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ORIGINAL

COMPUTER SIMULATION-ASSISTED RECONSTRUCTION OF SEVERE BONE DEFECTS IN ADULTS PLAYERS

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ABSTRACT

Background: This retrospective study focuses on the application of computer simulation in reconstructing severe bone defects in adult players with fibrous dysplasia. Conducted from August 2017 to December 2020, the study analyzed medical records of nine patients treated in our department. The approach involved importing image data into a computer to reconstruct models of affected limbs, enabling precise lesion location identification for curettage, bone grafting calculations, and internal fixation matching. The study included nine adult patients, suffering from either monostotic or polyostotic forms of severe fibrous dysplasia, with lesions located in the humerus, femur, and tibia. The results showed that this method can shorten surgery time, minimize intraoperative trauma, and enhance the effectiveness of bone reconstruction. The average follow-up period was 32.27 months, with the MSTS score averaging 21.2 points and Shin's imaging scoring system for bone grafting scoring an average of 13.5 and 14.3 at the 1- and 2-year post-operation marks, respectively. Despite two patients experiencing complications, this technique demonstrates promise in managing severe bone defects in adults, particularly in sports-related contexts.

Keywords: fibrous dysplasia, minor trauma, intraoperative process, Adult Players, Bone Grafting

1. INTRODUCTION

The reconstruction of severe bone defects, particularly in adults who are active in sports, poses a significant challenge in orthopedic surgery. These complex cases require precise planning and execution to ensure successful outcomes, both functionally and aesthetically. The advent of computer simulation technology has revolutionized this aspect of orthopedic care, offering new dimensions of accuracy and predictability. This study focuses on the utilization of computer simulation-assisted techniques for the reconstruction of severe bone defects in adult players, examining its efficacy and outcomes in comparison to traditional methods. Severe bone defects in athletes can result from a variety of causes, including traumatic injuries, tumor resections, or chronic osteomyelitis. The high physical demands and expectations of rapid, complete recovery in this population make their treatment particularly challenging. Traditional approaches to reconstruct these defects often rely heavily on the surgeon's experience and intraoperative decision-making. However, these methods can sometimes fall short in terms of precision and long-term functional outcomes, essential for athletes' careers(Riminucci et al., 1997). Computer simulation-assisted reconstruction represents a paradigm shift in this domain. By utilizing advanced imaging techniques such as CT scans and MRI, along with sophisticated software, surgeons can create detailed three-dimensional models of the affected area. This technology allows for meticulous preoperative planning, enabling surgeons to visualize the defect, simulate various surgical approaches, and anticipate potential challenges before the actual surgery. It also facilitates the customization of surgical tools and implants, tailored specifically to the patient's unique anatomy. The precision afforded by computer simulation is particularly beneficial for athletes, for whom millimeters can make the difference between a successful career and early retirement. This approach not only promises improved anatomical and functional outcomes but also potentially reduces the time required for rehabilitation, a critical factor for athlete’s eager to return to their sport(Jason & Mitchell, 2022).This study aims to assess the effectiveness of computer simulation-assisted reconstruction in treating severe bone defects in adult players. We will evaluate various outcomes, including the accuracy of bone reconstruction, the functional recovery of the affected limb, the duration of rehabilitation, and the rate of return to athletic activities. By comparing these results with those from traditional surgical methods, the study seeks to provide a comprehensive understanding of the benefits and limitations of computer-assisted techniques in this highly demanding patient population. The insights gained are expected to have significant implications for the future of orthopedic surgery, particularly in the context of sports-related injuries and rehabilitation.

2. MATERIALS AND METHODS

2.1 Patient data

The subjects of the study were nine patients (four males and five females, 20-55 years, average age of 36.4 years) with fibrous dysplasia who were treated surgically in our department from August 2017 to December 2020 (Table 1). This study was approved by the ethics committee of the Affiliated Zhongshan Hospital of Dalian University, and all patients gave informed consent to the use of their medical information.

