 3 delayed consolidation

*indicates Harris hip score or a modified Harris hip score[17]; AVN; avascular necrosis of the femoral head; DDH, developmental dislocation of the hip; ER, external rotation; fx., fracture; MMC, meningomyelocele; PFFD, proximal femoral focal deficiency; NA, unknown; m, month; P, reduced but persistent T-sign; PTI, pin tract infection; RP, residual poliomyelitis; subacetab., subacetabular; T, Trendelenburg; W, WOMAC score; y, year.

Table 2. Summary of the English literature on Ilizarov hip reconstruction (continued)

Author (publi-cation year)	Etiology (no. of patient)	Age at op (yrs)	Type of support (no. of patient)	Hip function*		Postop T-sign (no. of patient)	Follow -up	Complications & Comments
				Preop	Postop			
Shetty et al[28] (2008)	Spondylo-epiphyseal dysplasia congenita (8 bilat.)	16.4 (9-25)	subacetab.	67.9 (54-85)	79.1 (68-87)	none (6 hips); P (10 hips)	25.9m	3 PTI; 3 knee stiffness; 1 delayed consolidation
Gursu et al[21] (2010)	DDH(12 unilat, 1 bilat); septic hip (8)	22.6 (12-34)	subacetab.	48.2 (28-79)	80.1 (60-93)	none (13 hips); P (8 hips)	33.5m (16-45)	15 PTI; 2 prox. fx.; 2delayed union; 6 knee stiffness; 1 depression
Krieg et al[33] (2010)	spina bifida(1)	14	subacetab.	NA	NA	improved	12m	none; prox: locking compression plate, distal: Fitbone□)
Mari-muth et al[27] (2011)	DDH(1); nonunion (NOF)(2); septic hip (6); tuber-culois(3)	23 (13-32)	subacetab.	44.3 (14-73)	70.8 (60-86)	none (9); P (3)	59.4m (38-86)	PTI almost all
Mah-ran et al[24] (2011)	DDH(9); septic hip (9); RP(2)	21.5 (14-30)	subacetab.	NA	NA	none (13); P (7)	6m	PTI almost all; 2 regenerate fx ; 2 premature consolidation; 4 delayed consolidation; 3 residual LLD > 3cm
Sabhar-wal & Mac-leod[29] (2011)	osteonecro-sis after leukemia (1)	13.5	subacetab.	26	88	none	3y	knee stiffness -> quadricepsplasty
Choi IH et al (unpub-lished data)	septic hip (11); DDH (2)	13.4 (6.4-16)	subacetab.	12(W)	6(W)	none (8); P (5)	5y (1-10.2)	repeat IHR in 3 patients; 4 PTI; 4 loss of support ;1 prox. fx.

*indicates Harris hip score or a modified Harris hip score[17]; AVN; avascular necrosis of the femoral head; DDH, developmental dislocation of the hip; ER, external rotation; fx., fracture; MMC, meningomyelocele; PFFD, proximal femoral focal deficiency; NA, unknown; m, month; P, reduced but persistent T-sign; PTI, pin tract infection; RP, residual poliomyelitis; subacetab., subacetabular; T, Trendelenburg; W, WOMAC score; y, year.

Table 3. K-value in the design of the biomechanical axis[18] (Refer to Fig. 1B, a= K x L))

β^0 \ α^o	5	10	15	20	25	30	35	40
5	0.50	0.67	0.76	0.81	0.85	0.87	0.89	0.91
10	0.34	0.51	0.61	0.68	0.74	0.78	0.81	0.84
15	0.26	0.41	0.52	0.60	0.66	0.71	0.75	0.78
20	0.21	0.35	0.45	0.53	0.60	0.65	0.71	0.74
25	0.17	0.30	0.40	0.48	0.55	0.61	0.66	0.71
30	0.15	0.27	0.37	0.45	0.51	0.58	0.63	0.68
35	0.14	0.25	0.34	0.42	0.49	0.55	0.61	0.67
40	0.12	0.23	0.31	0.40	0.47	0.53	0.59	0.65