What are the indications for reconstructive pelvic periacetabular osteotomy in patients with hip pain?

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Response/Recommendation:

Reconstructive pelvic osteotomy is an effective surgical intervention for young patients (<40 years) with symptomatic hip dysplasia (of at least 3 months duration), well preserved joint space (Tönnis ≤ 1), good joint congruency and good hip range of motion. Prior to offering this surgical option surgeon should engage in a comprehensive assessment of the patient that includes attention to age, severity of dysplasia, body habitus, and patient expectations.

Level of Evidence: Moderate

Rationale:

One form of reconstructive pelvic osteotomy (RPO), otherwise known as Periacetabular Osteotomy (PAO), was first described by Ganz et al. in 1988 (Ganz et al., 1988).This reconstructive osteotomy is a widely used technique for acetabular reorientation across the world. However, it is important to note that other forms of reconstructive pelvic osteotomy are also available and employed by surgeons. We conducted a systematic review to glean the outcome of reconstructive pelvic osteotomy and indications for such surgical intervention from the published literature. Majority of the published literature focuses on PAO. Thus, this document will focus on indications for PAO which may be generalized to other forms of reconstructive pelvic osteotomy.

Based on review of the literature, PAO appears to be a viable surgical intervention for patients with symptomatic hip dysplasia. The factors that need to be taken into account prior to offering this surgical option includes patient's age, severity of dysplasia, patient's body habitus, patient expectaions and possibly other factors.

PAO should only be offered to patients with symptomatic hip dysplasia, namely pain and/or instability of the hip. Patients with hip dysplasia typically experience pain in the groin, lateral hip, or buttock region. Pain is often exacerbated by activity and may be accompanied by feelings of instability. High activity level and severe dyplasia lead development of symptoms at younger age. (Matheney et al., 2016). The patients should have exhusted non-operative measures for pain control and the duration of pain should be at least 3 months based on some publications (Edelstein et al., 2021; Jacobsen et al., 2019), 6 months (Goronzy et al., 2017; Ziran et al., 2018) to 1 year (Beaulé et al., 2015, Ricciardi et al., 2017; Swarup et al., 2020).

Age is an important factor when considering PAO. In a systematic review and meta-analysis, a strong link between older age and a higher risk of PAO failure in the long term was reported, particularly beyond six years of follow-up (Tan et al., 2022). While there is no strict age limit for PAO, studies have suggested an age cut-off with 40 years appearing to be the upper limit (Lerch et al., 2017, Matheney et al., 2009, Lerch et al., 2017; Millis et al., 2009). We are aware of publications reporting good outcome of PAO in patients older than 40 and feel that PAO may be offered to a select group of patients who may be older than 40 years of age (Troelsen et al., 2009, Zhu et al., 2013, Millis et al., 2009, Muffly et al., 2021,Leopold et al., 2024, Garbuz et al., 2008, Novais et al., 2023).

