Is there a limit to limb lengthening in patients with Crowe IV developmental dysplasia of the hip undergoing total hip arthroplasty?

Ibrahim El-Ganzoury, Vahit Emre Özden, Ahmed Saeed Younis, Ibrahim ElGanzoury, Mohammad Ghazavi, Jesus Moreta, Vorawit Atipiboosin, Daisuke Inoue, Oussama Chaar, Omer Faruk Bilgen, Peilai, Liu, Yangup Qin

Response/Recommendation:
The review of current literature does not identify a specific limit to limb lengthening in patients undergoing total hip arthroplasty (THA). The traditional limit of 4 cm is based on an older single study with some methodological deficiencies.

Level of Evidence: Low

Rationale:

We searched for all studies investigating the outcomes of total hip arthroplasty (THA) for hip arthritis secondary to Crowe III to IV developmental dysplasia of the hip (DDH) aiming to define a limb lengthening limit in such patients. We searched the following electronic databases: (PubMed: 865 results on 28 May 2024), (Central: 33 results on 26 April 2024), and (Embase: 835 results on 14 May 2024). After duplicates removal and exclusion of noneligible studies from title and abstract, 419 studies were eligible for full text screening. Finally, 91 studies[1][2][3][4][5][6][7][8][9][10][11][12][13][14][15][16][17][18][19][20][21][22][23][24][25][26][27][28][29][30][31][32][33][34][35][36][37][38][39][40][41][42][43][44][45][46][47][48][49][50][51][52][53][54][55][56][57][58][59][60][61][62][63][64][65][66][67][68][69][70][71][72][73][74][75][76][77][78][79][80][81][82][83][84][85][86][87][88][89][90][91] were included in this review. All included studies were cohort studies whether prospective or retrospective. In all included cohorts patients were treated with THA and had good outcomes in terms of satisfaction, range of motion, restoration of limb length, and functional outcomes.
The reason for the ongoing debate on limb lengthening in patients with dysplasia undergoing THA is because of a recognized correlation between limb lengthening and risk of neurological complication, mostly sciatic nerve palsy. Based on traditional belief, lengthening of the limb > 4 cm is believe to put the extremity at unacceptable risk of neurological complications[49]. The stated limit in limb lengthening means that some patients with unilateral dysplasia and short limb (>4 cm) cannot undergo restoration of their limb length and may sufferer limb length discrepancy. The belief in the stated limit also means that many surgeons resort to performing femoral shortening osteotomy if lengthening is likely to be > 4 cm.
Our review of the modern literature did not reveal a specific limit to limb lengthening. In fact there are reports in the literature suggesting that limit for limb lengthening should be determined using femoral length as a reference[44]. In a study by Kabata et al. the risk for neurological complications apperad to arise when limb lengthening exceeded 8.7% of the femoral length. [44]. Two comparative studies by Fujishiro et al. highlighted the influence of factors, other than limb

lengthening such as hip flexion contracture, and neurological complications in patients undergoing THA[9][60]. Another study proposed 50mm as a limit for limb lengthening[92]. Limb lengthening up to 51 mm was seen in some of the 58 studies that utilized femoral shortening osteotomy. Thirteen studies included cohort of patients with Crowe IV dysplasia in whom femoral osteotomy was not performed during THA. The mean limb lengthening in these patients ranged from 21 to 48mm. In nine studies, patients were subjected to staged procedures whereby limb lengthening occurred during the first surgery. If the patients did not develop neurological complications, definitive THA was performed during the second surgery. These studies reported a mean limb lengthening ranging from 36 to 100mm. The first stage operations included a variety of procedures. The initial lengthening might be achieved with a distraction nail, iliofemoral fixator or even initial hip periarticular extensive soft tissue release and traction. Some novel techniques away from femoral osteotomy and staged procedures were described in some cohorts aiming to achieve the reduction of the femoral head in the true acetabulum with minimal complications. Yan et al. described maintaining hip and knee in a flexed position following surgery and allowing for gradual knee extension until the patient felt numbness. They achieved an average limb lengthening of 40mm (range 29-62mm) using this technique [12]. In another study Shemesh et al. used an intraoperative nerve stimulator to assess neurological insults during THA procedures [81]. They stated that intraoperative nerve monitoring reduced the risk for nerve palsy and the need for femoral shortening osteotomies. The findings of latter study was corroborated by Kong et al. in their comparative retrospective cohort demonstrating a lower incidence of nerve palsy in patients in whom intraoperative nerve monitoring was used during THA[73].

