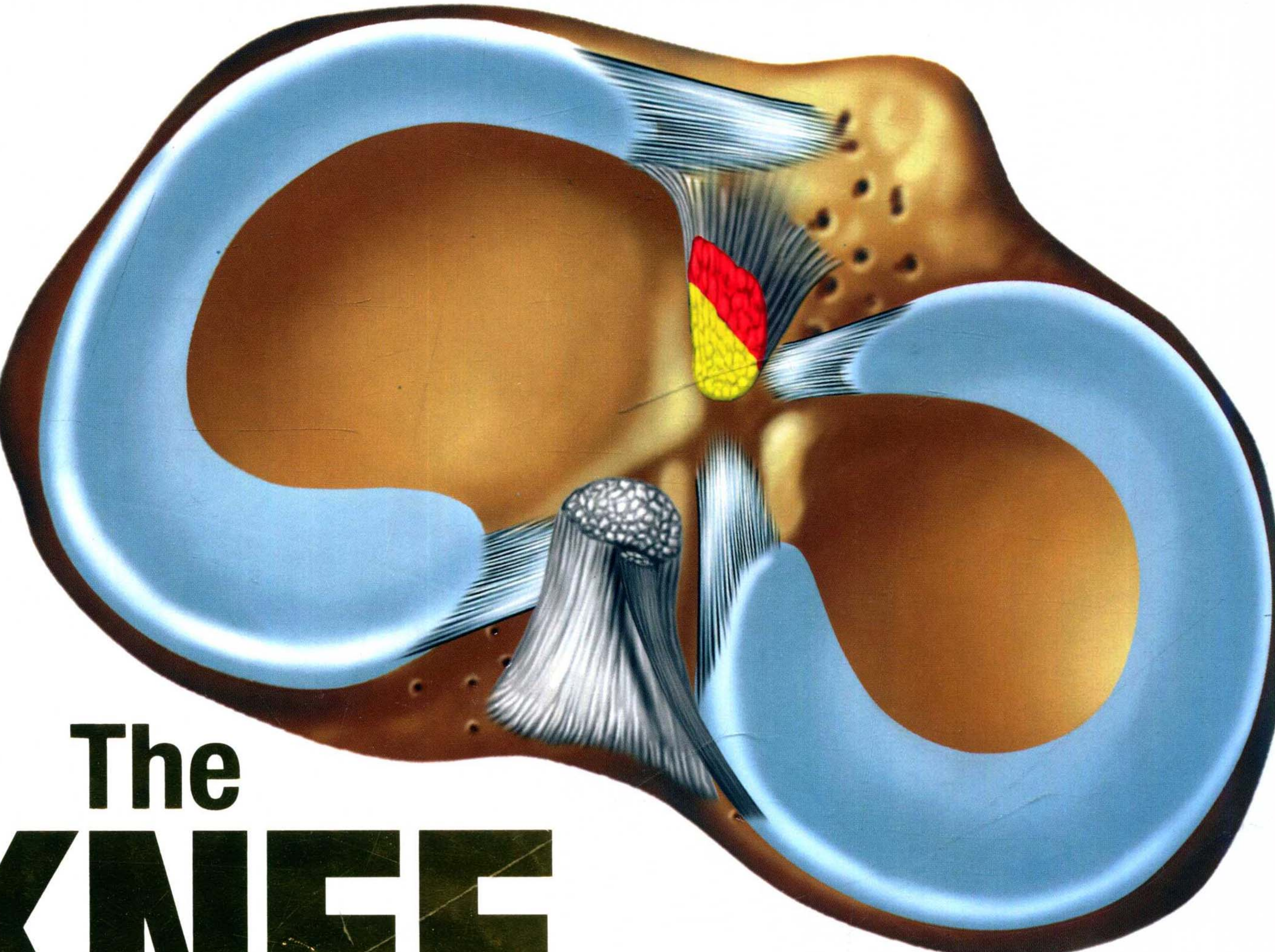
STOLLER'S
Orthopaedics and Sports Medicine