The severity of dysplasia is another important factor when considering PAO. The lateral center edge angle (LCEA), anterior center edge angle (ACEA) and acetabular index (AI) are common radiographic measurements used to quantify dysplasia severity (Lequesne & de, 1961; Murphy et al., 1995; Smith et al., 2021; Tannast et al., 2015; Wiberg, 1939) An LCEA of <20˚ is typically indicative of dysplasia, while an LCEA of 18˚ to 25˚ or 20˚ to 25˚ is considered borderline dysplasia (Kraeutler et al., 2020; McClincy et al., 2019; Murata et al., 2021; Swarup et al., 2020) Some studies suggest that patients with borderline dysplasia may benefit from hip arthroscopy, a less invasive procedure. (Andronic et al., 2024; Murata et al., 2021) While this may be true for some patients, it is important to note that borderline dysplasia is a heterogeneous diagnosis, and patients often present with additional radiographic signs of acetabular under coverage. These hips may be inappropriately labeled as borderline when considering LCEA alone. Therefore, it is crucial to conduct a comprehensive radiographic assessment, including measurements of the AWI and PWI (anterior and posterior wall indices) (Siebenrock et al., 2012; Stetzelberger et al., 2021) and the femoral epiphyseal acetabular roof (FEAR) index(Wyatt et al., 2017), to determine the severity and location of dysplasia accurately and delineate between instability and impingement in patients (McClincy et al., 2019). The presence of PWS (Posterior wall sign), COS (Cross Over Sign) and ISS (Ischial Spine Sign) were used as important plain radiographic indicators supported with MR (Magnetic Resonance) chondro-labral damage detected for reverse PAO in FAI femoroacetabular impingement with secondary acetabular retroversion.(Siebenrock et al., 2003) In anterior or posterior wall insufficiency and/or acetabular version anomalies, 2D imaging may not accurately reflect the true extent of three-dimensional femoral head coverage within the weight-bearing zone, potentially leading to an overestimation.(Dornacher et al., 2023; Kohno et al., 2020) CT measurements are crucial for understanding the three-dimensional nature of acetabular dysplasia, which is essential for planning corrective osteotomies.(Larson et al., 2015) This comprehensive understanding, along with a new description of dysplasia, helps to restore normal anatomy and minimize the risk of under-correcting in one plane while over-correcting in another. (Wilkin et al., 2017). Acetabular Sector Angle (Anterior – Posterior) measurements can identify areas of deficient acetabular coverage, aiding in the diagnosis and subtyping of hip dysplasia and influencing orthopedic surgical management. (Verhaegen et al., 2023)

When assessing a patient for PAO, it is important to consider the joint space and joint congruency. A comparative study found that failure risk increased due to the lack of femoral offset correction in aspherical femoral heads during PAO.(Albers et al., 2013) In intermediate to long-term (Albers et al., 2013; Grammatopoulos et al., 2016; Matheney et al., 2009) and long-term (more than 10 years) studies (Wells et al., 2017), the importance of joint congruence for survival has been emphasized, with incongruence identified as a significant risk factor for failure.

The degree of arthritis is crucial in determining the eligibility for PAO. Higher preoperative Tönnis (>1) grades are associated with poorer outcomes and an increased risk of conversion to THA (Dahl et al., 2014; Hartig-Andreasen et al., 2012; Kralj et al., 2005; Lerch et al., 2017; Stetzelberger et al., 2021; Troelsen et al., 2009; Ziran et al., 2018) A multicenter study noted a higher rate of hip replacement within ten years of PAO for patients with Tönnis grade 2 than those with better joint space (Tönnis <1). This progression was unrelated to patient demographic factors such as age and body mass index.(Wyles et al., 2019) Thus, the presence of moderate osteoarthritis may be considered a contraindication for PAO, and the decision to proceed with PAO in these cases should be made on a case-by-case basis, considering factors such as patient age, activity level, and joint congruency. The best method to determine the degree of arthritis in the joint still remains debatable. Some authorities suggest that imaging

with MRI, and possibly with contrasted techniques (dGEMRIC) provide better prognostic information for surgical success and may predict premature hip joint failure better than radiographic measures of osteoarthritis. (Kim et al., 2012).

The presence of obesity, has been identified as a risk factor for complications following PAO (Selberg et al., 2020) (Novais et al., 2015). However, obesity alone does not seem to compromise the outcome and survivorship of PAO. In fact in a multicenter, prospective study, patients who were overweight (>30kg/m^2) reported greater improvement in multiple patient-reported outcome measures following PAO (Clohisy et al., 2017). The authors hypothesized that the latter may be due to these patients having lower functional expectations and placing less demand on the hip (Clohisy et al., 2017).

In conclusion, and because of the invasive nature of pelvic osteotomy, carefull assessment of patient and expectations need to be taken into account prior to offering this surgical intervention. Reconstructive pelvic osteotomy appears to be a viable and excellent surgical option for young patients with symptomatic hip dysplasia who have well preserved joint space, congruent joint, and good hip range of motion.