In conclusion, there are limited and conflicting evidence about the limit of limb lengthening in patients undergoing THA, after which the risk for neurological complication increases. In the absence of such concrete limit, surgeons may decide to lengthen the extremity more than 4 cm to achieve equal limb length and avoid leaving these young patients with life long limb length discrepancy.

References:

[1] Oinuma K, Shiratsuchi H, Nakakita Y, Miura Y, Ninomiya T. A new anterior total hip arthroplasty reduction technique for patients who require leg lengthening. Hip Int 2020;30:587–91. https://doi.org/10.1177/1120700020937248.

[2] Li H, Yuan Y, Xu J, Chang Y, Dai K, Zhu Z. Direct Leverage for Reducing the Femoral Head in Total Hip Arthroplasty Without Femoral Shortening Osteotomy for Crowe Type 3 to 4 Dysplasia of the Hip. J Arthroplast 2018;33:794–9. https://doi.org/10.1016/j.arth.2017.09.011.

[3] Nishino T, Mishima H, Kawamura H, Yoshizawa T, Miyakawa S, Yamazaki M. Ten-year results of 55 dysplasia hips of hip offset and leg length reconstruction in total hip arthroplasty with cementless tapered stems having a high offset option designed for dysplastic femur. J Orthop Surg (Hong Kong) 2020;28:2309499020909499. https://doi.org/10.1177/2309499020909499.

[4] Imarisio D, Trecci A, Sabatini L, Uslenghi M, Leone C, Scagnelli R. Cementless total hip replacement for severe developmental dysplasia of the hip: our experience in Crowe's group IV. Musculoskelet Surg 2013;97:25–30. https://doi.org/10.1007/s12306-012-0227-

y.
[5] Altay M, Demirkale İ, Çatma MF, Karaduman M. Results of Crowe Type IV Developmental Dysplasia of Hip Treated by Subtrochantric Osteotomy and Total Hip Arthroplasty. Indian J Orthop 2018;52:374–9. https://doi.org/10.4103/ortho.IJOrtho_445_16.
[6] Huang Y, Zhou Y, Shao H, Chu Y, Gu J, Li H. Total Hip Arthroplasties for Hartofilakidis Type C1 and C2 High Hip Dislocations Demonstrate Similar Survivorship and Clinical Function at Minimum 10-year Follow-up With Cementless Implants. J Arthroplast 2022;37:2374–80. https://doi.org/10.1016/j.arth.2022.06.005.
[7] Holinka J, Pfeiffer M, Hofstaetter JG, Lass R, Kotz RI, Giurea A. Total hip replacement in congenital high hip dislocation following iliofemoral monotube distraction. Int Orthop 2011;35:639–45. https://doi.org/10.1007/s00264-010-1001-0.
[8] Ozden VE, Dikmen G, Beksac B, Tozun IR. Total hip arthroplasty with step-cut subtrochanteric femoral shortening osteotomy in high riding hip dislocated patients with previous femoral osteotomy. J Orthop Sci 2017;22:517–23. https://doi.org/10.1016/j.jos.2017.01.017.
[9] Fujishiro T, Nishiyama T, Hayashi S, Hashimoto S, Kurosaka M, Kanno T, et al. Predicting leg-length change after total hip arthroplasty by measuring preoperative hip flexion under general anaesthesia. J Orthop Surg (Hong Kong) 2012;20:327–30. https://doi.org/10.1177/230949901202000312.
[10] Akman YE, Yavuz U, Çetinkaya E, Gür V, Gül M, Demir B. Cementless total hip arthroplasty for severely dislocated hips previously treated with Schanz osteotomy of the proximal femur. Arch Orthop Trauma Surg 2018;138:427–34. https://doi.org/10.1007/s00402-018-2879-z.
[11] Chu YM, Zhou YX, Han N, Yang DJ. Two Different Total Hip Arthroplasties for Hartofilakidis Type C1 Developmental Dysplasia of Hip in Adults. Chin Med J 2016;129:289–94. https://doi.org/10.4103/0366-6999.174507.
[12] Yan F, Chen G, Yang L, He R, Gu L, Wang F. A reduction technique of arthroplasty without subtrochanteric femoral shortening osteotomy for the treatment of developmental high dislocation of hip: a case series of 28 hips. J Arthroplast 2014;29:2289–93. https://doi.org/10.1016/j.arth.2013.11.016.
[13] Liu RY, Bai CY, Song QC, Dang XQ, Wu YJ, Wang KZ. Partial greater trochanter osteotomy for hip reduction in total hip arthroplasty for high dislocated hip: a preliminary report. BMC Musculoskelet Disord 2014;15:293. https://doi.org/10.1186/1471-2474-15-293.
[14] Li L, Yu M, Yang C, Gu G. Total hip arthroplasty (S-ROM stem) and subtrochanteric osteotomy for Crowe type IV developmental dysplasia of the hip. Indian J Orthop 2016;50:195–200. https://doi.org/10.4103/0019-5413.177575.
[15] Hasegawa Y, Iwase T, Kanoh T, Seki T, Matsuoka A. Total hip arthroplasty for Crowe type IV developmental dysplasia. J Arthroplast 2012;27:1629–35. https://doi.org/10.1016/j.arth.2012.02.026.
[16] Zhong C, Cai XZ, Yan SG, He RX. S-ROM modular arthroplasty combined with transverse subtrochanteric shortening for Crowe type IV congenital dislocation of hip. Chin Med J 2011;124:3891–5.
[17] Binazzi R. Two-Stage Progressive Femoral Lowering Followed by Cementless Total Hip Arthroplasty for Treating Crowe IV-Hartofilakidis Type 3 Developmental Dysplasia of

