

DOUTORAMENTO
CIÊNCIAS MÉDICAS

Evaluation of the surgical treatment of proximal humerus fractures in a geriatric population

Rui Claro

D
2023



Evaluation of the surgical treatment of proximal humerus fractures in a geriatric population
Rui Miguel Teixeira Claro



RUI MIGUEL TEIXEIRA CLARO

EVALUATION OF THE SURGICAL TREATMENT OF PROXIMAL HUMERUS FRACTURES IN A GERIATRIC POPULATION

Application Thesis for Doctoral Degree in Medical Sciences

School of Medicine and Biomedical Sciences (ICBAS-UP)

University of Porto

SUPERVISOR

António Fonseca Oliveira, MD, PhD

Invited Full Professor

School of Medicine and Biomedical Sciences (ICBAS-UP)

Head of Orthopedic Department

Centro Hospitalar Universitário de Santo António (CHUdSA)

Portugal

DOUTORAMENTO
CIÊNCIAS MÉDICAS

EVALUATION OF THE SURGICAL TREATMENT OF PROXIMAL HUMERUS FRACTURES IN A GERIATRIC POPULATION

Rui Miguel Teixeira Claro

D

2023



“Nothing in life is to be feared, it is only to be understood.
Now is the time to understand more, so that we may fear less.”

Marie Curie

Para a Rita, para a Sara e para a Orquídea...

“Se il per sempre non esiste lo inventeremo noi.”
Nikki Erlick, *The Measure*

LIST OF PUBLICATIONS
ACKNOWLEDGEMENTS
CURRICULUM VITAE

LIST OF PUBLICATIONS

Claro R, Ribau A, Fonte H, Amorim-Barbosa T, Barros LH, Sevivas N. Improved outcomes of older patients with acute and displaced proximal humerus fractures treated with window bone ingrowth fracture-specific stem reverse shoulder arthroplasty. *BMC Geriatr*. 2023 Sep 12;23(1):553. doi:10.1186/s12877-023-04210-8. PMID: 37700237; PMCID: PMC10498537.

Claro R, Barros B, Ferreira C, Ribau A, Barros LH. Comparative Analysis of Proximal Humerus Fracture Management in Elderly Patients: Complications of Open Reduction and Internal Fixation by “shoulder surgeons” and “non-shoulder surgeons” - A Retrospective Study. *Clin Shoulder Elb*. 2023. (Accepted on September 24, 2023. Manuscript ID: CiSE-23-089).

Amorim-Barbosa T, Ribau A, Fonte H, Barros LH, **Claro R**. Comparative clinical and radiologic evaluation between patients undergoing standard reversed shoulder arthroplasty or bony increased offset. *Clin Shoulder Elb*. 2023 Mar;26(1):3-9. doi: 10.5397/cise.2022.01270. Epub 2023 Jan 17. PMID: 36919501; PMCID: PMC10030991.

Claro R, Ribau A, Fonte H, Diniz S, Barros L, Sousa R, Rodrigues-Pinto R. Surgical treatment for acute and displaced proximal humerus fractures in elderly patients: hemiarthroplasty vs. reverse shoulder arthroplasty, *Seminars in Arthroplasty: JSES*. 2022 Dec;32(4):728-735. doi: 10.1053/j.sart.2022.06.005.

Fonte H, Amorim-Barbosa T, Diniz S, Barros L, Ramos J, **Claro R**. Shoulder Arthroplasty Options for Glenohumeral Osteoarthritis in Young and Active Patients (<60 Years Old): A Systematic Review. *J Shoulder Elb Arthroplast*. 2022 Mar 23;6:24715492221087014. doi: 10.1177/24715492221087014. PMID: 35669623; PMCID: PMC9163728.

Nunes B, Linhares D, Costa F, Neves N, **Claro R**, Silva MR. Lateralized versus nonlateralized glenospheres in reverse shoulder arthroplasty: a systematic review with meta-analysis. *J Shoulder Elbow Surg*. 2021 Jul;30(7):1700-1713. doi: 10.1016/j.jse.2020.09.041. Epub 2020 Nov 4. PMID: 33160029.

Barros LH, Figueiredo S, Marques M, Rodrigues C, Ramos J, **Claro R**. Tuberosity Healing after Reverse Shoulder Arthroplasty for Proximal Humerus Fractures: Is there Clinical Improvement? *Rev Bras Ortop (Sao Paulo)*. 2020 Dec;55(6):748-754. doi: 10.1055/s-0039-3402459. Epub 2020 Feb 7. PMID: 33364654; PMCID: PMC7748945.

ACKNOWLEDGEMENTS

A doctoral thesis is never an individual work. Therefore, at the end of this stage, I would like to thank all those who in some way contributed to ensuring that all this work was carried out in the best way possible. All those who encouraged me and made me believe that all of this was possible.

I believe that doctors need to integrate clinical practice with dedicated research in their field to effectively aid and alleviate the suffering of patients. This dual commitment is essential for advancing our understanding of disease mechanisms and continually improving disease prevention and treatment methods.

The development of this work has been made possible through significant collaboration and contributions from various individuals and institutions. I wish to express my sincere gratitude to everyone who played a role in this effort in different ways.

I begin by acknowledging my supervisor, Prof. Doutor António Oliveira, without whom this thesis would not have been possible. I sincerely thank him for his invaluable guidance, support, and the opportunity to work in his Orthopedic Department at Centro Hospitalar Universitário de Santo António. I am truly grateful for his investment in me and committed to making him proud throughout my professional journey. Additionally, I appreciate the tools he provided to facilitate my work and his constant friendship, willingness to listen, advise, and engage in discussions. My heartfelt gratitude goes out to him for his unwavering support over the years.

Secondly, I'd like to express my gratitude and pay tribute to the memory of Prof. Doutor Joan Armengol Barallat, who co-supervised this thesis during its initial stages before his untimely passing. I appreciate him for serving as a role model as both a professor and a scientist, for our meaningful discussions, and for the valuable questions, comments, suggestions, and advice that contributed to my growth as a medical professional and a scientist.

I would like to extend my gratitude to my mentor, Dr. José Manuel Lourenço, for his invaluable friendship and for introducing me to the world of treating patients with shoulder pathology. I greatly value his honesty, curiosity, wisdom, and commitment to patient well-being. Our discussions, advice, and the memorable moments we've shared will always hold a special place in my memory.

Next, I want to highlight and commend the contributions of my friend, Dr. Ana Ribau. Her dedication to scientific rigor, constructive feedback, hard work, continuous assistance, and constant presence were indispensable in the completion of this thesis.

To all my teachers and professors, from primary school through university, and throughout my journey to becoming a doctor.

I want to convey my thanks to Dr. José Carlos Vilarinho, Dr. Pedro Varanda, and Prof. Dr. Paulo Amado for extending the opportunity to work alongside their teams. I am grateful for the support and resources they provided, which allowed me to conduct my clinical work in private settings at Hospital Privado de Alfena - Grupo TrofaSaude, Instituto Cuf Porto, and Hospital Lusíadas Porto.

To Dr. José Figueiredo, for his friendship, exemplary conduct, and valuable advice.

To Dra. Isabel Gonçalves for her friendship, invaluable advice, guidance, and the meaningful moments I encountered during my training in the Orthopedic Department.

To Dr. Ângelo Encarnação for his friendship and invaluable advice. His guidance and the experiences I had during my training in the Orthopedic Department were truly significant.

To Dr. Armando Campos for his friendship, technical proficiency, surgical expertise, and the invaluable experiences I acquired while collaborating in the emergency service and throughout my training in the Orthopedic Department. Additionally, I'm thankful for his presence during various moments, helping and support during challenging times.

To Dr. Paulo Costa for his friendship, his expertise in technical details and surgical skills, and for the valuable experiences I gained while working together in the emergency service and throughout my training journey in the Orthopedic Department.

To Dr. Paulo Pereira, in recognition of his unwavering friendship, exceptional expertise, surgical prowess, and the invaluable experiences I have acquired during our collaboration in the emergency service and throughout my career in the Orthopedic Department.

To all my colleagues at the Orthopedic Department of Centro Hospitalar Universitário de Santo António who, in various ways, contributed to this thesis, whether directly or indirectly.

I'd like to extend my gratitude to all the nurses, technicians, assistants, and all other hospital staff at Centro Hospitalar Universitário de Santo António who have worked with me, directly or indirectly. Together, we have fulfilled the noble commitment of providing the best possible care to our patients.

To Dr. Luis Henrique Barros, my dear friend and colleague in the "Shoulder Unit" at the Orthopedic Department of Centro Hospitalar Universitário de Santo António. Our extensive conversations, friendship, and collaborative teamwork have been invaluable to me.

To Dr. Eurico Silva, a fellow colleague in the "Shoulder Unit" at the Orthopedic Department of Centro Hospitalar Universitário de Santo António. I appreciate his friendship, our collaborative teamwork, and the invaluable advice he has provided.

To Dra. Carolina Afonso, a cherished friend, and esteemed colleague, for the enriching dialogues, our close companionship, and our synergistic collaboration, all of which have held immeasurable significance in my life.

To Dr. Hélder Fonte, my dear friend and colleague, for our extensive conversations, friendship, and collaborative teamwork, which have been truly invaluable to me.

To Prof. Dr. Ricardo Sousa and Prof. Dr. Ricardo Rodrigues-Pinto for their friendship and for the numerous scientific discussions we have engaged in together.

To my close friends, Dr. Luis Dias da Costa, and Dr. Pedro Neves, for their companionship, extensive conversations, moments of camaraderie, and the collaborative projects we embarked on together.

To my dear friend and colleague, Dr. João Amaro, I extend my heartfelt gratitude for our extensive conversations, unwavering friendship, collaborative teamwork, and the countless invaluable multidisciplinary dialogues bridging the realms of orthopedics and physical medicine and rehabilitation.

To my dear friends, Dr. Ricardo Moreira and Dr. Luis Osório, for their exemplary qualities in humanism, academics, and science. The cherished moments of laughter we have shared, and our enduring friendship will stay with me throughout my life. You serve as continuous sources of inspiration for me as role models.

To all my friends who have crossed paths with me at some point.

To my beloved in-laws and brothers-in-law, I want to express my profound gratitude for the unwavering support you have consistently offered and the enduring presence you bring into my life.

Finally, I extend my heartfelt thanks to my parents for their unwavering encouragement, support, and boundless love, which were indispensable for the completion of this thesis. They have always been there for me, providing not only their support but also setting a proud example for me to follow.

To my beloved siblings, Pedro, and Cristina, I hold immense affection for your unwavering support and constant presence in my life. Your dependable presence and support mean the world to me, and I am eternally grateful.

I want to express my deepest gratitude to my wife, Orquídea, who has been my rock, the friendly shoulder, the right advice at the right time, for being the silence, for being the discussion, for being the passion... throughout our journey together. You are my everything.

To my cherished daughters, Rita, and Sara, you represent the new day, the exploration of the unknown, the soaring flight of freedom, and above all, you embody love.

I owe everything I am to my family – my parents, sister, brother, wife, and daughters. They are my foundation and my greatest source of strength and inspiration.

CURRICULUM VITAE

RUI MIGUEL TEIXEIRA CLARO

DATE OF BIRTH 22/01/1977 | NATIONALITY Portuguese

SPECIALTY

Orthopedics

DIFFERENTIATION AREA

Shoulder and Elbow

ACADEMIC EDUCATION

Since 2017: PhD Student in Medical Sciences at School of Medicine and Biomedical Sciences - University of Porto (ICBAS-UP)

1995 - 2001: Degree in Medicine – Faculty of Medicine of the University of Porto.

1983-1995: Primary, Basic, and Secondary education in Vila Nova de Gaia.

PEDAGOGICAL AND RESEARCH ACTIVITIES

2012 - 2019: Monitor of Orthopedics discipline of the Medicine Course at ICBAS-UP

Research in medical, basic, experimental, and clinical sciences, in various topics: orthopedics and traumatology in general; degenerative and traumatic pathology of the shoulder and elbow; musculoskeletal tumors of the shoulder and elbow; osteoarticular infection; shoulder and elbow arthroplasties.

ACADEMIC ORIENTATION (DOCTORATE AND MASTER)

Supervisor of 3 Final Dissertations on the Integrated Master's Degree in Medicine – ICBAS-UP

MEMBER OF AN ACADEMIC JURY

Jury Member in 10 Dissertation Exams for the Integrated Master's Degree in Medicine – ICBAS-UP

CLINICAL ACTIVITY

Since 2020: Consultant Orthopedic Surgeon

Since 2023: Member of the Shoulder Unit at Santa Maria do Porto Hospital

2022 - 2023: Member of the Shoulder Unit at Hospital Lusíadas Porto

2018-2020: Member of the Shoulder Unit at Hospital São Francisco do Porto

Since 2016: Member of the Multidisciplinary Joint Hypermobility Group at CHUdSA

2012 - 2021: Member of the Medical Department of Atlético Voleibol Clube (female volleyball club)

2012 - 2022: Member of the Shoulder Unit at Instituto CUF Porto

2012-2018: Member of the Shoulder Unit at Hospital Privado de Alfena (Grupo Trofa Saúde)

2011-2012: Member of the Shoulder Unit at PLANICARE – work accident consultation
Since 2011: Head of the Shoulder Unit, Orthopedic Department, Centro Hospitalar Universitário de Santo António (CHUdSA)
Since 2010: Orthopedic Specialist, Orthopedic Department, CHUdSA
2009: EFORT Spring Traveling Fellowship – Norway. Elected representative of the Portuguese Society of Orthopedics and Traumatology (SPOT)
2009: Fellowship at Dr. Javier Mir - Vall d'Hebron Hospital, Barcelona, Spain
2008: Fellowship at Dr. Gilles Walch - Centre Orthopédique Santy, Lyon, France
2006: Fellowship at Prof. Dr. Romain Seil - Centre Hospitalier de Luxembourg, Luxembourg
2004 - 2010: Orthopedic Internship, Orthopedic Department, CHUdSA – HSA
2002 - 2004: General Internship, Centro Hospitalar de Vila Nova de Gaia

SCIENTIFIC SOCIETIES

2022: Portuguese National Delegate of European Society for Surgery of the Shoulder and the Elbow (SECEC-ESSSE)
Since 2020: Member of the “Registry Committee” of SECEC-ESSSE
2020 - 2022: President of Portuguese Society of Shoulder and Elbow Surgery (SPOC)
2018 - 2020: President of the organizing committee of the Portuguese Society of Shoulder and Elbow
2017-2018: Coordinator of Shoulder and Elbow Section of the Portuguese Society of Orthopedics and Traumatology
Since 2004: Member of Portuguese Society of Orthopedics and Traumatology (SPOT)
Since 2008: Member of SECEC-ESSSE
Since 2023: Corresponding Member of the American Shoulder and Elbow Surgeons (ASES)
Since 2020: Member of SPOC
Since 2001: Member of Portuguese Medical Society

SCIENTIFIC ACTIVITY

2023: Chairman of the International Advanced Shoulder Surgery Course “4th Oporto Shoulder Course”
2022: Chairman of the course “3rd Oporto Shoulder Course”
2019: Chairman of the course “2nd Oporto Shoulder Course”
2018: Chairman of the course “Oporto Shoulder Course”
2011: Chairman of the meeting “Shoulder Pathology” at CHUdSA
Participation in multiple communications / round tables / lectures at national and international scientific meetings
Participation in national and international Research Projects
Reviewer of Scientific Journal "Journal of Shoulder and Elbow Surgery"
Reviewer of Scientific Journal "Shoulder & Elbow"
Reviewer of Scientific Journal "BMJ Case Reports"

ARTICLES IN INTERNATIONAL JOURNALS

1. **Claro R**, Barros B, Ferreira C, Ribau A, Barros LH. Comparative Analysis of Proximal Humerus Fracture Management in Elderly Patients: Complications of Open Reduction and Internal Fixation by “shoulder surgeons” and “non-shoulder surgeons” - A Retrospective Study. *Clin Shoulder Elb*. 2023. (Accepted on September 24, 2023. Manuscript ID: CiSE-23-089).
2. **Claro R**, Ribau A, Fonte H, Amorim-Barbosa T, Barros LH, Sevivas N. Improved outcomes of older patients with acute and displaced proximal humerus fractures treated with window bone ingrowth fracture-specific stem reverse shoulder arthroplasty. *BMC Geriatr*. 2023. 23, 553. doi: 10.1186/s12877-023-04210-8.
3. **Claro R**, Fonte H. Superior capsular reconstruction: current evidence and limits. *EFORT Open Rev*. 2023 May 9;8(5):340-350. doi: 10.1530/EOR-23-0027. PMID: 37158430; PMCID: PMC10233801.
4. Diogo Rocha Carvalho, **Rui Claro**. Isolated fracture of the coracoid's process base 9-years after a Latarjet procedure: A novel case report. *Int J Case Rep Orthop* 2023;5(1):01-06. DOI: 10.22271/27078345.2023.v5.i1a.134
5. Amorim-Barbosa T, Ribau A, Fonte H, Barros LH, **Claro R**. Comparative clinical and radiologic evaluation between patients undergoing standard reversed shoulder arthroplasty or bony increased offset. *Clin Shoulder Elb*. 2023 Mar;26(1):3-9. doi: 10.5397/cise.2022.01270. Epub 2023 Jan 17. PMID: 36919501; PMCID: PMC10030991.
6. **Claro R**, Ribau A, Fonte H, Diniz S, Barros L, Sousa R, Rodrigues-Pinto R. Surgical treatment for acute and displaced proximal humerus fractures in elderly patients: hemiarthroplasty vs. reverse shoulder arthroplasty, *Seminars in Arthroplasty: JSES*. 2022 Dec;32(4):728-735. doi: 10.1053/j.sart.2022.06.005.
7. Diniz SE, Vale J, Fonte H, Xará-Leite F, Barros LH, **Claro R**. Asymmetric Bilateral Chronic Shoulder Dislocation in a Young Patient - A Rare Case Report. *J Orthop Case Rep*. 2022 Oct;12(10):91-96. doi: 10.13107/jocr.2022.v12.i10.3382. PMID: 36874885; PMCID: PMC9983375.
8. Fonte H, Amorim-Barbosa T, Diniz S, Barros L, Ramos J, **Claro R**. Shoulder Arthroplasty Options for Glenohumeral Osteoarthritis in Young and Active Patients (<60 Years Old): A Systematic Review. *J Shoulder Elb Arthroplast*. 2022 Mar 23; 6:24715492221087014. doi: 10.1177/24715492221087014. PMID: 35669623; PMCID: PMC9163728.
9. Campos-Pereira E, Henrique-Barros L, **Claro R**. Pyrocarbon Humeral Head in a Shoulder Hemiarthroplasty: Preliminary Results at 3 Years Follow-Up and Review of the Current Literature. *Case Rep Orthop*. 2021 Apr 14; 2021:6633690. doi: 10.1155/2021/6633690. PMID: 33954000; PMCID: PMC8060089.
10. Rodrigues C, **Claro R**. Unusual Stress Fracture in a CrossFit Athlete: A Case Report. *JBJS Case Connect*. 2021 Jan 14;11(1): e20.00135. doi: 10.2106/JBJS.CC.20.00135. PMID: 33502133.
11. Nunes B, Linhares D, Costa F, Neves N, **Claro R**, Silva MR. Lateralized versus nonlateralized glenospheres in reverse shoulder arthroplasty: a systematic review with meta-analysis. *J Shoulder Elbow Surg*. 2021 Jul;30(7):1700-1713. doi: 10.1016/j.jse.2020.09.041. Epub 2020 Nov 4. PMID: 33160029.
12. Barros LH, Figueiredo S, Marques M, Rodrigues C, Ramos J, **Claro R**. Tuberosity Healing after Reverse Shoulder Arthroplasty for Proximal Humerus Fractures: Is there Clinical Improvement? *Rev Bras Ortop (Sao Paulo)*. 2020 Dec;55(6):748-754. doi: 10.1055/s-0039-3402459. Epub 2020 Feb 7. PMID: 33364654; PMCID: PMC7748945.
13. Xará-Leite F, Barros LH, **Claro R**. Arthroscopic Superior Capsular Reconstruction with Achilles Tendon Allograft: A Good Option for Irreparable Supraspinatus Tendon Tears. *Techniques in Orthopaedics* 36(4): p 455-459, December 2021. | DOI: 10.1097/BTO.0000000000000499.

14. Garrigues GE, Zmistowski B, Cooper AM, Green A; **ICM Shoulder Group**. Proceedings from the 2018 International Consensus Meeting on Orthopedic Infections: management of periprosthetic shoulder infection. *J Shoulder Elbow Surg*. 2019 Jun;28(6S): S67-S99. doi: 10.1016/j.jse.2019.04.015. PMID: 31196516.
15. Barros L H, Rodrigues C, **Claro R**. Suprascapular neuropathy in a young male handball player: case report. *Acta of Shoulder and Elbow Surgery*. Jan – June 2019;3(1):16-18.
16. Santos C, Pereira MA, Silva LF, **Claro R**, Trigueiros MN, da Silva JC. Surgical treatment of rhizarthrosis: trapeziectomy with or without ligamentoplasty versus total prosthesis. *Rev Bras Ortop*. 2015 Nov 16;46(1):83-6. doi: 10.1016/S2255-4971(15)30181-6. PMID: 27026991; PMCID: PMC4799204.
17. Sousa JM, Oliveira F, **Claro R**, Cardoso P, Trigueiros M, Silva C. Mão Reumatóide: revisão de 124 Próteses Mcf de Silicone. *Revista Iberoamericana de Cirugía de la Mano* 2010; 38(01): 047-052. DOI: 10.1055/s-0037-1606767.
18. Silva C, Trigueiros M, Lemos R, **Claro R**, Santos C, Castro H. Artroplastia total do punho na artrite reumatóide. Resultados dos primeiros 11 doentes operados. *Revista Iberoamericana de Cirugía de la Mano* 2010; 38(01): 040-046. DOI: 10.1055/s-0037-1606766.
19. Sousa R, **Claro R**, Trigueiros M, Lourenco J, Silva C. Prótese total do cotovelo: análise retrospectiva a médio prazo dos 10 primeiros casos. *Revista Iberoamericana de Cirugía de la Mano* 2009; 37(02): 098-103. DOI: 10.1055/s-0037-1606753.
20. **Claro R**, Sousa R, Massada M, Ramos J, M Lourenço J. Bilateral posterior fracture-dislocation of the shoulder: Report of two cases. *Int J Shoulder Surg*. 2009 Apr;3(2):41-5. doi: 10.4103/0973-6042.57935. PMID: 20661400; PMCID: PMC2904541.
21. **Claro R**, Vilaca A, Negrao P, Trigueiros M, Silva C. Artroplastia total trapézio-metacarpiana. Resultado a curto prazo de 2 implantes diferentes. *Revista Iberoamericana de Cirugía de la Mano* 2008; 36(01): 014-019. DOI: 10.1055/s-0037-1606722
22. Azevedo LF, Salgueiro LF, **Claro R**, Teixeira-Pinto A, Costa-Pereira A. Diet and gastric cancer in Portugal — a multivariate model. *European Journal of Cancer Prevention* 8(1): p 41-48, February 1999.

ARTICLES IN NATIONAL JOURNALS

1. Sousa R, **Claro R**, Massada M, Pereira A, Campos A. Rotura espontânea simultânea do tendão quadrícipital e rotuliano contralateral tratada com âncoras de sutura. *Revista Portuguesa de Ortopedia e Traumatologia* 2009; R 17: 38-44.
2. **Claro R**, Lourenco J. Reparação da coifa dos rotadores com ou sem acromioplastia? - revisão da literatura. *Revista Portuguesa de Ortopedia e Traumatologia* 2009; 17 I: 29-37.
3. Sousa J, **Claro R**, Gomes A, Muras J, Cardoso P, Serra L. Tratamento cirúrgico da síndrome do túnel tarsico: revisão de 16 casos. *Revista Portuguesa de Ortopedia e Traumatologia* 2009; 17 I: 9-14.
4. Sousa R, **Claro R**, Massada M, Pereira A, Sousa J, Costa P. Fractura-avulsão da tuberosidade do calcâneo: caso clínico e revisão da literatura. *Revista Portuguesa de Ortopedia e Traumatologia* 2008; R 11: 25-28.
5. **Claro R**, Vilaça A, Sousa J, Trigueiros T, Silva C. Neuropatia do cubital associada a ressalto da porção medial do tricipite. *Revista Portuguesa de Ortopedia e Traumatologia* 2007; 15 III: 37-41. **Best Clinical Note / Review Article Award from the Portuguese Journal of Orthopedics and Traumatology 2008.**
6. **Claro R**, Lourenco J. Patologia da articulação esterno-clavicular – artigo de revisão. *Revista Portuguesa de Ortopedia e Traumatologia* 2007; 15 III: 11-19
7. **Claro R**, Vilaca A, Pereira H, Sousa J, Goncalves I. Pseudoainhum associado a Psoríase e Vitiligo – Caso Clínico. *Revista Portuguesa de Ortopedia e Traumatologia* 2007; 15 II: 93-98
8. **Claro R**, Pereira H, Vilaca A, Pires J, Goncalves I. Neuropatia do nervo mediano por luxação oculta do semilunar - caso clínico. *Revista Portuguesa de Ortopedia e Traumatologia* 2006; 14 III: 55-59.
9. **Claro R**, Vilaca A, Encarnacao A, Cardoso P. Hiperparatiroidismo Críptico. *Revista Portuguesa de Ortopedia e Traumatologia* 2005; III 13: 27-31.

BOOK CHAPTERS

1. **Claro R**, Barros L, Gomes NS, Sousa R. Workup and Management of Infection in Shoulder Arthroplasty. Massive and Irreparable Rotator Cuff Tears: From Basic Science to Advanced Treatments. Springer, April 2020: 329-338.
2. **Claro R**, Aido R, Lourenco JM. Instabilidade Gleno-umeral. Traumatologia Desportiva. Pedro Pessoa and Henry Jones. Lidel, July 2014: 88-90.
3. Pereira H, **Claro R**. Traumatismo dos membros e extremidades. Curso de Evidência na Emergência: Manual de Procedimentos. António H. Carneiro, Elisabete Neutel. Edição do REANIMA 2009, Porto: 315-324.
4. **Claro R**, Lourenco JM. Patologia da articulação esterno-clavicular. O Ombro. António Cartucho, João Espregueira-Mendes. Lidel, Outubro 2009: 139-146.
5. Lourenco JM, Ramos J, **Claro R**. Artrose do Ombro: Omartrose Centrada. O Ombro. António Cartucho, João Espregueira-Mendes. Lidel, Outubro 2009: 271-280.
6. Seil R, **Claro R**. UKA Revision – Literature and results. 12èmes Journées Lyonnaises de Chirurgie du Genou 2006; 327-331.

INDEX

LIST OF PUBLICATIONS	XI
ACKNOWLEDGMENTS	XIII
CURRICULUM VITAE	XVII
ABSTRACT	XXV
RESUMO	XXIX
I. OVERALL INTRODUCTION	1
1.1. Introduction	3
1.2. Clinical and Radiographic Assessment	4
1.3. Classification	5
1.4. Treatment Overview	6
1.5. Nonoperative treatment	7
1.6. Surgical Treatment	8
1.6.1. Open Reduction and Internal Fixation	8
1.6.2. Hemiarthroplasty	10
1.6.3. Reverse Shoulder Arthroplasty	11
1.6.3.1. Reverse Shoulder Arthroplasty Versus Open Reduction and Internal Fixation	13
1.6.3.2. Reverse Shoulder Arthroplasty Versus Hemiarthroplasty	14
1.6.4. Complications	15
References	16
II. OBJECTIVES	25
1. Objectives	27
References	30
III. COMPLICATIONS OF OPEN REDUCTION AND INTERNAL FIXATION	31
1. Introduction	33
2. Methods	34
3. Results	35
4. Discussion	40
5. Conclusions	42
References	44
IV. HEMIARTHROPLASTY VERSUS REVERSE SHOULDER ARTHROPLASTY	47
1. Introduction	49
2. Methods	50

3. Results	52
4. Discussion	56
5. Conclusions	58
References	59

V. TUBEROSITY HEALING AND FUNCTIONAL RESULTS

1. Introduction	65
2. Material and Methods	66
3. Results	68
4. Discussion	74
References	76

VI. PROSPECTIVE STUDY

1. Introduction	81
2. Materials and Methods	82
3. Results	87
4. Discussion	91
5. Conclusions	94
References	95

VII. OVERALL DISCUSSION, FUTURE PERSPECTIVES AND CONCLUSIONS

1. Overall discussion, future perspectives, and conclusions	101
2. Open Reduction and Internal Fixation analysis	102
3. Hemiarthroplasty versus Reverse Shoulder Arthroplasty analysis	103
4. Reverse Shoulder Arthroplasty analysis	104
5. Future Perspectives and Conclusions	106
References	108

ABSTRACT

EVALUATION OF THE SURGICAL TREATMENT OF PROXIMAL HUMERUS FRACTURES IN A GERIATRIC POPULATION

Proximal humeral fractures (PHF) are common fragility fractures in older patients that occur with low-energy trauma mechanisms and are sentinel markers of both poor bone and general health. At 1 year after a PHF, the mortality rate is 10% regardless of treatment.

The successful restoration of shoulder function is challenged by various factors, including patient anatomy, fracture pattern, pre-injury functional state, medical comorbidities, and the skill level of the surgeon.

Currently, 67% to 85% of PHF are treated non-operatively, and the best treatment for older patients remains controversial. Conservative management with short-term immobilization may be suitable for stable, minimally displaced, and displaced fractures, and may yield satisfactory functional outcomes. Conservative treatment may also be appropriate for complex fractures in elderly or cognitively impaired patients, individuals with nonfunctional limbs, or those with significant medical comorbidities.

Complex fractures, including Neer's three- or four-part fractures, head-splitting, pathological, and open fractures, typically necessitate surgical management, such as Open Reduction and Internal Fixation (ORIF) with a locking plate, anterograde intramedullary nailing, or even an arthroplasty.

ORIF is associated with complications, including nonunion, implant failure/migration, osteonecrosis, infection, posttraumatic osteoarthritis, and postoperative shoulder stiffness. Reoperation may be required for implant removal due to implant failure, avascular necrosis, impingement/stiffness, pain, discomfort, or infection. Complication rates ranging from 38% to 44% have been reported in elderly patients, with reoperation rates ranging from 11% to 12%. Most complications occur within the initial three weeks after surgery, coinciding with the start of physical rehabilitation.

Reverse Shoulder Arthroplasty (RSA) has become the preferred prosthetic treatment option for complex PHF in older patients requiring surgical treatment because it is less dependent on tuberosity healing for the maintenance of function and stability. Multiple studies have demonstrated improved functional outcomes in patients who underwent RSA compared to those who underwent Hemiarthroplasty (HA). Tuberosity healing after RSA for fractures

depends on several factors, including the repair technique, prosthesis design, patient comorbidities, and postoperative rehabilitation. Implant variables such as an inlay versus an onlay humeral implant, glenosphere offset, humeral component neck–shaft angle, and the use of a humeral implant with a “window” for autologous bone graft change the postoperative position of the tuberosities and consequent tension and healing of the tuberosity repair. However, few studies have compared the effects of changing these factors.