The KNEE

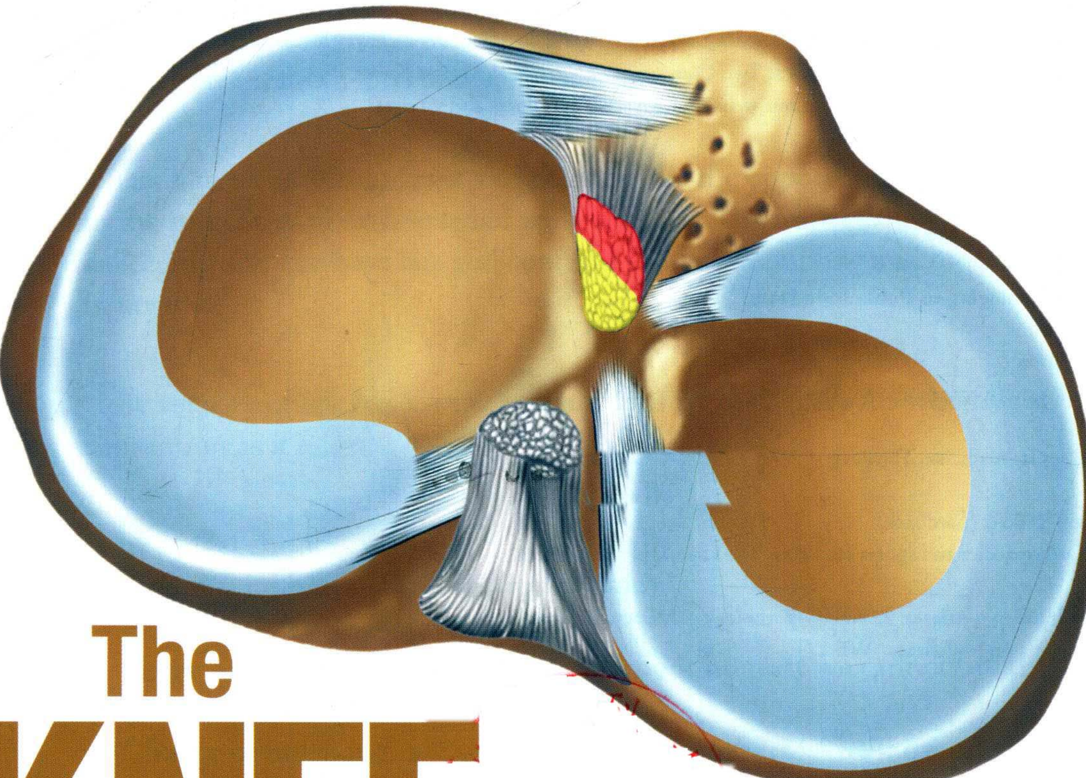
David W. Stoller

Illustrations by Salvador Beltran

Wolters Kluwer

STOLLER'S

Orthopaedics and Sports Medicine



The KNEE

David W. Stoller, MD, FACR

National Director,
Orthopaedic and Musculoskeletal Imaging, RadNet
Medical Director,
Orthopaedic and Musculoskeletal Imaging, Beverly Radiology, Northern California, San Francisco, California
Affiliate Member,
American Shoulder and Elbow Surgeons

Wolters Kluwer

Philadelphia • Baltimore • New York • London
Buenos Aires • Hong Kong • Sydney • Tokyo

Acquisitions Editor: Ryan Shaw
Product Development Editor: Kate Heaney
Production Project Manager: Alicia Jackson
Designer: Larry Pezzato
Senior Manufacturing Coordinator: Beth Welsh
Marketing Manager: Dan Dressler
Prepress Vendor: Absolute Service, Inc.

9 8 7 6 5 4 3 2 1

Printed in the United States of America

Library of Congress Cataloging-in-Publication Data

Stoller, David W., author.
Stoller's orthopaedics and sports medicine. The knee / David W. Stoller.
p. ; cm.
Orthopaedics and sports medicine. The knee
Knee
ISBN 978-1-4963-1828-2 (hardback)
I. Title. II. Title: Orthopaedics and sports medicine. The knee. III. Title: Knee.
[DNLM: 1. Knee Injuries—Atlases. 2. Knee—pathology—Atlases. 3. Knee Joint—pathology—Atlases. 4. Magnetic Resonance Imaging—Atlases. WE 17]
RD561
617.5'82—dc23
2015024070

LWW.com

DEDICATION

To my family and friends for their support and understanding. To my parents for their inspiration, love, and encouragement.

I have always been cognizant and thankful for the opportunity to contribute to the specialties of orthopaedics and radiology. The respect shown by my colleagues and students has and continues to be a humbling and motivating force in my life.

The veracity of truth is a trenchant ally against the consensus who follow convention as if dogma.

The model checklist:

- Honesty, humility in thought and action
- Excel for others through example.
- Never compromise on the truth for without honesty we cannot build knowledge.
- Change of heart and mind through teaching others is the most powerful and natural healing force of the human spirit.

To Howard Berger, MD, President of RadNet, for supporting the development of a world class orthopaedic imaging program.