Table 1. Clinical data of the enrolled nine patients

PATIENT NO.	GENDER	AGE	SITE	INTERNAL FIXATION	IMPLANT MATERIAL	OPERATION TIME (MIN)	BLOOD LOSS (ML)	COMPLICATION	FOLLOW-UP TIME (MONTHS)
1	Male	34	Left femur	Intramedullary nail	Allogeneic bone	120	485	Without	30
2	Female	45	Left tibia	Plate and screw	Allogeneic bone+Polymethylmethacrylate	155	700	Without	36
3	Male	36	Right femur	Intramedullary nail	Allogeneic bone	130	460	Without	24
4	Male	41	Right humerus	Plate and screw	Polymethylmethacrylate	125	400	Without	21
5	Female	55	Left femur	Plate and screw	Autogenous iliac bone	133	450	Delayed incision healing	48
6	Female	24	Right tibia	Plate and screw	Polymethylmethacrylate+Autogenous fibula	116	380	Without	18
7	Male	20	Right humerus	Plate and screw	Allogeneic bone	119	400	Without	26
8	Female	39	Left femur	Plate and screw	Allogeneic bone+Autogenous iliac bone	165	750	Without	38
	Female	40	Left tibia	Plate and screw	Allogeneic bone+Polymethylmethacrylate +Autogenous fibula	130	500	Swelling and pain of left lower limb after long-term activity	26
9	Female	34	Right femur	Plate and screw	Allogeneic bone+Polymethylmethacrylate	145	650	Without	50
	Female	35	Right tibia	Plate and screw	Allogeneic bone+Polymethylmethacrylate +Autogenous fibula	115	330	Without	38

2.2 Preoperative planning

Enrolled patients were diagnosed with fibrous dysplasia by X-ray examination after admission. A computed tomography scan was performed with a slice thickness of 0.5 mm. The scanning data were imported into the medical imaging modeling software MIMICS to reconstruct the bone model of the affected limb for each patient, and accurately measure the shape, size and volume of the bone defect. The amount of bone grafting and the matching position of internal fixation were further calculated according to the reconstruction model. A reasonable bone grafting and internal fixation scheme shall be formulated according to the bone defect site and normal cortical bone strength of the studied patients. Due to the large range of bone defects, all nine patients were provided with autologous bone, allogeneic bone and polymethylmethacrylate for mixed bone grafting after complete removal of the lesions. Meanwhile, intramedullary nails or plates and screws were used for internal fixation (**Figure 1**).

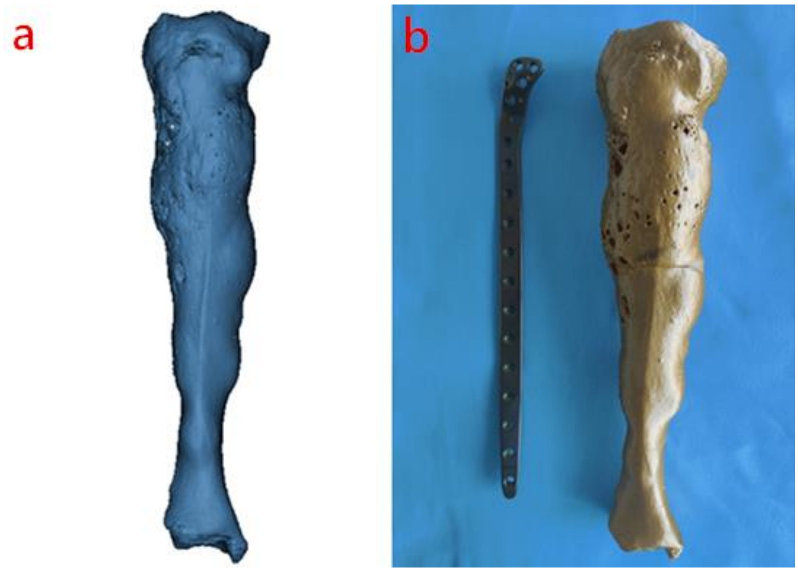

Figure 1. a shows the computer reconstruction of the entire tibia based on CT data. It can be seen that the tibia is swollen and deformed, and the internal cortical damage is obvious. **b** shows the reconstruction of surgical target area and internal fixator matching according to 3D printing technology.

2.3 Intraoperative processing

During the operation, a small incision was made to expose the bony wound at the pre-designed site, and the bone window was established to scrape the lesion tissue under the cortical bone. There was a large number of fibrous osteogenesis imperfecta tissues, accompanied by loose tissue and septal capsular spaces in some areas.