References:

Albers, C. E., Steppacher, S. D., Ganz, R., Tannast, M., & Siebenrock, K. A. (2013). Impingement adversely affects 10-year survivorship after periacetabular osteotomy for DDH hip [Article]. *Clinical Orthopaedics and Related Research*, *471*(5), 1602-1614. https://doi.org/10.1007/s11999-013-2799-8

Andronic, O., Chaharbakhshi, E. O., Zingg, P. O., Germann, C., Rahm, S., Lall, A. C., & Domb, B. G. (2024). No Difference in Patient-Reported Outcomes for Periacetabular Osteotomy and Hip Arthroscopy With Capsular Plication in the Setting of Borderline Hip Dysplasia: A Propensity-Matched Multicenter Study With Minimum 5-Year Follow-Up. *Arthroscopy*, *40*(3), 754-762. https://doi.org/10.1016/j.arthro.2023.06.045

Beaulé, P. E., Dowding, C., Parker, G., & Ryu, J. J. (2015). What factors predict improvements in outcomes scores and reoperations after the Bernese periacetabular osteotomy? *Clin Orthop Relat Res*, *473*(2), 615-622. https://doi.org/10.1007/s11999-014-3980-4

Clohisy, J. C., Ackerman, J., Baca, G., Baty, J., Beaulé, P. E., Kim, Y.-J., Millis, M. B., Podeszwa, D. A., Schoenecker, P. L., Sierra, R. J., Sink, E. L., Sucato, D. J., Trousdale, R. T., & Zaltz, I. (2017). Patient-Reported Outcomes of Periacetabular Osteotomy from the Prospective ANCHOR Cohort Study. *The Journal of Bone and Joint Surgery*, *99*(1), 33-41. https://doi.org/10.2106/JBJS.15.00798

Dahl, L. B., Dengso, K., Bang-Christiansen, K., Petersen, M. M., & Sturup, J. (2014). Clinical and radiological outcome after periacetabular osteotomy: a cross-sectional study of 127 hips operated on from 1999-2008. *Hip Int*, *24*(4), 369-380. https://doi.org/10.5301/hipint.5000129

Dornacher, D., Lutz, B., Fuchs, M., Zippelius, T., & Reichel, H. (2023). Acetabular deficiency in borderline hip dysplasia is underestimated by lateral center edge angle alone. *Arch Orthop Trauma Surg*, *143*(7), 3937-3944. https://doi.org/10.1007/s00402-022-04652-6

Edelstein, A. I., Nepple, J. J., Abu-Amer, W., Pascual-Garrido, C., Goss, C. W., & Clohisy, J. C. (2021). What Mid-term Patient-reported Outcome Measure Scores, Reoperations, and Complications Are Associated with Concurrent Hip Arthroscopy and Periacetabular

Osteotomy to Treat Dysplasia with Associated Intraarticular Abnormalities? *Clin Orthop Relat Res*, *479*(5), 1068-1077. https://doi.org/10.1097/corr.0000000000001599

Ganz, R., Klaue, K., Vinh, T. S., & Mast, J. W. (1988). A new periacetabular osteotomy for the treatment of hip dysplasias. Technique and preliminary results. *Clin Orthop Relat Res*(232), 26-36. https://www.ncbi.nlm.nih.gov/pubmed/3383491

Garbuz, D. S., Awwad, M. A., & Duncan, C. P. (2008). Periacetabular Osteotomy and Total Hip Arthroplasty in Patients Older Than 40 Years. *the Journal of Arthroplasty*, *23*(7), 960-963. https://doi.org/10.1016/j.arth.2007.08.015

Goronzy, J., Franken, L., Hartmann, A., Thielemann, F., Postler, A., Paulus, T., & Günther, K. P. (2017). What Are the Results of Surgical Treatment of Hip Dysplasia With Concomitant Cam Deformity? *Clin Orthop Relat Res*, *475*(4), 1128-1137. https://doi.org/10.1007/s11999-016-5054-2