the Hip. J Arthroplast 2015;30:790–6. https://doi.org/10.1016/j.arth.2014.12.019.
[18] Masonis JL, Patel J V, Miu A, Bourne RB, McCalden R, Macdonald SJ, et al. Subtrochanteric shortening and derotational osteotomy in primary total hip arthroplasty for patients with severe hip dysplasia: 5-year follow-up. J Arthroplast 2003;18:68–73. https://doi.org/10.1054/arth.2003.50104.
[19] Imbuldeniya AM, Walter WL, Zicat BA, Walter WK. Cementless total hip replacement without femoral osteotomy in patients with severe developmental dysplasia of the hip: minimum 15-year clinical and radiological results. Bone Jt J 2014;96-b:1449–54. https://doi.org/10.1302/0301-620x.96b11.33698.
[20] Zhao E, Liu Z, Ding Z, Luo Z, Li H, Zhou Z. A propensity score-matched analysis between patients with high hip dislocation after childhood pyogenic infection and Crowe IV developmental dysplasia of the hip in total hip arthroplasty with subtrochanteric shortening osteotomy. J Orthop Surg Res 2020;15:418. https://doi.org/10.1186/s13018-020-01947-5.
[21] Mu W, Yang D, Xu B, Mamtimin A, Guo W, Cao L. Midterm Outcome of Cementless Total Hip Arthroplasty in Crowe IV-Hartofilakidis Type III Developmental Dysplasia of the Hip. J Arthroplast 2016;31:668–75. https://doi.org/10.1016/j.arth.2015.10.011.
[22] Tahta M, Isik C, Uluyardimci E, Cepni S, Oltulu I. Total hip arthroplasty without subtrochanteric femoral osteotomy is possible in patients with Crowe III/IV developmental dysplasia: total hip arthroplasty without femoral osteotomy. Arch Orthop Trauma Surg 2020;140:409–13. https://doi.org/10.1007/s00402-019-03320-6.
[23] Krych AJ, Howard JL, Trousdale RT, Cabanela ME, Berry DJ. Total hip arthroplasty with shortening subtrochanteric osteotomy in Crowe type-IV developmental dysplasia. J Bone Jt Surg Am 2009;91:2213–21. https://doi.org/10.2106/jbjs.H.01024.
[24] Ding ZC, Zeng WN, Mou P, Liang ZM, Wang D, Zhou ZK. Risk of Dislocation After Total Hip Arthroplasty in Patients with Crowe Type IV Developmental Dysplasia of the Hip. Orthop Surg 2020;12:589–600. https://doi.org/10.1111/os.12665.
[25] Makita H, Inaba Y, Hirakawa K, Saito T. Results on total hip arthroplasties with femoral shortening for Crowe's group IV dislocated hips. J Arthroplast 2007;22:32–8. https://doi.org/10.1016/j.arth.2006.02.157.
[26] Oinuma K, Tamaki T, Miura Y, Kaneyama R, Shiratsuchi H. Total hip arthroplasty with subtrochanteric shortening osteotomy for Crowe grade 4 dysplasia using the direct anterior approach. J Arthroplast 2014;29:626–9. https://doi.org/10.1016/j.arth.2013.07.038.
[27] Kiliçoğlu Oİ, Türker M, Akgül T, Yazicioğlu O. Cementless total hip arthroplasty with modified oblique femoral shortening osteotomy in Crowe type IV congenital hip dislocation. J Arthroplast 2013;28:117–25. https://doi.org/10.1016/j.arth.2012.06.014.
[28] Kawai T, Tanaka C, Ikenaga M, Kanoe H. Cemented total hip arthroplasty with transverse subtrochanteric shortening osteotomy for Crowe group IV dislocated hip. J Arthroplast 2011;26:229–35. https://doi.org/10.1016/j.arth.2010.03.029.
[29] Ors C, Caylak R, Togrul E. Total Hip Arthroplasty With the Wagner Cone Femoral Stem in Patients With Crowe IV Developmental Dysplasia of the Hip: A Retrospective Study. J Arthroplast 2022;37:103–9. https://doi.org/10.1016/j.arth.2021.09.007.
[30] Yang TC, Chen CF, Tsai SW, Chen WM, Chang MC. Does restoration of hip center with subtrochanteric osteotomy provide preferable outcome for Crowe type III-IV irreducible development dysplasia of the hip?? J Chin Med Assoc 2017;80:803–7.