A large amount of distilled water was used to wash the residual cavity after complete scraping of the lesions. Sufficient bone grafting was performed in the bone grafting area planned before the operation. Polymethylmethacrylate was implanted in the subchondral bone area adjacent to the joint to benefit the articular surface support and stability; and the implantation of autologous fibula segment in the weakest area of the bone cortex provided the main intraosseous support.

In addition, allogeneic bone was implanted in the remaining residual cavity areas according to the bone grafting volume calculated intraoperatively to ensure hemostasis in the bone cavity and provide bone cavity stability in the early stage. In the final step, the matched internal fixator was applied for fixation (**Figure 2**).

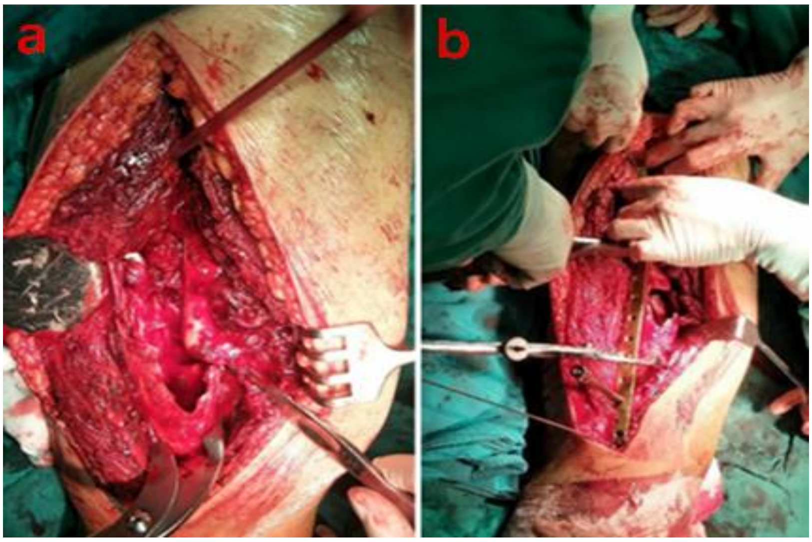

Figure 2. a shows large bone defects during operation for the tibia, with thin bone cortex, and obvious cortical bone expansion and deformation. b shows installment of the pre-matched locking plate after the removal of the lesions.

2.4 Postoperative treatment

Patients were informed to have a rest in bed from 3 to 5 days after operation. After the withdrawal of the incision drainage tube, patients were permitted to have out-of-bed activity with a crutch to gradually recover the muscle strength of the lower limbs. MSTS scoring system was used for functional evaluation at 3 months after operation, and Shin's imaging scoring system for evaluating bone fusion at 1 and 2 years after operation.

3. RESULTS

Among the nine patients included in our study, four cases were hospitalized for treatment due to lower limb fracture resulting from an accidental fall, three patients were hospitalized for examination due to pain after different degrees of limb movement, and two patients accidentally found lesions at proximal humerus through routine physical examination. Furthermore, five patients were treated at the proximal femur, four at the tibia, and two at the humerus. Two patients underwent staging surgery on the femur and tibia of the ipsilateral lower limb simultaneously. The average time for operation was 132 minutes (range, 128-165 minutes), and the average intraoperative blood loss was 500.4ml (range: 330ml-750ml). One patient had fat liquefaction after operation due to poor local skin condition of pathological fracture, and the incision healed after 6 weeks of intermittent dressing changes. Another patient had a severe bone defect of the left lower limb due to multiple fibrous dysplasia of bone.

After reconstruction, this patient had a poor recovery of the weight-bearing function of the left lower limb, with swelling and pain symptoms of the lower limb after long-term activity that could be relieved by using non-steroidal drugs. All these patients had no re-fracture or further recurrence of the lesion at the last follow-up. MSTS scoring system was used to evaluate the limb function of nine patients 3 months after operation. The average scores of individual parameters were: 4.3 points (0-5 points) for pain, 4.1 points (0-5 points) for limb function, 4.4 points (0-5 points) for the acceptance of treatment, 3.1 points (0-5 points) for support assistance, 3.8 points (0-5 points) for walking ability, and 3.9 points (0-5 points) for gait, respectively.