CONTRIBUTORS

David W. Stoller, MD, FACR
National Director Orthopaedic and Musculoskeletal Imaging, RadNet Medical
Director Orthopaedic and Musculoskeletal Imaging, Beverly Radiology—
Northern California San Francisco, California
Affiliate Member, American Shoulder and Elbow Surgeons

CASE CONTRIBUTORS

Lesley J. Anderson, MD
Assistant Clinical Professor of Orthopaedic Surgery
University of California, San Francisco
Orthopaedic Surgeon
California Pacific Medical Center
San Francisco, California

Piers Barry, MD
Orthopaedic Surgeon
Post Street Orthopaedics and Sports Medicine
San Francisco, California

W. Dilworth Cannon, MD
Professor of Clinical Orthopaedic Surgery
UCSF Sports Medicine Center
University of California
San Francisco, California

James L. Chen, MD
Orthopaedic Surgeon
SportsMed Orthopaedic Group
Faculty, San Francisco Orthopaedic Residency
Clinical Preceptor, University of California San Francisco
San Francisco, California

Garry E. Gold, MD
Professor of Radiology and (by courtesy) Bioengineering and Orthopaedic Surgery
Associate Chair for Research, Radiology
Stanford University
Palo Alto, California

Hollis G. Potter, MD
Chairman, Department of Radiology & Imaging
Hospital for Special Surgery
Professor of Radiology
Weill Medical College of Cornell University

Edward Shin, MD
Orthopaedic Surgeon
Orthopaedic SportsMed Group
San Francisco, California

Kevin R. Stone, MD
Orthopaedic Surgeon
The Stone Clinic
San Francisco, California

Eugene M. Wolf, MD
Department of Orthopaedic Surgery
St. Mary's Medical Center
San Francisco, California

SCIENTIFIC/RESEARCH CONTRIBUTORS

Weitian Chen
Assistant Professor
Department of Imaging & Interventional Radiology
Faculty of Medicine
The Chinese University of Hong Kong

Adriana Kanwischer, BS
Global Product Marketing Leader
MR Premium Segment
GE Healthcare

Jose G. Tamez-Peña, PhD
Chief Technology Officer
Qmetrics Technologies

Melissa E. Sims, MD, MPH
Musculoskeletal Radiologist
San Mateo, California

PREFACE

Stoller's Orthopaedics and Sports Medicine: The Knee represents an ambitious and comprehensive undertaking for both myself and Wolters Kluwer. In order to organize this wealth of information and images in an accessible manner, a unique new format has been developed. A bulleted text that is concise provides for direct and rapid comprehension of a wealth of orthopaedic advancements. Our knowledge of knee anatomy and pathology is a rapidly changing and fluid body of knowledge. **For example, Dr. Freddie Fu's most recent work (2016) on the anterolateral complex has shown that the anterolateral ligament is a disputed structure and is in fact part of the ITB deep capsulo-osseous layer.**

Special features include:

- Comprehensive collections of color illustrations and arthroscopic cases of orthopaedic pathoanatomy
- Key concepts section introductions to emphasize and reinforce critical information
- Detailed figure legends rich in content provide descriptive information and introduce novel concepts.
- 3T and high resolution MR images to demonstrate critical structures in functional knee anatomy and pathology.
- Evolved checklist approach as the keystone for accurate and reproducible image interpretation
- Updated concepts in the knee including:
  - Prospective diagnosis of meniscal tear patterns
  - Meniscal allograft transplantation
  - ACL graft isometry and anatomic double-bundle ACL reconstruction
  - Posterolateral corner and posteromedial corner
  - Multiple–ligament injuries
  - Restorative techniques for articular cartilage

David W. Stoller, MD, FACR
National Director
Orthopaedic and Musculoskeletal Imaging, RadNet
Medical Director
Orthopaedic and Musculoskeletal Imaging, Beverly Radiology, Northern California
San Francisco, California
Affiliate Member
American Shoulder and Elbow Surgeons

ACKNOWLEDGMENTS

Undertaking the writing of this text has provided a unique opportunity to contribute to the emerging field of orthopaedic magnetic resonance imaging (MRI). Orthopaedic MRI has earned respect as a distinct subspecialty and is now a primary modality in the diagnosis of internal derangement of the joints. I would like to acknowledge the contributions of the following individuals:

> J.A. Gosling, MD, MB, ChB; P.F. Harris, MD, MB, ChB, MSc; J.R. Humpherson, MB, ChB; J. Whitmore, MD, MB, BS, LRCP, MRCS; and P.L.T. Willan, MB, ChB, FRCS, for providing quality gross anatomic color plates from their text, *Human Anatomy*, Second Edition, Gower Medical Publishing.

The expert staff at Wolters Kluwer, for their efforts and appreciation of the necessary quality required to bring this text to fruition, including Lisa McAllister, VP & Publisher, Medicine & Advanced Practice; Ryan Shaw, Acquisitions Editor; Kate Heaney, Product Development Editor; Larry Pezatto, Creative Services Director; and Crystal Perkins, West Coast production liaison for Wolters Kluwer.

Special acknowledgment for Doug Smock for a lifetime of excellence as a creative force in design and creative services for my books with LWW and Wolters Kluwer over the past two decades.

Qmetrics Technologies

Melissa E. Sims, MD, MPH for reference compilation.