In the elderly population, the evaluation of complications and outcomes related to the various surgical treatments is of utmost importance in refining/guiding the decision-making process for treating PHF. Therefore, this study aimed to evaluate the occurrence of complications, including the need for revision surgery, in elderly patients with PHF who underwent operative treatment with ORIF, HA, and RSA. And identify possible surgical options that improve functional results.

We evaluated patients aged 70 or older with an acute and displaced PHF treated primarily with a surgical procedure and identified implant survival rate, mortality, morbidity, complications, reoperations, and functional and radiological outcomes. We also conducted an evaluation of the impact of a fracture-specific RSA design compared to a standard RSA stem, considering various tuberosity fixation methods, on implant survival rates, functional improvements, and procedure safety.

We hypothesized that RSA with a fracture-specific design using a “window” stem and with a strong tuberosity fixation would improve anatomical tuberosity repair and consolidation, thereby providing better functional results.

After analyzing the data obtained during the investigation, to promote optimal anatomical consolidation of the tuberosities and improve functional recovery of the affected upper limb, it is advisable to prioritize the use of a fracture-specific stem with a window for bone ingrowth. Additionally, when feasible during the surgical procedure, the implementation of a robust fixation technique, should be considered. This combined approach offers the potential to mitigate the risk of tuberosity mal-union or non-union, which holds particular significance in the context of this age group.

RSA as the primary treatment of displaced PHF in a geriatric population allowed the return to activities of daily living for 73.2% of patients and functional mobility of the shoulder for almost half of the patients studied (45.5%); however, dementia was negatively correlated with the ability to return to activities of daily living. These factors, particularly for the older population, which often lives alone and needs to recover quickly, suggest that RSA should

be the preferred surgical option because of its good results when dealing with displaced PHF. Nonetheless, older people should always undergo rigorous preoperative assessments. Their treatment should be optimised according to the surgical risk profile before surgery, and the option for surgical treatment should always be evaluated on a case-by-case basis.

RESUMO

AVALIAÇÃO DO TRATAMENTO CIRÚRGICO DAS FRATURAS PROXIMAIS DO ÚMERO NUMA POPULAÇÃO GERIÁTRICA

As fraturas proximais do úmero (FPU) são fraturas de fragilidade, comuns em doentes idosos, que ocorrem por mecanismos de trauma de baixa energia e são marcadores sentinela de má qualidade óssea e declínio geral da saúde. Um ano após uma FPU, a taxa de mortalidade é de 10%, independentemente do tratamento.

A recuperação bem-sucedida da função do ombro é influenciada por vários fatores, incluindo a anatomia do doente, o padrão de fratura, o estado funcional pré-lesão, comorbidades médicas e a experiência do cirurgião.

Atualmente, 67% a 85% das FPU são tratadas de forma não cirúrgica, e o melhor tratamento para doentes idosos permanece controverso. O tratamento conservador, com imobilização por um curto período, pode ser adequado para fraturas estáveis, minimamente desviadas ou mesmo com desvio, e pode produzir resultados funcionais satisfatórios. O tratamento conservador também pode ser apropriado para fraturas complexas em doentes idosos ou com deficiência cognitiva, indivíduos com membros não funcionais ou aqueles com comorbidades médicas significativas.

Fraturas complexas, incluindo fraturas de três ou quatro partes de Neer, fraturas “head-split”, patológicas e fraturas expostas, normalmente necessitam de tratamento cirúrgico: redução aberta e fixação interna (RAFI), haste intramedular anterógrada ou até mesmo uma artroplastia.

A opção por RAFI está associada a complicações, incluindo a pseudartrose, falência/migração do implante, osteonecrose, infecção, artrose pós-traumática e rigidez pós-operatória do ombro. A reoperação pode ser necessária para a remoção do implante devido a falência deste, à presença de necrose avascular, rigidez, dor, desconforto ou infecção. Taxas de complicações entre 38% a 44% foram reportadas em doentes idosos, com taxas de reoperação entre 11% a 12%. A maioria das complicações ocorre nas primeiras três semanas após a cirurgia, coincidindo com o início da reabilitação física.

A Artroplastia Total Invertida do Ombro (ATIO) tornou-se a opção de tratamento protésico preferida para uma FPU complexa em doentes idosos, que necessitam de tratamento

cirúrgico, porque é menos dependente da consolidação das tuberosidades umerais para a manutenção da função e estabilidade articulares. Vários estudos demonstraram melhores resultados funcionais em doentes submetidos a uma ATIO em comparação com aqueles submetidos a uma Hemiartroplastia (HA). A consolidação das tuberosidades após ATIO depende de vários fatores, incluindo a técnica de fixação, desenho da prótese, comorbidades do doente e reabilitação pós-operatória. Variáveis relacionados com o implante, como implante umeral “inlay” versus “onlay”, “offset” da glenosfera, ângulo cervico-diafisário do componente umeral e uso de implante umeral com “janela” para enxerto ósseo autólogo, podem alterar a posição pós-operatória das tuberosidades e por consequência criar tensão e alterações na consolidação/reparação das tuberosidades. No entanto, poucos estudos compararam os efeitos da mudança destes fatores.

Investigar as complicações e resultados associados a diferentes tratamentos cirúrgicos numa população geriátrica, desempenha um papel crítico na orientação das decisões de tratamento, perante uma FPU. Este estudo tem como objetivo avaliar a ocorrência de complicações, incluindo a necessidade de cirurgia de revisão, em doentes idosos com FPU submetidos a tratamento cirúrgico com RAFI, HA e ATIO. E identificar possíveis opções cirúrgicas que possam melhorar o resultado funcional destes doentes.

Avaliamos doentes com 70 ou mais anos de idade, com FPU aguda e com desvio, tratados cirurgicamente, e identificamos a taxa de sobrevida do implante, a mortalidade, a morbilidade, as complicações associadas, as taxas de revisão, e os resultados funcionais e radiológicos. Também avaliamos o impacto de um desenho específico de ATIO para fraturas em comparação com uma haste umeral de ATIO padrão, considerando diferentes métodos de fixação das tuberosidades, na melhoria da função e na segurança do procedimento.

Hipotetizamos que a ATIO com um desenho específico para fraturas, usando haste com “janela” para colocação de enxerto autólogo e utilizando uma firme fixação das tuberosidades, melhorará a fixação das tuberosidades umerais, promovendo uma consolidação anatómica destas e proporcionando assim melhores resultados funcionais.

Após a análise dos dados obtidos durante a investigação, tendo como objetivo uma consolidação anatómica das tuberosidades e melhorar a recuperação funcional do membro superior afetado, é aconselhável priorizar o uso de uma ATIO com haste umeral específica para fraturas, com “janela” para integração óssea. Para além do exposto, quando viável durante o procedimento cirúrgico, deve ser considerada a implementação de uma técnica de fixação robusta das tuberosidades. Esta abordagem combinada, parece oferecer a

melhor opção para mitigar o risco de não-consolidação, migração ou mesmo pseudartrose das tuberosidades, o que tem particular importância no contexto desta faixa etária.

A utilização de uma ATIO como tratamento primário de FPU com desvio em população geriátrica, permitiu o retorno às atividades de vida diária em 73,2% dos doentes e uma mobilidade funcional do ombro em quase metade dos doentes estudados (45,5%); no entanto, a demência foi negativamente correlacionada com a capacidade de regressar às atividades de vida diária.

Esses fatores, principalmente para a população idosa que muitas vezes mora sozinha e precisa de uma célere recuperação, sugerem que a ATIO poderá ser a opção cirúrgica a utilizar no tratamento de FPU agudas e desviadas. No entanto, estes doentes idosos devem ser sempre submetidos a avaliações pré-operatórias rigorosas e o tratamento deve ser otimizado de acordo com o perfil de risco cirúrgico antes da cirurgia. A opção pelo tratamento cirúrgico deve ser sempre avaliada caso a caso.

I. OVERALL INTRODUCTION

1. INTRODUCTION

Proximal humerus fractures (PHF), constituting approximately 5% of all fractures, represent a significant orthopedic concern, particularly within the context of the aging population [1]. Among fractures occurring in individuals aged 65 and older, they stand as the third most prevalent type [1-4]. Notably, these fractures exhibit a distinct gender and age predisposition, with a marked prevalence among women, accounting for around 70% of cases, and a peak incidence observed between the ages of 80 and 84 years [4-10].

Initial projections painted a concerning trajectory, envisioning a potential tripling in PHF rates by the year 2030 [9]. However, more recent data have depicted a different narrative, revealing a plateau in incidence from 2006 to 2012 and subsequently moderating these projections [11].

In a recent retrospective study conducted in Portugal [12] spanning from 2000 to 2015, a thorough analysis was performed on a substantial cohort of 19,290 patients. Over this investigated period, there was a noticeable increase in both the absolute number and the incidence of PHF. The demographic landscape revealed an average age at diagnosis of 62.6 ± 21.0 years, with a significant representation of elderly individuals, constituting 57% of the studied population, of whom 63.5% were female. The multifaceted clinical course of these patients provided further insights, with an average hospitalization duration of 10.0 ± 14.1 days. Interestingly, this study showed an upward trend among patients undergoing arthroplasty procedures ($P < .001$) and those with concurrent fractures (25%, $P < .001$). Among the various management strategies, surgical intervention was predominant, involving 14,482 patients. Of these, Open Reduction and Internal Fixation (ORIF) was the most common approach, accounting for 28% of surgical cases. The study's examination of mortality patterns offered insights into the clinical significance of PHF, with an inpatient mortality rate of 3.2%. Notably, this rate exhibited a statistically significant increase among patients with associated fractures, indicating a 2.77-fold higher risk of lower limb fractures compared to upper limb fractures. The shifting landscape of PHF management revealed interesting trends, marked by a noticeable increase in surgical treatment. Importantly, the distribution of specific surgical techniques displayed distinctive dynamics, with a significant rise in open reduction and internal fixation, as well as increased use of arthroplasty procedures, especially Reverse Shoulder Arthroplasty (RSA). This evolving landscape is likely influenced by a combination of factors, including advancements in biomechanical implant properties, the nuanced interplay of fracture patterns, and a growing emphasis on achieving improved functionality and quality of life outcomes.

While high-energy trauma often affects younger patients, the overarching mechanism responsible for these fractures is predominantly falls from a standing height [13, 14]. These low-energy fragility fractures serve as critical indicators of compromised bone health and a broader decline in overall well-being. Highlighting their clinical significance, PHF are accompanied by a notable 10% mortality rate within the first-year post-injury, irrespective of treatment approach [15].

1.2. Clinical and Radiographic Assessment

Evaluating patients with PHF is a critical task for surgeons, requiring a comprehensive understanding of various clinical aspects. The following discussion outlines key elements in the assessment of PHF, including historical, physical, and radiographic features, as well as the integration of neurovascular and bone health perspectives.

The initial evaluation involves a thorough review of the patient's medical history and a detailed physical examination. This assessment requires a keen focus on the patient's overall functional status, considering factors such as activity level, dominant hand, and living arrangements. Additionally, any prior shoulder injuries or underlying rotator cuff issues should be explored, as they can influence treatment decisions. The presence of associated injuries, particularly head trauma or concurrent fractures in other extremities, is particularly relevant, especially in elderly or medically complex patients.

Recognizing potential neurovascular implications is crucial in the clinical evaluation of PHF. Attention to possible brachial plexus or axillary nerve injuries is essential, with a special emphasis on assessing deltoid function [16-18]. Neurological integrity plays a pivotal role in the assessment, as studies have highlighted the prevalence of associated neurologic injuries, including injuries to the axillary, suprascapular, and radial nerves [19]. Checking distal pulses in every case is essential, and Doppler ultrasound can be a valuable tool when clinical suspicion warrants vascular assessment [19].

Radiographic imaging is an invaluable resource for gaining insights into the complex nature of PHF. Various views, such as anteroposterior, true anteroposterior, scapular Y, and axillary views, provide critical information about the typical displacement patterns seen in PHF. In cases where conventional axillary radiographs pose challenges due to patient intolerance, alternative approaches like "trauma axillary" or Velpeau views can be considered.

The role of Computed Tomography (CT) imaging becomes prominent when complex fracture patterns are not clearly defined. In such situations, CT imaging becomes a valuable tool for expediting pre-operative planning [17, 18]. On the other hand, Magnetic Resonance Imaging (MRI) has a more limited role in acute PHF cases, primarily used to detect rotator cuff injuries or diagnose non-displaced greater tuberosity fractures [16, 20].

1.3. Classification

The history of PHF classification systems has seen continuous refinement and evolution, reflecting the dynamic nature of orthopedic knowledge. In 1934, Ernest Codman introduced an early classification system for PHF, marking the beginning of orthopedic taxonomy development [21]. Codman's system identified four anatomical components: the articular surface, humeral shaft, lesser tuberosity, and greater tuberosity. However, this initial framework did not consider fracture displacement and failed to categorize surgical and anatomic neck fractures [22].

A significant milestone in PHF classification came with the Neer classification system, which has become a cornerstone in orthopedics [23]. Neer expanded on Codman's foundational components by quantifying and qualifying fracture displacement. He introduced a quantitative measure, defining fragments as distinct entities when displacement exceeded 1 cm or angulation surpassed 45 degrees. This formed the basis for categorizing fractures into one-part through four-part fractures. Neer further classified displaced fractures into six subgroups, covering a range of displacement scenarios, including minimal displacement, displaced surgical neck fractures, displaced anatomic neck fractures, displaced lesser tuberosity fractures, displaced greater tuberosity fractures, and fracture-dislocations. Despite its widespread use, the Neer classification's reliability among observers varies from fair to moderate [24].

Alternative classification paradigms have added diversity to the taxonomy of PHF. The AO Foundation/Orthopedic Trauma Association (AO/OTA) classification, developed in the 1980s, categorizes fractures based on dislocation, anatomic location, and articular surface involvement [25]. This classification divides PHF into three primary fracture types: unifocal extra-articular, bifocal extra-articular, and articular. It further breaks down fractures into 27 subgroups, considering parameters like impaction, displacement extent, and fragment dislocation. One notable feature of the AO/OTA system is its inclusion of valgus impacted PHF, which previous classification systems did not cover.

The Codman-Hertel classification system, introduced in 2004, focuses on predictors of humeral head avascular necrosis caused by fractures [26]. This system associates fracture morphology with the risk of humeral head ischemia, identifying fractures involving the medial calcar (<8mm), rupture of the medial hinge, head splitting fractures, and fracture dislocations as significant factors [26]. In parallel, the Resch classification also introduces a nuanced approach, considering varus and valgus impacted fractures [27, 28].

It's essential to highlight the pioneering work of Majed et al., who conducted a crucial study on the inter-rater reliability of various PHF classification systems [29]. Importantly, the Codman-Hertel classification demonstrated the highest inter-rater reliability, surpassing the AO/OTA classification, which showed the lowest reliability in this evaluation.

1.4. Treatment Overview

Interestingly, patient-specific factors like living arrangements, participation in recreational activities, and independence in daily tasks play a significant role in determining outcomes. Patients lacking social support or functional autonomy are more vulnerable to adverse results [6]. Managing these fractures is a complex task due to the interplay of medical complexities, functional aspects, and fracture-specific characteristics. Currently, treatment options range from nonoperative methods, used in 67–85% of cases, to various surgical interventions [1, 7, 30].

Surgical interventions are becoming more prevalent in this evolving landscape, driven by technological advancements, and changing patient preferences [1, 5, 14]. Open Reduction Internal Fixation (ORIF) remains a consistent choice, while the use of Hemiarthroplasty (HA) has decreased, and RSA has gained popularity [1, 7, 8, 10, 11, 30, 31]. The utilization of RSA for PHF varies across reports but shows a consistent upward trend over the past decade, ranging from 26% in 2011 to 67.4% in 2015 [1, 7, 10, 11, 30, 31].

The selection of a surgical approach for PHF depends on various individual factors, including anatomy, fracture classification, pre-existing functional abilities, concurrent medical conditions, and the surgeon's skill and preferences. This complex array of variables emphasizes the importance of a comprehensive understanding of PHF and its multifaceted management.

1.5. Nonoperative Treatment

In the field of PHF management, there is a significant interest in finding effective approaches. Current evidence highlights the limitations of nonoperative methods when dealing with displaced 3- and 4-part fractures. These approaches consistently lead to reduced functional scores and limited range of motion, especially in individuals who are actively engaged in independent lifestyles [32, 33]. Moreover, as fracture patterns become more complex and displacement increases, nonoperative treatments tend to result in unfavorable outcomes, affecting both functional measures and range of motion [34].

However, within this context, there is an opportunity to selectively use nonoperative treatments, especially for cases with simpler fracture patterns, minimal displacement, or patients with lower functional requirements. Evidence supporting this idea comes from observations of satisfactory functional outcomes in patients with specific types of fractures. These include translated 2-part PHF [14], valgus impacted 1- and 2-part fractures [35, 36], and fractures with less than 5 mm displacement of the greater tuberosity [37]. In these situations, a careful approach involving close observation over a 3- to 4-week period, followed by the gradual inclusion of passive range of motion exercises during the fracture healing phase, can significantly restore functional capacity.

Recent findings from the PROFHER Trial [38], a rigorous multicenter randomized clinical trial, shed light on the intricate relationship between surgical and nonsurgical approaches for PHF. Interestingly, the trial's 5-year follow-up study [39] highlighted the absence of significant differences between the surgical and nonsurgical groups at both the 2-year [38] and 5-year intervals [39]. However, it is important to interpret these results cautiously because a substantial portion of the studied fractures did not align with the typical displaced 3- and 4-part fractures that are often candidates for surgical intervention. Furthermore, the diversity of surgical techniques used, including ORIF, intramedullary nails, HA, and a heterogeneous category of "other" procedures, adds complexity to result interpretation. Notably, around 80% of the excluded patients from the final analysis, totaling 1000 individuals out of 1250, could have been eligible for surgery, raising concerns about potential selection bias.

Considering this, achieving the best possible functional recovery for active patients dealing with highly displaced fractures is a top priority for both patients and the surgical community. Beyond the usual use of slings for immobilization, there is a collective effort to explore new approaches that help individuals regain their peak functional abilities.

1.6. Surgical Treatment

For many decades, dealing with PHF has posed a persistent challenge for clinicians and researchers [40]. The historical progression of treatment approaches tells an intriguing story, unveiling a series of evolving insights.

In medical history, the 19th century introduced the Hippocratic method, involving careful reduction maneuvers followed by bandaging and delayed splinting. With the 20th century came surgical and anesthetic advancements, which drove the exploration of ORIF techniques [41]. The concept of shoulder arthroplasty had its roots in the late 1800s when Jules Emile Pean pioneered it in 1893 to address tuberculosis-related issues [42].

However, it was Dr. Charles Neer II who played a pivotal role in advancing shoulder arthroplasty in 1955. His groundbreaking work focused on humeral head replacement as a strategic solution to avoid avascular necrosis and the complexities of a flail shoulder that often resulted from open reduction and excision in PHF cases [43]. Dr. Neer's visionary contributions extended beyond the operating room as he introduced a classification system for PHF in 1970 along with criteria to evaluate treatment outcomes [22]. In a subsequent report, he elaborated on the nuances of treating 3- and 4-part PHF, showing the limitations of closed treatment for active patients, the effectiveness of ORIF for 3-part fractures, and the superiority of HA for the 4-part group [44]. However, even as he made these advances, Dr. Neer acknowledged the inherent imperfections of these strategies and expressed "limited expectations" for achieving optimal limb function [44].

After these important contributions, the following years saw a surge in scientific inquiry and innovation. Dr. Neer's fundamental concepts provided the groundwork for numerous research efforts, all with the goal of untangling the intricacies of PHF and enhancing treatment methods to benefit patients.

1.6.1. Open Reduction and Internal Fixation

The treatment landscape for 3- and 4-part PHF saw extensive exploration during the 1980s and 1990s. This period witnessed the use of ORIF techniques with various constructs, such as non-locking plates, wires, and pins. However, the outcomes varied considerably across these approaches [45-48], resulting in complication rates and success levels that were generally marginally acceptable.

Percutaneous pinning proved effective for young patients with simple fractures and strong bone quality but was insufficient for addressing fractures in osteoporotic bone. The introduction of pre-contoured locking plates, notably the proximal humerus internal locking system (PHILOS® plate - Depuy Synthes, Oberdorf, Switzerland), showed promising biomechanical potential and initially produced favorable functional outcomes when compared with other surgical procedures. However, long-term follow-up revealed a pattern of frequent complications, including high rates of screw perforation into the glenohumeral joint and screw cut-outs [49-57]. A comprehensive prospective multicenter study in 2009 by Brunner et al. highlighted a significant 9% implant-related complication rate and an overall complication rate of 35% at the 1-year mark using the PHILOS system. Primary screw perforations (14%) and secondary screw perforations (8%) were the most common implant-related complications [49]. Owsley and Gorczyca also reported a 36% radiographic complication rate, which included 23% intra-articular screw displacement and 25% varus displacement exceeding 10°. Notably, patients over the age of 60 were significantly more at risk for these complications (57% versus (vs.) 22%, $p = 0.0015$) [55].

In addition to technological advancements, progress has been made in understanding the optimal strategies for performing ORIF. Key success factors have been identified, such as restoring or preserving the medial calcar [58], avoiding varus alignment [59], and adopting less aggressive proximal screw fixation [60]. While not universally validated from a biomechanical perspective, rotator cuff sutures have become standard among fracture surgeons for fragment mobilization, provisional reduction, and final construct integration [61]. Recent assessments of PHF managed with newer locking plates have shown a reduction in complications and improved outcomes. In the most recent three-year period analyzed (2011–2013), failures due to loss of fixation significantly decreased (5.7% vs. 12.8%, $p = 0.006$), as did the overall revision rate (3.2% vs. 15.3%, $p = 0.00004$) compared to the initial three-year interval of the study (2002–2004) [62]. These improvements in ORIF outcomes in recent years can be attributed to several factors, including an improved understanding of patient prognostic indicators, refined surgical techniques, and the accumulated experience of surgeons. While advancements in locking technology have been limited since the introduction of the PHILOS® plate, the optimization of its implementation has been instrumental. Additionally, the evolution of arthroplasty technology has provided surgeons with alternative approaches to managing fractures that, in earlier decades, would have leaned toward the use of locking plate technology.

1.6.2. Hemiarthroplasty

Dr. Neer played a pivotal role in establishing humeral head replacement as a strategic option for managing complex PHF, offering an alternative to acute humeral head excision and glenohumeral arthrodesis while preventing or addressing osteonecrosis [43]. A significant aspect of Dr. Neer's work focused on classifying the risk of osteonecrosis, which he reported to be as high as 75% in 4-part fractures treated with ORIF [22]. Building on these insights, Hertel et al. conducted an important study to identify factors contributing to osteonecrosis, highlighting (1) insufficient medial calcar extension (< 8 mm), (2) disrupted periosteal hinge, and (3) anatomical neck fracture as key factors [26]. Further analysis revealed that the presence of all three risk factors, along with suboptimal reduction, correlated with an increased risk of osteonecrosis, although this affected only 3.7% of patients [63].

Despite the potential for osteonecrosis following PHF, contemporary research has shown significantly lower rates with nonoperative treatments, at 2% overall [36], and only 7.9% for operatively managed 3- and 4-part fractures [57]. The incidence of symptomatic osteonecrosis in nonoperatively treated 3- and 4-part fractures is a mere 1.6% [64]. In the current surgical landscape, which offers various effective options, the choice of surgical approach for complex PHF should be based on the surgeon's ability to achieve anatomically accurate reconstruction and maintain reduction rather than the likelihood of head viability.

However, the use of HA is limited and typically reserved for exceptional cases involving unreconstructible fractures in active young adult patients. Experienced shoulder surgeons generally advise restraint in adopting HA for fractures, with no more than one such case annually, even for “busy” surgeons. While initial pain relief often occurs in HA studies, functional outcomes and range of motion results vary considerably and can be unsatisfactory in many cases [65, 66]. A randomized controlled trial by Boons et al. in 2012 found no significant differences in older individuals treated nonoperatively compared to those undergoing HA for 4-part fractures [67]. Recovery and functional capacity after HA are notably compromised in older patients (>55 years old) [68, 69].

HA strategies also have their challenges, with failure and unfavorable outcomes linked to factors such as prosthesis height overstuffing or excessive humeral length augmentation (>10 mm), humeral head retroversion exceeding 40° , inferior placement of the greater tuberosity (10 mm below the head's tangent line), and superior placement of the greater tuberosity (5 mm above the head's tangent line) [70]. Successful outcomes depend on careful attention to anatomic tuberosity healing, appropriate head size and height,

prevention of tuberosity resorption, and the preservation of rotator cuff integrity [71]. Indications for HA are limited, and the procedure requires a high level of technical skill and relies on the unpredictable process of tuberosity healing. Therefore, HA is best suited for younger patients facing unreconstructible PHF.

1.6.3. Reverse Shoulder Arthroplasty

The introduction of RSA marked a significant milestone. It was initially designed to address rotator cuff arthropathy. However, early challenges led to a transformative advancement championed by Dr. Grammont in 1985. Dr. Grammont introduced four fundamental principles for RSA design: (1) prosthesis stability, (2) a weight-bearing convex component with a concave support counterpart, (3) centralization of the sphere around the glenoid neck, and (4) a medially and inferiorly positioned center of rotation. These principles, coined by Dr. Grammont, still guide RSA implant designs and surgical techniques today [42].

The United States Food and Drug Administration (FDA) endorsed RSA in November 2003, leading to a substantial increase in its utilization in shoulder arthroplasty since 2003 [72]. This rise in RSA use corresponded with an increase in literature and empirical evidence supporting its effectiveness in treating PHF [73-80]. Challenges and variable outcomes associated with nonoperative measures, ORIF, and HA, especially in older populations, drove the adoption of RSA. A key advantage of RSA was its independence from rotator cuff (tuberosity) healing.

One important subgroup extensively studied in the context of RSA includes older adults (age ≥ 65) dealing with 3-part, 4-part, or head-splitting proximal humerus fractures. Initial assessments of RSA for acute PHF showed promising results, including improved mobility, functional outcomes, and the potential for increased range of motion, although often accompanied by the movement of tuberosities seen on radiographs [78]. These initial investigations highlighted pain relief, positive functional outcome scores, and a significant improvement in range of motion [78-80].

Over time, RSA has undergone continuous refinement, with advancements in surgical techniques, implant technology, and more precise patient selection processes. A retrospective review in 2016, involving 52 patients aged 59 to 89 years, with an average follow-up of 35 months, reported a mean postoperative Constant score of 62 (range 16–69) for RSA treatment of 3- and 4-part PHF [74]. In another prospective case series led by Wright et al., including 30 patients aged over 59 years with a 2.5-year follow-up, RSA led to

a mean active forward elevation of 130° postoperatively, with a remarkable 97% radiographic stability rate [75]. A quality-of-life analysis conducted by Wolfensperger et al. showed that 84% of 33 highly independent patients had regained their previous level of independence within 6 months after surgery, increasing to 91% at the 1-year postoperative mark [77].

Despite the consistent and reliable outcomes of RSA, it is important to acknowledge that these results do not fully restore normal shoulder function. Therefore, nonoperative management should still be considered a viable option, especially for individuals with low functional demands, compromised medical conditions, or a strong aversion to surgery. A retrospective comparative study by Roberson et al. in 2017, while having certain selection biases, found minimal functional, range of motion, or other clinical differences between RSA and nonoperative management at the 1-year follow-up for 3- and 4-part PHF [81]. Before surgery, patients should be informed that the goal is to achieve around 80% of "normal" shoulder function, emphasizing pain-free mobility and self-care. It is worth noting that while forward elevation can be more predictably improved, outcomes regarding rotation tend to be less certain. While many patients can successfully reach the back of their head and perineum, tasks like unfastening a bra may remain challenging.

Moreover, RSA is also employed as a salvage procedure when conventional treatments as conservative, ORIF, or HA have not effectively managed PHF. In comparison to primary RSA cases, using RSA as a salvage option is associated with higher complication rates, more frequent revisions, and slightly reduced functional outcomes. Comparative analyses indicate that acute RSA outperforms RSA used for cases of malunion, nonunion, or conversion from previous ORIF or HA procedures. Additionally, RSA for malunion or nonunion scenarios tends to yield better results than revisions following HA procedures [73]. A case-control study by Sebastia-Forcada et al. in 2017 emphasized the superior functional outcomes in the primary RSA group compared to the secondary RSA group, which followed failed ORIF attempts [82]. A similar retrospective review by Shannon et al. in 2016 revealed that while functional outcomes were largely comparable, the delayed RSA group had a higher complication rate [76]. A comprehensive systematic review and meta-analysis by Torchia et al. in 2019, comparing acute and delayed RSA for PHF, supported the lack of differences in clinical outcome scores, forward flexion, or the all-cause reoperation rate between primary and secondary RSA cases [83]. It's worth noting that while RSA offers favorable salvage outcomes, primary cases often result in superior functional outcomes and fewer complications.

In summary, RSA, introduced as an innovative intervention, has evolved significantly. Guided by design principles and empirical evidence, it has become a transformative solution for patients dealing with PHF complexities. Although outcomes vary somewhat, RSA's consistent progress continues to offer improved function, pain relief, and an enhanced quality of life for patients facing the challenges of PHF.

1.6.3.1. Reverse Shoulder Arthroplasty Versus Open Reduction and Internal Fixation

Patients who undergo ORIF tend to experience fewer short-term complications compared to those who choose RSA or HA [84]. Additionally, it is worth noting that individuals receiving RSA have a higher 90-day readmission rate compared to those opting for ORIF [85]. This discrepancy arises from variations in patient medical profiles and fracture complexities, which naturally differ between these treatment groups. However, a limitation of large database studies like these is their inability to stratify outcomes based on patient-specific comorbidities, fracture patterns, and classifications.

In 2014, Chalmers and colleagues conducted a retrospective comparative analysis comparing ORIF to RSA for PHF. While the study did not reveal significant differences in functional outcomes, it did show that a significant proportion of RSA patients achieved forward flexion beyond 90° compared to their ORIF counterparts [86]. Further insights can be drawn from a 2015 systematic review led by Gupta and colleagues, which included a comprehensive analysis of 92 studies involving over 45,000 patients. This review delved into the surgical management landscape for complex PHF and found a complication rate of 15% for ORIF, along with a reoperation rate of 12.7%. In comparison, RSA had an 18.9% complication rate, coupled with a reoperation rate of 5.0% [87]. The differences revealed in these comparative analyses emphasize the need for a holistic understanding of patient selection criteria, age demographics, and the influence of medical comorbidities that impact treatment decisions.

When examining the variations in readmission rates and short-term complication profiles between RSA and ORIF, it becomes clear that these differences may be linked to selection biases, changes in patient age, and the effect of medical comorbidities that affect treatment choices. However, amid these considerations, the resilience of RSA as a treatment option starts to emerge. Its durability, along with its relatively lower revision rates, reinforces its role as a robust approach for managing PHF. This characteristic not only

contributes to the evolving landscape of treatment options but also underscores the importance of long-term functional outcomes when weighing the pros and cons of different surgical interventions.