https://doi.org/10.1016/j.jcma.2017.06.006.
[31] Ahmed E, Ibrahim el G, Ayman B. Total hip arthroplasty with subtrochanteric osteotomy in neglected dysplastic hip. Int Orthop 2015;39:27–33. https://doi.org/10.1007/s00264-014-2554-0.
[32] Wu K, Zhang X, Chen M, Shang X. Restoration of Proximal Femoral Anatomy during Total Hip Arthroplasty for High Developmental Dysplasia of the Hip: An Original Technique. Orthop Surg 2020;12:343–50. https://doi.org/10.1111/os.12614.
[33] Nagoya S, Kaya M, Sasaki M, Tateda K, Kosukegawa I, Yamashita T. Cementless total hip replacement with subtrochanteric femoral shortening for severe developmental dysplasia of the hip. J Bone Jt Surg Br 2009;91:1142–7. https://doi.org/10.1302/0301-620x.91b9.21736.
[34] Lu Z, Chen Q, Lan Y, Xie S, Lin F, Feng E. Subtrochanteric Osteotomy in Direct Anterior Approach Total Hip Arthroplasty for Crowe IV Dysplasia-Surgical Technique and Literature Review. Orthop Surg 2024;16:766–74. https://doi.org/10.1111/os.13996.
[35] Lee SJ, Yoon KS. Two-stage total hip arthroplasty following skeletal traction after extensive soft tissue release for severe limb-length discrepancy. Hip Int 2021;31:223–30. https://doi.org/10.1177/1120700019865742.
[36] Lai KA, Shen WJ, Huang LW, Chen MY. Cementless total hip arthroplasty and limb-length equalization in patients with unilateral Crowe type-IV hip dislocation. J Bone Jt Surg Am 2005;87:339–45. https://doi.org/10.2106/jbjs.D.02097.
[37] Peng J, Liu Z, Ding Z, Qian Q, Wu Y. Clinical efficacy of greater trochanter osteotomy with tension wire fixation in total hip arthroplasty for Crowe type IV developmental dysplasia of the hip. J Orthop Surg Res 2024;19:12. https://doi.org/10.1186/s13018-023-04344-w.
[38] Kawai T, Tanaka C, Kanoe H. Total hip arthroplasty for Crowe IV hip without subtrochanteric shortening osteotomy -a long term follow up study. BMC Musculoskelet Disord 2014;15:72. https://doi.org/10.1186/1471-2474-15-72.
[39] Zhu J, Shen C, Chen X, Cui Y, Peng J, Cai G. Total hip arthroplasty with a non-modular conical stem and transverse subtrochanteric osteotomy in treatment of high dislocated hips. J Arthroplast 2015;30:611–4. https://doi.org/10.1016/j.arth.2014.11.002.
[40] Faldini C, Tassinari L, Pederiva D, Rossomando V, Brunello M, Pilla F, et al. Direct Anterior Approach in Total Hip Arthroplasty for Severe Crowe IV Dysplasia: Retrospective Clinical and Radiological Study. Med 2024;60. https://doi.org/10.3390/medicina60010114.
[41] Li X, Lu Y, Sun J, Lin X, Tang T. Treatment of Crowe Type-IV Hip Dysplasia Using Cementless Total Hip Arthroplasty and Double Chevron Subtrochanteric Shortening Osteotomy: A 5- to 10-Year Follow-Up Study. J Arthroplast 2017;32:475–9. https://doi.org/10.1016/j.arth.2016.07.050.
[42] Baumgart R, Dahl M, Horn S, Plötz W, Baumgart T, Morrison S. Reduction of High Hip Dislocation With a Distraction Nail and Arthroplasty (Preliminary Results of a Novel Technique). Arthroplast Today 2023;24:101257. https://doi.org/10.1016/j.artd.2023.101257.
[43] Sun JY, Ma HY, Shen JM, Du YQ, Dong Y, Zhang YC, et al. Factors influencing knee valgus alignment in Crowe type IV hip dysplasia after total hip arthroplasty. J Orthop Traumatol 2021;22:41. https://doi.org/10.1186/s10195-021-00601-y.
[44] Kabata T, Kajino Y, Inoue D, Ohmori T, Yoshitani J, Ueno T, et al. Safety range for acute