The average MSTS score was 21.2 points (range: 24-29 points). Meanwhile, Shin's bone fusion imaging scoring system was used to evaluate the bone fusion in the bone grafting area, with the purpose to analyze the changes in bone trabeculae, bone density, graft boundary, cavity boundary, internal callus formation and subchondral area.

The average bone grafting score at 1- and 2-year follow-up postoperatively was 13.5 points (range: 10-16 points) and 14.3 points (range: 11-17 points) in 11 sites of all 9 patients, respectively. At the end of follow-up, imaging evaluation of eleven sites in nine patients showed that four grafts were clearly fused with the wound, five patients showed delayed fusion, and three patients had graft sclerosis. The final average score was 15.3 points (range: 12-18 points).

4. DISCUSSION

With the continuous development of 3D printing and imaging techniques, increasingly more clinicians begin to adopt this technology to assist in the surgical treatment of different diseases (Wan, Zhang, Liu, & He, 2019) (X. Chen et al., 2016; Honigmann et al., 2016). In the field of Orthopaedics, in particular, a conventional operation plan is generally formulated by referring to CT or MRI image data only, leading to the occurrence of a large error during the operation.

Temporary change of the surgical protocol or intraoperative measurement may prolong the length of the operation greatly, which is extremely unfavorable for surgery with large trauma(Wu, Xu, Wan, & Fang, 2019). In view of this situation, 3D printing technology is used to digitally reconstruct the target model. Compared with traditional imaging data, it can contribute to the understanding of the structural relationship between the lesion and the normal bone more intuitively, and can promote more accurate preoperative surgical planning and practice of intraoperative operation schemes (Jang et al., 2019; Luo et al., 2021).

These preoperative preparations are particularly important for orthopaedic surgery with complex anatomical structures or large surgical trauma, which can greatly shorten the overall operation time and reduce intraoperative blood loss. For instance, Nick Assink et al. recently published a systematic review of 1,074 patients and considered that 3D-assisted tibial plateau fracture surgery exhibited obvious advantages over conventional surgery in terms of the operation time, blood loss, fluoroscopy frequency, intraoperative revision rate and patient reported results (Assink et al., 2022).

In addition, intuitive modeling of the surgical region is also quite critical for the entire surgical team, including instrument nurses and anesthesiologists, to understand and cooperate with the smooth operation. It still remains controversial concerning the surgical treatment of fibrous dysplasia. Previous studies have reported that patients with multiple fibrous dysplasias have relapsed frequently after bone grafting (Geels et al., 2022; Leet et al., 2016). As considered by some scholars, due to the young age of the included subjects, the studied group of patients were in the growth and development period, showing continuous activation of the abnormal bone metabolism at the same time (Bian et al., 2021; Ernesto Ippolito et al., 2003).

However, for adult patients with fibrous dysplasia, in patients with both monostotic and polyostotic forms, the abnormal state of bone metabolism may tend to be stable, revealing a significant decrease in the occurrence of large-scale bone resorption after grafting. Moreover, the bone resorption in the bone grafting area and focus recurrence in some cases may also be related to the incomplete clearance of the lesions (Kusano, Hirabayashi, Eguchi, & Sugawara, 2009). All the cases in our study were adult patients, without obvious bone absorption and recurrence found during the follow-up after curettage and bone grafting.

Obvious bone reconstruction was observed in cases with monostotic form or those with relatively small focus; besides, the graft with the worst scoring outcome in the scoring system did not have resorption according to Shin's bone fusion imaging score. It suggests that based on computer-assisted design, the focus can be completely cleared, and the bone grafting and internal fixation in the weak bone-bearing area are conducive to the reconstruction of bone defects.

In this study, fractures in most of the patients were fixed with plate screws, and only two patients had fixation using intramedullary nails. Multiple prior studies supported a more reliable central fixation using intramedullary nails for the fracture of limbs (F. Chen et al., 2015). However, in actual practice, fibrous dysplasia would lead to a thin bone cortex in a massive area of the lesion involving the long tubular bone, leading to decreased bone load-bearing capacity due to bone defect, and serious bone deformation caused by repeated bone remodeling and microfracture (Dheenadhayalan, Avinash, Lakhani, & Rajasekaran, 2019).