1.6.3.2. Reverse Shoulder Arthroplasty Versus Hemiarthroplasty

In the field of PHF management, the significant rise in RSA adoption and a corresponding decrease in HA usage have led to ongoing research and comparative investigations [1, 30]. A comprehensive systematic review and meta-analysis conducted by Austin and colleagues in 2019 analyzed 421 RSA cases and 492 HA cases. The results showed that RSA outperformed HA in several key aspects, including postoperative pain scores, functional outcomes, and forward flexion. In contrast, HA had a higher risk of reoperation, highlighting the clinical effectiveness of RSA [88]. Shukla et al., in their 2016 meta-analysis, also found numerous benefits associated with RSA, such as improved forward flexion, abduction, tuberosity healing, and functional scores, while HA had an advantage in external rotation [89].

Similarly, Ferrel and colleagues' 2014 systematic review explored the nuanced differences between these two surgical interventions. RSA excelled in forward flexion, while HA showed superiority in external rotation. Complication rates differed significantly, with RSA at 9.6% and HA at 4.1%. Remarkably, the reoperation rate for RSA remained low at 1%, while HA had a slightly higher rate at 4% [90]. A comprehensive systematic review and meta-analysis by Gallinet et al. in 2018 echoed these findings, emphasizing RSA's better clinical outcome scores and forward flexion, while attributing improved internal and external rotation capabilities to HA recipients. The analysis also highlighted a higher incidence of complications and reoperations in RSA patients compared to elevated revision rates within the HA group [91]. A systematic review by Namdari et al. in 2013 revealed that RSA had 4.0 times greater odds of postoperative complications but stressed that many of these complications had minimal clinical impact [92].

Further delving into the comparison between the RSA and HA, particularly in older adults dealing with 3-part, 4-part, and head-splitting PHF, reveals crucial insights. First and foremost, RSA consistently delivers more favorable and reliable functional outcomes. While complication rates may vary, RSA demonstrates a clear advantage in terms of lower revision rates. A noteworthy aspect is the consideration of purely radiographic complications, which remain less explored in terms of clinical implications [92]. Unlike the complex dependencies seen in HA, RSA outcomes are not solely reliant on tuberosity

healing and rotator cuff integrity [71]. Nevertheless, the importance of both anatomic tuberosity healing and tuberosity healing should not be underestimated, potentially enhancing constraint, and improving shoulder range of motion in RSA patients [93-96].

1.6.4. Complications

In a retrospective review conducted in 2019 across multiple centers, 898 patients who underwent RSA for PHF revealed diverse outcomes. The study identified a composite complication rate of 12.5%, including a subsequent 5% revision rate and a 6% mortality rate within the first year postoperatively. Reasons for revision included instability (2.5%), aseptic loosening of the humeral component (1.5%), peripheral nerve injury (1.3%), infection (1.3%), aseptic loosening of the glenoid component (1.2%), periprosthetic fracture (0.9%), complex regional pain syndrome (0.7%), and various medical complications (3.1%) [97]. Similarly, another retrospective review in the same year focusing on RSA's role in PHF reported a 22% complication rate and a corresponding 5.1% revision rate. Instability was the predominant complication at 33%, followed by scapular notching at 11.9% [98]. Despite variations in reporting complication rates due to classification systems and reporting protocols, there is a consistent revision rate of approximately 5% for RSA across studies [87, 97, 98].

Recently, Bacle et al. published a significant study, providing insights into RSA's long-term implant survival. While their study covered various clinical indications, it showcased an implant survival rate of 93% over a decade [99]. This finding holds particular significance when considering fractures, especially in the context of elderly patients dealing with severe fractures. It highlights RSA's potential as a reliable intervention that could significantly impact this patient group, potentially leading to improved outcomes.

References

1. Hasty, E.K., et al., *Trends in Surgical Management and Costs for Operative Treatment of Proximal Humerus Fractures in the Elderly*. Orthopedics, 2017. **40**(4): p. e641-e647.
2. Lauritzen, J.B., et al., *Changing incidence and residual lifetime risk of common osteoporosis-related fractures*. Osteoporos Int, 1993. **3**(3): p. 127-32.
3. Seeley, D.G., et al., *Which fractures are associated with low appendicular bone mass in elderly women? The Study of Osteoporotic Fractures Research Group*. Ann Intern Med, 1991. **115**(11): p. 837-42.
4. Court-Brown, C.M. and B. Caesar, *Epidemiology of adult fractures: A review*. Injury, 2006. **37**(8): p. 691-7.
5. Bell, J.E., et al., *Trends and variation in incidence, surgical treatment, and repeat surgery of proximal humeral fractures in the elderly*. J Bone Joint Surg Am, 2011. **93**(2): p. 121-31.
6. Clement, N.D., et al., *The outcome of proximal humeral fractures in the elderly: predictors of mortality and function*. Bone Joint J, 2014. **96-B**(7): p. 970-7.
7. Han, R.J., et al., *Proximal humerus fragility fractures: recent trends in nonoperative and operative treatment in the Medicare population*. J Shoulder Elbow Surg, 2016. **25**(2): p. 256-61.
8. Kim, S.H., R.M. Szabo, and R.A. Marder, *Epidemiology of humerus fractures in the United States: nationwide emergency department sample, 2008*. Arthritis Care Res (Hoboken), 2012. **64**(3): p. 407-14.
9. Palvanen, M., et al., *Update in the epidemiology of proximal humeral fractures*. Clin Orthop Relat Res, 2006. **442**: p. 87-92.
10. Rajaei, S.S., et al., *Increasing Use of Reverse Total Shoulder Arthroplasty for Proximal Humerus Fractures in Elderly Patients*. Orthopedics, 2017. **40**(6): p. e982-e989.
11. Schairer, W.W., et al., *Arthroplasty treatment of proximal humerus fractures: 14-year trends in the United States*. Phys Sportsmed, 2017. **45**(2): p. 92-96.
12. Relvas Silva, M., et al., *Proximal humerus fractures: epidemiology and trends in surgical management of hospital-admitted patients in Portugal*. JSES Int, 2022. **6**(3): p. 380-384.
13. Court-Brown, C.M., et al., *Fractures in older adults. A view of the future?* Injury, 2018. **49**(12): p. 2161-2166.
14. Court-Brown, C.M., A. Garg, and M.M. McQueen, *The epidemiology of proximal humeral fractures*. Acta Orthop Scand, 2001. **72**(4): p. 365-71.

15. Myeroff, C.M., et al., *Predictors of Mortality in Elder Patients With Proximal Humeral Fracture*. Geriatr Orthop Surg Rehabil, 2018. **9**: p. 2151458517728155.
16. Crosby, L.A. and R.J. Neviaser, *Proximal Humerus Fractures*. 2015.
17. Maier, D., et al., *Proximal humeral fracture treatment in adults*. J Bone Joint Surg Am, 2014. **96**(3): p. 251-61.
18. Schumaier, A. and B. Grawe, *Proximal Humerus Fractures: Evaluation and Management in the Elderly Patient*. Geriatric Orthopaedic Surgery & Rehabilitation, 2018. **9**.
19. Visser, C.P.J., et al., *Nerve lesions in proximal humeral fractures*. Journal of Shoulder and Elbow Surgery, 2001. **10**(5): p. 421-427.
20. Neer, C.S., *Four-segment classification of proximal humeral fractures: Purpose and reliable use*. Journal of Shoulder and Elbow Surgery, 2002. **11**(4): p. 389-400.
21. Codman, E.A., *The shoulder : rupture of the supraspinatus tendon and other lesions in or about the subacromial bursa*. 1984, Malabar, Fla: R.E. Kreiger.
22. Neer, C.S., 2nd, *Displaced proximal humeral fractures. I. Classification and evaluation*. J Bone Joint Surg Am, 1970. **52**(6): p. 1077-89.
23. Chung, S.W., et al., *Automated detection and classification of the proximal humerus fracture by using deep learning algorithm*. Acta Orthopaedica, 2018. **89**(4): p. 468-473.
24. Gracitelli, M.E.C., et al., *Intraobserver and interobserver agreement in the classification and treatment of proximal humeral fractures*. Journal of Shoulder and Elbow Surgery, 2017. **26**(6): p. 1097-1102.
25. Müller, M.E., et al., *The Comprehensive Classification of Fractures of Long Bones*. 1990.
26. Hertel, R., et al., *Predictors of humeral head ischemia after intracapsular fracture of the proximal humerus*. J Shoulder Elbow Surg, 2004. **13**(4): p. 427-33.
27. Resch, H., E. Beck, and I. Bayley, *Reconstruction of the valgus-impacted humeral head fracture*. Journal of Shoulder and Elbow Surgery, 1995. **4**(2): p. 73-80.
28. Resch, H., et al., *Classification of proximal humeral fractures based on a pathomorphologic analysis*. Journal of Shoulder and Elbow Surgery, 2016. **25**(3): p. 455-462.
29. Majed, A., et al., *Proximal humeral fracture classification systems revisited*. J Shoulder Elbow Surg, 2011. **20**(7): p. 1125-32.
30. Dillon, M.T., et al., *The increasing role of reverse total shoulder arthroplasty in the treatment of proximal humerus fractures*. Injury, 2019. **50**(3): p. 676-680.

31. Rosas, S., et al., *Trends in surgical management of proximal humeral fractures in the Medicare population: a nationwide study of records from 2009 to 2012*. J Shoulder Elbow Surg, 2016. **25**(4): p. 608-13.
32. Rasmussen, S., et al., *Displaced proximal humeral fractures: results of conservative treatment*. Injury, 1992. **23**(1): p. 41-3.
33. Zyto, K., *Non-operative treatment of comminuted fractures of the proximal humerus in elderly patients*. Injury, 1998. **29**(5): p. 349-52.
34. Foruria, A.M., et al., *The pattern of the fracture and displacement of the fragments predict the outcome in proximal humeral fractures*. J Bone Joint Surg Br, 2011. **93**(3): p. 378-86.
35. Court-Brown, C.M., H. Cattermole, and M.M. McQueen, *Impacted valgus fractures (B1.1) of the proximal humerus. The results of non-operative treatment*. J Bone Joint Surg Br, 2002. **84**(4): p. 504-8.
36. Iyengar, J.J., et al., *Nonoperative treatment of proximal humerus fractures: a systematic review*. J Orthop Trauma, 2011. **25**(10): p. 612-7.
37. Platzer, P., et al., *Displaced fractures of the greater tuberosity: a comparison of operative and nonoperative treatment*. J Trauma, 2008. **65**(4): p. 843-8.
38. Rangan, A., et al., *Surgical vs nonsurgical treatment of adults with displaced fractures of the proximal humerus: the PROFHER randomized clinical trial*. JAMA, 2015. **313**(10): p. 1037-47.
39. Handoll, H.H., et al., *Five-year follow-up results of the PROFHER trial comparing operative and non-operative treatment of adults with a displaced fracture of the proximal humerus*. Bone Joint J, 2017. **99-B**(3): p. 383-392.
40. Brorson, S., *Management of fractures of the humerus in Ancient Egypt, Greece, and Rome: an historical review*. Clin Orthop Relat Res, 2009. **467**(7): p. 1907-14.
41. Brorson, S., *Management of proximal humeral fractures in the nineteenth century: an historical review of preradiographic sources*. Clin Orthop Relat Res, 2011. **469**(4): p. 1197-206.
42. Flatow, E.L. and A.K. Harrison, *A history of reverse total shoulder arthroplasty*. Clin Orthop Relat Res, 2011. **469**(9): p. 2432-9.
43. Neer, C.S., 2nd, *Articular replacement for the humeral head*. J Bone Joint Surg Am, 1955. **37-A**(2): p. 215-28.
44. Neer, C.S., 2nd, *Displaced proximal humeral fractures. II. Treatment of three-part and four-part displacement*. J Bone Joint Surg Am, 1970. **52**(6): p. 1090-103.
45. Esser, R.D., *Open reduction and internal fixation of three- and four-part fractures of the proximal humerus*. Clin Orthop Relat Res, 1994(299): p. 244-51.

46. Moda, S.K., et al., *Open reduction and fixation of proximal humeral fractures and fracture-dislocations*. J Bone Joint Surg Br, 1990. **72**(6): p. 1050-2.
47. Sehr, J.R. and R.M. Szabo, *Semitubular blade plate for fixation in the proximal humerus*. J Orthop Trauma, 1988. **2**(4): p. 327-32.
48. Zyto, K., et al., *Treatment of displaced proximal humeral fractures in elderly patients*. J Bone Joint Surg Br, 1997. **79**(3): p. 412-7.
49. Brunner, F., et al., *Open reduction and internal fixation of proximal humerus fractures using a proximal humeral locked plate: a prospective multicenter analysis*. J Orthop Trauma, 2009. **23**(3): p. 163-72.
50. Charalambous, C.P., et al., *Proximal humeral internal locking system (PHILOS) for the treatment of proximal humeral fractures*. Arch Orthop Trauma Surg, 2007. **127**(3): p. 205-10.
51. Fankhauser, F., et al., *A new locking plate for unstable fractures of the proximal humerus*. Clin Orthop Relat Res, 2005(430): p. 176-81.
52. Jost, B., et al., *Locking plate fixation of fractures of the proximal humerus: analysis of complications, revision strategies and outcome*. J Shoulder Elbow Surg, 2013. **22**(4): p. 542-9.
53. Koukakis, A., et al., *Fixation of proximal humerus fractures using the PHILOS plate: early experience*. Clin Orthop Relat Res, 2006. **442**: p. 115-20.
54. Olerud, P., et al., *Internal fixation versus nonoperative treatment of displaced 3-part proximal humeral fractures in elderly patients: a randomized controlled trial*. J Shoulder Elbow Surg, 2011. **20**(5): p. 747-55.
55. Owsley, K.C. and J.T. Gorczyca, *Displacement/Screw Cutout After Open Reduction and Locked Plate Fixation of Humeral Fractures*. The Journal of Bone & Joint Surgery, 2008. **90**(2): p. 233-240.
56. Owsley, K.C. and J.T. Gorczyca, *Fracture displacement and screw cutout after open reduction and locked plate fixation of proximal humeral fractures [corrected]*. J Bone Joint Surg Am, 2008. **90**(2): p. 233-40.
57. Thanasas, C., et al., *Treatment of proximal humerus fractures with locking plates: a systematic review*. J Shoulder Elbow Surg, 2009. **18**(6): p. 837-44.
58. Gardner, M.J., et al., *The importance of medial support in locked plating of proximal humerus fractures*. J Orthop Trauma, 2007. **21**(3): p. 185-91.
59. Solberg, B.D., et al., *Locked plating of 3- and 4-part proximal humerus fractures in older patients: the effect of initial fracture pattern on outcome*. J Orthop Trauma, 2009. **23**(2): p. 113-9.

60. Namdari, S., et al., *Fixation strategies to prevent screw cut-out and malreduction in proximal humeral fracture fixation*. Clin Orthop Surg, 2012. **4**(4): p. 321-4.
61. Arvesen, J.E., et al., *Biomechanical Contribution of Tension-Reducing Rotator Cuff Sutures in 3-Part Proximal Humerus Fractures*. J Orthop Trauma, 2016. **30**(8): p. e262-6.
62. Haasters, F., et al., *Complications of locked plating for proximal humeral fractures-are we getting any better?* J Shoulder Elbow Surg, 2016. **25**(10): p. e295-303.
63. Campochiaro, G., et al., *Complex proximal humerus fractures: Hertel's criteria reliability to predict head necrosis*. Musculoskelet Surg, 2015. **99 Suppl 1**: p. S9-15.
64. Edelson, G., et al., *Natural history of complex fractures of the proximal humerus using a three-dimensional classification system*. J Shoulder Elbow Surg, 2008. **17**(3): p. 399-409.
65. Zyto, K., et al., *Outcome after hemiarthroplasty for three- and four-part fractures of the proximal humerus*. J Shoulder Elbow Surg, 1998. **7**(2): p. 85-9.
66. Antuna, S.A., J.W. Sperling, and R.H. Cofield, *Shoulder hemiarthroplasty for acute fractures of the proximal humerus: a minimum five-year follow-up*. J Shoulder Elbow Surg, 2008. **17**(2): p. 202-9.
67. Boons, H.W., et al., *Hemiarthroplasty for humeral four-part fractures for patients 65 years and older: a randomized controlled trial*. Clin Orthop Relat Res, 2012. **470**(12): p. 3483-91.
68. Dimakopoulos, P., N. Potamitis, and E. Lambiris, *Hemiarthroplasty in the treatment of comminuted intraarticular fractures of the proximal humerus*. Clin Orthop Relat Res, 1997(341): p. 7-11.
69. Sowa, B., et al., *Functional results of hemi- and total shoulder arthroplasty according to diagnosis and patient age at surgery*. Acta Orthop, 2017. **88**(3): p. 310-314.
70. Boileau, P., et al., *Tuberosity malposition and migration: reasons for poor outcomes after hemiarthroplasty for displaced fractures of the proximal humerus*. J Shoulder Elbow Surg, 2002. **11**(5): p. 401-12.
71. Hackett, D.J., Jr., J.E. Hsu, and F.A. Matsen, 3rd, *Primary Shoulder Hemiarthroplasty: What Can Be Learned From 359 Cases That Were Surgically Revised?* Clin Orthop Relat Res, 2018. **476**(5): p. 1031-1040.
72. Kim, S.H., et al., *Increasing incidence of shoulder arthroplasty in the United States*. J Bone Joint Surg Am, 2011. **93**(24): p. 2249-54.
73. Dezfuli, B., et al., *Outcomes of reverse total shoulder arthroplasty as primary versus revision procedure for proximal humerus fractures*. J Shoulder Elbow Surg, 2016. **25**(7): p. 1133-7.

74. Grubhofer, F., et al., *Reverse total shoulder arthroplasty for acute head-splitting, 3- and 4-part fractures of the proximal humerus in the elderly*. J Shoulder Elbow Surg, 2016. **25**(10): p. 1690-8.
75. Wright, J.O., et al., *Uncemented Reverse Total Shoulder Arthroplasty as Initial Treatment for Comminuted Proximal Humerus Fractures*. J Orthop Trauma, 2019. **33**(7): p. e263-e269.
76. Shannon, S.F., et al., *Reverse shoulder arthroplasty for proximal humeral fractures: outcomes comparing primary reverse arthroplasty for fracture versus reverse arthroplasty after failed osteosynthesis*. J Shoulder Elbow Surg, 2016. **25**(10): p. 1655-60.
77. Wolfensperger, F., et al., *Reverse shoulder arthroplasty for complex fractures of the proximal humerus in elderly patients: impact on the level of independency, early function, and pain medication*. J Shoulder Elbow Surg, 2017. **26**(8): p. 1462-1468.
78. Bufquin, T., et al., *Reverse shoulder arthroplasty for the treatment of three- and four-part fractures of the proximal humerus in the elderly: a prospective review of 43 cases with a short-term follow-up*. J Bone Joint Surg Br, 2007. **89**(4): p. 516-20.
79. Klein, M., et al., *Treatment of comminuted fractures of the proximal humerus in elderly patients with the Delta III reverse shoulder prosthesis*. J Orthop Trauma, 2008. **22**(10): p. 698-704.
80. Lenarz, C., et al., *Is reverse shoulder arthroplasty appropriate for the treatment of fractures in the older patient? Early observations*. Clin Orthop Relat Res, 2011. **469**(12): p. 3324-31.
81. Roberson, T.A., et al., *Nonoperative management versus reverse shoulder arthroplasty for treatment of 3- and 4-part proximal humeral fractures in older adults*. J Shoulder Elbow Surg, 2017. **26**(6): p. 1017-1022.
82. Sebastia-Forcada, E., et al., *Outcomes of Reverse Total Shoulder Arthroplasty for Proximal Humeral Fractures: Primary Arthroplasty Versus Secondary Arthroplasty After Failed Proximal Humeral Locking Plate Fixation*. J Orthop Trauma, 2017. **31**(8): p. e236-e240.
83. Torchia, M.T., et al., *Acute versus delayed reverse total shoulder arthroplasty for the treatment of proximal humeral fractures in the elderly population: a systematic review and meta-analysis*. J Shoulder Elbow Surg, 2019. **28**(4): p. 765-773.
84. Cvetanovich, G.L., et al., *Open reduction internal fixation has fewer short-term complications than shoulder arthroplasty for proximal humeral fractures*. J Shoulder Elbow Surg, 2016. **25**(4): p. 624-631 e3.

85. Zhang, A.L., W.W. Schairer, and B.T. Feeley, *Hospital readmissions after surgical treatment of proximal humerus fractures: is arthroplasty safer than open reduction internal fixation?* Clin Orthop Relat Res, 2014. **472**(8): p. 2317-24.
86. Chalmers, P.N., et al., *Reverse total shoulder arthroplasty for acute proximal humeral fracture: comparison to open reduction-internal fixation and hemiarthroplasty.* J Shoulder Elbow Surg, 2014. **23**(2): p. 197-204.
87. Gupta, A.K., et al., *Surgical management of complex proximal humerus fractures-a systematic review of 92 studies including 4500 patients.* J Orthop Trauma, 2015. **29**(1): p. 54-9.
88. Austin, D.C., et al., *Decreased Reoperations and Improved Outcomes With Reverse Total Shoulder Arthroplasty in Comparison to Hemiarthroplasty for Geriatric Proximal Humerus Fractures: A Systematic Review and Meta-Analysis.* J Orthop Trauma, 2019. **33**(1): p. 49-57.
89. Shukla, D.R., et al., *Hemiarthroplasty versus reverse shoulder arthroplasty for treatment of proximal humeral fractures: a meta-analysis.* J Shoulder Elbow Surg, 2016. **25**(2): p. 330-40.
90. Ferrel, J.R., T.Q. Trinh, and R.A. Fischer, *Reverse total shoulder arthroplasty versus hemiarthroplasty for proximal humeral fractures: a systematic review.* J Orthop Trauma, 2015. **29**(1): p. 60-8.
91. Gallinet, D., et al., *Is reverse total shoulder arthroplasty more effective than hemiarthroplasty for treating displaced proximal humerus fractures in older adults? A systematic review and meta-analysis.* Orthop Traumatol Surg Res, 2018. **104**(6): p. 759-766.
92. Namdari, S., J.G. Horneff, and K. Baldwin, *Comparison of hemiarthroplasty and reverse arthroplasty for treatment of proximal humeral fractures: a systematic review.* J Bone Joint Surg Am, 2013. **95**(18): p. 1701-8.
93. Reuther, F., M. Petermann, and R. Stangl, *Reverse Shoulder Arthroplasty in Acute Fractures of the Proximal Humerus: Does Tuberosity Healing Improve Clinical Outcomes?* J Orthop Trauma, 2019. **33**(2): p. e46-e51.
94. Jain, N.P., et al., *Tuberosity healing after reverse shoulder arthroplasty for complex proximal humeral fractures in elderly patients-does it improve outcomes? A systematic review and meta-analysis.* J Shoulder Elbow Surg, 2019. **28**(3): p. e78-e91.
95. Simovitch, R.W., et al., *Effect of Tuberosity Healing on Clinical Outcomes in Elderly Patients Treated With a Reverse Shoulder Arthroplasty for 3- and 4-Part Proximal Humerus Fractures.* J Orthop Trauma, 2019. **33**(2): p. e39-e45.

96. Torrens, C., et al., *Reverse shoulder arthroplasty for the treatment of acute complex proximal humeral fractures: Influence of greater tuberosity healing on the functional outcomes*. J Orthop Surg (Hong Kong), 2018. **26**(1): p. 2309499018760132.
97. Gallinet, D., et al., *Reverse shoulder arthroplasty for recent proximal humerus fractures: Outcomes in 422 cases*. Orthop Traumatol Surg Res, 2019. **105**(5): p. 805-811.
98. Klug, A., et al., *Complications after surgical treatment of proximal humerus fractures in the elderly—an analysis of complication patterns and risk factors for reverse shoulder arthroplasty and angular-stable plating*. Journal of Shoulder and Elbow Surgery, 2019. **28**(9): p. 1674-1684.
99. Bacle, G., et al., *Long-Term Outcomes of Reverse Total Shoulder Arthroplasty: A Follow-up of a Previous Study*. J Bone Joint Surg Am, 2017. **99**(6): p. 454-461.

II. OBJECTIVES

1. OBJECTIVES

Proximal humeral fractures pose a complex clinical challenge, with around 15% of cases requiring surgery. Various surgical techniques are available, including Kirschner wire fixation, screw fixation, plate fixation, intramedullary fixation, and prosthetic replacement [1]. Among these, the locking plate system has become the preferred choice for addressing two- and three-part fractures, offering the potential to restore anatomical alignment and achieve 80% to 85% recovery in joint mobility compared to the unaffected side [2]. However, this approach comes with a significant challenge in the form of a high complication rate, which can reach up to 49% [3].

Historically, complex PHF, characterized by 3- or 4-part configurations in osteoporotic bone, fracture-dislocations, or those involving over 40% to 50% of the joint surface, have typically been treated with HA [4]. HA is a technically intricate procedure that aims to restore the tuberosity's anatomy, humerus length, and retroversion to optimal parameters. However, long-term follow-up studies have often reported suboptimal functional outcomes and reduced overall satisfaction ratings, largely due to issues like tuberosity malunion, non-union, and reabsorption [5, 6].

In this context, the advent of RSA has brought promise, especially for patients dealing with shoulder arthropathy resulting from rotator cuff tear, concurrent degenerative arthropathy and rotator cuff failure, painful pseudoparalysis of the shoulder, or pseudarthrosis of PHF [7-9]. Originally conceived as an alternative for complex PHF [10-12], RSA appears to offer functional outcomes that are less dependent on tuberosity healing and rotator cuff integrity. Patients undergoing RSA often experience faster recoveries with less demanding rehabilitation, setting it apart from the recovery trajectory observed in HA [8].

The rising incidence of PHF in the elderly population raises important questions about the best treatment approaches, including considerations of functional outcomes, pain relief, rehabilitation duration, and economic implications. Despite the prevalence of these fractures and the associated healthcare costs, the current medical landscape lacks clear scientific evidence to definitively determine the superior treatment modality. As we navigate the evolving field of medicine, our future challenge is to identify the specific patient profiles that will benefit most from surgical intervention while continuously refining surgical techniques to achieve the best outcomes for each unique fracture pattern.

This doctoral thesis focuses on a thorough examination of surgical approaches for PHF in individuals aged 70 years and older. Given the changing field of medicine, a significant challenge arises in identifying specific patient groups that will derive the greatest advantages from surgical procedures. At the same time, it's crucial to carefully customize surgical methods to achieve the best results for various types of fractures.

Outlined below are the principal objectives driving this research:

1. Retrospective Analysis of ORIF Complications: The primary objective involves a detailed retrospective investigation into complications observed in patients aged 70 years and older with PHF. This analysis focuses on cases that underwent ORIF at Centro Hospitalar Universitário de Santo António.
2. Retrospective Study of Arthroplasty Approach: The second part of this study comprises a retrospective analysis of elderly patients who received either HA or RSA for PHF. This research was conducted at Centro Hospitalar Universitário de Santo António.
3. Prospective Assessment of Complex Fractures: A prospective study that investigates RSA as the primary treatment for acute 3- and 4-part PHF in patients aged 70 years or older at Centro Hospitalar Universitário de Santo António.
4. Tuberosity healing and functional results: A comprehensive assessment of radiological and functional outcomes in the elderly population following the use of a RSA as the primary treatment for acute 3- and 4-part PHF. With an aim to identify possible improved results through successful consolidation of the tuberosities.
5. Radiological and Functional Outcomes of Different Humeral Implants in RSA: This aspect involves a detailed examination of radiological and functional results, aiming to compare two different humeral implants. These evaluations occur in the context of total RSA, shedding light on its role in treating complex PHF in older adults.
6. Comparative Tuberosity Fixation Techniques: The last aspect focuses on a detailed investigation of three different tuberosity fixation methods. Carried out within the context of RSA, this examination explores the management of complex PHF in older adults, revealing the complex relationship between radiological and functional results.

This comprehensive effort aims to enhance our knowledge of surgical approaches for PHF, revealing the intricate relationships among surgical methods, patient characteristics, and overall results. The ultimate goal of this thesis is to influence clinical practices by elucidating the complexities involved in managing PHF in older adults.

References

1. Lanting, B., et al., *Proximal humeral fractures: a systematic review of treatment modalities*. J Shoulder Elbow Surg, 2008. **17**(1): p. 42-54.
2. Thanasas, C., et al., *Treatment of proximal humerus fractures with locking plates: a systematic review*. J Shoulder Elbow Surg, 2009. **18**(6): p. 837-44.
3. Sproul, R.C., et al., *A systematic review of locking plate fixation of proximal humerus fractures*. Injury, 2011. **42**(4): p. 408-13.
4. Mighell, M.A., et al., *Outcomes of hemiarthroplasty for fractures of the proximal humerus*. J Shoulder Elbow Surg, 2003. **12**(6): p. 569-77.
5. Boileau, P., et al., *Tuberosity malposition and migration: reasons for poor outcomes after hemiarthroplasty for displaced fractures of the proximal humerus*. J Shoulder Elbow Surg, 2002. **11**(5): p. 401-12.
6. Hasan, S.S., et al., *Characteristics of unsatisfactory shoulder arthroplasties*. J Shoulder Elbow Surg, 2002. **11**(5): p. 431-41.
7. Boileau, P., et al., *Reverse total shoulder arthroplasty after failed rotator cuff surgery*. J Shoulder Elbow Surg, 2009. **18**(4): p. 600-6.
8. Gerber, C., S.D. Pennington, and R.W. Nyffeler, *Reverse total shoulder arthroplasty*. J Am Acad Orthop Surg, 2009. **17**(5): p. 284-95.
9. Wall, B., et al., *Reverse total shoulder arthroplasty: a review of results according to etiology*. J Bone Joint Surg Am, 2007. **89**(7): p. 1476-85.
10. Bufquin, T., et al., *Reverse shoulder arthroplasty for the treatment of three- and four-part fractures of the proximal humerus in the elderly: a prospective review of 43 cases with a short-term follow-up*. J Bone Joint Surg Br, 2007. **89**(4): p. 516-20.
11. Cazeneuve, J.F. and D.J. Cristofari, *[Grammont reversed prosthesis for acute complex fracture of the proximal humerus in an elderly population with 5 to 12 years follow-up]*. Rev Chir Orthop Reparatrice Appar Mot, 2006. **92**(6): p. 543-8.
12. Levy, J.C. and B. Badman, *Reverse shoulder prosthesis for acute four-part fracture: tuberosity fixation using a horseshoe graft*. J Orthop Trauma, 2011. **25**(5): p. 318-24.

III.