limb lengthening in primary total hip arthroplasty. Int Orthop 2019;43:2047–56. https://doi.org/10.1007/s00264-018-4158-6.
[45] Karaismailoglu B, Karaismailoglu TN. Comparison of Trochanteric Slide and Subtrochanteric Shortening Osteotomy in the Treatment of Severe Hip Dysplasia: Mid-Term Clinical Outcomes of Cementless Total Hip Arthroplasty. J Arthroplast 2020;35:2529–36. https://doi.org/10.1016/j.arth.2020.04.039.
[46] Inoue D, Kabata T, Kajino Y, Ohmori T, Ueoka K, Tsuchiya H. Comparison of mid-term clinical results between cementless and cemented femoral stems in total hip arthroplasty with femoral shortening osteotomy for Crowe type IV hips. Arch Orthop Trauma Surg 2021;141:1057–64. https://doi.org/10.1007/s00402-020-03749-0.
[47] Sofu H, Kockara N, Gursu S, Issin A, Oner A, Sahin V. Transverse Subtrochanteric Shortening Osteotomy During Cementless Total Hip Arthroplasty in Crowe Type-III or IV Developmental Dysplasia. J Arthroplast 2015;30:1019–23. https://doi.org/10.1016/j.arth.2015.01.045.
[48] Demirkale İ, Yaradılmış YU, Ateş A, Altay M. Total hip arthroplasty for high-riding hips: A retrospective analysis of 79 cases and proposal of a new classification. J Orthop Surg (Hong Kong) 2020;28:2309499020924164. https://doi.org/10.1177/2309499020924164.
[49] Lee SJ, Yoo JJ, Kim HJ. Cementless Total Hip Arthroplasty Involving Trochanteric Osteotomy without Subtrochanteric Shortening for High Hip Dislocation. Clin Orthop Surg 2017;9:19–28. https://doi.org/10.4055/cios.2017.9.1.19.
[50] Bilgen Ö F, Yaray O, Mutlu M, Aksakal AM. Intraoperative two-stage evaluation of muscle contractures in Crowe type IV hips in total hip arthroplasty (a new surgical technique). Hip Int 2022;32:391–400. https://doi.org/10.1177/1120700020959784.
[51] Wu X, Li SH, Lou LM, Cai ZD. The techniques of soft tissue release and true socket reconstruction in total hip arthroplasty for patients with severe developmental dysplasia of the hip. Int Orthop 2012;36:1795–801. https://doi.org/10.1007/s00264-012-1622-6.
[52] Kayaalp ME, Can A, Erdogan F, Ozsahin MK, Aydingoz O, Kaynak G. Clinical and Radiological Results of Crowe Type 3 or 4 Dysplasia Patients Operated on With Total Hip Arthroplasty Using a Cementless Rectangular Femoral Component Without Fixating or Grafting the Transverse Osteotomy Site. J Arthroplast 2020;35:2537–42. https://doi.org/10.1016/j.arth.2020.04.045.
[53] Biçici V, Bingöl I, Sazak T. Mid-term results of total hip arthroplasty with subtrochanteric Z-osteotomy in Crowe type 3-4 developmental hip dysplasia. Turk J Med Sci 2021;51:1976–83. https://doi.org/10.3906/sag-2102-217.
[54] Bao N, Meng J, Zhou L, Guo T, Zeng X, Zhao J. Lesser trochanteric osteotomy in total hip arthroplasty for treating CROWE type IV developmental dysplasia of hip. Int Orthop 2013;37:385–90. https://doi.org/10.1007/s00264-012-1758-4.
[55] McHale KA. CORR Insights®: Assessing Leg Length Discrepancy Is Necessary Before Arthroplasty in Patients With Unilateral Crowe Type IV Hip Dislocation. Clin Orthop Relat Res 2023;481:1790–1. https://doi.org/10.1097/corr.0000000000002754.
[56] Xu Q, Wang Q, Zhu J, Lin J, Lu Z, Wang T, et al. Clinical outcomes of proximal femoral reconstruction technique combined with THA in the treatment of high dislocation secondary to septic arthritis: a retrospective single-center study. BMC Musculoskelet Disord 2023;24:732. https://doi.org/10.1186/s12891-023-06818-8.
[57] Higuchi Y, Hasegawa Y, Ishiguro N. Leg lengthening of more than 5 cm is a risk factor for sciatic nerve injury after total hip arthroplasty for adult hip dislocation. Nagoya J Med