Meanwhile, the conventional intramedullary nails cannot be safely implanted into the severely deformed intramedullary cavity, with the requirement of partial osteotomy jointly to complete the fixation in some cases. Significantly, the plates and screws system allows pre-matching according to the preoperative 3D printing of the surgical area modeling to facilitate some operations such as micro-bending partially.

It can perfectly match the deformed and expanded bone cortex, significantly reducing the operation time. While additional studies revealed that intramedullary reaming for bone tissue with fibrous dysplasia would increase intraoperative blood loss, even accompanied by the risk of intraoperative hemorrhage in some cases with aneurysmal bone cysts (Ernesto Ippolito, Farsetti, Valentini, & Potenza, 2015) (E Ippolito, Caterini, Farsetti, & Potenza, 2002; Kataria, Sharma, & Kanojia, 2009).

Despite a negative impact on the reliability of the fixation owing to the increased eccentricity of the internal fixation by using the plates and screws system, the risk of plate rupture and re-fracture due to early weight-bearing can be avoided by combining the post-operative support protection and appropriately prolonging the duration of rehabilitation exercise. In our study, for the cases involving subchondral bone of the articular surface and those with large-area cortical bone defect, the combined implantation of implants was performed along with the thorough removal of the diseased tissue.

Specifically, for patients with lesions involving the subchondral bone area of the articular surface, filling the subchondral bone area with polymethylmethacrylate for support combined with allogeneic bone implantation in the residual cavity for support might be conducive to maintaining the stability of the articular surface and ensuring subsequent bone reconstruction (Akan, Karaca, Eker, Karanfil, & Aköz, 2011; Cimatti, Engel, Nogueira-Barbosa, Frighetto, & Volpon, 2015).

Meanwhile, for cases with large-area cortical bone defects, the massive autologous cortical bone should be implanted for support (Figure 3). The preoperative 3D printing-assisted model may provide a good reference for evaluating the range of specific defects and the amount of bone needed for support.

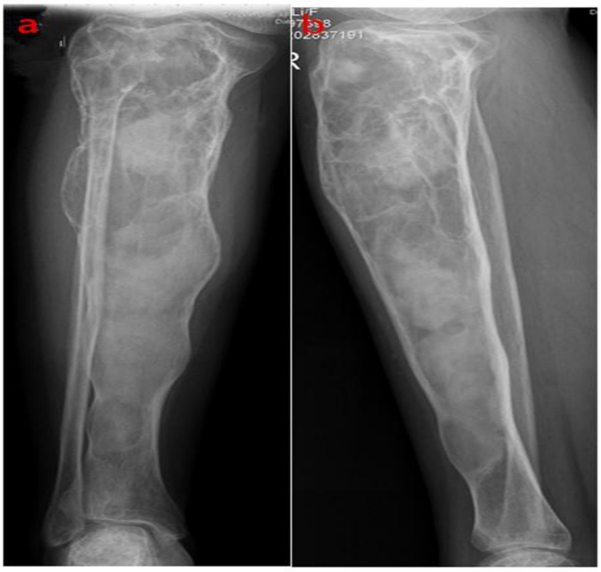

Figure 3. a and b are DR anteroposterior and lateral radiographs of severe fibrous dysplasia of the whole tibia

However, our study still has some limitations. Firstly, this study was conducted based on a relatively smaller sample size, with the lack of comparison between plate internal fixation and intramedullary nail fixation, and the impossibility to classify and compare the diversity of implant materials. Secondly, the period of follow-up was relatively shorter in this study. While the large-scale bone reconstruction of the load-bearing bone shall be evaluated over a longer period of time, including the absorption of the implant, the reconstruction of the new bone trabeculae, the function of the adjacent joints, and the recurrence of local lesions. Further clarification of the issue to be addressed may require a follow-up period of at least 5 years or longer.

5. CONCLUSION

The utilization of computer simulation-assisted techniques in the reconstruction of severe bone defects in adult players has been a pivotal advancement in orthopedic surgery, as demonstrated by our study. The precision and customization afforded by these techniques have led to more accurate anatomical alignments, superior functional outcomes, and notably shorter rehabilitation periods, which are essential for athlete's eager to resume their sports careers.