COMPLICATIONS OF OPEN REDUCTION AND INTERNAL FIXATION

1. INTRODUCTION

Proximal humeral fractures (PHF), which constitute approximately 5% of all diagnosed fractures and exhibit a bimodal distribution, are becoming increasingly prevalent due to demographic changes. Among the elderly, PHF are the third-most common fractures and are often associated with osteoporosis. [1-6]

Conservative management with short-term immobilization may be suitable for stable, minimally displaced, and displaced fractures, and may yield satisfactory functional outcomes. Conservative treatment may also be appropriate for complex fractures in elderly or cognitively impaired patients, individuals with nonfunctional limbs, or those with significant medical comorbidities. [7, 8]

Complex fractures, including 3- or 4-part fractures, head-splitting, pathological, and open fractures, typically necessitate surgical management, such as ORIF with a locking plate, anterograde intramedullary nailing, or arthroplasty. Primary arthroplasty may be preferable for comminuted humeral head fractures without reconstruction options, head-split fractures, and patients over 70 years of age who are at a high risk of osteonecrosis. [9, 10]

However, plate and screw fixation repair is associated with complications, including nonunion, implant failure/migration, osteonecrosis, infection, posttraumatic osteoarthritis, and postoperative shoulder stiffness. Reoperation may be required for implant removal due to implant failure, avascular necrosis, impingement/stiffness, pain, discomfort, or infection. Complication rates ranging from 38% to 44% have been reported in elderly patients, with reoperation rates ranging from 11% to 12%. [11, 12] The majority of complications occur within the initial three weeks after surgery, coinciding with the start of physical rehabilitation.

Investigating the complications and outcomes associated with different surgical treatments plays a critical role in guiding treatment decisions for PHF. Therefore, this study aimed to evaluate the occurrence of complications, including the need for revision surgery, in elderly patients with PHF who underwent operative treatment with ORIF using locking plates and screws. Additionally, this study aimed to compare results between surgeons specializing in shoulder surgery ("shoulder surgeons") and surgeons without specialization in shoulder surgery ("non-shoulder surgeons").

2. METHODS

This retrospective analysis focused on the surgical activities of a single orthopedic department between January 1, 2011, and December 31, 2021. The study cohort consisted of patients aged 70 years or older who underwent ORIF using the Philos® locking plate (Depuy Synthes, Oberdorf, Switzerland) for PHF. Data were extracted from a comprehensive single-center database and collected from medical records.

In this retrospective analysis of surgical treatments for PHF, the study cohort was stratified into two distinct categories: "shoulder surgeons" and "non-shoulder surgeons." The "shoulder surgeons" group comprised patients who underwent surgery performed by orthopedic professionals from the department who were fellowship-trained with expertise exclusively in shoulder-related diagnoses, treatments, and surgical interventions. This subgroup underwent surgery performed by orthopedic surgeons with more than five years of dedicated experience, encompassing a diverse spectrum of shoulder-specific procedures, such as rotator cuff repairs, labral repairs, shoulder arthroscopy, proximal humerus fracture management, and shoulder replacement surgeries. These experts demonstrated an in-depth comprehension of the intricate shoulder anatomy and biomechanics, remaining well-informed about the latest advancements in shoulder surgery techniques and technologies. Conversely, the "non-shoulder surgeons" group consisted of patients who underwent surgery performed by general orthopedic practitioners and surgeons primarily focusing on musculoskeletal issues beyond the shoulder joint. While proficient in addressing a wide range of musculoskeletal conditions throughout the body, including shoulder-related concerns, their experience and knowledge pertaining to shoulder-specific pathologies and surgical procedures were comparatively limited.

The decision to perform surgery was based on a preoperative consensus reached by two independent surgeons who agreed that achieving a satisfactory outcome with conservative treatment was not feasible. The exclusion criteria included pathological fractures and a time interval of >6 weeks from the occurrence of the fracture to the surgical procedure. All surgeries were performed successively according to the rotation of the emergency department schedule. No surgery was scheduled for a particular surgeon. No patient was assigned to a specific surgeon. Prior to inclusion in the study, ethical approval was obtained from the appropriate committees, as mandated by local regulations, and informed consent was obtained from all participating individuals.

All patients underwent preoperative assessments using radiography and CT. Follow-up evaluations were performed by a senior surgeon at specific intervals, namely, 2 weeks, 1 month, 3 months, 6 months, 1 year, and annually thereafter. Plain radiography in the anteroposterior views in neutral rotation, external rotation, and internal rotation, as well as lateral scapular shoulder or Y-views and Velpeau views were performed during these follow-up visits. Follow-up consultations included radiographic assessments at four weeks, three months, six months, and one year, followed by annual assessments.

Demographic data were extracted from clinical records and included variables such as sex, age at the time of fracture, American Society of Anesthesiology (ASA) score, Neer classification, time from fracture to surgery, visual analog scale score, duration of follow-up, mortality rate, occurrence of complications (including avascular necrosis of the humeral head and implant failure, such as screw pull-out and pseudarthrosis), and the need for revision surgery.

Descriptive statistics were used to summarize the demographic data and prevalence results. For categorical variables, the number of cases and percentages were reported, and the chi-squared test or Fisher's exact test (applied when more than 20% of cells had expected frequencies below 5, or any cell had an expected frequency below 1.1) was used to compare the proportions between groups. Continuous variables are presented as mean and standard deviation if they followed a normal distribution or as median and interquartile range (IQR) if they did not follow a normal distribution. The Shapiro–Wilk test was used to assess the distribution of the variables, and the t-test (for normally distributed variables) or Mann–Whitney U test (for non-normally distributed variables) was used to compare means between groups.

All statistical analyses were performed using the IBM SPSS Statistics software (version 24.0; New York, New York, USA). Statistical significance was defined as a two-tailed P-value of <0.05. When appropriate, a 95% confidence interval was reported.

3. RESULTS

A descriptive analysis of the participants is presented in Table 1. A total of 83 participants (mean age, 77 years; range, 70–89 years) were included in the study. The mean follow-up period was 537 days (range, 370–3841 days). According to Neer's classification, 36.1%, 48.2%, and 15.7% of the patients showed 2-part, 3-part, and 4-part fractures, respectively.

The overall number of surgeons involved was 12, including four “shoulder surgeons” and eight “non-shoulder surgeons”.

Table 1. Descriptive analysis

	Frequency	Percent
Gender		
Female	67	80.7%
Male	16	19.3%
Neer’s Classification		
2-part	30	36.1%
3-part	40	48.2%
4-part	13	15.7%

According to Neer’s classification, fractures treated by “non-shoulder surgeons” included 17 (32.7%) 2-part fractures, 27 (51.9%) 3-part fractures, and 8 (15.4%) 4-part fractures. The fractures treated by “shoulder surgeons” included 13 (41.9%) 2-part fractures, 13 (41.9%) 3-part fractures, and 5 (16.1%) 4-part fractures (Table 2). No statistically significant differences in the complexity of fractures based on Neer’s classification were observed between “shoulder surgeons” and “non-shoulder surgeons” ($P = 0.590$). Overall, 16.9% of the patients had complications, including avascular necrosis and implant failure in 4.8% and 15.7% of the patients, respectively. Three patients experienced both complications.

Table 2. Distribution of fractures between the “shoulder surgeons” and “non-shoulder surgeons” groups

Neer’s Classification	“Shoulder Surgeon”	“Non-shoulder Surgeon”
2-part	41.9%	32.7%
3-part	41.9%	51.9%
4-part	16.1%	15.4%

According to the Shapiro–Wilk test, age did not follow a normal distribution, with a median age of 76 years (IQR, 4.8 years) in the group without complications and 76 years (IQR, 4 years) in the group with complications. However, the two groups showed no statistically significant difference ($P = 0.643$; Mann–Whitney U test). In evaluations based on gender, 18.8% of male patients and 16.4% of female patients showed complications, with no significant sex-related differences ($P = 0.825$).

The time until surgery was also evaluated and did not follow a normal distribution, with a median time of 4 days (IQR, 5 days) in the group without complications and 2 days (IQR, 1 day) in the group with complications. The difference between the two groups was statistically significant according to the Mann–Whitney U test ($P < 0.001$).

The frequencies of complications in relation to Neer’s classification (2-part, 3-part, and 4-part) are presented in Table 3. The differences in the frequencies of complications between Neer classes were not statistically significant ($P = 0.188$). Differences in the frequency of complications between “shoulder surgeons” and “non-shoulder surgeons” were also evaluated; the overall frequency of complications was 21.2% in procedures performed by “non-shoulder surgeons” and 9.7% in those performed by “shoulder surgeons. However, the difference between the two groups was not statistically significant ($P = 0.162$; Table 4).

Table 3. Frequency of complications, including implant failure and avascular necrosis of the humeral head, in relation to Neer's Classification

	Neer's 2-part		Neer's 3-part		Neer's 4-part		p
	N	%	N	%	N	%	
Implant failure	6	20%	3	7.5%	4	30.8%	0.096
Avascular necrosis	2	6.7%	1	2.5%	1	7.7%	0.629
Complications overall	6	20%	4	10%	4	30.8%	0.188

Table 4. Frequency of complications when patients were treated by "shoulder surgeons" vs. "non-shoulder surgeons"

	"Shoulder Surgeon"		"Non-shoulder surgeon"		p
	N	%	N	%	
Implant failure	3	9.7	10	19.2%	0.233
Avascular necrosis	2	6.5%	2	3.8%	0.627
Complications overall	3	9.7%	11	21.2%	0.162

The overall frequency of revision surgery was 15.7% (n = 13; Table 5). In the analyses based on Neer's classification, 2 (6.7%), 7 (17.5%), and 4 (30.8%) patients with 2-part, 3-part, and 4-part fractures underwent revision surgery, with no statistically significant difference among the groups ($P = 0.122$). When the frequency of revision surgery was evaluated by comparing the patients treated by "shoulder surgeons" and "non-shoulder surgeons," revision surgeries were required for 10 patients (19.2%) treated by "non-

shoulder surgeons” and three patients (9.7%) treated by “shoulder surgeons,” although this difference was also not statistically significant ($P = 0.233$).

Table 5. Frequency of revision surgery overall, according to Neer’s classification, and based on whether the patients were treated by a “shoulder surgeon” or “non-shoulder surgeons”

	Overall	Neer’s Classification			“Shoulder surgeon”	“Non-shoulder surgeon”
		2-part	3-part	4-part		
Revision Surgery	15.7%	6.7%	17.5%	30.8%	9.7%	19.2%

The overall implant survival rates were 82.7% at 1 year, 82.7% at 2 years, and 65.5% at 5 years (Fig. 1). During the follow-up period, 24 patients died; the overall survival rate was 96.9% at 1 year, 84.5% at 2 years, and 44.7% at 5 years (Fig. 2).

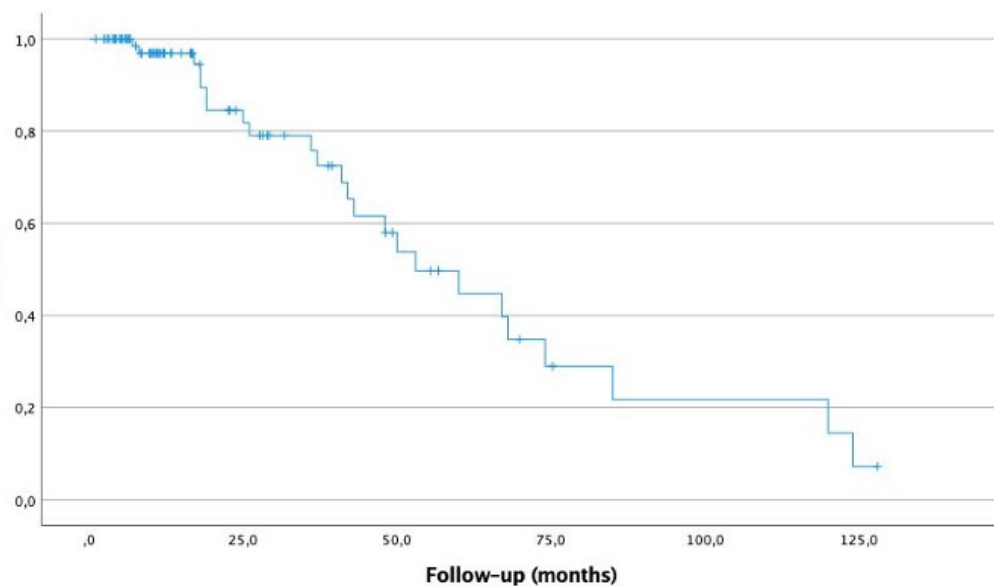


Figure 1. Implant survival rate

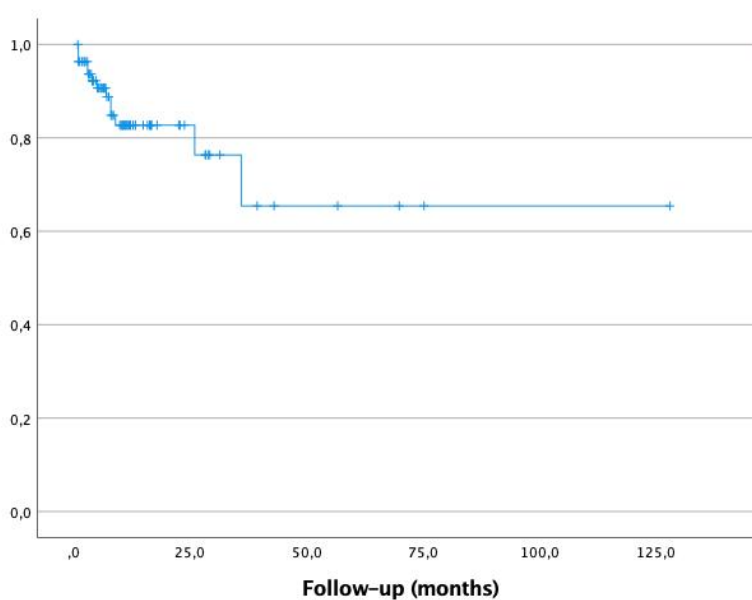


Figure 2. Mortality rate

4. DISCUSSION

This study provides valuable insights into the management of PHF in elderly populations. Management of PHF in the elderly remains a challenge, and treatment approaches show substantial variations across different regions. The rates of surgical interventions for PHF also display significant variability, highlighting the absence of a consensus regarding the optimal approach to these fractures. [13]

The findings highlight the high rate of radiographic failure and reoperation following ORIF for PHF, particularly in cases treated by “non-shoulder surgeons”. While the greater success of “shoulder surgeons” could be attributed to their enhanced expertise within this specific anatomical domain and their use of surgical techniques designed to minimize the risk of vascular injuries, thereby mitigating the potential for avascular necrosis. It is conceivable that their greater familiarity with precise fracture reduction and screw placement aids in preventing substantial reductions from slipping. The reduced occurrence of complications among specialists in this field may also stem from the notably shorter surgical time durations they typically achieve, owing to their extensive knowledge of the shoulder's intricate anatomy. Existing literature on ORIF for PHF has identified several variables associated with successful radiographic outcomes. Achieving anatomic reduction and restoring the calcar have been shown to decrease the incidence of complications such as varus collapse,

nonunion, malunion, and screw cutout. [14-16] These factors play crucial roles in determining the long-term stability and functional outcomes of patients with PHF.

The survival rate of this specific population, consisting of individuals aged >70 years in our study, highlighted the notable longevity of these patients. Consequently, from the perspective of enhancing the patients' quality of life, well-informed decision-making regarding treatments that effectively address the fracture are crucial since they can significantly influence the patient's overall quality of life.

Regrettably, the incidence of complications following ORIF for PHF has consistently remained elevated. Recent studies have reported complication rates at the two-year mark ranging from 20% to 60% [17]. Among the most frequently encountered complications associated with proximal humerus plating are screw cutouts and intra-articular screw complications, tuberosity displacement or non-union, impingement, rotator cuff lesions, malunion or non-union, secondary displacement, osteonecrosis of the humeral head, posttraumatic osteoarthritis, screw loosening, heterotopic ossification, infections, and implant failure [17]. Several risk factors have been identified as contributors to these complications following ORIF for PHF, shedding light on patients who may be at a higher risk. These risk factors encompass fracture-dislocations, smoking, obesity, advanced age, and the presence of comorbidities [18, 19]. Notably, specific factors associated with an increased risk of osteonecrosis include fracture-dislocation, disruption of the medial hinge (calcar), and limited metaphyseal head extension (<8 mm) [20]. Furthermore, the risk of screw cutout is amplified in cases involving advanced age, non-anatomic calcar reduction, fracture-dislocation, and fractures falling within the AO/OTA 11-C2 category (impressed fractures with significant displacement) [21].

Fracture complexity is theoretically expected to be associated with increased complication rates and the need for revision surgeries, although this trend did not reach statistical significance in the present study. In our study, when comparing surgeries performed by "shoulder surgeons" and "non-shoulder surgeons", the latter group showed a nearly two-fold higher rate of complications and revision surgeries. This difference was particularly notable in terms of implant failure rates, suggesting that dedicated shoulder surgeons are more likely to avoid complications and reoperations in this specific patient population.

A previous study reported reoperation rates of 11% and 2.2% in the hemiarthroplasty and reverse shoulder arthroplasty groups, respectively. [22] Our study's radiographic failure rate of 16.9% and reoperation rate of 15.7% with the option of arthroplasty indicated worse

radiological outcomes. This comparison suggests that ORIF for PHF in elderly patients may result in higher complication and recurrence rates than those of arthroplasty.

Another significant finding was that fractures with a higher Neer classification were prioritized for earlier surgical intervention. This trend indicates a tendency among orthopedic surgeons to address more complex cases promptly, potentially aiming to mitigate the risk of complications such as avascular necrosis.

This study had some limitations. The retrospective design inherently restricted the establishment of causal relationships and relied on correlational findings. Additionally, the relatively rare occurrence of ORIF for PHF in these specific elderly population resulted in a small sample size, potentially limiting the ability to detect significant differences in failure rates and functional outcomes. Furthermore, the involvement of 12 surgeons with varying levels of experience introduced potential variations in the surgical techniques and rehabilitation protocols. Despite these limitations, our analysis underscores the notion that even with well-reduced fractures, patients undergoing ORIF for PHF in the elderly population do not achieve robust radiological outcomes.

5. CONCLUSIONS

The results of this study highlight the considerable incidence of complications and the increased likelihood of reoperation associated with ORIF procedures for PHF in the elderly population, particularly when performed by “non-shoulder surgeons”. In cases where achieving satisfactory fracture reduction is challenging, arthroplasty may be a more favorable alternative treatment.

These findings emphasize the critical importance of employing meticulous surgical techniques and ensuring appropriate patient selection to optimize outcomes in patients with PHF, especially in the elderly population. Recognizing the expertise of dedicated shoulder surgeons is crucial to achieve better results and minimize complications.

Additional research is imperative to explore innovative approaches and advance management strategies for PHF. Future studies should focus on refining the surgical techniques, developing patient-specific treatment algorithms, and investigating the roles of arthroplasty options in specific fracture patterns and patient populations. Continued

research efforts and concurrent changes in clinical practice will contribute to improving the outcomes of patients with PHF and providing optimal care for this population.

References

1. Passaretti, D., et al., Epidemiology of proximal humeral fractures: a detailed survey of 711 patients in a metropolitan area. *Journal of Shoulder and Elbow Surgery*, 2017. 26(12): p. 2117-2124.
2. Calvo, E., et al., Nondisplaced proximal humeral fractures: high incidence among outpatient-treated osteoporotic fractures and severe impact on upper extremity function and patient subjective health perception. *Journal of Shoulder and Elbow Surgery*, 2011. 20(5): p. 795-801.
3. Rotman, D., et al., Mortality After Complex Displaced Proximal Humerus Fractures in Elderly Patients: Conservative Versus Operative Treatment With Reverse Total Shoulder Arthroplasty. *Geriatric Orthopaedic Surgery & Rehabilitation*, 2018. 9.
4. Maugendre, E., et al., Epidemiology and mortality in older patients treated by reverse shoulder arthroplasty for displaced proximal humerus fractures. *Orthopaedics & Traumatology: Surgery & Research*, 2019. 105(8): p. 1509-1513.
5. Court-Brown, C.M. and B. Caesar, Epidemiology of adult fractures: A review. *Injury*, 2006. 37(8): p. 691-697.
6. Court-Brown, C.M., A. Garg, and M.M. McQueen, The epidemiology of proximal humeral fractures. *Acta Orthop Scand*, 2001. 72(4): p. 365-71.
7. Villodre-Jiménez, J., et al., Tratamiento de las fracturas de húmero proximal en pacientes mayores de 65 años con prótesis inversa: resultados y complicaciones. *Revista Española de Cirugía Ortopédica y Traumatología*, 2017. 61(1): p. 43-50.
8. Gaebler, C., M. McQueen, and C. Court-Brown, Minimally displaced proximal humeral fractures Epidemiology and outcome in 507 cases. *Acta Orthopaedica Scandinavica*, 2009. 74(5): p. 580-585.
9. Owsley, K.C. and J.T. Gorczyca, Displacement/Screw Cutout After Open Reduction and Locked Plate Fixation of Humeral Fractures. *The Journal of Bone & Joint Surgery*, 2008. 90(2): p. 233-240.
10. Laux, C.J., et al., Current concepts in locking plate fixation of proximal humerus fractures. *J Orthop Surg Res*, 2017. 12(1): p. 137.
11. Klug, A., et al., Complications after surgical treatment of proximal humerus fractures in the elderly—an analysis of complication patterns and risk factors for reverse shoulder arthroplasty and angular-stable plating. *Journal of Shoulder and Elbow Surgery*, 2019. 28(9): p. 1674-1684.

12. Barlow, J.D., et al., Locking plate fixation of proximal humerus fractures in patients older than 60 years continues to be associated with a high complication rate. *Journal of Shoulder and Elbow Surgery*, 2020. 29(8): p. 1689-1694.
13. Okike, K., et al., Factors associated with the decision for operative versus non-operative treatment of displaced proximal humerus fractures in the elderly. *Injury*, 2013. 44(4): p. 448-455.
14. Padegimas, E.M., et al., Defining optimal calcar screw positioning in proximal humerus fracture fixation. *Journal of Shoulder and Elbow Surgery*, 2017. 26(11): p. 1931-1937.
15. Padegimas, E.M., et al., Failure to restore the calcar and locking screw cross-threading predicts varus collapse in proximal humerus fracture fixation. *Journal of Shoulder and Elbow Surgery*, 2020. 29(2): p. 291-295.
16. Schnetzke, M., et al., Quality of Reduction Influences Outcome After Locked-Plate Fixation of Proximal Humeral Type-C Fractures. *Journal of Bone and Joint Surgery*, 2016. 98(21): p. 1777-1785.
17. Tepass, A., et al., Complication rates and outcomes stratified by treatment modalities in proximal humeral fractures: a systematic literature review from 1970-2009. *Patient Saf Surg*, 2013. 7(1): p. 34.
18. Petrigliano, F.A., et al., Factors predicting complication and reoperation rates following surgical fixation of proximal humeral fractures. *J Bone Joint Surg Am*, 2014. 96(18): p. 1544-51.
19. Spross, C., et al., The PHILOS plate for proximal humeral fractures--risk factors for complications at one year. *J Trauma Acute Care Surg*, 2012. 72(3): p. 783-92.
20. Hertel, R., et al., Predictors of humeral head ischemia after intracapsular fracture of the proximal humerus. *J Shoulder Elbow Surg*, 2004. 13(4): p. 427-33.
21. Boesmueller, S., et al., Risk factors for humeral head necrosis and non-union after plating in proximal humeral fractures. *Injury*, 2016. 47(2): p. 350-5.
22. Claro, R., et al., Surgical treatment for acute and displaced proximal humerus fractures in elderly patients: hemiarthroplasty vs. reverse shoulder arthroplasty. *Seminars in Arthroplasty: JSES*, 2022. 32(4): p. 728-735.

IV.

HEMIARTHROPLASTY VERSUS REVERSE SHOULDER ARTHROPLASTY

1. INTRODUCTION

Proximal humerus fractures are the second most common upper extremity fractures and the third most common fractures in elderly patients, accounting for 5%-6% of all fractures [1-5] and 50% of all humerus fractures [6-9]. PHF are up to 4 times more frequent in females.[1, 3, 5, 10] The incidence increases with age, with more than 70% occurring in patients over the age of 60.[9] With increasing life expectancy, these injuries will become more frequent, associated with a substantial limitation in mobility and impaired quality of life and the best treatment for elderly patients is still a matter of controversy.

Most PHF, especially in elderly patients, can be treated nonoperatively, but 3-part and 4-part fractures and fracture–dislocations are often indicated for surgery [11]. Locking plate technology has expanded the indications for ORIF of PHF but has its own set of complications [12, 13]. When there is concern about the viability of the humeral head, including head-splitting or depression fractures, or the ability to achieve an acceptable reduction and secure fixation, arthroplasty is a dependable option [14-17]. HA has proven to reliably reduce pain, but postoperative functional outcomes have been less predictable. However, in elderly patients, the main engine of HA – a functional rotator cuff – may be a limitation. The problems related to the rotator cuff that usually occur after HA are the non-union or malunion of the tuberosities that leads to deficiency and/or dysfunction of the rotator cuff. Despite being effective in relieving pain, the HA is associated with poor functional outcomes and relatively low Constant scores, which make RSA a much more appealing solution for use in displaced PHF with poor rotator cuff and non-union of the tubercles in elderly patients, even in comparison with angular stable plate fixation [1, 2, 4, 10, 18].

PHF increase the 1-year mortality rate in elderly patients. One-year mortality rates after PHF, treated conservatively or surgically was found to be between 5% and 22% [1, 19-25]. These mortality rates are also observed in other fragility fractures like hip fractures where 1-year mortality rate is as high as 40%. The causes of increased mortality after one year are not well defined. It has been questioned if they represent an indicator of frailty or a cause of mortality [1]. Gaining a comprehensive understanding of the mortality risk associated with these procedures is of paramount importance to make accurate decisions.

The aim of this study was to retrospectively evaluate patients older than 75 years-of age primarily treated with RSA or with HA after PHF and to compare the mortality, morbidity,

complications, reoperations, and functional results. Our hypothesis was that RSA is a safe procedure with a high implant survival and with better functional results for these patients.

2. METHODS

A retrospective analysis was performed on the surgical activity of a single Orthopaedic Department between January 1st, 2004 and January 1st, 2020. All surgeries performed for PHF during that period were collected. The inclusion criteria were: patients 75 years of age or older submitted to RSA or HA as a primary option for displaced PHF and a minimum 1 year follow up. The exclusion criteria were pathologic fractures and waiting time to surgery longer than 6 weeks.

The indication for surgical treatment with an arthroplasty was a 3- or 4-part fracture whose anatomical reduction was not achieved intraoperatively or whose fracture configuration, assessed by x-ray and CT scan, an anatomical reduction was not expected.

All procedures were performed through a deltopectoral approach. All patients were provided with an Aequalis Reversed II Fracture implant (Tornier, Memphis, TN, USA) or an Aequalis Fracture implant (Tornier, Memphis, TN, USA). The surgery was always performed by one of the two senior shoulder surgeons. The long head of biceps tendon, whenever it was present, it was tenodesed to the pectoralis major. All the humeral implants were cemented. The humeral stem diameter corresponded to the diameter of the last broach used. A specially shaped cancellous bone graft was harvested from the fractured head using specific instruments and was placed into a specially shaped window in the humeral implant. Prosthesis implantation was performed with the help of a specific instrumentation to control height (with a sliding ruler) and retroversion (with a version rod aligned on the forearm).

Regarding the HA, the retroversion of the humeral implant was set according to the bicipital groove and the size of the head according to the shape of the best reconstruction of the anatomical head.

Concerning the RSA, the retroversion was set at 20° by aligning the version rod with the forearm. After retraction of the tuberosities, reaming of the glenoid surface was performed with a cannulated reamer inserted over a guidewire, and a central hole for the glenoid peg was drilled at 0° of inferior tilt. The baseplate was always impacted and secured in place

with 4 screws (2 compression and 2 locking). The diameter of the glenosphere was always the same: a standard 36-mm-diameter glenosphere.

Regarding the fixation of the tuberosities, their re-insertion was always made in the same way by the two groups, according to Boileau's principles [26].

All hemiarthroplasties were performed until January 2010 and all RSA were performed after January 2010.

Demographic data was collected from patient clinical records and included: gender, age at the time of fracture, ASA score, comorbidities, associated injuries, time until surgery, functional mobility (forward elevation $>120^\circ$, internal rotation $>$ lumbosacral junction, external rotation $>$ hand to top of head with elbow forward), return to activities of daily living (short questionnaire based on International Physical Activity Questionnaire Short Form, filled by the surgeon during the follow-up consultations, comparing the level of activity before and after the fracture), survival rate, complications (tuberosities nonunion, tuberosities malunion, heterotopic ossification, glenoid erosion, notching, loosening, re-operation, infection and instability of the implant) and mortality.

A pre-surgery assessment was performed with an x-ray and a CT-scan for all patients. All patients were observed at follow-up by a senior surgeon at 2 weeks, one month, 3 months, 6 months, one year, and annually thereafter. An X-ray study (face view: in neutral rotation, external rotation and internal rotation; Lamy's sagittal view and Bloom-Obata axial view) was performed during the follow-up consultations at 4 weeks post-op, at 3 months, at 6 months, at the end of one year and annually thereafter, was performed during follow-up consultations.

IBM SPSS Statistics 24® was used for the statistical analysis with the statistical significance set at $p < 0.05$. The groups were compared using the Student's t-test two-tail and Mann-Whitney test (quantitative variables) or the Fisher and Pearson Chi squared test (qualitative variables). Survival curves were obtained using the Kaplan-Meier method and the Log-rank test was performed to compare survival rates.

3. RESULTS

Between January 1, 2004 and January 1, 2020, 974 PHF were treated operatively. Of those, 73 fulfilled the inclusion criteria and were included in the study. Analyzing the surgical options, 577 patients underwent open reduction and osteosynthesis with a plate and 107 underwent nailing. Twelve patients under the age of 75 underwent HA and 117 cases under the age of 75 underwent an RSA. Of the remaining 88 patients, 30 did not complete the 1-year follow-up, 42 waited more than 6 weeks before surgery, and 16 underwent surgery for a pathological fracture.

All fractures were classified as Neer type 3 or 4. Thirty-four cases were classified as 3-part (12 underwent HA and 22 underwent RSA) and 39 cases were classified as 4-part (16 HA and 23 RSA). There were no differences in the distribution of these types between the two groups HA versus RSA ($p=0.615$).

From the 73 patients, 10 were males and 63 were females, with a median clinical follow-up of 64 months (34 SD, 0-199). Twenty-eight patients underwent HA and 45 RSA. The mean age at the time of the fracture was 78 years old (5.6 SD). Forty-one patients (56%) were ASA 2. Table 1 show the demographic characteristics and comorbidities and Table 2 details the surgical characteristics.