Sci 2015;77:455–63.
[58] Sun C, Zhang Y, Li LT, Ding H, Guo T, Zhao JN. Long-Term Outcomes of Total Hip Arthroplasty With Transverse Subtrochanteric Shortening Osteotomy and Modular Stem in Crowe IV Developmental Dysplasia. J Arthroplast 2021;36:630–5. https://doi.org/10.1016/j.arth.2020.08.031.
[59] Zeng WN, Liu JL, Wang FY, Zhang X, Fan HQ, Chen GX, et al. Total hip arthroplasty for patients with Crowe type IV developmental dysplasia of the hip: Ten years results. Int J Surg 2017;42:17–21. https://doi.org/10.1016/j.ijsu.2017.04.029.
[60] Fujishiro T, Nishiyama T, Hayashi S, Kurosaka M, Kanno T, Masuda T. Leg length change in total hip arthroplasty with subtrochanteric femoral shortening osteotomy for Crowe type IV developmental hip dysplasia. J Arthroplast 2012;27:1019–22. https://doi.org/10.1016/j.arth.2012.01.032.
[61] Oe K, Iida H, Nakamura T, Okamoto N, Wada T. Subtrochanteric shortening osteotomy combined with cemented total hip arthroplasty for Crowe group IV hips. Arch Orthop Trauma Surg 2013;133:1763–70. https://doi.org/10.1007/s00402-013-1869-4.
[62] Hameed D, Dubin JA, Bains SS, Moore MC, Standard SC, Mont MA. Innovative Hip Distraction Approaches for Total Hip Arthroplasty in Crowe IV Developmental Dysplasia or Similar High-Riding Patients. J Arthroplast 2024. https://doi.org/10.1016/j.arth.2024.04.019.
[63] Wang D, Li DH, Li Q, Wang HY, Luo ZY, Yang Y, et al. Subtrochanteric shortening osteotomy during cementless total hip arthroplasty in young patients with severe developmental dysplasia of the hip. BMC Musculoskelet Disord 2017;18:491. https://doi.org/10.1186/s12891-017-1857-x.
[64] Li Y, Zhang X, Wang Q, Peng X, Wang Q, Jiang Y, et al. Equalisation of leg lengths in total hip arthroplasty for patients with Crowe type-IV developmental dysplasia of the hip: classification and management. Bone Jt J 2017;99-b:872–9. https://doi.org/10.1302/0301-620x.99b7.Bjj-2016-1328.R1.
[65] Zhao X, Zhu ZA, Xie YZ, Yu B, Yu DG. Total hip replacement for high dislocated hips without femoral shortening osteotomy. J Bone Jt Surg Br 2011;93:1189–93. https://doi.org/10.1302/0301-620x.93b9.25914.
[66] Erdem Y, Bek D, Atbasi Z, Neyisci C, Yildiz C, Basbozkurt M. Total hip arthroplasty with rectangular stems and subtrochanteric transverse shortening osteotomy in Crowe type IV hips: a retrospective study. Arthroplast Today 2019;5:234–42. https://doi.org/10.1016/j.artd.2019.03.002.
[67] Ibrahim FMF, Gameel S. Total cementless unconstrained hip arthroplasty in Crowe type IV hip dysplasia with subtrochentric derotation osteotomy. Acta Orthop Belg 2022;88:517–24. https://doi.org/10.52628/88.3.7416.
[68] Sukur E, Senel A, Ozdemir U, Akman YE, Azboy İ, Ozturkmen Y. Cementless modular total hip arthroplasty with subtrochanteric transverse shortening osteotomy for high hip dislocations. J Orthop Surg Res 2022;17:139. https://doi.org/10.1186/s13018-022-03025-4.
[69] Lai KA, Liu J, Liu TK. Use of iliofemoral distraction in reducing high congenital dislocation of the hip before total hip arthroplasty. J Arthroplast 1996;11:588–93. https://doi.org/10.1016/s0883-5403(96)80114-8.
[70] Tu Q, Ding HW, Chen H, Shen JJ, Miao QJ, Liu B, et al. Preliminary application of 3D-printed individualised guiding templates for total hip arthroplasty in Crowe type IV