Grammatopoulos, G., Wales, J., Kothari, A., Gill, H. S., Wainwright, A., & Theologis, T. (2016). What Is the Early/Mid-term Survivorship and Functional Outcome After Bernese Periacetabular Osteotomy in a Pediatric Surgeon Practice? *Clin Orthop Relat Res*, *474*(5), 1216-1223. https://doi.org/10.1007/s11999-015-4386-7

Hartig-Andreasen, C., Troelsen, A., Thillemann, T. M., & Soballe, K. (2012). What factors predict failure 4 to 12 years after periacetabular osteotomy? *Clin Orthop Relat Res*, *470*(11), 2978-2987. https://doi.org/10.1007/s11999-012-2386-4

Jacobsen, J. S., Søballe, K., Thorborg, K., Bolvig, L., Storgaard Jakobsen, S., Hölmich, P., & Mechlenburg, I. (2019). Patient-reported outcome and muscle–tendon pain after periacetabular osteotomy are related: 1-year follow-up in 82 patients with hip dysplasia. *Acta Orthopaedica*, *90*(1), 40-45. https://doi.org/10.1080/17453674.2018.1555637

Kim, S. D., Jessel, R., Zurakowski, D., Millis, M. B., & Kim, Y. J. (2012). Anterior delayed gadolinium-enhanced MRI of cartilage values predict joint failure after periacetabular osteotomy [Conference Paper]. *Clinical Orthopaedics and Related Research*, *470*(12), 3332-3341. https://doi.org/10.1007/s11999-012-2519-9

Kohno, Y., Nakashima, Y., Fujii, M., Shiomoto, K., & Iwamoto, M. (2020). Acetabular retroversion in dysplastic hips is associated with decreased 3D femoral head coverage independently from lateral center-edge angle. *Arch Orthop Trauma Surg*, *140*(7), 869-875. https://doi.org/10.1007/s00402-019-03277-6

Kraeutler, M. J., Safran, M. R., Scillia, A. J., Ayeni, O. R., Garabekyan, T., & Mei-Dan, O. (2020). A Contemporary Look at the Evaluation and Treatment of Adult Borderline and Frank Hip Dysplasia. *Am J Sports Med*, *48*(9), 2314-2323. https://doi.org/10.1177/0363546519881411

Kralj, M., Mavčič, B., Antolič, V., Iglič, A., & Kralj-Iglič, V. (2005). The Bernese periacetabular osteotomy: Clinical, radiographic and mechanical 7-15-year follow-up of 26 hips [Article]. *Acta Orthopaedica*, *76*(6), 833-840. https://doi.org/10.1080/17453670510045453

Larson, C. M., Moreau-Gaudry, A., Kelly, B. T., Byrd, J. W., Tonetti, J., Lavallee, S., Chabanas, L., Barrier, G., & Bedi, A. (2015). Are normal hips being labeled as pathologic? A CT-based method for defining normal acetabular coverage. *Clin Orthop Relat Res*, *473*(4), 1247-1254. https://doi.org/10.1007/s11999-014-4055-2

Leopold, V. J., Hipfl, C., Perka, C., Hardt, S., & Becker, L. (2024). Periacetabular osteotomy for symptomatic hip dysplasia in middle aged patients: does age alone matter? *Arch Orthop Trauma Surg*, *144*(3), 1065-1070. https://doi.org/10.1007/s00402-023-05160-x

Lequesne, M., & de, S. (1961). [False profile of the pelvis. A new radiographic incidence for the study of the hip. Its use in dysplasias and different coxopathies]. *Rev Rhum Mal Osteoartic*, *28*, 643-652.