Table 1. Demographic characteristic and comorbidities

Variable	Hemiarthroplasty		RSA		P values
	n (%)	Mean (SD)	n (%)	Mean (SD)	
Gender					.908
Male	4 (14.3)		6 (13.3)		
Female	24 (85.7)		39 (86.7)		
Age (y)		75 (4.6)		80 (5.2)	<.001
ASA					.224
I	0		0		
II	18 (64.3)		23 (51.1)		
III	10 (35.7)		20 (44.4)		
IV	0		2 (4.5)		
Comorbidities					
Diabetes mellitus	4 (14.3)		10 (22.2)		.552
Hypertension	18 (6.5)		34 (75.6)		.588
Heart failure	6 (23.1)		18 (40.0)		.196
Respiratory failure	1 (3.6)		9 (20.0)		.081
Renal failure	1 (3.6)		6 (13.3)		.251
History of stroke	0		8 (17.8)		.023
Obesity	9 (3.3)		12 (26.7)		.591
Dementia	0		6 (13.3)		.079
Charlson Comorbidity Index					.05
3	6 (23.1)		7 (15.6)		
4	15 (57.7)		14 (31.1)		
5	5 (19.2)		11 (24.4)		
>=6	0		13 (28.9)		

RSA, reverse shoulder arthroplasty; SD, standard deviation; ASA, American Society of Anesthesiologists.

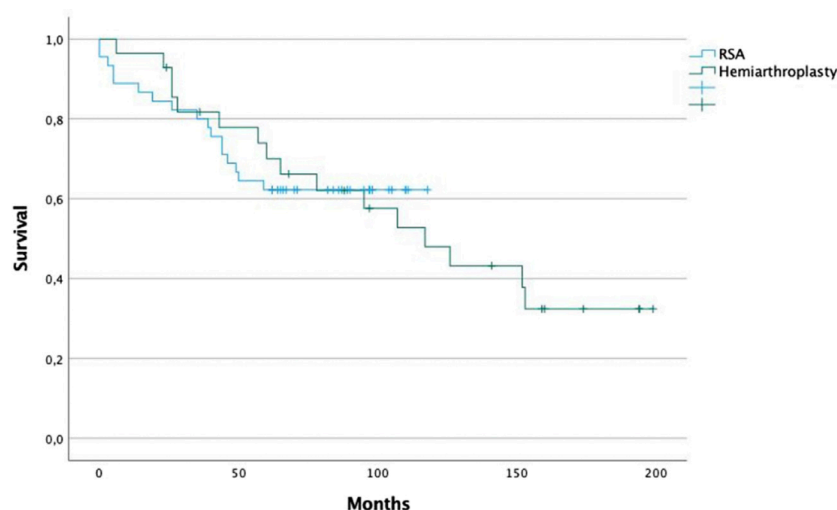
Table 2. Surgical characteristics

Variable	Hemiarthroplasty		RSA		P values
	n (%)	Mean (SD)	n (%)	Mean (SD)	
Time to surgery (d)		2.4 (2.5)		6.8 (9.3)	.017
Length of Hospital stay after surgery (d)		3.6 (3.3)		6.8 (13.6)	.685
Transfusion	3 (10.7)		6 (13.3)		.783
Follow-up (mo)		96.3 (60.3)		64.2 (34.0)	.048
RSA, reverse shoulder arthroplasty; SD, standard deviation.					

There were no significant differences between the HA group and the RSA group regarding, gender, ASA score, need for transfusion or hospital stay. Patients in the HA group were younger ($p<0.001$), with a lower time from fracture to surgery ($p=0.017$).

Survival rate

For the assessment of survival rates, the need for revision surgery or the patient's death was considered as a survival endpoint. Regarding HA, only one patient with HA died within a year, corresponding to a survival rate of 96.4%. The survival rate of the HA group at 5 years was 70%. (Figure 1). Concerning the RSA group, five patients died within a year, corresponding to a survival rate of 88.9%. The survival rate at 5 years was 66.2 %. (Figure 1). The mean survival time for HA was 117.9 months (13.6 SD, CI 95% 91.2-144.6), and for RSA it was 84.0 months (6.7 SD; CI 95% 59.1-82.1) although the difference in survival time did not reach statistical significance ($p=0.974$).

**Figure 1.** RSA and HA survival.

Concerning HA, no differences were identified for survival rates between subgroups under or over 80 years of age ($p=0.423$) or subgrouping by ASA score ($p=0.546$). Regarding RSA, there were also no differences in the survival rates between subgroups under or over 80 years of age, although the mean survival rate for the group under 80 was 80.6 (8.1 SD) and for the group over 80 was 62.1 (8.3 SD) ($p=0.166$) (Figure 2a). On the other hand, the survival rates of the patients with RSA were significantly higher for ASA 2 compared to ASA 3 or 4 ($p=0.01$, 87.2 $\pm$ 6.1 and 53.0 $\pm$ 8.7, respectively) (Figure 2b).

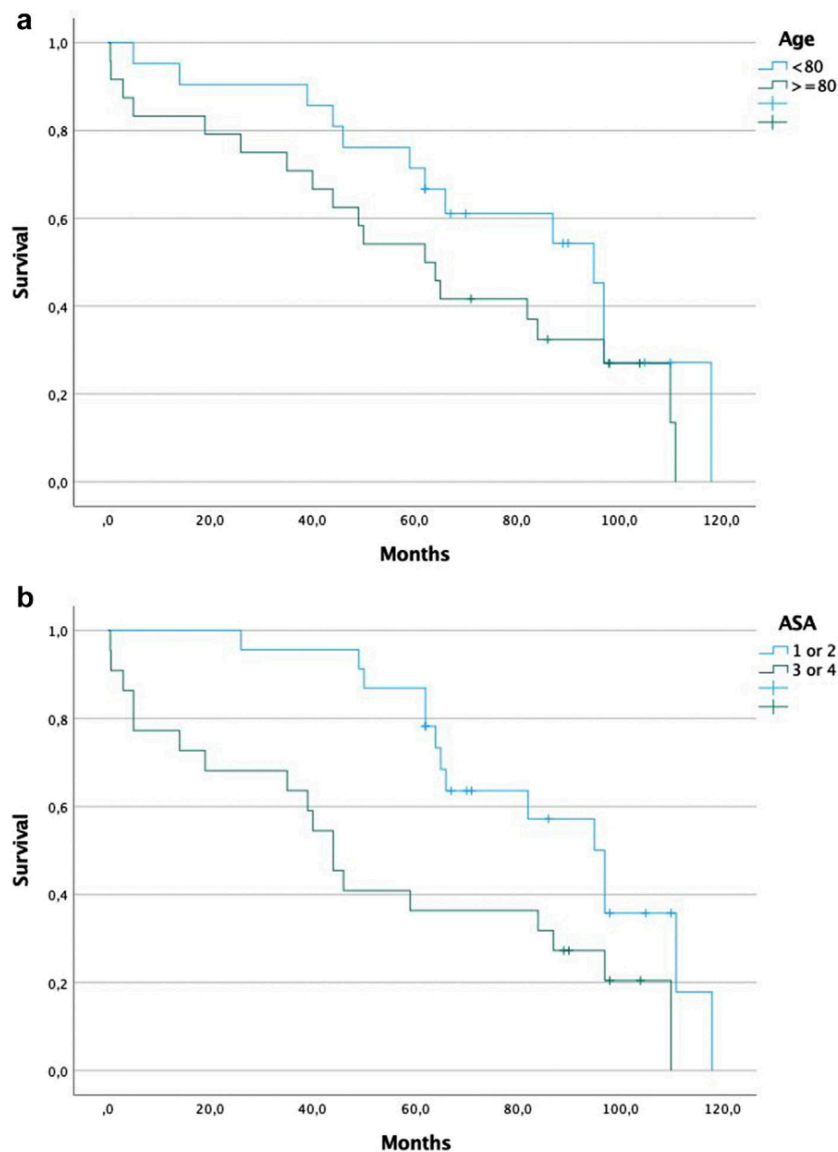


Figure 2. (a) RSA survival rate by age. (b) RSA survival rate by ASA score. ASA, American Society of Anesthesiologists.

Risk factors for mortality

There was only one early death in the HA group, so no variables were tested. No risk factors were identified for mortality within 5 years (gender $p=0.520$; ASA $p=0.482$; age $p=0.859$; time until surgery $p=0.886$; Charlson index $p=0.839$) (table 3). In the RSA group, with a higher ASA score ($p=0.023$) and a longer time until surgery was associated ($p=0.013$) with a higher 6 months mortality. No other associations were found (table 4). The ASA score ($p<0.001$) was the only risk factor identified for mortality at 5 years (table 5).

Table 3. Risk factors for mortality within 5 y in HA group

Variable	Survival (n = 18)		Dead within 5 y (n = 10)		P values
	n (%)	Mean (SD)	n (%)	Mean (SD)	
Gender (female)	16 (88.9)		8 (80)		.520
ASA (3)	6 (33.3)		4 (40)		.482
Age		74.7 (5.2)		75 (3.7)	.859
Time to surgery (d)		2.4 (2.8)		2.3 (1.9)	.886
Charlson Index score (5)	3 (16.6)		2 (20)		.839

SD, standard deviation; ASA, American Society of Anesthesiologists.

Table 4. Risk factors for mortality within 6 months in RSA group

Variable	Survival (n = 40)		Dead within 6 mo (n = 5)		P values
	n (%)	Mean (SD)	n (%)	Mean (SD)	
Gender (female)	36 (90)		3 (60)		.130
Dementia	4 (10)		2 (40)		.107
ASA (3)	16 (40)		4 (80)		.023
Age		79.4 (5.0)		84.6 (4.4)	.55
Time to surgery (d)		7.3 (9.7)		3.0 (1.2)	.013
Charlson Index score (5)	9 (22.5)		2 (40)		.562

SD, standard deviation; ASA, American Society of Anesthesiologists; RSA, reverse shoulder arthroplasty.

Table 5. Risk factors for mortality within 5 y in RSA group

Variable	Survival (n = 28)		Dead within 5 y (n = 17)		P values
	n (%)	Mean (SD)	n (%)	Mean (SD)	
Gender (female)	25 (89)		14 (82)		.658
Dementia	4 (14.3)		2 (11.8)		.808
ASA (3)	8 (29)		14 (82)		<.01
Age		79.2 (5.1)		81.3 (5.2)	.196
Time to surgery (d)		6.7 (7.4)		6.9 (12.0)	.928
Charlson Index core (5)	8 (28.6)		3 (17.6)		.464

SD, standard deviation; ASA, American Society of Anesthesiologists; RSA, reverse shoulder arthroplasty.

Functional outcomes

In the group of hemiarthroplasties, 56% returned to their normal daily living activities, while in the RSA 92% did that, representing a significant difference ($p=0.007$). Regarding acquiring functional mobilities, in the group of hemiarthroplasties only 28% had functional mobilities compared with 56% in the group of RSA ($p=0.057$).

Complications

The following complications were evaluated: tuberosities nonunion, tuberosities malunion, heterotopic ossification, glenoid erosion, notching, loosening, re-operation, infection, and instability. There were 22 patients (78.6%) with complications in the HA group, and 28 (62.2%) in the RSA group ($p=0.144$).

Hemiarthroplasties had more prosthetic loosening (lucent zone of more than 2 mm at the bone-prosthesis interface or at the bone-cement interface) compared with RSA. We did not find migration or movement of the humeral component in the different implants. Three hemiarthroplasties were converted to RSA, and we verified 1 RSA infection. The complications of both procedures are presented in table 6.

Table 6. Complications

Overall complications	Hemiarthroplasty n (%)	RSA n (%)	P values
	22 (78.6%)	28 (62.2%)	.144
Loosening	6 (21.4)	2 (4.4)	.024
Heterotopic ossification	7 (25)	10 (22.2)	.785
Tuberosity nonunion	13 (46.4)	15 (33.3)	.263
Reoperation	3 (11)	1 (2.2)	.121
RSA, reverse shoulder arthroplasty.			

4. DISCUSSION

Treatment of PHF depends on fracture type, stability, and fragment displacement. Approximately 80% of PHF are nondisplaced or minimally displaced [22], and nonoperative treatment is successful [23]. The optimum treatment becomes less clear in more complex displaced fracture patterns such as those occurring in the elderly.

Over the last decade there has been an increase in the use of RSA, especially among elderly patients [24, 25]. The poor bone quality of these patients causes complex fracture patterns that render ORIF impossible to perform, and when they are performed, they often entail high complication rates, up to 50% in some series [27].

Grubhofer et al (2016) reported very satisfactory subjective and objective outcomes of RSA for displaced PHF in the osteoporotic bones [28]. Villodre-Jiménez et al (2016) advocated the use of RSA for 3- and 4-part PHF in elderly patients [29]. In a retrospective study of 179 RSA performed in patients older than 80 years, Clark et al (2019) reported a low rate of medical and surgical complications and concluded that age alone should not be a contra-indication to primary RSA.[29]

Others advocated that this procedure should not be considered in elderly patients because recent studies failed to show better functional results after surgical treatment (ORIF, HA and RSA) when compared to conservative treatment and thus concluded that there is no benefit in surgery [30, 31]. Thus, the identification of risk factors for mortality in these patients proves essential.

Driven by this literature that indicated RSA as probably the best surgical option for complex fractures of the proximal humerus in elderly people, it was the choice of our shoulder unit to preferentially use RSA instead of HA from January 2010 onwards. This study reveals this change of option and seeks to retrospectively assess the differences using these two concepts in an aging and often debilitated population.

In this study, patients who underwent RSA as a primary treatment for displaced PHF had a high survival rate – 88.9% at 1 year and 66.2% at 5 years - with a one-year mortality rate of 8.1%, similar to other studies.[1, 3] A large population-based study in Canada reported a 1-year mortality rate for elderly patients with PHF between 10.2% and 22.6% in men and between 5.3% and 10.2% in women.[19] Maugender et al. (2019) observed a higher mortality rate during the first-year post-fracture in men (who were younger and with more comorbidities). No significant differences were found at one-year regarding gender, age, diabetes, dyslipidemia, hypertension, history of stroke, obesity, dementia or other additional fractures.[3]

This study showed that a higher ASA score, but not older age, is associated with early mortality and overall mortality in RSA, suggesting that age alone should not represent an absolute contra-indication for RSA.

Comparing the two surgical options, both had similar survival rates and complication rates (a slightly higher rate of stem loosening and reoperation in the HA group, but not statistically significant). Furthermore, RSA allowed for a higher rate of return to activities of daily living (92% vs. 56%) and a higher probability of a functional shoulder mobility. These factors, particularly in an aging population, often living alone and in need of a quick recovery, establish RSA as the surgical alternative yielding the best results.

Nonetheless, elderly people should always have a rigorous pre-operative assessment and be optimized according to the surgical risk profile before surgery and the option for surgical treatment should always be case-by-case evaluated.

This study has some limitations, particularly owing to its retrospective nature and to the relatively small number of patients in each group, which may render the data insufficient to detect smaller differences between groups. Especially in studying mortality within the subgroups, much higher subject numbers are needed to meaningfully compare groups and account for confounding factors. The relatively long follow-up, the use of the same implant in all surgeries and the fact that all surgeries were performed by senior shoulder surgeons are the strengths of this study. Thus, more studies are needed to clarify all the factors that can help surgeons with the decision procedure.

5. CONCLUSION

Patients who underwent RSA as a primary treatment for displaced PHF had a high survival rate (88.9% at 1 year and 66.2% at 5 years) and better functional results compared to patients treated with HA. Higher ASA scores are a risk factor for early mortality and should be taken into account to prevent early death. Frailty, together with an ASA score, may aid in identifying poor surgical candidates who may be proposed for conservative treatment. With proper patient selection, RSA is a safe procedure for the treatment of PHF, especially in an elderly population.

REFERENCES

1. Rotman, D., et al., Mortality After Complex Displaced Proximal Humerus Fractures in Elderly Patients: Conservative Versus Operative Treatment with Reverse Total Shoulder Arthroplasty. *Geriatr Orthop Surg Rehabil*, 2018. 9: p. 2151459318795241.
2. Verdano, M.A., et al., Grammont versus lateralizing reverse shoulder arthroplasty for proximal humerus fracture: functional and radiographic outcomes. *Musculoskelet Surg*, 2018. 102(Suppl 1): p. 57-65.
3. Maugendre, E., et al., Epidemiology and mortality in older patients treated by reverse shoulder arthroplasty for displaced proximal humerus fractures. *Orthop Traumatol Surg Res*, 2019. 105(8): p. 1509-1513.
4. Fitschen-Oestern, S., et al., Reversed shoulder arthroplasty for the treatment of proximal humerus fracture in the elderly. *J Orthop*, 2020. 17: p. 180-186.
5. Court-Brown, C.M. and B. Caesar, Epidemiology of adult fractures: A review. *Injury*, 2006. 37(8): p. 691-7.
6. Kim, S.H., R.M. Szabo, and R.A. Marder, Epidemiology of humerus fractures in the United States: nationwide emergency department sample, 2008. *Arthritis Care Res (Hoboken)*, 2012. 64(3): p. 407-14.
7. Launonen, A.P., et al., Epidemiology of proximal humerus fractures. *Arch Osteoporos*, 2015. 10: p. 209.
8. Myeroff, C.M., et al., Predictors of Mortality in Elder Patients With Proximal Humeral Fracture. *Geriatr Orthop Surg Rehabil*, 2018. 9: p. 2151458517728155.
9. Palvanen, M., et al., Update in the epidemiology of proximal humeral fractures. *Clin Orthop Relat Res*, 2006. 442: p. 87-92.
10. Dhaliwal, K., et al., The Role of Reverse Shoulder Arthroplasty in Elderly Trauma: A Systematic Review. *Cureus*, 2020. 12(5): p. e8180.
11. McLean, A.S., et al., Nationwide trends in management of proximal humeral fractures: an analysis of 77,966 cases from 2008 to 2017. *J Shoulder Elbow Surg*, 2019. 28(11): p. 2072-2078.
12. Egol, K.A., et al., Early complications in proximal humerus fractures (OTA Types 11) treated with locked plates. *J Orthop Trauma*, 2008. 22(3): p. 159-64.
13. Robinson, C.M., et al., Complications and Long-Term Outcomes of Open Reduction and Plate Fixation of Proximal Humeral Fractures. *J Bone Joint Surg Am*, 2019. 101(23): p. 2129-2139.

14. Wiesel, B.B., S. Nagda, and G.R. Williams, Technical pitfalls of shoulder hemiarthroplasty for fracture management. *Orthop Clin North Am*, 2013. 44(3): p. 317-29, viii.
15. Kontakis, G., et al., Early management of proximal humeral fractures with hemiarthroplasty: a systematic review. *J Bone Joint Surg Br*, 2008. 90(11): p. 1407-13.
16. Valenti, P., et al., Shoulder hemiarthroplasty for proximal humeral fractures: analysis of clinical and radiographic outcomes at midterm follow-up: a series of 51 patients. *Eur J Orthop Surg Traumatol*, 2017. 27(3): p. 309-315.
17. Goldman, R.T., et al., Functional outcome after humeral head replacement for acute three- and four-part proximal humeral fractures. *J Shoulder Elbow Surg*, 1995. 4(2): p. 81-6.
18. Bufquin, T., et al., Reverse shoulder arthroplasty for the treatment of three- and four-part fractures of the proximal humerus in the elderly: a prospective review of 43 cases with a short-term follow-up. *J Bone Joint Surg Br*, 2007. 89(4): p. 516-20.
19. Morin, S., et al., Mortality rates after incident non-traumatic fractures in older men and women. *Osteoporos Int*, 2011. 22(9): p. 2439-48.
20. Brauer, C.A., et al., Incidence and mortality of hip fractures in the United States. *JAMA*, 2009. 302(14): p. 1573-9.
21. Johnell, O., et al., Mortality after osteoporotic fractures. *Osteoporos Int*, 2004. 15(1): p. 38-42.
22. Villodre-Jimenez, J., et al., Reverse shoulder arthroplasty in 3- and 4-part proximal humeral fractures in patients aged more than 65 years: Results and complications. *Rev Esp Cir Ortop Traumatol*, 2017. 61(1): p. 43-50.
23. Gaebler, C., M.M. McQueen, and C.M. Court-Brown. Minimally displaced proximal humeral fractures: epidemiology and outcome in 507 cases. *Acta Orthop Scand*, 2003. 74(5): p. 580-5.
24. Schairer, W.W., et al., Arthroplasty treatment of proximal humerus fractures: 14-year trends in the United States. *Phys Sportsmed*, 2017. 45(2): p. 92-96.
25. Schairer, W.W., et al., Reverse shoulder arthroplasty versus hemiarthroplasty for treatment of proximal humerus fractures. *J Shoulder Elbow Surg*, 2015. 24(10): p. 1560-6.
26. Boileau, P., et al., Reverse shoulder arthroplasty for acute fractures in the elderly: is it worth reattaching the tuberosities? *J Shoulder Elbow Surg*, 2019. 28(3): p. 437-444.
27. Owsley, K.C. and J.T. Gorczyca, Fracture displacement and screw cutout after open reduction and locked plate fixation of proximal humeral fractures [corrected]. *J Bone Joint Surg Am*, 2008. 90(2): p. 233-40.

28. Grubhofer, F., et al., Reverse total shoulder arthroplasty for acute head-splitting, 3- and 4-part fractures of the proximal humerus in the elderly. *J Shoulder Elbow Surg*, 2016. 25(10): p. 1690-8.
29. Clark, N.J., et al., Primary reverse shoulder arthroplasty in patients older than 80 years of age: survival and outcomes. *Bone Joint J*, 2019. 101-B (12): p. 1520-1525.
30. Rangan, A., et al., Surgical vs nonsurgical treatment of adults with displaced fractures of the proximal humerus: the PROFHER randomized clinical trial. *JAMA*, 2015. 313(10): p. 1037-47.
31. Roberson, T.A., et al., Nonoperative management versus reverse shoulder arthroplasty for treatment of 3- and 4-part proximal humeral fractures in older adults. *J Shoulder Elbow Surg*, 2017. 26(6): p. 1017-1022.

V.

TUBEROSITY HEALING AND FUNCTIONAL RESULTS

1. INTRODUCTION

The last 20 years witnessed an increased incidence of PHF, representing 5% of all fractures; currently, this is the third most frequent fracture among the elderly.[1, 2] Moreover, fractures in this population tend to be more complex, such as three- or four-part fractures and dislocated fractures.[3] These data show that PHF is a public health problem that tends to get worse as the population ages.

In most PHF, especially the simpler ones, conservative treatment remains the therapy of choice, with good results.[4, 5] However, the optimal treatment for three- or four-part fractures in the elderly remains questionable. Decisions must be individualized, depending on the comorbidities, functional needs, bone quality and surgeon experience.[6] Several studies suggest that ORIF and HA are not recommended in large comminution fractures and in patients with osteoporotic bone.[7] In such cases, ORO is associated with high rates of humeral head avascular necrosis, loss of glenoid reduction and screw-induced destruction. The results of the HAs are unpromising and unpredictable[8]: a randomized trial[9] demonstrated a functional outcome similar to that of the conservative treatment. The bimodal distribution of the HA results, that is, either excellent or very poor, depends on tuberosity healing,[10] which is usually decreased in patients with osteoporotic bone and/or comminuted fractures, as in the elderly.[11, 12]

Thus, RSA has gained popularity in the treatment of these fractures because their results are more consistent and predictable.[8] Garrigues et al.[13] concluded that patients with RSA present better functional outcomes than patients with HA. Since RSA were designed not to require the rotator cuff, tuberosity healing was not a concern in the initial studies.[14] However, the absence of the rotator cuff, especially the infraspinatus and the minor teres, is associated with worse results (decreased external rotation). Subsequent studies have shown that tuberosity healing leads to superior functional outcomes in both RSA and HA.[8, 15, 16] Although we are aware of the significance of tuberosity healing in obtaining better functional results, few studies show its clinical impact on the patient.

The main objective of the present study was to compare the functional results of patients with complex PHF submitted to RSA and healed or non-healed tuberosities. The secondary objective was to determine the rate of tuberosity healing with this type of prosthesis.

2. MATERIAL AND METHODS

Study Design

After approval by the institutional Ethics Committee, a retrospective cohort study with prospective data collection was performed between January 2011 and December 2015, aiming to evaluate tuberosity healing in patients aged ≥ 65 years undergoing RSA for PHF treatment. The inclusion criteria were patients aged ≥ 65 years, submitted to RSA placement due to complex PHF in 3 or 4 parts according to the Neer classification,[5] with or without dislocation, and a minimum follow-up time of 24 months. Patients with previous local surgery and a time from the traumatic event to the surgery longer than four weeks were excluded. Surgeries were performed by two senior orthopedists dedicated to shoulder pathology, after the patient's consent.

During the study period, 46 patients underwent RSA for PHF treatment. After applying the inclusion and exclusion criteria, 28 patients were included in the study (Figure 1).

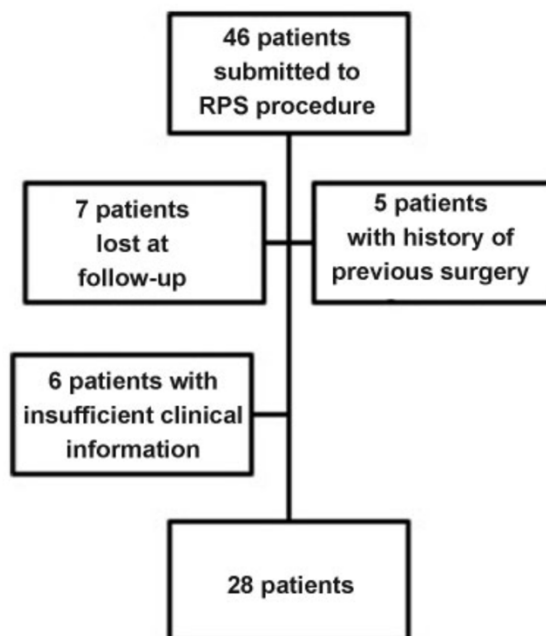


Figure 1. Patients included in the study after the application of the inclusion and exclusion criteria. Abbreviation: RPSs.

Surgical Technique

The surgeries were performed under general anesthesia with the patients in the “beach chair” position and using the deltopectoral approach. The prosthesis was always the same (Aequalis Reversed Fracture, Tornier, Edina, MN, US).

The following signs of fracture irreparability were also evaluated intraoperatively: a) tuberosity comminution; b) indistinguishable fragments; c) osteoporotic bone; d) marked fracture deviation with calcar comminution.

The long portion of the biceps (LPB) tendon and its gutter served as references for the attachment of the tuberosities. The LPB tenodesis and supraspinatus tendon excision were performed systematically. Tuberosity fixation was prepared with four non-absorbable sutures (Ethibond no. 5; Ethicon, Somerville, New Jersey, US), two through the infraspinatus tendon and two through the minor teres. Two additional sutures were passed through the subscapularis tendon in four-part fractures.

After channel preparation, the stem height was measured using the calcar and tuberosity reduction as references. If the calcar was absent, the soft tissue tension after prosthesis reduction was evaluated: deltoid muscle and joint tendon tension, as well as the distance between the upper edge of the pectoralis major muscle and the acromion, which should be about 5.6 cm.[17] The prosthesis version used the system guide with the forearm as a reference, using 20° of retroversion to provide greater stability.[18]

The glenoid was prepared and the definitive components were placed. The stems were cemented distally to the metaphyseal region, enabling a hybrid fixation. After the cement dried, the prosthesis was reduced, the soft tissue height and tension were evaluated again, and the size of the polyethylene was chosen. The soft parts were properly tensioned when it was difficult to achieve dislocation with axial and lateral forces.[19]

Tuberosity fixation was performed according to Pascal Boileau,[20] using the previously placed non-absorbable sutures and adding another two similar sutures passed through two holes in the humeral shaft prior to cementation. Thus, after tuberosity reduction, the infraspinatus, minor teres and subscapular tendon sutures fix the tuberosities as horizontal cerclages, and the wires passing through the diaphysis neutralize the construction as two vertical tension bands (one for each tuberosity).

Postoperatively, the limb was immobilized with support for 3 weeks, and then pendular movements were allowed. Elevation and abduction movements were only allowed after six weeks, followed by appropriate rehabilitation.

Radiological Evaluation

Tuberosity healing was assessed radiographically using neutral, internal and external rotation and lateral views six months after surgery.[11] Tuberosities above the polyethylene, more than 1 cm away from their anatomical position or not present were considered non-healed. In case of doubt, a CT scan was requested at six months after surgery as an additional tool, enabling the evaluation of bone continuity between the diaphysis and the tuberosities. The classification of the fractures and tuberosity healing were determined by two shoulder surgeons, and all divergences were solved with the opinion of a third shoulder surgeon.

Functional Evaluation

All patients were evaluated at 2, 6 and 12 weeks, 6 and 12 months and then annually. The functional results were determined using the Constant scoring (CS) system and recording active mobility in forward elevation (FE), abduction, external rotation (ER) and internal rotation (IR). The range of motion was measured in degrees with a goniometer, and the rotations were performed with the elbow close to the body. The Visual Analogue Scale (VAS) was also used. Intra- and postoperative complications were recorded. The results of the patients with healed and non-healed tuberosities were compared.

Statistical Analysis

The mean values of the CS, range of motion and VAS were compared using the nonparametric Mann-Whitney U test due to the sample size. The Pearson Chi-squared test was used in binomial variables to safeguard cell counts ≥ 5 .

3. RESULTS

Epidemiological Data

In total, 28 patients were included: 22 (78.6%) females and 6 (21.4%) males, with a mean age of 70.1 years (ranging from 65.2 to 89.8 years). There were 5 3-part fractures and 23

4- part fractures. The mean follow-up was of 58.4 months (ranging from 32.5 to 88.2 months).

Tuberosity Healing

Healing was observed in 21 (75%) patients (Figure 2). In total, 3 patients had tuberosity resorption, and 4 had tuberosity migration, representing a total of 7 (25%) patients with non-healed tuberosities (Figure 3). Table 1 shows the distribution of independent variables in both groups.

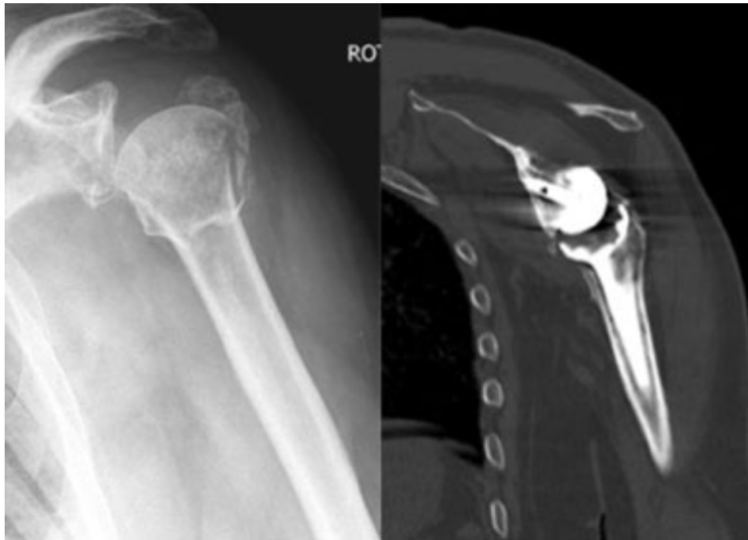


Figure 2. CT scan demonstrating tuberosity healing.