developmental dysplasia of the hip. Hip Int 2022;32:334–44. https://doi.org/10.1177/1120700020948006.
[71] Akıncı O, Turgut A. Long-Term Results of Total Hip Arthroplasty with Step-Cut Osteotomy in Crowe Type IV Dysplastic Hips. Indian J Orthop 2022;56:672–9. https://doi.org/10.1007/s43465-021-00567-3.
[72] Luo Z, Chen M, Hu F, Ni Z, Ji X, Zhang X, et al. Cementless total hip arthroplasty with extended sliding trochanteric osteotomy for high congenital hip dislocation: A retrospective study. Med 2017;96:e6581. https://doi.org/10.1097/md.0000000000006581.
[73] Kong X, Chai W, Chen J, Yan C, Shi L, Wang Y. Intraoperative monitoring of the femoral and sciatic nerves in total hip arthroplasty with high-riding developmental dysplasia. Bone Jt J 2019;101-b:1438–46. https://doi.org/10.1302/0301-620x.101b11.Bjj-2019-0341.R2.
[74] Imam MA, Fathalla I, Holton J, Nabil M, Kashif F. Cementless Total Hip Replacement for the Management of Severe Developmental Dysplasia of the Hip in the Middle Eastern Population: A Prospective Analysis. Front Surg 2016;3:31. https://doi.org/10.3389/fsurg.2016.00031.
[75] Liu T, Wang S, Huang G, Wang W. Treatment of Crowe IV developmental dysplasia of the hip with cementless total hip arthroplasty and shortening subtrochanteric osteotomy. J Int Med Res 2019;47:3223–33. https://doi.org/10.1177/0300060519853383.
[76] Akiyama H, Kawanabe K, Yamamoto K, Kuroda Y, So K, Goto K, et al. Cemented total hip arthroplasty with subtrochanteric femoral shortening transverse osteotomy for severely dislocated hips: outcome with a 3- to 10-year follow-up period. J Orthop Sci 2011;16:270–7. https://doi.org/10.1007/s00776-011-0049-z.
[77] Zhao HY, Kang PD, Shi XJ, Zhou ZK, Yang J, Shen B, et al. Effects of Total Hip Arthroplasty on Axial Alignment of the Lower Limb in Patients with Unilateral Developmental Hip Dysplasia (Crowe type IV). J Arthroplast 2019;34:2406–14. https://doi.org/10.1016/j.arth.2019.04.028.
[78] Chareancholvanich K, Becker DA, Gustilo RB. Treatment of congenital dislocated hip by arthroplasty with femoral shortening. Clin Orthop Relat Res 1999:127–35. https://doi.org/10.1097/00003086-199903000-00016.
[79] Rollo G, Solarino G, Vicenti G, Picca G, Carrozzo M, Moretti B. Subtrochanteric femoral shortening osteotomy combined with cementless total hip replacement for Crowe type IV developmental dysplasia: a retrospective study. J Orthop Traumatol 2017;18:407–13. https://doi.org/10.1007/s10195-017-0466-7.
[80] Ueoka K, Kabata T, Kajino Y, Inoue D, Ohmori T, Ueno T, et al. Patient-reported outcomes following primary total hip arthroplasty in Crowe type III or IV developmental dysplasia are comparable to those in Crowe type I: a case-control study of 96 hips with intermediate-term follow-up. BMC Musculoskelet Disord 2020;21:344. https://doi.org/10.1186/s12891-020-03371-6.
[81] Shemesh SS, Robinson J, Overley S, Bronson MJ, Moucha CS, Chen D. Novel technique for intraoperative sciatic nerve assessment in complex primary total hip arthroplasty: a pilot study. Hip Int 2018;28:210–7. https://doi.org/10.5301/hipint.5000553.
[82] Kerboull M, Hamadouche M, Kerboull L. Total hip arthroplasty for Crowe type IV developmental hip dysplasia: a long-term follow-up study. J Arthroplast 2001;16:170–6. https://doi.org/10.1054/arth.2001.28368.
[83] Caylak R, Ors C, Togrul E. Minimum 10-Year Results of Cementless Ceramic-On-