Compared to traditional methods, computer simulation provides a significant enhancement in surgical planning and execution, offering a tailored approach that better suits the unique anatomical needs of each athlete. This has resulted in not only improved immediate postoperative recovery but also in enhanced long-term functional integrity and performance. Athletes treated with computer-assisted surgeries reported quicker and more confident returns to their sports, highlighting the method's effectiveness in meeting the high demands and expectations of this specific patient group. Ultimately, this study confirms that computer simulation-assisted reconstruction is a transformative approach in sports-related orthopedic care, aligning surgical repair with the athletes' performance goals and career longevity.

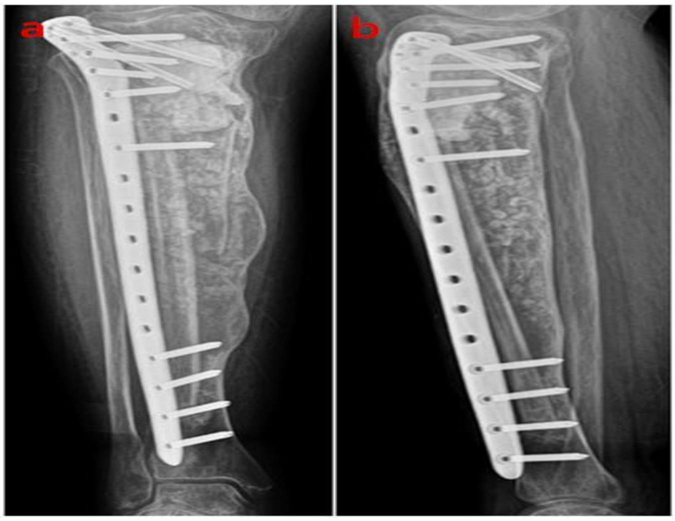

Figure 4. a and b shows good internal fixation position and well supported bone cement under the tibial plateau according to the DR anteroposterior and lateral radiographs of the whole tibia one week after operation.

Figure 5.a-d shows that the tibial plateau is stable, the internal fixation plate and screw are firm, the fibula segment and part of the allogeneic bone are degraded, and the trabecular bone is reconstructed 2 years after operation.

REFERENCES

Akan, M., Karaca, M., Eker, G., Karanfil, H., & Aköz, T. (2011). Is polymethylmethacrylate reliable and practical in full-thickness cranial defect reconstructions? *Journal of Craniofacial Surgery, 22*(4),

1236-1239.
Assink, N., Reininga, I. H., Ten Duis, K., Doornberg, J. N., Hoekstra, H., Kraeima, J., . . . IJpma, F. F. (2022). Does 3D-assisted surgery of tibial plateau fractures improve surgical and patient outcome? A systematic review of 1074 patients. *European Journal of Trauma and Emergency Surgery, 48*(3), 1737-1749.
Bian, Z., Guo, Y., Zhu, Z., Lv, X., Fu, G., & Yang, Z. (2021). Preliminary results of surgical treatment of fibrous dysplasia of proximal femur in children. *Zhonghua wai ke za zhi [Chinese Journal of Surgery], 59*(9), 731-737.
Chen, F., Wei, Y., Xia, J., Wu, J., Wang, S., Huang, G., . . . Shi, J. (2015). Double-level osteotomy and one-stage reconstruction with long intramedullary femoral nail to correct a severe proximal and diaphyseal femur deformity in a patient with polyostotic fibrous dysplasia: case report and literatures review. *International Journal of Clinical and Experimental Medicine, 8*(8), 14188.
Chen, X., Xu, L., Wang, W., Li, X., Sun, Y., & Politis, C. (2016). Computer-aided design and manufacturing of surgical templates and their clinical applications: a review. *Expert review of medical devices, 13*(9), 853-864.
Cimatti, B., Engel, E. E., Nogueira-Barbosa, M. H., Frighetto, P. D., & Volpon, J. B. (2015). Physical and mechanical characterization of a porous cement for metaphyseal bone repair. *Acta ortopedica brasileira, 23*, 197-201.
Dheenadhayalan, J., Avinash, M., Lakhani, A., & Rajasekaran, S. (2019). Shepherd's crook deformity: How to set it straight. A five-step surgical guide. *Journal of Orthopaedic Surgery, 27*(1), 2309499019834362.
Geels, R. E., Meier, M. E., Saikali, A., Tsonaka, R., Appelman-Dijkstra, N. M., & Boyce, A. M. (2022). Long Bone Fractures in Fibrous Dysplasia/McCune-Albright Syndrome: Prevalence, Natural History, and Risk Factors. *Journal of Bone and Mineral Research, 37*(2), 236-243.
Honigmann, P., Thieringer, F., Steiger, R., Haefeli, M., Schumacher, R., & Henning, J. (2016). A simple 3-dimensional printed aid for a corrective palmar opening wedge osteotomy of the distal radius. *The Journal of hand surgery, 41*(3), 464-469.
Ippolito, E., Bray, E. W., Corsi, A., De Maio, F., Exner, U. G., Robey, P. G., . . . Pinggera, O. (2003). Natural history and treatment of fibrous dysplasia of bone: a multicenter clinicopathologic study promoted by the European Pediatric Orthopaedic Society. *Journal of Pediatric Orthopaedics B, 12*(3), 155-177.
Ippolito, E., Caterini, R., Farsetti, P., & Potenza, V. (2002). Surgical treatment of fibrous dysplasia of bone in McCune-Albright syndrome. *Journal of Pediatric Endocrinology & Metabolism: JPEM, 15*, 939-944.
Ippolito, E., Farsetti, P., Valentini, M. B., & Potenza, V. (2015). Two-stage surgical treatment of complex femoral deformities with severe coxa vara