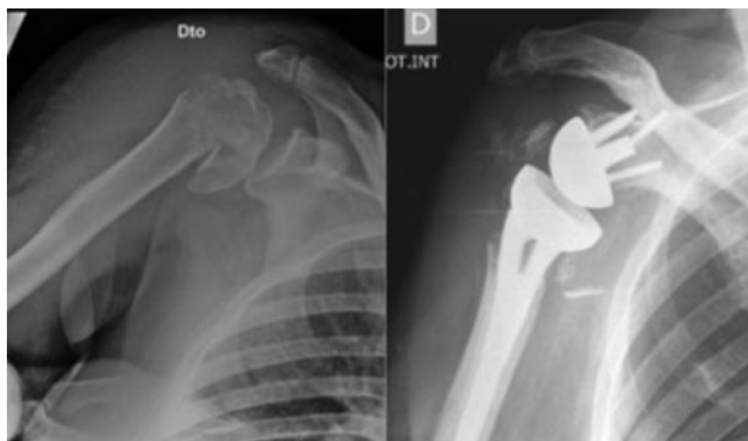


Figure 3. Radiograph showing non-healed tuberosities.

Table 1. Tuberosity healing and distribution of independent variables in both groups

Variable	Tuberosity healing		p-value
	Yes (n = 21)	No (n = 7)	
Female gender (%)	16 (76.2%)	6 (85.7%)	0.595*
Median age ¹ [minimum-maximum]	73.6 [60.2–82.1]	70.9 [60.7–89.8]	0.876**
Median follow-up period (months) [minimum-maximum]	56.5 [33.2–88.2]	46.8 [32.5–73.1]	0.140**

Notes: Distribution of independent variables by study group and respective statistical comparison; no statistical differences were observed for any variable. *Chi-squared test. **Mann-Whitney U test.

Functional Results

Most patients (75.0%) presented no pain at rest or during their daily activities.

The differences in the functional outcomes of patients with healed and non-healed tuberosities are described in Table 2. Statistically significant differences were observed regarding the CS, FE, IR and ER. Figures 4–8 demonstrate the variable distribution in both groups.

Table 2. Comparison of functional results in both groups (healed versus non-healed tuberosities)

Functional evaluation	Tuberosity healing		p-value
	Yes (n = 21)	No (n = 7)	
Constant score	79.0 (5;0)	55.0 (11;0)	$p < 0.001^*$
Forward elevation	135.0° (46;0°)	90.0° (70;0°)	$p = 0.02^*$
Abduction	105.0° (45;0°)	75.0° (60;0°)	$p = 0.435$
Internal rotation	60.0° (45;0°)	30.0° (0;0°)	$p = 0.01^*$
External rotation	60.0° (32;5°)	30.0° (0;0°)	$p = 0.03^*$
Visual Analog Scale score	1.0 (0;5)	1.0 (1;0)	$p = 0.836$

Note: Continuous variables were presented as median values and the respective 25th percentile-75th percentiles. * $p < 0.05$.

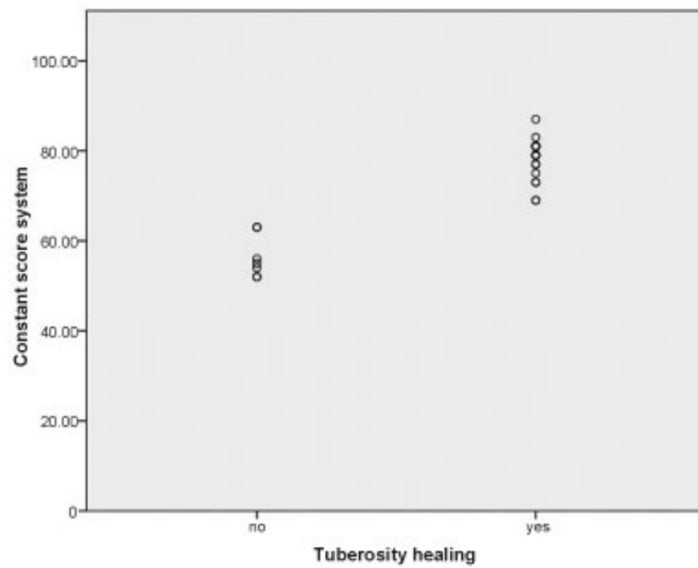


Figure 4. Constant score distribution by groups (healed versus non-healed tuberosties).

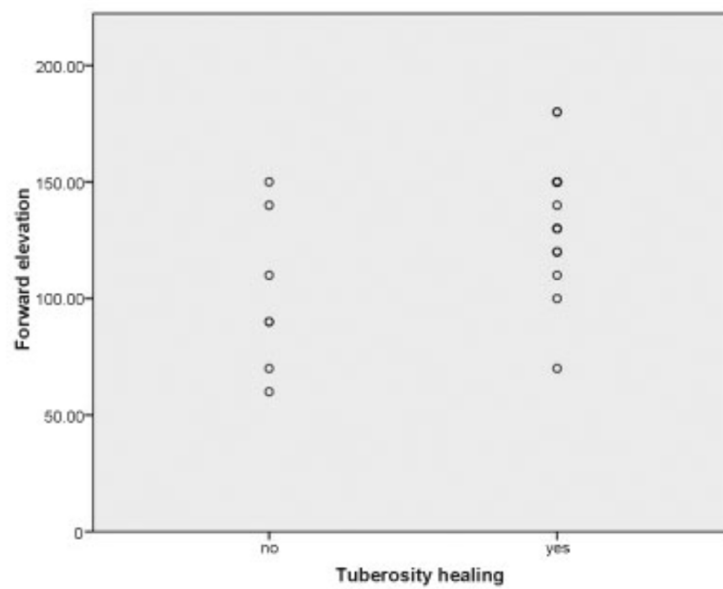


Figure 5. Distribution of forward shoulder elevation by groups (healed versus non-healed tuberosties).

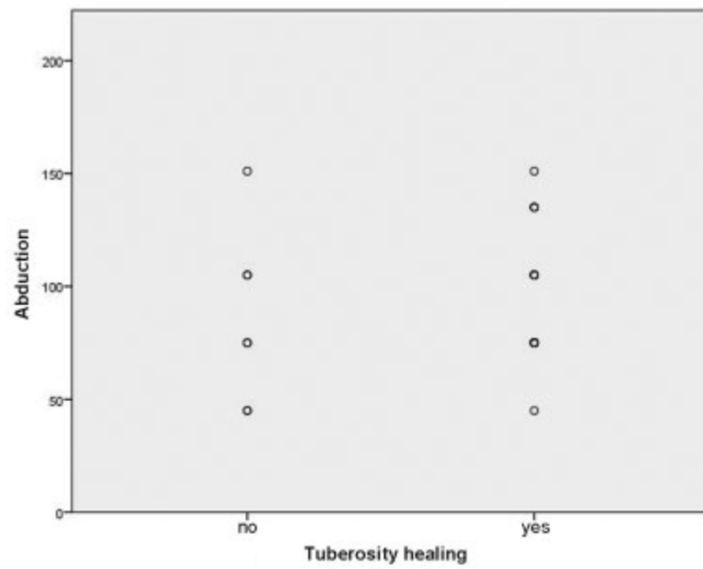


Figure 6. Shoulder abduction distribution by groups (healed versus non- healed tuberosities).

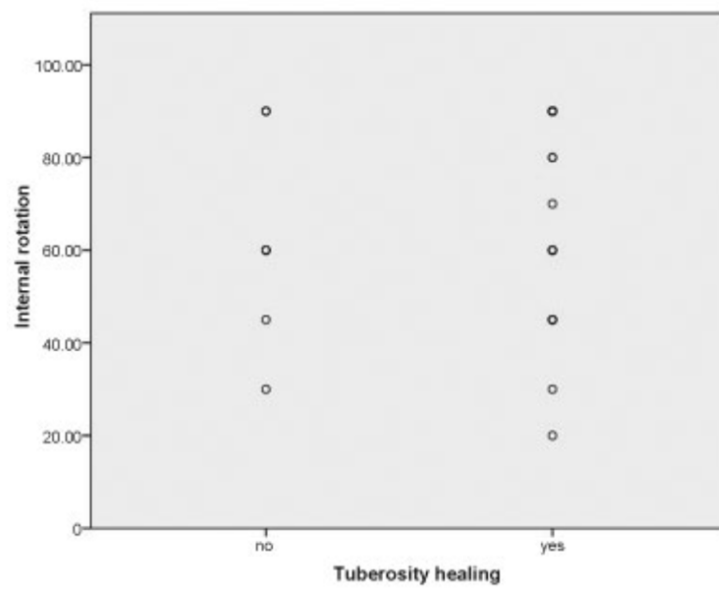


Figure 7. Distribution of internal shoulder rotation by groups (healed versus non-healed tuberosities).

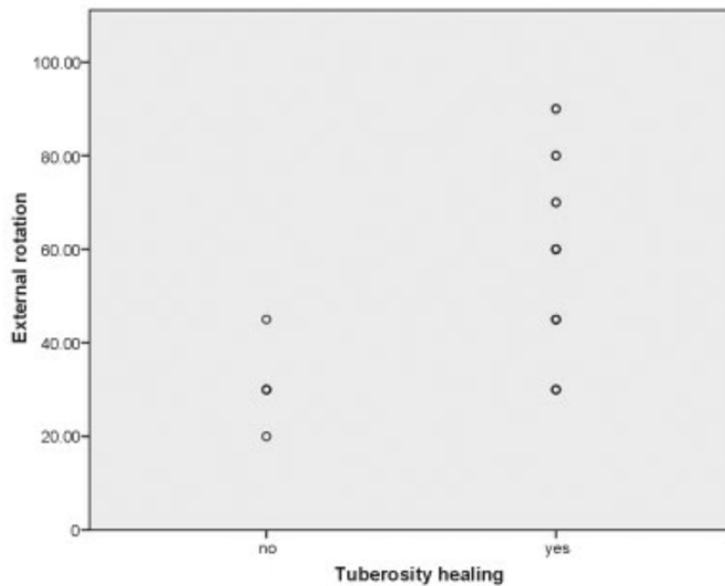


Figure 8. Distribution of external shoulder rotation by groups (healed versus non-healed tuberosities).

In the multivariate analysis of the potential influence of gender and/or age on outcomes, a statistically significant non-interference was found for the CS ($p=0.630$ and $p=0.868$ respectively), FE ($p=0.157$ and $p=0.853$ respectively), abduction ($p=0.566$ and $p=0.497$ respectively), IR ($p=0.431$ and $p=0.601$ respectively), ER ($p=0.239$ and $p=0.526$ respectively) and VAS ($p=0.164$ and $p=0.722$ respectively). However, when healing was isolated as a variable in the model, only the CS ($p < 0.001$) and IR ($p=0.002$) sustained a statistically significant relationship.

Complications

There were no episodes of dislocation or instability. There was an acute superficial infection that was submitted to debridement and corresponded to one of the cases of non-healed tuberosity.

4. DISCUSSION

RSA are increasingly used in patients with PHF, especially in the elderly. Initially, the longevity of these prostheses was a concern, but good outcomes from medium- and long-term studies have expanded their use. Du et al.[21] reported that RSA were associated with a significant increase in CS and decreased re-interventions compared to HA. In addition, Klein et al.[16] reported improvements in the CS and a short-form health survey. In a prospective study evaluating patients with complex PHF undergoing RSA, Bufquin et al.[15] concluded that tuberosity non-healing does not necessarily lead to a poor outcome. Torrens et al.[22] stated that clinical results are superimposable, not depending on tuberosity healing. RSA are based on the classical principles of the prosthesis developed by Grammont: a) a semi-constrictive fixed point (fulcrum) prosthesis enabling the deltoid to elevate the arm in a way that does not require rotator cuff action, and b) a lower, medialized center of rotation, which enables deltoid extension and thus decreases the force required for arm abduction.[23, 24] As such, RSA can lead to good outcomes even without tuberosity healing. However, more recent studies suggest that tuberosity integration and proper rotator cuff function have a functional benefit for patients, increasing range of motion, especially in rotation. Our study found a statistically significant improvement in FE (127.5° versus 101.4), ER (60° versus 30°) and IR (64.8° versus 34.3°). These results reinforce the data reported in the literature. Lenarz et al.[25] described an FE of 139° and an ER of 27°, whereas Valenti et al.[26] obtained a CS of 55, 112° of FE, 97° of abduction and 12.7° of ER. Gallinet et al.[8] demonstrated 104° of FE and 33° of ER. A recent systematic review[27] summarizes well the results of these studies, concluding that tuberosity healing seems to translate into superior functional outcomes, especially regarding rotations. In addition, a slight improvement in the range of motion of the patients can translate into a real improvement in their quality of life. We observed that increased patient mobility corresponded to CS improvement (79 versus 55). Boileau et al.[28] summarize their study by stating that tuberosity healing not only improves FE and ER, but also the patients' quality of life.

As for the second objective of the study, tuberosity healing occurred in 75% of the patients. This percentage is in line with more recent studies,[22, 29, 30] and it is superior to older works. Boileau et al.[28] describe a higher healing rate, of 84%, arguing that tuberosity healing in fractures submitted to RSA is a reproducible procedure even in the elderly. In addition, newly developed prostheses, designed specifically for fractures and presenting a window in the metaphyseal region, enable better tuberosity integration and healing.

Some studies advocate that all plans are improved by tuberosity healing.[29] We had no significant improvement in abduction (106° versus 83°), but this measure was superior in patients with healed tuberosities. The VAS scores were similar in both groups, showing that tuberosity healing does not interfere with pain.

The procedure showed a low incidence of complications, with only one infection, which was completely eliminated with debridement and antibiotic therapy. There were no dislocations, instabilities or neurological injuries.

The limitations of the present work are those inherent to retrospective studies. Furthermore, the use of nonparametric tests, due to the relatively small sample size, does not enable a wide discrimination in the data analysis despite the statistical significance of the results. Further randomized studies are required to definitively prove the superiority of the functional outcomes associated with tuberosity healing.

In conclusion, our study showed the superiority of the CS, FE, ER and IR when the tuberosities were healed, which occurred in 75% of the cases.

REFERENCES

1. Sanders, R.J., et al., *Locking plate versus nonsurgical treatment for proximal humeral fractures: better midterm outcome with nonsurgical treatment*. J Shoulder Elbow Surg, 2011. **20**(7): p. 1118-24.
2. Khatib, O., I. Onyekwelu, and J.D. Zuckerman, *The incidence of proximal humeral fractures in New York State from 1990 through 2010 with an emphasis on operative management in patients aged 65 years or older*. Journal of Shoulder and Elbow Surgery, 2014. **23**(9): p. 1356-1362.
3. Court-Brown, C.M., A. Garg, and M.M. McQueen, *The epidemiology of proximal humeral fractures*. Acta Orthop Scand, 2001. **72**(4): p. 365-71.
4. Court-Brown, C.M., A. Garg, and M.M. McQueen, *The translated two-part fracture of the proximal humerus. Epidemiology and outcome in the older patient*. J Bone Joint Surg Br, 2001. **83**(6): p. 799-804.
5. Neer, C.S., 2nd, *Displaced proximal humeral fractures. I. Classification and evaluation*. J Bone Joint Surg Am, 1970. **52**(6): p. 1077-89.
6. Maier, D., et al., *Proximal humeral fracture treatment in adults*. J Bone Joint Surg Am, 2014. **96**(3): p. 251-61.
7. Jobin, C.M., et al., *Reverse shoulder arthroplasty for the management of proximal humerus fractures*. J Am Acad Orthop Surg, 2015. **23**(3): p. 190-201.
8. Gallinet, D., et al., *Three or four parts complex proximal humerus fractures: hemiarthroplasty versus reverse prosthesis: a comparative study of 40 cases*. Orthop Traumatol Surg Res, 2009. **95**(1): p. 48-55.
9. Boons, H.W., et al., *Hemiarthroplasty for humeral four-part fractures for patients 65 years and older: a randomized controlled trial*. Clin Orthop Relat Res, 2012. **470**(12): p. 3483-91.
10. Sirveaux, F., O. Roche, and D. Mole, *Shoulder arthroplasty for acute proximal humerus fracture*. Orthop Traumatol Surg Res, 2010. **96**(6): p. 683-94.
11. Boileau, P., et al., *Can surgeons predict what makes a good hemiarthroplasty for fracture?* J Shoulder Elbow Surg, 2013. **22**(11): p. 1495-506.
12. Boileau, P., et al., *Tuberosity malposition and migration: reasons for poor outcomes after hemiarthroplasty for displaced fractures of the proximal humerus*. J Shoulder Elbow Surg, 2002. **11**(5): p. 401-12.

13. Garrigues, G.E., et al., *Hemiarthroplasty versus reverse total shoulder arthroplasty for acute proximal humerus fractures in elderly patients*. Orthopedics, 2012. **35**(5): p. e703-8.
14. Cazeneuve, J.F. and D.J. Cristofari, *The reverse shoulder prosthesis in the treatment of fractures of the proximal humerus in the elderly*. J Bone Joint Surg Br, 2010. **92**(4): p. 535-9.
15. Bufquin, T., et al., *Reverse shoulder arthroplasty for the treatment of three- and four-part fractures of the proximal humerus in the elderly: a prospective review of 43 cases with a short-term follow-up*. J Bone Joint Surg Br, 2007. **89**(4): p. 516-20.
16. Klein, M., et al., *Treatment of comminuted fractures of the proximal humerus in elderly patients with the Delta III reverse shoulder prosthesis*. J Orthop Trauma, 2008. **22**(10): p. 698-704.
17. Murachovsky, J., et al., *Pectoralis major tendon reference (PMT): a new method for accurate restoration of humeral length with hemiarthroplasty for fracture*. J Shoulder Elbow Surg, 2006. **15**(6): p. 675-8.
18. Nalbone, L., et al., *Optimal positioning of the humeral component in the reverse shoulder prosthesis*. Musculoskelet Surg, 2014. **98**(2): p. 135-42.
19. Ladermann, A., T.B. Edwards, and G. Walch, *Arm lengthening after reverse shoulder arthroplasty: a review*. Int Orthop, 2014. **38**(5): p. 991-1000.
20. Boileau, P., G. Walch, and S.G. Krishnan, *Tuberosity Osteosynthesis and Hemiarthroplasty for Four-Part Fractures of the Proximal Humerus*. Techniques in Shoulder and Elbow Surgery, 2000. **1**(2): p. 96-109.
21. Du, S., et al., *Interventions for Treating 3- or 4-part proximal humeral fractures in elderly patient: A network meta-analysis of randomized controlled trials*. Int J Surg, 2017. **48**: p. 240-246.
22. Torrens, C., et al., *Reverse shoulder arthroplasty for the treatment of acute complex proximal humeral fractures: Influence of greater tuberosity healing on the functional outcomes*. J Orthop Surg (Hong Kong), 2018. **26**(1): p. 2309499018760132.
23. Henninger, H.B., et al., *Effect of deltoid tension and humeral version in reverse total shoulder arthroplasty: a biomechanical study*. J Shoulder Elbow Surg, 2012. **21**(4): p. 483-90.

24. Boileau, P., et al., *Grammont reverse prosthesis: design, rationale, and biomechanics*. J Shoulder Elbow Surg, 2005. **14**(1 Suppl S): p. 147S-161S.
25. Lenarz, C., et al., *Is reverse shoulder arthroplasty appropriate for the treatment of fractures in the older patient? Early observations*. Clin Orthop Relat Res, 2011. **469**(12): p. 3324-31.
26. Valenti, P., et al., *Mid-term outcome of reverse shoulder prostheses in complex proximal humeral fractures*. Acta Orthop Belg, 2012. **78**(4): p. 442-9.
27. Jain, N.P., et al., *Tuberosity healing after reverse shoulder arthroplasty for complex proximal humeral fractures in elderly patients-does it improve outcomes? A systematic review and meta-analysis*. J Shoulder Elbow Surg, 2019. **28**(3): p. e78-e91.
28. Boileau, P., et al., *Reverse shoulder arthroplasty for acute fractures in the elderly: is it worth reattaching the tuberosities?* J Shoulder Elbow Surg, 2019. **28**(3): p. 437-444.
29. Garofalo, R., et al., *Reverse shoulder arthroplasty for proximal humerus fracture using a dedicated stem: radiological outcomes at a minimum 2 years of follow-up-case series*. J Orthop Surg Res, 2015. **10**: p. 129.
30. Formaini, N.T., et al., *Tuberosity healing after reverse shoulder arthroplasty for acute proximal humerus fractures: the "black and tan" technique*. J Shoulder Elbow Surg, 2015. **24**(11): p. e299-306.

VI.

PROSPECTIVE STUDY

1. INTRODUCTION

PHF are often observed fragility fractures in elderly individuals, typically resulting from low-energy trauma mechanisms. These fractures serve as significant indicators of compromised health [1-5]. At 1 year after a PHF, the mortality rate is 10% regardless of treatment [6]. Patients who do not live alone, do not live in their own home, do not participate in recreational activities, and cannot independently perform activities of daily living are at significantly higher risk for poor outcomes [7].

Several factors, such as patient anatomy, fracture pattern, pre-injury functional status, medical comorbidities, and surgeon skill level, make it difficult to successfully regain a functional shoulder. Currently, 67% to 85% of PHF are treated non-operatively [8, 9], and the best treatment for older patients remains controversial. Nevertheless, the rate of surgical intervention is increasing [8, 10]. The use of ORIF has remained stable in recent years, that of HA has decreased, and that of RSA has increased [11].

RSA has become the preferred prosthetic treatment option for complex PHF in older patients requiring surgical treatment because it is less dependent on tuberosity healing for the maintenance of function and stability. Multiple studies have demonstrated improved functional outcomes in patients who underwent RSA compared to those who underwent HA [12]. However, achieving tuberosity healing is desirable after RSA because patients with tuberosity healing may have improved functional outcomes [13].

Tuberosity healing after RSA for fractures depends on several factors, including the repair technique, prosthesis design, patient comorbidities, and postoperative rehabilitation. Implant variables such as an inlay versus an onlay humeral implant, glenosphere offset, humeral component neck–shaft angle, and the use of a humeral implant with a “window” for autologous bone graft change the postoperative position of the tuberosities and consequent tension and healing of the tuberosity repair [9, 11-14]. However, few studies have compared the effects of changing these factors.

We evaluated patients 70 years of age or older treated primarily with RSA after displaced PHF and identified mortality, morbidity, complications, reoperations, and functional outcomes. We also evaluated the effect of a fracture-specific RSA design with different tuberosity fixation methods on the implant survival rate and safety of the procedure.

We hypothesized that RSA with a fracture-specific design using a “window” stem and with a strong tuberosity fixation would improve anatomical tuberosity repair and consolidation, thereby providing better functional results.

2. MATERIALS AND METHODS

A retrospective analysis of the surgical activity of a single orthopedic department between January 1, 2010 and December 31, 2019 was performed. Data from all surgeries performed for PHF during the study period were prospectively collected. The inclusion criteria were patients 70 years of age or older who underwent RSA as a primary option for displaced PHF (displaced Neer types 3 and 4) and a minimum of 2 years of follow-up. The decision for RSA was based on pre-operative consensus among two independent surgeons who agreed that achieving a satisfactory reduction intra-operatively was not feasible. The exclusion criteria were pathologic fractures and time to surgery of more than 6 weeks. Before inclusion, approval from the ethical committees was obtained as required by local regulations, and informed consent was obtained from all participants.

A preoperative assessment was performed using radiography and CT scan for all patients. Follow-up was conducted by a senior surgeon at 2 weeks, 1 month, 3 months, 6 months, and 1 year, and then annually thereafter. Plain radiography (anteroposterior views in neutral rotation, external rotation, and internal rotation; lateral scapula shoulder or Y view; Velpeau view) was performed during the follow-up consultations at 4 weeks, 3 months, 6 months, and 1 year, and then annually thereafter. For all patients, the mean cortical thickness was measured using Tingart's method at the time of the first X-ray examination [15]. Tuberosity healing was classified as anatomical healing, malunion and non-union, and resorption according to the classification by Imiolczyk et al. (Figure 1) [14]. Furthermore, heterotopic ossification (a modified Brooker classification system for the hip was used for its grading) [16], implant loosening (which was evaluated according to the classification of Gruen et al, [17] adapted to the shoulder), and scapular notching (was evaluated according to the Nerot-Sirveaux classification) [18, 19] were included in the radiological evaluation.

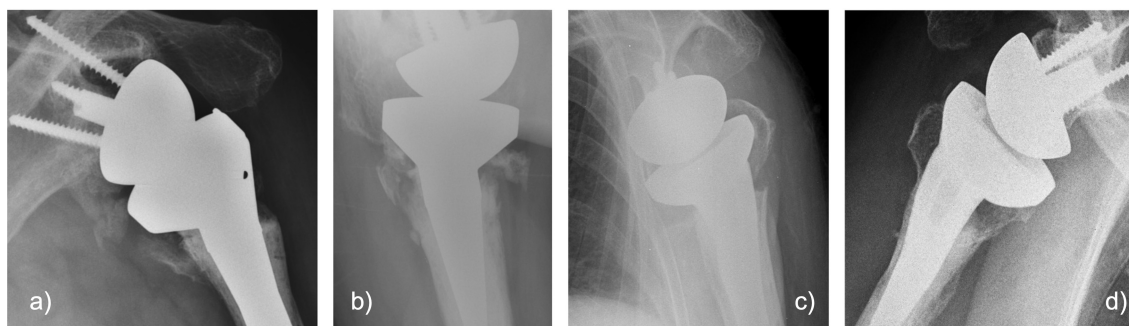


Figure 1. Radiographic evaluation of tuberosity healing. Four different classifications: (a) resorption; (b) non-union; (c) malunion; and (d) anatomical healing.

Demographic data were collected from the clinical records and included sex, age at the time of fracture, ASA score, comorbidities, Charlson comorbidity index [20], associated injuries, time to surgery, Constant shoulder score[21], visual analogue scale score, functional mobility based on the study by Namdari et al. [22] (forward elevation $>115^{\circ}$, $>40^{\circ}$ of extension, abduction at least 120° , $>105^{\circ}$ of cross-body adduction, external rotation with the arm 90° , abduction $>50^{\circ}$, and internal rotation with the arm at the side $>95^{\circ}$), return to activities of daily living (short questionnaire based on the International Physical Activity Questionnaire Short Form [23] completed by the surgeon during the follow-up consultations comparing the level of activity before and after the fracture), mortality rate, complications (tuberosity non-union, tuberosity malunion, heterotopic ossification, glenoid erosion, notching, loosening, re-operation, infection, and instability of the implant), and mortality.

Surgical technique

Surgery was performed by a senior shoulder surgeon using a deltopectoral approach for all patients. The long head of the biceps tendon was tenodesed to the pectoralis major whenever it was present. Closed suction drainage was used and removed within 24 h for all patients.

All humeral implants were cemented and assembled using a specific instrument to control the height (a sliding ruler). Retroversion was set at 20° by aligning the version rod with the forearm. The humeral stem diameter corresponded to the diameter of the last broach used. The humeral implant selected for the study was an implant with a specific stem for the fracture (Aequalis Reversed-fracture implant; Tornier, Memphis, TN, USA). This fracture-specific stem is a monobloc stem with a hydroxyapatite coating and metaphyseal window for bone augmentation to encourage fracture healing, especially tuberosity healing (Figure

2). In these cases, a specially shaped cancellous bone graft was harvested from the fractured head using appropriate instruments and placed into a designated window in the prosthesis. Whenever this implant was not available because of distribution issues, a similar humeral stem without a window compatible with the same glenoid implant was used (Aequalis Reversed II; Tornier, Memphis, TN, USA). This conventional stem consists of two components: a cobalt-chrome diaphyseal stem and a metaphysis with an anti-rotation design (Figure 3).

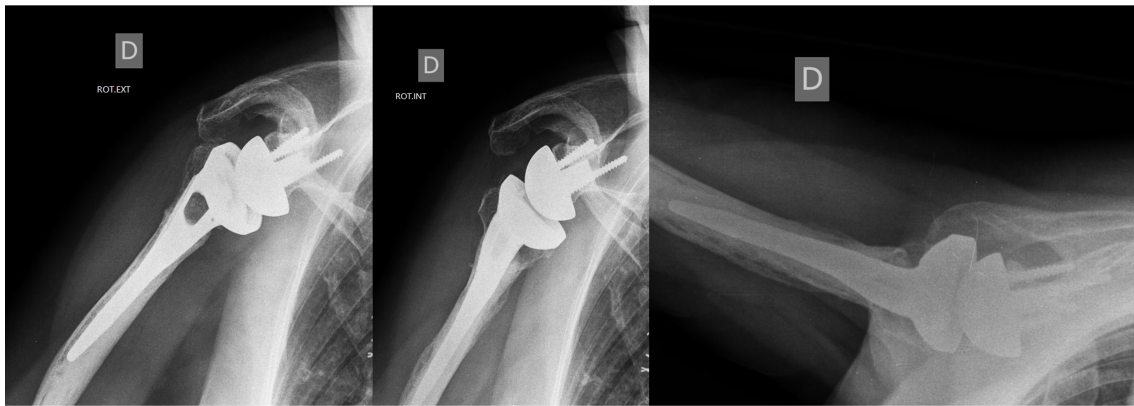


Figure 2. X-ray evaluation of the fracture-specific humeral stem (Aequalis Reversed-Fracture implant; Tornier, Memphis, TN, USA).

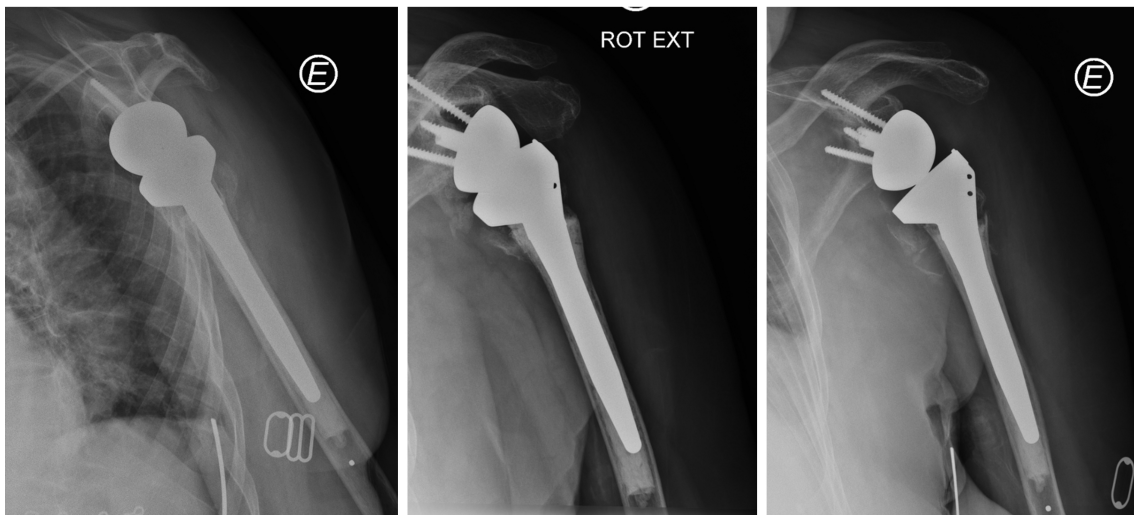


Figure 3. X-ray evaluation of the conventional humeral stem (Aequalis Reversed II implant; Tornier, Memphis, TN, USA).