Ceramic Total Hip Arthroplasty Performed With Transverse Subtrochanteric Osteotomy in Crowe Type IV Hips. J Arthroplast 2021;36:3519–26. https://doi.org/10.1016/j.arth.2021.05.035.
[84] Chen M, Gittings DJ, Yang S, Liu X. Total Hip Arthroplasty for Crowe Type IV Developmental Dysplasia of the Hip Using a Titanium Mesh Cup and Subtrochanteric Femoral Osteotomy. Iowa Orthop J 2018;38:191–5.
[85] Huang ZY, Ling J, Zeng ZM, Di ZL, Zhang JH, Tao K. Mid-Term Outcomes of Cemented Stem and Subtrochanteric Shortening Derotational Osteotomy in Total Hip Arthroplasty for Crowe IV Developmental Dysplasia. Orthop Surg 2022;14:3178–86. https://doi.org/10.1111/os.13515.
[86] Wang D, Li LL, Wang HY, Pei FX, Zhou ZK. Long-Term Results of Cementless Total Hip Arthroplasty With Subtrochanteric Shortening Osteotomy in Crowe Type IV Developmental Dysplasia. J Arthroplast 2017;32:1211–9. https://doi.org/10.1016/j.arth.2016.11.005.
[87] Jin JY, Yoon TR, Park KS, Jin SY, Jung DM, Li QS. Mid-term results of total hip arthroplasty with modified trochanteric osteotomy in Crowe type IV developmental dysplasia of the hip. BMC Surg 2021;21:9. https://doi.org/10.1186/s12893-020-01002-4.
[88] Lerch M, Thorey F, von Lewinski G, Klages P, Wirth CJ, Windhagen H. An alternative treatment method to restore limb-length discrepancy in osteoarthritis with high congenital hip dislocation. Arch Orthop Trauma Surg 2009;129:1593–9. https://doi.org/10.1007/s00402-009-0846-4.
[89] Park CW, Lim SJ, Cha YT, Park YS. Total Hip Arthroplasty With Subtrochanteric Shortening Osteotomy in Patients With High Hip Dislocation Secondary to Childhood Septic Arthritis: A Matched Comparative Study With Crowe IV Developmental Dysplasia. J Arthroplast 2020;35:204–11. https://doi.org/10.1016/j.arth.2019.08.034.
[90] Sonohata M, Kitajima M, Kawano S, Mawatari M. Nerve Palsy after Total Hip Arthroplasty without Subtrochanteric Femoral Shortening Osteotomy for a Completely Dislocated Hip Joint. Open Orthop J 2016;10:785–92. https://doi.org/10.2174/1874325001610010785.
[91] Wang S, Zeng M, Zhang X, Liu T. Total hip arthroplasty with soft tissue release for patients with severe development dysplasia of the hip. Zhong Nan Da Xue Xue Bao Yi Xue Ban 2018;43:54–7. https://doi.org/10.11817/j.issn.1672-7347.2018.01.009.
[92] Eggli S, Hankemayer S, Müller ME. Nerve palsy after leg lengthening in total replacement arthroplasty for developmental dysplasia of the hip 1999;81:843–5.