Lerch, T. D., Steppacher, S. D., Liechti, E. F., Tannast, M., & Siebenrock, K. A. (2017). One-third of Hips After Periacetabular Osteotomy Survive 30 Years With Good Clinical Results, No Progression of Arthritis, or Conversion to THA. *Clin Orthop Relat Res*, *475*(4), 1154-1168. https://doi.org/10.1007/s11999-016-5169-5

Matheney, T., Kim, Y. J., Zurakowski, D., Matero, C., & Millis, M. (2009). Intermediate to long-term results following the Bernese periacetabular osteotomy and predictors of clinical outcome. *J Bone Joint Surg Am*, *91*(9), 2113-2123. https://doi.org/10.2106/JBJS.G.00143

Matheney, T., Zaltz, I., Kim, Y. J., Schoenecker, P., Millis, M., Podeszwa, D., Zurakowski, D., Beaule, P., Clohisy, J., & Group, A. S. (2016). Activity Level and Severity of Dysplasia Predict Age at Bernese Periacetabular Osteotomy for Symptomatic Hip Dysplasia. *J Bone Joint Surg Am*, *98*(8), 665-671. https://doi.org/10.2106/JBJS.15.00735

McClincy, M. P., Wylie, J. D., Yen, Y. M., & Novais, E. N. (2019). Mild or Borderline Hip Dysplasia: Are We Characterizing Hips With a Lateral Center-Edge Angle Between 18 degrees and 25 degrees Appropriately? *Am J Sports Med*, *47*(1), 112-122. https://doi.org/10.1177/0363546518810731

Melkus, G., Beaulé, P. E., Wilkin, G., & Rakhra, K. S. (2021). What Is the Correlation Among dGEMRIC, T1p, and T2* Quantitative MRI Cartilage Mapping Techniques in Developmental Hip Dysplasia? *Clin Orthop Relat Res*, *479*(5), 1016-1024. https://doi.org/10.1097/corr.0000000000001600

Millis, M. B., Kain, M., Sierra, R., Trousdale, R., Taunton, M. J., Kim, Y. J., Rosenfeld, S. B., Kamath, G., Schoenecker, P., & Clohisy, J. C. (2009). Periacetabular osteotomy for acetabular dysplasia in patients older than 40 years: a preliminary study. *Clin Orthop Relat Res*, *467*(9), 2228-2234. https://doi.org/10.1007/s11999-009-0824-8

Muffly, B. T., Zacharias, A. J., Jochimsen, K. N., Duncan, S. T., Jacobs, C. A., & Clohisy, J. C. (2021). Age at the Time of Surgery Is Not Predictive of Early Patient-Reported Outcomes After Periacetabular Osteotomy. *the Journal of Arthroplasty*, *36*(10), 3388-3391. https://doi.org/10.1016/j.arth.2021.05.029

Murata, Y., Fukase, N., Martin, M., Soares, R., Pierpoint, L., Dornan, G. J., Uchida, S., & Philippon, M. J. (2021). Comparison Between Hip Arthroscopic Surgery and Periacetabular Osteotomy for the Treatment of Patients With Borderline Developmental Dysplasia of the Hip: A Systematic Review. *Orthopaedic Journal of Sports Medicine*, *9*(5). https://doi.org/10.1177/23259671211007401

Murphy, S. B., Ganz, R., & Muller, M. E. (1995). The prognosis in untreated dysplasia of the hip. A study of radiographic factors that predict the outcome. *J Bone Joint Surg Am*, *77*(7), 985-989. https://www.ncbi.nlm.nih.gov/pubmed/7608241

Novais, E. N., Ferraro, S. L., Miller, P., Kim, Y. J., Millis, M. B., & Clohisy, J. C. (2023). Periacetabular Osteotomy for Symptomatic Acetabular Dysplasia in Patients ≥40 Years Old: Intermediate and Long-Term Outcomes and Predictors of Failure. *J Bone Joint Surg Am*, *105*(15), 1175-1181. https://doi.org/10.2106/jbjs.23.00001

Novais, E. N., Potter, G. D., Clohisy, J. C., Millis, M. B., Kim, Y. J., Trousdale, R. T., Carry, P. M., & Sierra, R. J. (2015). Obesity is a major risk factor for the development of complications after peri-acetabular osteotomy. *Bone Joint J*, *97-B*(1), 29-34. https://doi.org/10.1302/0301-620x.97b1.34014