After retraction of the tuberosities, the glenoid surface was reamed with a cannulated reamer inserted over a guidewire, and a central hole for the glenoid peg was drilled at 0° of inferior tilt. The baseplate was always impacted and secured in place with four screws (two compression and two locking screws). A standard 36-mm-diameter glenosphere was used for all patients.

Regarding fixation of the tuberosities, reinsertion was always attempted. When intraoperative fixation was possible, two of the four senior surgeons [RC and LB] always used technique A (Figure 4) according to Boileau's principles [24]. This technique was defined as a minimum of two no. 5 Ethibond sutures (Ethicon Inc., Somerville, NJ, USA) passing through the tendon–bone interface of the tuberosities and embracing the humeral implant (horizontal cerclage sutures), two vertical no. 5 Ethibond sutures (vertical tension-band sutures), and a minimum of two no. 5 Ethibond sutures attaching both tuberosities. The other two senior surgeons [JL and JR] always used technique B (Figure 5), whereby only one suture passed through the tuberosities and embraced the humeral implant without vertical sutures; only one intertuberosity suture could be used. The technique was classified as technique C if fixation was not possible because of poor bone quality, absence of tuberosity, or absence of tendons (chronic ruptures and significant tendon retraction). All surgeries were performed successively according to the rotation of the emergency department schedule. No surgery was scheduled for a particular surgeon. No patient was assigned to a specific surgeon.

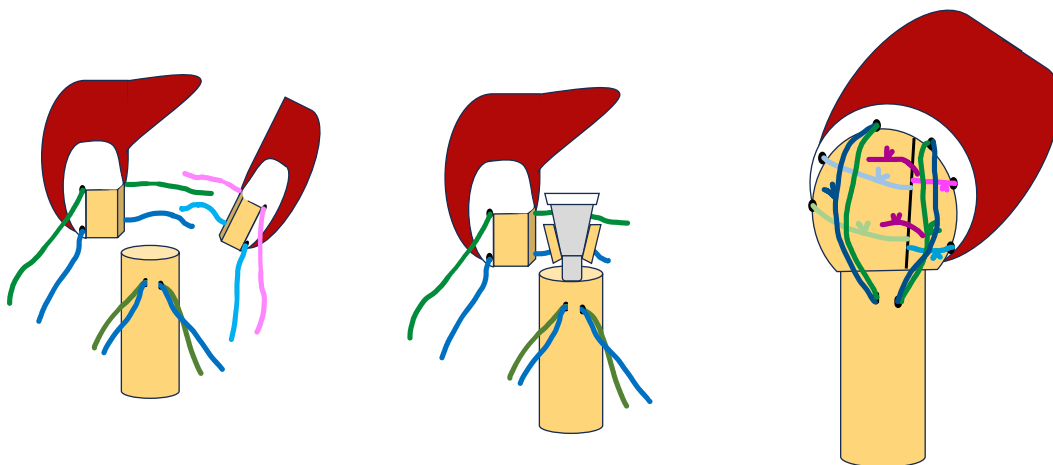


Figure 4. Schematic figures with Technique A.

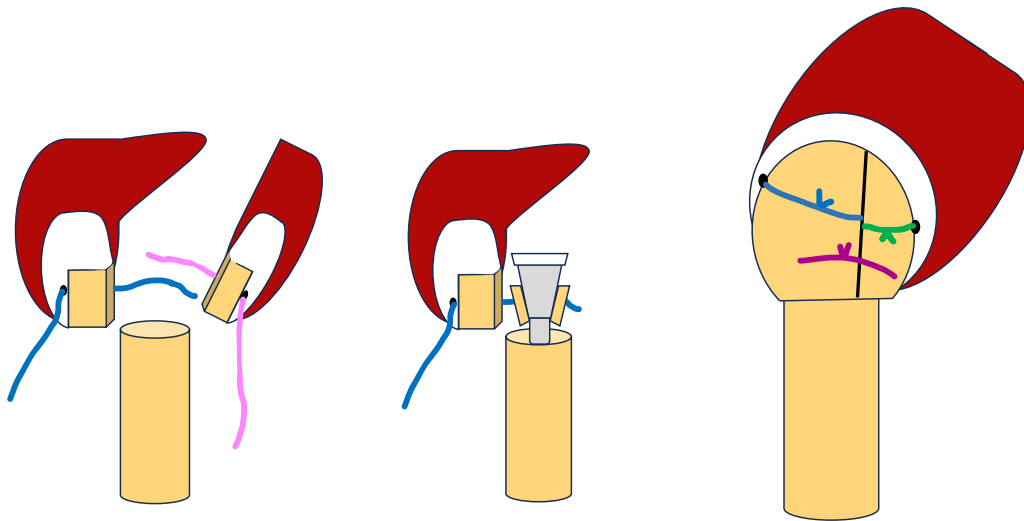


Figure 5. Schematic figures with Technique B.

After surgery, the shoulder was immobilized with a brace for 4 weeks. Active wrist and elbow movements were immediately allowed. Passive mobilization of the shoulder was allowed at 2 weeks and active mobilization was allowed at 6 weeks postoperatively. All patients underwent the same rehabilitation protocol.

The demographic data were presented by descriptive statistic. For categorical variables, the number of cases and percentages were presented, and the chi-square test or Fisher's exact test were used to compare proportions between groups. Continuous variables were presented as means and standard deviations (SD). The Shapiro-Wilk test was used to assess the distribution of the variables, and the t-test and Mann-Whitney U test (for non-normally distributed variables) were utilized to compare means between groups.

All statistical analyses were performed using IBM SPSS Statistics (version 24.0; New York, New York, USA). Statistical significance was defined as a two-tailed P-value less than 0.05 and 95% confidence interval (CI) was reported. The multivariable analysis was performed including all variables that demonstrate a difference in the univariate analysis with $p \leq 0.2$, through a binomial logistic regression.

3. RESULTS

Between January 1, 2010 and December 31, 2019, 653 patients with PHF were included in the study. Of these patients, 420 underwent open reduction and osteosynthesis with a plate, 32 underwent nailing, 10 underwent HA, 12 underwent surgery for pathological fractures, 45 patients younger than 70 years underwent RSA and 22 waited for more than 6 weeks before surgery was performed, were excluded. Finally, 112 met the inclusion criteria.

Of the 112 patients included (112 shoulders), 15 were men and 97 were women; the mean clinical follow-up was 52 months (SD, 27.9 months). The mean age at the time of fracture was 78.6 years (SD, 5.82 years). According to the Charlson comorbidity index, 41 patients had a score of 4 and 17 patients had a score ≥ 6 . Sixty-three patients (56.25%) had an ASA score of II, 47 (41.96%) had an ASA score of III, and two (1.79%) had an ASA score of IV. The mean time from trauma to surgery was 6.9 days (SD, 7.84 days).

All fractures were classified as Neer types 3 and 4. Fifty patients (45%) had three-part fractures and 62 patients (55%) had four-part fractures. The mean cortical thickness was 2.83 mm (SD, 0.672 mm). The Aequalis Reversed-Fracture stem (Tornier, Memphis, TN, USA) humeral implant was used for 86 patients (76.8%). The Aequalis Reversed II humeral stem (Tornier, Memphis, TN, USA) was implanted in 26 patients (23.2%). Regarding the tuberosity fixation technique, the tuberosities were attached using technique A for 76 patients (67.9%), technique B for 25 patients (22.3%) and technique C for 11 patients (9.8%) (Tables 1 and 2, respectively). Of all patients who received a fracture-specific humeral implant, 59 patients (69%) underwent technique A fixation, 19 patients (22%) underwent technique B fixation, and 8 patients (9%) underwent technique C fixation. Of all patients who received the non-fracture humeral stem, 17 patients (65%) underwent technique A fixation, 6 patients (23%) underwent technique B fixation, and 3 patients (12%) underwent technique C fixation.

Table 1. Demographic characteristics and comorbidities

Variable	n (%)	Mean (SD)
Sex		
Male	15 (13.4)	
Female	97 (86.6)	
Age (years)		78.6 (5.82)
ASA score		
II	63 (56.25)	
III	47 (41.96)	
IV	2 (1.79)	
Comorbidities		
Diabetes mellitus	25 (22.3)	
Hypertension	71 (63.4)	
Heart failure	37 (33)	
Respiratory failure	19 (17)	
Renal failure	10 (8.9)	
History of stroke	11 (9.8)	
Obesity	34 (30.4)	
Dementia	10 (8.9)	
Charlson comorbidity index		
2	6 (5.4)	
3	19 (17)	
4	41 (36.6)	
5	26 (23.2)	
≥ 6	17 (15.2)	
ASA American Society of Anesthesiology, SD Standard deviation		

Table 2. Surgical characteristics

Variable	N (%)	Mean (SD)
Laterality		
Right	65 (57.1)	
Neer's classification		
3	50 (44.6)	
4	62 (55.4)	
Mean cortical thickness (mm)		2.83 (0.672)
Implant		
ARF	86 (76.8)	
Other	26 (23.2)	
Tuberosity fixation technique		
Technique A	76 (67.9)	
Technique B	25 (22.3)	
Technique C	11 (9.8)	
Postoperative transfusion	15 (13.4)	
Time to surgery (days)		6.9 (7.84)
Length of postoperative hospital stay (days)		5.2 (10.31)
Follow-up (months)		52 (27.9)
ARF Aequalis Reversed II humeral stem, SD Standard deviation		

To assess survival rates, the need for revision surgery or patient death was considered a survival endpoint. The overall survival rate at 2 years of follow-up was 88.2%; however, it decreased to 79% at 5 years. Figure 6 shows the Kaplan–Meier survival curve.

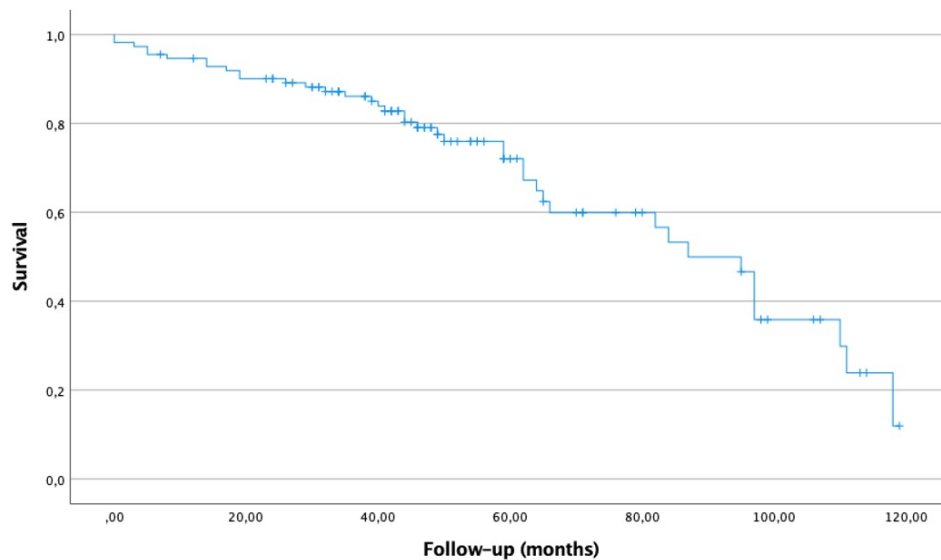


Figure 6. Overall survival.

Regarding functional outcomes, the majority of patients (73.2%) returned to their normal activities of daily living, and 45.5% of patients achieved functional mobility (Table 3). The mean visual analog scale score was 3.6 (SD, 2.31).

Table 3. Postoperative outcomes

Variable	N (%)	Mean (SD)
Complications		
Infection	2 (1.8)	
Dislocation	1 (0.9)	
Revision surgery	3 (2.7)	
Return to daily activities	82 (73.2)	
Functional mobility	51 (45.5)	
Constant score		59.4 (10.40)
VAS		3.6 (2.31)
<i>SD</i> Standard deviation, <i>VAS</i> Visual analogue scale		

Only three patients (2.7%) had complications (two infections [1.8%] and one dislocation [0.9%]) that required revision surgery (Table 3).

Of the initial 112 patients, 19 missed radiological appointments during the first 2 years of follow-up. Therefore, only 93 patients underwent shoulder radiograph evaluation during a minimum of 2 years of follow-up and were included in the subsequent analysis (Table 4).

Table 4. Radiological outcomes

Variable	N (%)
Tuberosity anatomic consolidation	58 (62%)
Tuberosity malunion	13 (14%)
Tuberosity nonunion	15 (16%)
Tuberosity resorption	7 (8%)
Scapular notching	26 (28%)
Heterotopic ossification	35 (38%)
Implant loosening	3 (3%)

In the multivariate analysis, the type of humeral implant ($p=0.051$; 95% confidence interval [CI] 0.997–12.964, odds ratio (OR)= 3.595), tuberosity fixation technique ($p=0.041$; 95% CI 0.179–0.963, OR= 0.415), tuberosity anatomical consolidation ($p<0.001$; 95% CI 2.236–23.031, OR= 7.315), and dementia ($p=0.014$; 95% CI 0.010–0.601, OR=0.077) were the only factors that influenced the achievement of functional mobility.

Additionally, the tuberosity fixation technique ($p<0.01$; 95% CI 5.387 - 0.686) and tuberosity anatomical consolidation ($p<0.01$; 95% CI 10.471–16.969) were associated with an improved Constant score (Table 5).

Tuberosity anatomic consolidation was associated with the type of humeral implant ($p<0.001$; 95% CI 1.476–13.811,) and fixation technique ($p<0.001$; 95% CI 0.169–0.740). No associations with Neer's fracture classification ($p=0.934$, 95% CI 0.19- 1.33), time to surgery ($p=0.295$ 95% CI -13.11-4.61), or cortical thickness ($p=0.717$, 95% CI 0.6-3.61) were observed between groups (Table 5).

Table 5. Associations with the Constant score, with tuberosity anatomic consolidation, and with the return to activities of daily living

	Associations with the Constant score					Associations with tuberosity anatomic consolidation					Associations with the return to activities of daily living			
	Median Constant Score	P (univariable)	P (multivariable)	95% CI		Tuberosity anatomic consolidation	P (univariable)	P (multivariable)	95% CI		Return to activities of daily living	P (univariable)	P (multivariable)	95% CI
Tuberosity fixation technique		<0.001	0.012	-5.387 to 0.686		Tuberosity fixation technique	<0.001	<0.001	0.169-0.740		Tuberosity fixation technique	<0.01	<0.01	1.871-514.94
Technique A	62.67					Technique A	44 (79%)				Technique A	57 (89%)		
Technique B	55.32					Technique B	11 (50%)				Technique B	19 (86%)		
Technique C	49.70					Technique C	3 (22%)				Technique C	6 (45%)		
Implant		0.006	0.14	0.110-1.491		Implant	0.028	<0.001	1.476-13.811		Implant	0.139	0.04	0.004-0.778
ARF	49.61					ARF	47 (69%)				ARF	62 (91%)		
Other	35.57					Other	11 (44%)				Other	70 (80%)		
Sex		0.362	-	-		Sex	0.399	-	-		Sex	0.850	-	-
Female	45.89					Female	53 (64%)				Female	73 (88%)		
Male	38.00					Male	5 (26%)				Male	9 (20%)		
ASA		0.500	-	-		ASA	0.088	0.165	0.205-1.418		ASA	0.592	-	-
1	60.4					1	38 (70%)				1	49 (91%)		
2	57.8					2	19 (50%)				2	32 (84%)		
3	60.00					3	1 (100%)				3	1 (100%)		
Age		0.042	0.622	-0.246 to 0.409		Age	0.004	0.165	0.193-1.324		Age	0.057	0.122	0.678-1.047
Dementia		0.398	-	-		Dementia	0.993	-	-		Dementia	0.019	<0.01	2.796-1443.883
Yes	36.42					Yes	5 (62.5%)				Yes	5 (63%)		
No	45.63					No	53 (62.5%)				No	72 (83%)		
Charlson comorbidity index		0.131	0.052	-2.619 to 0.013		Charlson comorbidity index	0.133	-	-		Charlson comorbidity index	0.232	-	-
Neer classification		0.264	-	-		Neer's classification	0.934	-	-		Neer's classification	0.195	-	-
1	48.23					1	26 (62%)				1	39 (93%)		
2	42.12					2	32 (63%)				2	42 (84%)		
Cortical thickness		<0.001	0.269	-4.280 to 1.211		Cortical thickness	0.717	-	-		Cortical thickness	0.120	-	-
Time to surgery		0.028	0.568	-0.104 to 0.279		Time to surgery	0.295	-	-		Time to surgery	0.168	-	-
Length of postoperative hospital stay (days)		0.011	0.086	-0.372 to 0.025		Length of postoperative hospital stay (days)	0.241	-	-		Length of postoperative hospital stay (days)	0.02	0.162	0.063-3.716
Diabetes		0.338	-	-		Diabetes	0.637	-	-		Diabetes	0.394	-	-
Yes	40.39					Yes	14 (38%)				Yes	20 (83%)		
No	46.46					No	44 (64%)				No	62 (90%)		
Heart failure		0.744	-	-		Heart failure	0.795	-	-		Heart failure	0.537	-	-
Yes	43.75					Yes	20 (61%)				Yes	30 (91%)		
No	45.64					No	38 (63%)				No	52 (87%)		
Respiratory failure		0.724	-	-		Respiratory failure	0.439	-	-		Respiratory failure	0.366	-	-
Yes	42.90					Yes	12 (71%)				Yes	16 (94%)		
No	45.43					No	46 (61%)				No	66 (87%)		
Renal failure		0.557	-	-		Renal failure	0.129	0.626	0.116-3.665		Renal failure	0.951	-	-
Yes	39.50					Yes	3 (38%)				Yes	7 (88%)		
No	45.47					No	55 (65%)				No	75 (88%)		
Obesity		0.578	-	-		Obesity	0.275	-	-		Obesity	0.468	-	-
Yes	42.97					Yes	23 (70%)				Yes	28 (85%)		
No	46.14					No	35 (58%)				No	54 (90%)		
HBP		0.700	-	-		HBP	0.525	-	-		HBP	0.948	-	-
Yes	44.21					Yes	36 (60%)				Yes	53 (88%)		
No	46.41					No	22 (67%)				No	29 (88%)		
Stroke		0.313	-	-		Stroke	0.298	-	-		Stroke	0.310	-	-
Yes	53.22					Yes	7 (78%)				Yes	7 (78%)		
No	44.08					No	51 (61%)				No	75 (89%)		
Postoperative transfusion		0.280	-	-		Postoperative transfusion	0.572	-	-		Postoperative transfusion	0.09	-	-
Yes	36.70					Yes	6 (55%)				Yes	8 (73%)		
No	46.65					No	52 (63%)				No	74 (90%)		
Notching		0.982	-	-		Notching	0.058	0.069	0.116-1.086		Notching	0.132	0.140	0.001-2.549
Yes	44.90					Yes	12 (46%)				Yes	25 (96%)		
No	45.04					No	46 (69%)				No	57 (85%)		
Tuberosity anatomic consolidation		<0.001	<0.001	10.471-16.969		Tuberosity anatomic consolidation	-	-	-		Tuberosity anatomic consolidation	<0.01	0.402	2.769-54.228
Yes	58.94					Yes	-				Yes	57 (98%)		
No	21.38					No	-				No	25 (75%)		

ARF, Aequalis reverse fracture; ASA, American Society of Anesthesiology; CI, confidence interval; HBP, high blood pressure

The factors associated with the ability to return to performing activities of daily living were the type of implant (p=0.044; 95% CI, 1.05–92.47), tuberosity fixation technique (p=0.12; 95% CI 0.051–0.695), and dementia (p=0.014; 95% CI 0.002–0.493) (Table 5).

4. DISCUSSION

To the best of our knowledge, this study is one of the few that evaluated a fracture-specific design using a “window” humeral stem and a standard humeral stem for the treatment of acute and displaced PHF in older patients. We compared different fixation techniques for tuberosities and their ability to improve anatomical consolidation and provide better

functional results. Our results revealed that consolidation of the tuberosity in the anatomic position is associated with the use of a fracture-specific stem and strong fixation technique.

Although approximately 80% of PHF are non-displaced or minimally displaced [25], and because non-operative treatment is successful [26], optimal treatment becomes less clear for more complex displaced fracture patterns, such as those that occur in the older people.

The poor bone quality of older patients causes complex fracture patterns that make ORIF impossible; when performed, ORIF result in a high rate of complications, with some series reporting a complication rate as high as 50% [27].

Tuberosity integration with RSA is not as important for function as it is with HA; therefore, for older patients with osteoporotic bones, the use of RSA has some advantages, at least theoretically. If the tuberosities heal in an anatomical position, then, theoretically, RSA will be advantageous in terms of final functional outcomes. Moreover, eventually, the use of specific stems for fractures will be necessary to obtain anatomical healing of the tuberosities.

A recent meta-analysis comparing the fracture-specific stem design for HA and RSA has reported favorable outcomes for fracture stems regardless of different rehabilitation protocols or tuberosity refixation techniques [28]. Different conclusions were presented by Imiolczyk et al. [14]; in their study, fracture stem designs with an open metaphyseal window for bone ingrowth did not improve tuberosity healing.

Tuberosity healing rates of 65% to 84% have been described in the literature, and our study revealed a healing rate of 76% (62% anatomical consolidation and 14% malunion) [24, 29-31]. Our study revealed that consolidation of tuberosity in the anatomic position was associated with the use of a fracture-specific stem ($P<0.01$) and the fixation technique used ($P<0.01$), but that there was no association with Neer's classification ($P=0.934$), time to surgery ($P=0.295$), or cortical thickness ($P=0.717$).

Our data also suggested that the tuberosity fixation technique and anatomical consolidation of the tuberosity are associated with improvements in the Constant score, thus corroborating the findings of Grubhofer et al. [31], Boileau et al. [24], Barros et al. [32], and Jain et al. [13], who reported that patients with tuberosity healing had improved functional outcomes and subjective function.

Hence, in order to promote optimal anatomical consolidation and improve functional recovery of the affected upper limb, it is advisable to prioritize the use of a fracture-specific stem with a window for bone ingrowth. Additionally, when feasible during the surgical

procedure, the implementation of a robust fixation technique, as outlined by Boileau et al. [24], should be considered. This combined approach offers the potential to mitigate the risk of tuberosity mal-union or non-union, which holds particular significance in the context of this age group.

RSA allowed the return to activities of daily living for 73.2% of patients and functional mobility of the shoulder for almost half (45.5%) of the patients studied (45.5%); however, dementia was negatively correlated with the ability to return to activities of daily living. These factors, particularly for the older population who often live alone and need to recover quickly, suggest that RSA should be the preferred surgical option because of its good results when dealing with displaced PHF. Nonetheless, older people should always undergo rigorous preoperative assessments. Their treatment should be optimized according to the surgical risk profile before surgery, and the option for surgical treatment should always be evaluated on a case-by-case basis.

This study had some limitations. First, the relatively small number of patients and relatively high rate of loss to radiological follow-up (16.96%) may have hindered the detection of small differences between groups. This was because of the age and morbidities of the patient cohort and was typical of other cohort studies of RSA for PHF, which reported dropout rates of approximately 29% to 34% [24, 29, 31]. Second, only a two-dimensional radiographic evaluation of tuberosity healing was performed. Three-dimensional CT scan may provide a more accurate evaluation of tuberosity integration and positioning, but at the expense of higher radiation exposure. Third, the clinical evaluation at follow-up was performed by the senior surgeon who performed the surgery. Fourth, a relatively small number of patients were treated with a conventional humeral stem. A randomized, comparative, control study should be performed to avoid these limitations.

Nevertheless, the strengths of our study include the long follow-up period, the use of the same glenoid reconstruction, and the same neck–shaft angle of the humeral stem (Grammont type, 155°). Furthermore, all surgeries were performed by senior orthopedic surgeons, and the same rehabilitation protocol was used for all patients to investigate the effects of different stem designs and different tuberosity fixation techniques. Studies with larger patient cohorts are necessary to clarify all factors that can help surgeons select the optimal procedure.

5. CONCLUSION

RSA is often used for complex and displaced PHF in older patients. Dementia was negatively correlated with functional outcomes. Better clinical and radiological results can be achieved with a window bone ingrowth fracture-specific stem combined with strong tuberosity fixation.

REFERENCES

1. Rotman D, Giladi O, Senderey AB, Dallich A, Dolkart O, Kadar A, Maman E, Chechik O (2018) Mortality After Complex Displaced Proximal Humerus Fractures in Elderly Patients: Conservative Versus Operative Treatment With Reverse Total Shoulder Arthroplasty. *Geriatr Orthop Surg Rehabil* 9:2151459318795241. DOI 10.1177/2151459318795241
2. Verdano MA, Aliani D, Galavotti C, Maroun C, Vailanti E, Ceccarelli F (2018) Grammont versus lateralizing reverse shoulder arthroplasty for proximal humerus fracture: functional and radiographic outcomes. *Musculoskelet Surg* 102:57-65. DOI 10.1007/s12306-018-0565-5
3. Maugendre E, Gadiouseux B, Chantelot C, Clavert P, Ramdane N, Werthel JD, Boileau P, Sofcot (2019) Epidemiology and mortality in older patients treated by reverse shoulder arthroplasty for displaced proximal humerus fractures. *Orthop Traumatol Surg Res* 105:1509-1513. DOI 10.1016/j.otsr.2019.07.026
4. Fitschen-Oestern S, Behrendt P, Martens E, Finn J, Schiegnitz J, Borzikowsky C, Seekamp A, Weuster M, Lippross S (2020) Reversed shoulder arthroplasty for the treatment of proximal humerus fracture in the elderly. *J Orthop* 17:180-186. DOI 10.1016/j.jor.2019.08.029
5. Court-Brown CM, Caesar B (2006) Epidemiology of adult fractures: A review. *Injury* 37:691-697. DOI 10.1016/j.injury.2006.04.130
6. Kim SH, Szabo RM, Marder RA (2012) Epidemiology of humerus fractures in the United States: nationwide emergency department sample, 2008. *Arthritis Care Res (Hoboken)* 64:407-414. DOI 10.1002/acr.21563
7. Clement ND, Duckworth AD, McQueen MM, Court-Brown CM. The outcome of proximal humeral fractures in the elderly: predictors of mortality and function. *Bone Joint J*. 2014 Jul;96-B(7):970-7. doi: 10.1302/0301-620X.96B7.32894. PMID: 24986953.
8. Brauer CA, Coca-Perrillon M, Cutler DM, Rosen AB (2009) Incidence and mortality of hip fractures in the United States. *JAMA* 302:1573-1579. DOI 10.1001/jama.2009.1462
9. Dhaliwal K, Shahid ZY, Choudhry B, Zhao C (2020) The Role of Reverse Shoulder Arthroplasty in Elderly Trauma: A Systematic Review. *Cureus* 12:e8180. DOI 10.7759/cureus.8180

10. Bufquin T, Hersan A, Hubert L, Massin P (2007) Reverse shoulder arthroplasty for the treatment of three- and four-part fractures of the proximal humerus in the elderly: a prospective review of 43 cases with a short-term follow-up. *J Bone Joint Surg Br* 89:516-520. DOI 10.1302/0301-620X.89B4.18435
11. Kelly BJ, Myeroff CM (2020) Reverse Shoulder Arthroplasty for Proximal Humerus Fracture. *Curr Rev Musculoskelet Med* 13:186-199. DOI 10.1007/s12178-020-09597-0
12. O'Sullivan J, Ladermann A, Parsons BO, Werner B, Steinbeck J, Tokish JM, Denard PJ (2020) A systematic review of tuberosity healing and outcomes following reverse shoulder arthroplasty for fracture according to humeral inclination of the prosthesis. *J Shoulder Elbow Surg* 29:1938-1949. DOI 10.1016/j.jse.2020.03.032
13. Jain NP, Mannan SS, Dharmarajan R, Rangan A (2019) Tuberosity healing after reverse shoulder arthroplasty for complex proximal humeral fractures in elderly patients-does it improve outcomes? A systematic review and meta-analysis. *J Shoulder Elbow Surg* 28:e78-e91. DOI 10.1016/j.jse.2018.09.006
14. Imiolczyk JP, Moroder P, Scheibel M (2021) Fracture-Specific and Conventional Stem Designs in Reverse Shoulder Arthroplasty for Acute Proximal Humerus Fractures-A Retrospective, Observational Study. *J Clin Med* 10. DOI 10.3390/jcm10020175
15. Tingart MJ, Apreleva M, von Stechow D, Zurakowski D, Warner JJ (2003) The cortical thickness of the proximal humeral diaphysis predicts bone mineral density of the proximal humerus. *J Bone Joint Surg Br* 85:611-617. DOI 10.1302/0301-620x.85b4.12843
16. Della Valle AG, Ruzo PS, Pavone V, Tolo E, Mintz DN, Salvati EA (2002) Heterotopic ossification after total hip arthroplasty. *The Journal of Arthroplasty* 17:870-875. DOI 10.1054/arth.2002.34819
17. Gruen TA, McNeice GM, Amstutz HC (1979) "Modes of failure" of cemented stem-type femoral components: a radiographic analysis of loosening. *Clin Orthop Relat Res*:17-27
18. Young BL, Cantrell CK, Hamid N (2018) Classifications in Brief: The Nerot-Sirveaux Classification for Scapular Notching. *Clin Orthop Relat Res* 476:2454-2457. DOI 10.1097/CORR.0000000000000442
19. Sirveaux F, Favard L, Oudet D, Huquet D, Walch G, Mole D (2004) Grammont inverted total shoulder arthroplasty in the treatment of glenohumeral osteoarthritis with massive rupture of the cuff. *The Journal of Bone and Joint Surgery British volume* 86-B:388-395. DOI 10.1302/0301-620x.86b3.14024

20. Charlson ME, Pompei P, Ales KL, MacKenzie CR (1987) A new method of classifying prognostic comorbidity in longitudinal studies: development and validation. *J Chronic Dis* 40:373-383. DOI 10.1016/0021-9681(87)90171-8
21. Constant CR, Murley AH (1987) A clinical method of functional assessment of the shoulder. *Clin Orthop Relat Res*:160-164
22. Namdari S, Yagnik G, Ebaugh DD, Nagda S, Ramsey ML, Williams GR, Jr., Mehta S (2012) Defining functional shoulder range of motion for activities of daily living. *J Shoulder Elbow Surg* 21:1177-1183. DOI 10.1016/j.jse.2011.07.032
23. Sember V, Meh K, Soric M, Starc G, Rocha P, Jurak G (2020) Validity and Reliability of International Physical Activity Questionnaires for Adults across EU Countries: Systematic Review and Meta Analysis. *Int J Environ Res Public Health* 17. DOI 10.3390/ijerph17197161
24. Boileau P, Alta TD, Decroocq L, Sirveaux F, Clavert P, Favard L, Chelli M (2019) Reverse shoulder arthroplasty for acute fractures in the elderly: is it worth reattaching the tuberosities? *J Shoulder Elbow Surg* 28:437-444. DOI 10.1016/j.jse.2018.08.025
25. Villodre-Jimenez J, Estrems-Diaz V, Diranzo-Garcia J, Bru-Pomer A (2017) Reverse shoulder arthroplasty in 3 and 4 part proximal humeral fractures in patients aged more than 65 years: Results and complications. *Rev Esp Cir Ortop Traumatol* 61:43-50. DOI 10.1016/j.recot.2016.09.005
26. Gaebler C, McQueen MM, Court-Brown CM (2003) Minimally displaced proximal humeral fractures: epidemiology and outcome in 507 cases. *Acta Orthop Scand* 74:580-585. DOI 10.1080/00016470310017992
27. Owsley KC, Gorczyca JT (2008) Fracture displacement and screw cutout after open reduction and locked plate fixation of proximal humeral fractures [corrected]. *J Bone Joint Surg Am* 90:233-240. DOI 10.2106/JBJS.F.01351
28. Onggo JR, Nambiar M, Onggo JD, Hau R, Pennington R, Wang KK (2021) Improved functional outcome and tuberosity healing in patients treated with fracture stems than nonfracture stems during shoulder arthroplasty for proximal humeral fracture: a meta-analysis and systematic review. *J Shoulder Elbow Surg* 30:695-705. DOI 10.1016/j.jse.2020.09.044
29. Schmalzl J, Jessen M, Sadler N, Lehmann LJ, Gerhardt C (2020) High tuberosity healing rate associated with better functional outcome following primary reverse shoulder

arthroplasty for proximal humeral fractures with a 135 degrees prosthesis. BMC Musculoskelet Disord 21:35. DOI 10.1186/s12891-020-3060-8

30. Simovitch RW, Roche CP, Jones RB, Routman HD, Marczuk Y, Wright TW, Zuckerman JD (2019) Effect of Tuberosity Healing on Clinical Outcomes in Elderly Patients Treated With a Reverse Shoulder Arthroplasty for 3- and 4-Part Proximal Humerus Fractures. J Orthop Trauma 33:e39-e45. DOI 10.1097/BOT.0000000000001348

31. Grubhofer F, Wieser K, Meyer DC, Catanzaro S, Beeler S, Riede U, Gerber C (2016) Reverse total shoulder arthroplasty for acute head-splitting, 3- and 4-part fractures of the proximal humerus in the elderly. J Shoulder Elbow Surg 25:1690-1698. DOI 10.1016/j.jse.2016.02.024

32. Barros LH, Figueiredo S, Marques M, Rodrigues C, Ramos J, Claro R (2020) Tuberosity Healing after Reverse Shoulder Arthroplasty for Proximal Humerus Fractures: Is there Clinical Improvement? Rev Bras Ortop (Sao Paulo) 55:748-754. DOI 10.1055/s-0039-3402459

VII.