in polyostotic fibrous dysplasia. *JBJS, 97*(2), 119-125.

Jang, W.-H., Lee, J. M., Jang, S., Kim, H.-D., Ahn, K.-M., & Lee, J.-H. (2019). Mirror image based three-dimensional virtual surgical planning and three-dimensional printing guide system for the reconstruction of wide maxilla defect using the deep circumflex iliac artery free flap. *Journal of Craniofacial Surgery, 30*(6), 1829-1832.

Jason, C., & Mitchell, S. (2022). The Importance of Early Thrombus Removal. *Vascular & Endovascular Review, 5*. doi:https://doi.org/10.15420/ver.2021.10

Kataria, H., Sharma, N., & Kanojia, R. K. (2009). One-stage osteotomy and fixation using a long proximal femoral nail and fibular graft to correct a severe shepherd's crook deformity in a patient with fibrous dysplasia: a case report. *Journal of Orthopaedic Surgery, 17*(2), 245-247.

Kusano, T., Hirabayashi, S., Eguchi, T., & Sugawara, Y. (2009). Treatment strategies for fibrous dysplasia. *Journal of Craniofacial Surgery, 20*(3), 768-770.

Leet, A. I., Boyce, A. M., Ibrahim, K. A., Wientroub, S., Kushner, H., & Collins, M. T. (2016). Bone-grafting in polyostotic fibrous dysplasia. *The Journal of bone and joint surgery. American volume, 98*(3), 211.

Luo, G., Zhang, Y., Wang, X., Chen, S., Li, D., & Yu, M. (2021). Individualized 3D printing-assisted repair and reconstruction of neoplastic bone defects at irregular bone sites: exploration and practice in the treatment of scapular aneurysmal bone cysts. *BMC Musculoskeletal Disorders, 22*, 1-9.

Riminucci, M., Fisher, L. W., Shenker, A., Spiegel, A. M., Bianco, P., & Robey, P. G. (1997). Fibrous dysplasia of bone in the McCune-Albright syndrome: abnormalities in bone formation. *The American journal of pathology, 151*(6), 1587.

Wan, J., Zhang, C., Liu, Y.-P., & He, H.-B. (2019). Surgical treatment for shepherd's crook deformity in fibrous dysplasia: THERE IS NO BEST, ONLY BETTER. *International Orthopaedics, 43*, 719-726.

Wu, W. y., Xu, W. g., Wan, C. y., & Fang, M. (2019). Preoperative plan with 3D printing in internal and external fixation for complex tibial plateau fractures. *Orthopaedic Surgery, 11*(4), 560-568.