Parry, J. A., Swann, R. P., Erickson, J. A., Peters, C. L., Trousdale, R. T., & Sierra, R. J. (2016). Midterm Outcomes of Reverse (Anteverting) Periacetabular Osteotomy in Patients With Hip Impingement Secondary to Acetabular Retroversion. *Am J Sports Med*, *44*(3), 672-676. https://doi.org/10.1177/0363546515620382

Ricciardi, B. F., Fields, K. G., Wentzel, C., Nawabi, D. H., Kelly, B. T., & Sink, E. L. (2017). Complications and short-term patient outcomes of periacetabular osteotomy for

symptomatic mild hip dysplasia [Article]. *Hip Int*, *27*(1), 42-48. https://doi.org/10.5301/hipint.5000420

Selberg, C. M., Davila-Parrilla, A. D., Williams, K. A., Kim, Y. J., Millis, M. B., & Novais, E. N. (2020). What Proportion of Patients Undergoing Bernese Periacetabular Osteotomy Experience Nonunion, and What Factors are Associated with Nonunion? *Clin Orthop Relat Res*, *478*(7), 1648-1656. https://doi.org/10.1097/corr.0000000000001296

Siebenrock, K. A., Kistler, L., Schwab, J. M., Büchler, L., & Tannast, M. (2012). The acetabular wall index for assessing anteroposterior femoral head coverage in symptomatic patients. *Clinical Orthopaedics and Related Research*, *470*(12), 3355-3360. https://doi.org/10.1007/s11999-012-2477-2

Siebenrock, K. A., Schaller, C., Tannast, M., Keel, M., & Buchler, L. (2014). Anteverting periacetabular osteotomy for symptomatic acetabular retroversion: results at ten years. *J Bone Joint Surg Am*, *96*(21), 1785-1792. https://doi.org/10.2106/JBJS.M.00842

Siebenrock, K. A., Schoeniger, R., & Ganz, R. (2003). Anterior femoro-acetabular impingement due to acetabular retroversion. Treatment with periacetabular osteotomy. *J Bone Joint Surg Am*, *85*(2), 278-286. https://doi.org/10.2106/00004623-200302000-00015

Smith, J. T., Jee, Y., Daley, E., Koueiter, D. M., Beck, M., & Zaltz, I. (2021). Can the Femoro-Epiphyseal Acetabular Roof (FEAR) Index Be Used to Distinguish Dysplasia from Impingement? *Clin Orthop Relat Res*, *Publish Ahead of Print*. https://doi.org/10.1097/CORR.0000000000001610

Stetzelberger, V. M., Leibold, C. S., Steppacher, S. D., Schwab, J. M., Siebenrock, K. A., & Tannast, M. (2021). The Acetabular Wall Index Is Associated with Long Term Conversion to THA after PAO. *Clin Orthop Relat Res*. https://doi.org/10.1097/CORR.0000000000001641

Swarup, I., Zaltz, I., Robustelli, S., & Sink, E. (2020). Outcomes of periacetabular osteotomy for borderline hip dysplasia in adolescent patients. *J Hip Preserv Surg*, *7*(2), 249-255. https://doi.org/10.1093/jhps/hnaa012

Tan, J. H. I., Tan, S. H. S., Rajoo, M. S., Lim, A. K. S., & Hui, J. H. (2022). Hip survivorship following the Bernese periacetabular osteotomy for the treatment of acetabular dysplasia: A systematic review and meta-analysis. *Orthop Traumatol Surg Res*, *108*(4), 103283. https://doi.org/10.1016/j.otsr.2022.103283

Tannast, M., Hanke, M. S., Zheng, G., Steppacher, S. D., & Siebenrock, K. A. (2015). What are the radiographic reference values for acetabular under- and overcoverage? *Clin Orthop Relat Res*, *473*(4), 1234-1246. https://doi.org/10.1007/s11999-014-4038-3