OVERALL DISCUSSION, FUTURE PERSPECTIVES AND CONCLUSIONS

1. OVERALL DISCUSSION, FUTURE PERSPECTIVES AND CONCLUSIONS

The worldwide shift toward an aging population, along with a consistent incidence of fractures when adjusted for age, indicates an upcoming increase in the impact of osteoporotic fractures [1]. Within this context, PHF are a significant concern, associated with substantial morbidity, functional limitations, and notable socioeconomic implications.

Between 2000 and 2015, Portugal observed a notable increase in PHF, especially among elderly women [2]. This aligns with existing literature [3-8]. While the choice between conservative and surgical approaches for PHF treatment remains complex, there is a noticeable trend leaning towards surgical management. This inclination, supported by Khatib et al. [9], is reinforced by continuous innovation, introducing new techniques and implants that improve clinical outcomes [1, 10]. The challenges faced in the past with conventional plate fixation in osteoporotic conditions are now mitigated by the rise of locking plates, enhancing biomechanical effectiveness and stability [11, 12]. As a result, ORIF has become more prevalent compared to closed reduction and internal fixation (CRIF). Similarly, the use of shoulder replacement in acute PHF treatment has undergone significant growth. These changes highlight various aspects, including evolving fracture patterns, improved surgical precision, and a growing awareness of the crucial role of accurate greater tuberosity reduction in optimizing shoulder function. This shift may be driven by the increasing desire for enhanced functionality among the geriatric population [3, 13].

However, the landscape remains contentious when it comes to determining the best treatment approaches for geriatric patients aged 65 and older. This debate is amplified by regional differences in treatment strategies [3]. In this context, the influence of decreased bone mineral density [14, 15] becomes significant, as there is a clear trend of fixation failure in ORIF within this age group [16]. This realization has led to a shift towards non-surgical options and consideration of arthroplasty, supported by a series of well-conducted studies from the past decade. These studies primarily focus on comparing non-surgical and surgical approaches and evaluating various surgical techniques [17].

Respected authors have embarked on an expedition to understand the intricacies of surgical techniques, exploring both ORIF and arthroplasty. They are shaping a landscape where the pursuit of optimized outcomes drives surgical innovation [6, 17-21]. However, uncertainties persist in this ongoing journey, emphasizing the need for continuous scholarly exploration to clarify the complex pathways of optimal PHF management. This endeavor aims to harmonize medical science with the multifaceted challenges of an aging population.

2. OPEN REDUCTION AND INTERNAL FIXATION ANALYSIS

The existing literature on ORIF for PHF has identified several critical factors associated with positive radiographic outcomes. Achieving anatomical reduction and restoring the integrity of the calcar have shown potential to significantly reduce complications like varus collapse, nonunion, malunion, and screw cutout [22-24]. These factors play a pivotal role in determining the long-term stability and functional recovery of PHF patients.

Our study highlighted an impressive survival rate among individuals aged over 70 years within this specific population, emphasizing their remarkable longevity. Therefore, it is crucial to prioritize treatment decisions that enhance the quality of life for these patients, as effective fracture management can significantly impact their overall well-being.

While fracture complexity theoretically correlates with increased complication rates and the potential need for revision surgeries, our study did not statistically establish this trend. Notably, when comparing surgical outcomes between "shoulder surgeons" and "non-shoulder surgeons," the latter group displayed a nearly twofold higher rate of complications and revision surgeries, particularly in terms of implant failures. This suggests that dedicated shoulder surgeons are better equipped to minimize complications and the necessity for reoperations in this specific patient cohort.

In our investigation, the rates of implant radiographic failure, avascular osteonecrosis, and revision surgeries were determined as 16.9%, 15.7%, and 15.7%, respectively. Complications were more prevalent in patients with Neer 3- and 4-part fractures. Although the statistical significance between surgeries performed by "shoulder surgeons" and "non-shoulder surgeons" did not materialize, the latter group exhibited an almost twofold increase in complications and the need for revision surgery.

Another significant finding emerged in the prioritization of fractures with higher Neer classifications for earlier surgical intervention. This trend implies a proactive approach among orthopedic surgeons to promptly address more intricate cases, likely aimed at mitigating complications such as avascular necrosis.

To address the aforementioned complications, various authors have explored the impact of reduced bone mineral density on ORIF outcomes. Studies have recognized osteoporotic fractures based on proximal humeral cortical thickness, with observed reductions at follow-up [16]. Multivariate regression analysis identified osteoporosis as a significant independent risk factor for failure [14]. Predictive factors for screw cutout following ORIF have also been

evaluated, demonstrating the importance of factors like deltoid tuberosity index and age [15].

The significance of medial calcar support is widely acknowledged in ORIF procedures. Inferomedial Locking Screws (IMS) positioned just above the calcar have showcased reduced rates of reduction loss and hardware complications [25-27]. Biomechanical studies have confirmed the efficacy of IMS in enhancing construct stability [27-29].

When concerns persist over reduced bone mineral density, and the goal remains anatomical reconstruction, several solutions have been evaluated. Cortical strut augmentation, often via a fibular strut allograft (FSA), stands as one such technique. This involves placing an intramedullary cortical allograft adjacent to the medial calcar to support or reconstruct the weakened medial column. Biomechanically, FSA has shown potential to enhance maximum failure load, initial stiffness, and resistance to varus loads [31-33].

Studies have compared using IMS alone versus IMS and FSA in treating geriatric patients with 3 and 4-part PHF involving medial comminution, highlighting improved outcomes with combined IMS and FSA [34]. Other retrospective studies have echoed better outcomes and favorable complication rates with FSA use [35-37]. However, concerns remain regarding the removal of a well-incorporated strut if patients progress to collapse, necessitating arthroplasty [38]. Other options, such as cement augmentation and intramedullary titanium mesh cage devices, are being investigated and appear promising in reducing failures during locking plate ORIF in cases of osteopenia, although their precise role in treatment remains unclear [39-44]. Arthroplasty presents a potentially more predictable solution for complex osteoporotic fractures as these techniques continue to be refined.

3. HEMIARTHROPLASTY VERSUS REVERSE SHOULDER ARTHROPLASTY ANALYSIS

Our comparative analysis of surgical modalities for managing displaced PHF has provided valuable insights into patient outcomes, contributing to the discourse on fracture management strategies. The use of RSA as the primary intervention for this challenging orthopedic condition has demonstrated a compelling narrative of improved survival rates, suggesting its potential as a significant treatment option. Notably, we observed a one-year survival rate of 88.9%, with a resilient 66.2% rate at five years, in line with findings reported in existing literature [45, 46]. Additionally, the comparable one-year mortality rate of 8.1% further strengthens the robustness of our findings in a broader context.

A subtle difference between the HA and RSA cohorts revealed a noteworthy trend. Although not statistically significant, the HA group showed a slightly higher incidence of stem loosening and reoperation. While this observation lacks statistical significance, it aligns with previous research and warrants further investigation to understand its potential clinical implications. Looking at the bigger picture, RSA demonstrates merit by achieving a higher rate of restoration to activities of daily living (92% vs. 56%), offering improved functional shoulder mobility. This difference, seen through the lens of real-world patient experiences, highlights RSA's potential to enhance postoperative quality of life.

In our analysis of patient demographics at the one-year mark, we found no significant differences across gender, age, or a range of comorbidities, including diabetes, dyslipidemia, hypertension, history of stroke, obesity, dementia, and additional fractures. However, there was a notable correlation between higher ASA scores and early mortality and overall mortality within the RSA cohort. This insight suggests that advanced age alone should not be a barrier to considering RSA as an intervention. This nuanced discovery, set against the backdrop of an aging population, reshapes the conversation around RSA candidacy and emphasizes the importance of comprehensive health assessment in making patient-centered surgical decisions.

These findings are particularly relevant in the context of an aging demographic, often characterized by solitary living arrangements and a need for swift recovery. In this context, RSA emerges as an optimal surgical option with the potential for unparalleled outcomes. With careful patient selection, RSA proves to be a safe and effective choice for addressing PHF, especially among the geriatric population. Consequently, our study promotes refined surgical decision-making, with RSA taking a central role in delivering improved clinical and functional outcomes.

4. REVERSE SHOULDER ARTHROPLASTY ANALYSIS

The interplay between advancing age and compromised bone quality in older patients presents challenges characterized by complex fracture patterns. These patterns often make the conventional approach of ORIF impractical, leading to a high rate of complications, with some series reporting rates as high as 50% [47].

In this context, RSA has gained favor, especially among elderly patients with PHF. Existing literature supports RSA's potential to significantly improve the Constant score, indicating enhanced functional outcomes [48, 49].

Notably, the role of tuberosity integration in RSA differs from that in HA, where it plays a less pivotal role in functional outcomes. This distinction implies the potential advantages of using RSA for older patients with osteoporotic bones.

Recent studies by Bufquin et al. [50] and Torrens et al. [51] challenge the notion that tuberosity non-healing necessarily leads to unfavorable outcomes in RSA. These findings suggest that RSA can yield positive results even without complete tuberosity healing [52, 53].

Contemporary discourse explores the relationship between tuberosity integration, rotator cuff function, and functional benefits for patients, particularly in rotation. Anatomical tuberosity healing holds the promise of further enhancing functional outcomes, potentially facilitated by specific stems designed for fractures [54, 55].

A recent meta-analysis comparing fracture-specific stem designs for HA and RSA found consistently favorable outcomes, regardless of rehabilitation protocols or tuberosity refixation techniques [54]. However, a study by Imiolczyk et al. [55] suggested that fracture stem designs featuring open metaphyseal windows for bone ingrowth may not necessarily improve tuberosity healing.

Our study aligns with the emerging theme of RSA's efficacy in managing displaced PHF in elderly patients. We observed statistically significant improvements in forward elevation, external rotation, and internal rotation following RSA as a primary treatment. These findings support the positive impact of RSA on functional outcomes and overall quality of life, as suggested by Boileau et al. [58].

Tuberosity healing rates vary widely in the literature, with our study reporting a healing rate of 76%, including 62% anatomical consolidation and 14% malunion. Factors influencing healing outcomes include the use of fracture-specific stems and fixation techniques, while dimensions like Neer's classification, time to surgery, and cortical thickness show no significant associations [58-61]. Our findings echo the benefits of tuberosity healing on functional outcomes and subjective well-being, in line with previous research [61, 58, 62].

While our study did not show a significant improvement in abduction, this metric did demonstrate better outcomes among patients with healed tuberosities. RSA emerged as a key player, facilitating a return to daily activities for 73.2% of patients and enhancing

shoulder mobility for 45.5% of those studied, particularly in the context of an aging population known to require swift recovery [59].

Our study also reflected a commendably low incidence of complications, with no instances of dislocations, instabilities, or neurological injuries reported.

In the pursuit of optimal functional recovery, our study highlights the importance of prioritizing a fracture-specific stem with a bone ingrowth window and a robust fixation technique. This approach holds promise for mitigating tuberosity malunion or non-union, a concern particularly relevant to the elderly population [58].

5. FUTURE PERSPECTIVES AND CONCLUSIONS

Our investigations have revealed noteworthy differences in functional outcomes between patients undergoing Reverse Shoulder Arthroplasty with Bone Increased Offset (BIO-RSA) and standard RSA [64, 65]. Specifically, patients who had BIO-RSA demonstrated improved passive external rotational capability and enhanced active internal rotation compared to those who received standard RSA. This distinction suggests that using a lateralized glenosphere may enhance functional mobility in RSA.

However, it's crucial to exercise caution when pursuing maximal lateralization. Excessive glenosphere lateralization could potentially increase tension on the rotator cuff, leading to unintended consequences, including a potential reduction in tuberosity consolidation rates and, consequently, compromised overall functional outcomes. The delicate balance between lateralization and its potential impact on rotator cuff function and tuberosity consolidation remains an ongoing area of investigation.

An ongoing prospective study at Centro Hospitalar Universitário de Santo António aims to further explore the dynamics at play in this context. By analyzing the outcomes of patients with acute and displaced PHF who have undergone RSA with a lateralized glenosphere, the study seeks to provide a clearer understanding of the functional mobility achieved through this approach.

In a distinct area of investigation, our research has underscored the potential applicability of RSA involving younger patients [66]. Particularly when achieving a satisfactory fracture reduction becomes challenging, RSA emerges as a potential solution that could potentially deliver superior outcomes compared to cases with suboptimal fracture alignment or HA.

This emphasizes the importance of customized treatment strategies that consider the unique anatomical and biomechanical characteristics of individual patients.

The use of RSA as the primary treatment for displaced and comminuted PHF in patients under 65 years of age should be a subject of study, particularly in comparison to the ORIF approach.

Another facet of our investigation explores the role of RSA as a salvage procedure for patients who have experienced treatment failure following non-operative approaches or surgical interventions like ORIF or HA. Can RSA serve as an effective solution in cases of suboptimal outcomes or unsuccessful prior interventions? This intriguing question drives an ongoing prospective study at Centro Hospitalar Universitário de Santo António, seeking to determine whether RSA, when used as a salvage procedure, can deliver superior results compared to its primary application.

As we navigate these uncharted areas of RSA application and its diverse implications, our research underscores the importance of comprehensive evaluation and ongoing inquiry. These investigations provide a promising avenue for unraveling the multifaceted dimensions of RSA's effectiveness, allowing for the refinement of clinical decision-making processes and the optimization of patient outcomes.

Despite the appeal of RSA, the path to surgical intervention for older individuals requires thorough preoperative assessments. Tailoring treatment to each patient's unique surgical risk profile is crucial, and the decision for surgical intervention must be carefully evaluated on a case-by-case basis.

In summary, this study explores the intricate domain of displaced PHF in older individuals and highlights the evolving significance of RSA as a therapeutic choice. Our research adds to the expanding pool of evidence, showcasing notable enhancements in functional outcomes and providing a promising outlook in the field of geriatric orthopedics.

REFERENCES

1. Harvey, N., E. Dennison, and C. Cooper, *Osteoporosis: impact on health and economics*. Nature Reviews Rheumatology, 2010. **6**(2): p. 99-105.
2. Relvas Silva, M., et al., *Proximal humerus fractures: epidemiology and trends in surgical management of hospital-admitted patients in Portugal*. JSES Int, 2022. **6**(3): p. 380-384.
3. Bell, J.E., et al., *Trends and variation in incidence, surgical treatment, and repeat surgery of proximal humeral fractures in the elderly*. J Bone Joint Surg Am, 2011. **93**(2): p. 121-31.
4. Court-Brown, C.M. and B. Caesar, *Epidemiology of adult fractures: A review*. Injury, 2006. **37**(8): p. 691-7.
5. Kannus, P., et al., *Rate of proximal humeral fractures in older Finnish women between 1970 and 2007*. Bone, 2009. **44**(4): p. 656-659.
6. Klug, A., et al., *Complications after surgical treatment of proximal humerus fractures in the elderly—an analysis of complication patterns and risk factors for reverse shoulder arthroplasty and angular-stable plating*. Journal of Shoulder and Elbow Surgery, 2019. **28**(9): p. 1674-1684.
7. McLean, A.S., et al., *Nationwide trends in management of proximal humeral fractures: an analysis of 77,966 cases from 2008 to 2017*. Journal of Shoulder and Elbow Surgery, 2019. **28**(11): p. 2072-2078.
8. Sumrein, B.O., et al., *Proximal humeral fractures in Sweden—a registry-based study*. Osteoporosis International, 2016. **28**(3): p. 901-907.
9. Khatib, O., I. Onyekwelu, and J.D. Zuckerman, *The incidence of proximal humeral fractures in New York State from 1990 through 2010 with an emphasis on operative management in patients aged 65 years or older*. Journal of Shoulder and Elbow Surgery, 2014. **23**(9): p. 1356-1362.
10. Hardeman, F., et al., *Predictive factors for functional outcome and failure in angular stable osteosynthesis of the proximal humerus*. Injury, 2012. **43**(2): p. 153-158.
11. Laux, C.J., et al., *Current concepts in locking plate fixation of proximal humerus fractures*. J Orthop Surg Res, 2017. **12**(1): p. 137.

12. Südkamp, N., et al., *Open Reduction and Internal Fixation of Proximal Humeral Fractures with Use of the Locking Proximal Humerus Plate*. The Journal of Bone and Joint Surgery-American Volume, 2009. **91**(6): p. 1320-1328.
13. Yahuaca, B.I., et al., *Acute surgical management of proximal humerus fractures: ORIF vs. hemiarthroplasty vs. reverse shoulder arthroplasty*. Journal of Shoulder and Elbow Surgery, 2020. **29**(7): p. S32-S40.
14. Jung, S.W., et al., *Factors that Influence Reduction Loss in Proximal Humerus Fracture Surgery*. J Orthop Trauma, 2015. **29**(6): p. 276-82.
15. Spross, C., et al., *How bone quality may influence intraoperative and early postoperative problems after angular stable open reduction-internal fixation of proximal humeral fractures*. J Shoulder Elbow Surg, 2017. **26**(9): p. 1566-1572.
16. Carbone, S. and M. Papalia, *The amount of impaction and loss of reduction in osteoporotic proximal humeral fractures after surgical fixation*. Osteoporos Int, 2016. **27**(2): p. 627-33.
17. Han, R.J., et al., *Proximal humerus fragility fractures: recent trends in nonoperative and operative treatment in the Medicare population*. J Shoulder Elbow Surg, 2016. **25**(2): p. 256-61.
18. Rosas, S., et al., *Trends in surgical management of proximal humeral fractures in the Medicare population: a nationwide study of records from 2009 to 2012*. J Shoulder Elbow Surg, 2016. **25**(4): p. 608-13.
19. Launonen, A.P., et al., *Operative versus non-operative treatment for 2-part proximal humerus fracture: A multicenter randomized controlled trial*. PLoS Med, 2019. **16**(7): p. e1002855.
20. Helfen, T., et al., *Operative treatment of 2-part surgical neck type fractures of the proximal humerus in the elderly: Cement augmented locking plate PHILOS vs. proximal humerus nail multiloc(R)*. Injury, 2020. **51**(10): p. 2245-2252.
21. Sebastia-Forcada, E., et al., *Outcomes of Reverse Total Shoulder Arthroplasty for Proximal Humeral Fractures: Primary Arthroplasty Versus Secondary Arthroplasty After Failed Proximal Humeral Locking Plate Fixation*. J Orthop Trauma, 2017. **31**(8): p. e236-e240.

22. Padegimas, E.M., et al., *Defining optimal calcar screw positioning in proximal humerus fracture fixation*. Journal of Shoulder and Elbow Surgery, 2017. **26**(11): p. 1931-1937.
23. Padegimas, E.M., et al., *Failure to restore the calcar and locking screw cross-threading predicts varus collapse in proximal humerus fracture fixation*. Journal of Shoulder and Elbow Surgery, 2020. **29**(2): p. 291-295.
24. Schnetzke, M., et al., *Quality of Reduction Influences Outcome After Locked-Plate Fixation of Proximal Humeral Type-C Fractures*. Journal of Bone and Joint Surgery, 2016. **98**(21): p. 1777-1785.
25. Erdogan, M., et al., *The effect of inferomedial screw on postoperative shoulder function and mechanical alignment in proximal humerus fractures*. Eur J Orthop Surg Traumatol, 2014. **24**(7): p. 1055-9.
26. Gardner, M.J., et al., *The importance of medial support in locked plating of proximal humerus fractures*. J Orthop Trauma, 2007. **21**(3): p. 185-91.
27. Zhang, W., et al., *The mechanical benefit of medial support screws in locking plating of proximal humerus fractures*. PLoS One, 2014. **9**(8): p. e103297.
28. Bai, L., et al., *Effect of Calcar Screw Use in Surgical Neck Fractures of the Proximal Humerus With Unstable Medial Support: A Biomechanical Study*. J Orthop Trauma, 2014. **28**(8): p. 452-7.
29. Burke, N.G., et al., *Locking plate fixation with and without inferomedial screws for proximal humeral fractures: a biomechanical study*. J Orthop Surg (Hong Kong), 2014. **22**(2): p. 190-4.
30. Little, M.T., et al., *The impact of preoperative coronal plane deformity on proximal humerus fixation with endosteal augmentation*. J Orthop Trauma, 2014. **28**(6): p. 338-47.
31. Bae, J.H., et al., *The biomechanical performance of locking plate fixation with intramedullary fibular strut graft augmentation in the treatment of unstable fractures of the proximal humerus*. J Bone Joint Surg Br, 2011. **93**(7): p. 937-41.
32. Chow, R.M., et al., *Proximal humeral fracture fixation: locking plate construct +/- intramedullary fibular allograft*. J Shoulder Elbow Surg, 2012. **21**(7): p. 894-901.

33. Osterhoff, G., et al., *Medial support by fibula bone graft in angular stable plate fixation of proximal humeral fractures: an in vitro study with synthetic bone*. J Shoulder Elbow Surg, 2011. **20**(5): p. 740-6.
34. Kim, D.S., et al., *Which additional augmented fixation procedure decreases surgical failure after proximal humeral fracture with medial comminution: fibular allograft or inferomedial screws?* J Shoulder Elbow Surg, 2018. **27**(10): p. 1852-1858.
35. Lee, S.H., et al., *Outcomes of locking plate fixation with fibular allograft augmentation for proximal humeral fractures in osteoporotic patients: comparison with locking plate fixation alone*. Bone Joint J, 2019. **101-B**(3): p. 260-265.
36. Matassi, F., et al., *Locking plate and fibular allograft augmentation in unstable fractures of proximal humerus*. Injury, 2012. **43**(11): p. 1939-42.
37. Neviaser, A.S., et al., *Endosteal strut augment reduces complications associated with proximal humeral locking plates*. Clin Orthop Relat Res, 2011. **469**(12): p. 3300-6.
38. Manzi, J.E., et al., *Failed Proximal Humerus Osteosynthesis Using Intramedullary Fibular Strut Allograft Conversion to Reverse Shoulder Arthroplasty*. Tech Hand Up Extrem Surg, 2020. **24**(1): p. 7-12.
39. Kathrein, S., et al., *Biomechanical comparison of an angular stable plate with augmented and non-augmented screws in a newly developed shoulder test bench*. Clin Biomech (Bristol, Avon), 2013. **28**(3): p. 273-7.
40. Roderer, G., et al., *Biomechanical in vitro assessment of screw augmentation in locked plating of proximal humerus fractures*. Injury, 2013. **44**(10): p. 1327-32.
41. Schliemann, B., et al., *Screw augmentation reduces motion at the bone-implant interface: a biomechanical study of locking plate fixation of proximal humeral fractures*. J Shoulder Elbow Surg, 2015. **24**(12): p. 1968-73.
42. Goodnough, L.H., et al., *Intramedullary Cage Fixation for Proximal Humerus Fractures Has Low Reoperation Rates at 1 Year: Results of a Multicenter Study*. J Orthop Trauma, 2020. **34**(4): p. 193-198.

43. Chen, H., et al., *Indirect Reduction and Strut Support of Proximal Humerus Fractures Using a Titanium Mesh in Elderly Patients: A Novel Technique*. J Orthop Trauma, 2020. **34**(4): p. e142-e147.
44. Siebenburger, G., et al., *Screw-tip augmentation versus standard locked plating of displaced proximal humeral fractures: a retrospective comparative cohort study*. J Shoulder Elbow Surg, 2019. **28**(7): p. 1326-1333.
45. Maugendre, E., et al., *Epidemiology and mortality in older patients treated by reverse shoulder arthroplasty for displaced proximal humerus fractures*. Orthop Traumatol Surg Res, 2019. **105**(8): p. 1509-1513.
46. Rotman, D., et al., *Mortality After Complex Displaced Proximal Humerus Fractures in Elderly Patients: Conservative Versus Operative Treatment With Reverse Total Shoulder Arthroplasty*. Geriatr Orthop Surg Rehabil, 2018. **9**: p. 2151459318795241.
47. Owsley, K.C. and J.T. Gorczyca, *Fracture displacement and screw cutout after open reduction and locked plate fixation of proximal humeral fractures [corrected]*. J Bone Joint Surg Am, 2008. **90**(2): p. 233-40.
48. Klein, M., et al., *Treatment of comminuted fractures of the proximal humerus in elderly patients with the Delta III reverse shoulder prosthesis*. J Orthop Trauma, 2008. **22**(10): p. 698-704.
49. Du, S., et al., *Interventions for Treating 3- or 4-part proximal humeral fractures in elderly patient: A network meta-analysis of randomized controlled trials*. Int J Surg, 2017. **48**: p. 240-246.
50. Bufquin, T., et al., *Reverse shoulder arthroplasty for the treatment of three- and four-part fractures of the proximal humerus in the elderly: a prospective review of 43 cases with a short-term follow-up*. J Bone Joint Surg Br, 2007. **89**(4): p. 516-20.
51. Torrens, C., et al., *Reverse shoulder arthroplasty for the treatment of acute complex proximal humeral fractures: Influence of greater tuberosity healing on the functional outcomes*. J Orthop Surg (Hong Kong), 2018. **26**(1): p. 2309499018760132.
52. Henninger, H.B., et al., *Effect of deltoid tension and humeral version in reverse total shoulder arthroplasty: a biomechanical study*. J Shoulder Elbow Surg, 2012. **21**(4): p. 483-90.

53. Boileau, P., et al., *Grammont reverse prosthesis: design, rationale, and biomechanics*. J Shoulder Elbow Surg, 2005. **14**(1 Suppl S): p. 147S-161S.
54. Onggo, J.R., et al., *Improved functional outcome and tuberosity healing in patients treated with fracture stems than nonfracture stems during shoulder arthroplasty for proximal humeral fracture: a meta-analysis and systematic review*. J Shoulder Elbow Surg, 2021. **30**(3): p. 695-705.
55. Imiolczyk, J.P., P. Moroder, and M. Scheibel, *Fracture-Specific and Conventional Stem Designs in Reverse Shoulder Arthroplasty for Acute Proximal Humerus Fractures-A Retrospective, Observational Study*. J Clin Med, 2021. **10**(2).
56. Lenarz, C., et al., *Is reverse shoulder arthroplasty appropriate for the treatment of fractures in the older patient? Early observations*. Clin Orthop Relat Res, 2011. **469**(12): p. 3324-31.
57. Valenti, P., et al., *Mid-term outcome of reverse shoulder prostheses in complex proximal humeral fractures*. Acta Orthop Belg, 2012. **78**(4): p. 442-9.
58. Boileau, P., et al., *Reverse shoulder arthroplasty for acute fractures in the elderly: is it worth reattaching the tuberosities?* J Shoulder Elbow Surg, 2019. **28**(3): p. 437-444.
59. Schmalzl, J., et al., *High tuberosity healing rate associated with better functional outcome following primary reverse shoulder arthroplasty for proximal humeral fractures with a 135 degrees prosthesis*. BMC Musculoskelet Disord, 2020. **21**(1): p. 35.
60. Simovitch, R.W., et al., *Effect of Tuberosity Healing on Clinical Outcomes in Elderly Patients Treated With a Reverse Shoulder Arthroplasty for 3- and 4-Part Proximal Humerus Fractures*. J Orthop Trauma, 2019. **33**(2): p. e39-e45.
61. Grubhofer, F., et al., *Reverse total shoulder arthroplasty for acute head-splitting, 3- and 4-part fractures of the proximal humerus in the elderly*. J Shoulder Elbow Surg, 2016. **25**(10): p. 1690-8.
62. Jain, N.P., et al., *Tuberosity healing after reverse shoulder arthroplasty for complex proximal humeral fractures in elderly patients-does it improve outcomes? A systematic review and meta-analysis*. J Shoulder Elbow Surg, 2019. **28**(3): p. e78-e91.

63. Garofalo, R., et al., *Reverse shoulder arthroplasty for proximal humerus fracture using a dedicated stem: radiological outcomes at a minimum 2 years of follow-up-case series*. J Orthop Surg Res, 2015. **10**: p. 129.
64. Nunes, B., et al., *Lateralized versus nonlateralized glenospheres in reverse shoulder arthroplasty: a systematic review with meta-analysis*. Journal of Shoulder and Elbow Surgery, 2021. **30**(7): p. 1700-1713.
65. Amorim-Barbosa, T., et al., *Comparative clinical and radiologic evaluation between patients undergoing standard reversed shoulder arthroplasty or bony increased offset*. Clinics in Shoulder and Elbow, 2023.
66. Fonte, H., et al., *Shoulder Arthroplasty Options for Glenohumeral Osteoarthritis in Young and Active Patients (<60 Years Old): A Systematic Review*. Journal of Shoulder and Elbow Arthroplasty, 2022. **6**.