Troelsen, A., Elmengaard, B., & Søballe, K. (2009). Medium-Term Outcome of Periacetabular Osteotomy and Predictors of Conversion to Total Hip Replacement. *The Journal of Bone and Joint Surgery-American Volume*, *91*(9), 2169-2179. https://doi.org/10.2106/jbjs.H.00994

Verhaegen, J. C. F., DeVries, Z., Horton, I., Slullitel, P. A., Rakhra, K., Beaule, P. E., & Grammatopoulos, G. (2023). Acetabular Sector Angles in Asymptomatic and Dysplastic Hips: Defining Dysplasia and Thresholds to Guide Management. *J Bone Joint Surg Am*, *105*(21), 1709-1720. https://doi.org/10.2106/JBJS.23.00022

Wells, J., Millis, M., Kim, Y. J., Bulat, E., Miller, P., & Matheney, T. (2017). Survivorship of the Bernese Periacetabular Osteotomy: What Factors are Associated with Long-term Failure? *Clin Orthop Relat Res*, *475*(2), 396-405. https://doi.org/10.1007/s11999-016-4887-z

Wiberg, G. (1939). Studies on dysplastic acetabula and congenital subluxation of the hip joint. With special reference to the complication of osteoarthritis. *Acta Chir Scand*, *83*(SUPPL. 58), 1-135.

Wilkin, G. P., Ibrahim, M. M., Smit, K. M., & Beaule, P. E. (2017). A Contemporary Definition of Hip Dysplasia and Structural Instability: Toward a Comprehensive Classification for Acetabular Dysplasia [Article]. *J Arthroplasty*, *32*(9S), S20-S27. https://doi.org/10.1016/j.arth.2017.02.067

Wyatt, M., Weidner, J., Pfluger, D., & Beck, M. (2017). The Femoro-Epiphyseal Acetabular Roof (FEAR) Index: A New Measurement Associated With Instability in Borderline Hip Dysplasia? *Clin Orthop Relat Res*, *475*(3), 861-869. https://doi.org/10.1007/s11999-016-5137-0

Wyles, C. C., Vargas, J. S., Heidenreich, M. J., Mara, K. C., Peters, C. L., Clohisy, J. C., Trousdale, R. T., & Sierra, R. J. (2019). Natural History of the Dysplastic Hip Following Modern Periacetabular Osteotomy. *J Bone Joint Surg Am*, *101*(10), 932-938. https://doi.org/10.2106/JBJS.18.00983

Zhang, Z., Ren, N., Cheng, H., Luo, D., Li, Y., & Zhang, H. (2023). Periacetabular osteotomy for Tonnis grade 2 osteoarthritis secondary to hip dysplasia. *Int Orthop*, *47*(7), 1707-1714. https://doi.org/10.1007/s00264-023-05795-w

Zhu, J., Chen, X., Cui, Y., Shen, C., & Cai, G. (2013). Mid-term results of Bernese periacetabular osteotomy for developmental dysplasia of hip in middle aged patients. *International Orthopaedics*, *37*(4), 589-594. https://doi.org/10.1007/s00264-013-1790-z

Ziran, N., Varcadipane, J., Kadri, O., Ussef, N., Kanim, L., Foster, A., & Matta, J. (2018). Ten- and 20-year Survivorship of the Hip After Periacetabular Osteotomy for Acetabular Dysplasia. *J Am Acad Orthop Surg*. https://doi.org/10.5435/JAAOS-D-17-00810

Zurmühle, C. A., Anwander, H., Albers, C. E., Hanke, M. S., Steppacher, S. D., Siebenrock, K. A., & Tannast, M. (2017). Periacetabular Osteotomy Provides Higher Survivorship Than Rim Trimming for Acetabular Retroversion. *Clinical Orthopaedics and Related Research*, *475*(4), 1138-1150. https://doi.org/10.1007/s11999-016-5177-5