Brent Berthy, General Manager, Invivo for his innovative MR coil development and support of MR education.

Robert Hoffman and Intelerad for their support in the storage of MR cases.

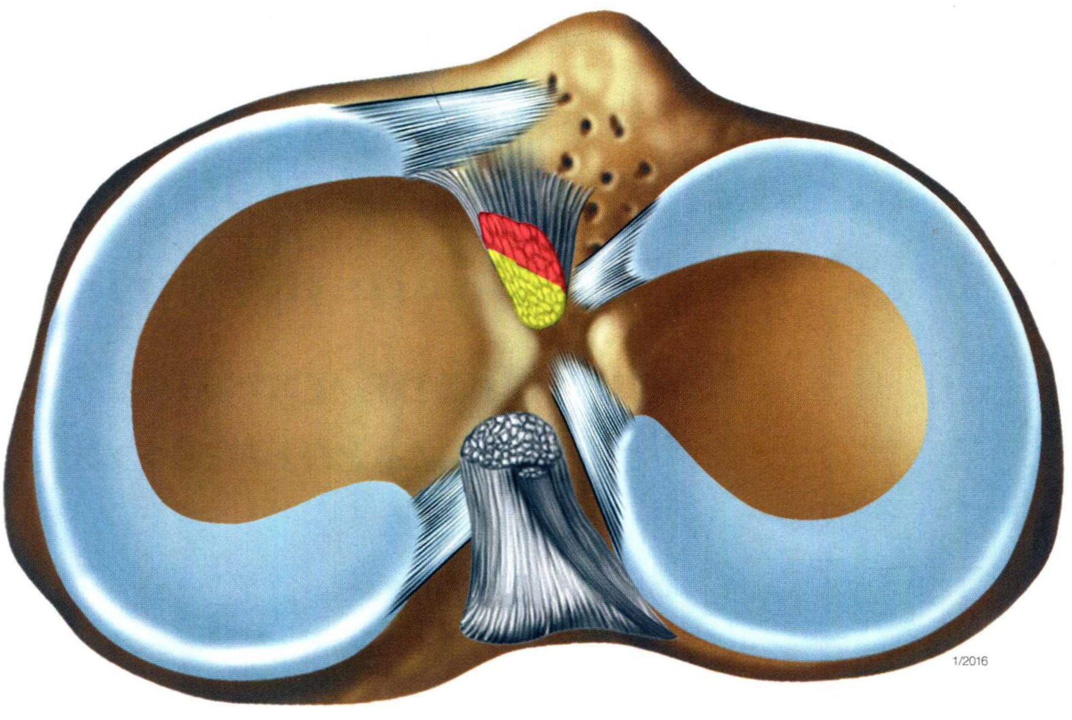
Ralph Stubenrauch, Clinical Applications Manager, RadNet for computer and PACs processing of 3T images.

W. Dilworth Cannon, MD; Scott Dye, MD; Greg Ondera, MD; and Plexus Communications for knee dissection and arthroscopy.

I would like to recognize the work of Michel Bonnin, MD and Freddie Fu, MD

> *The Knee Joint: Surgical Techniques and Strategies,*
> *Michel Bonnin, MD*
>
> *Master Techniques in Orthopaedic Surgery: Sports Medicine,*
> *Freddie H. Fu, MD, DSci(Hon), DPs(Hon)*

CONTENTS



1
Practical Guide to Knee MR Imaging

Practical Guide to Knee MR Imaging

Key Factors to Clinical Diagnostics

Motion Insensitivity

- Sequences and parameters that eliminate or reduce patient motion and flow-related artifacts

Uniform Fat Suppression

- Techniques insensitive to B_0 and B_1 inhomogeneity, preferably flexible on the amount of saturation

Contrast

- Consisting of T1, proton density (PD), and T2* weighting

High Resolution

- Required for visualizing submillimeter structures

Isotropic Resolution

- 3D imaging techniques for postacquisition reformatting

Off-Isocenter Image Quality

- Consistent image quality even when the knee is positioned away from isocenter

Reduced Distortion Around Metal

- Availability of advanced techniques for imaging around total knee arthroplasties as well as fixation screws

Efficient Surface Coils

- Coils that support parallel imaging, possess sufficient signal-to-noise ratio (SNR) with tissue depth, provide stability and comfort to the patient, and are easy to set up

Positioning

Radiofrequency (RF) Coils

- There are several commercial knee coil options to choose from, though compatibility will depend on the specific MR system vendor, model, and field strength. The most common are transmit/receive (TR) coils, which typically consist of a local transmit birdcage coil coupled with an array of receive elements. The benefits of a TR knee coil include reduced specific absorption rate (SAR) deposition to the patient, reduced signal wrapping from adjacent anatomy, and some performance improvement on the specific sequences.
- Whether TR or receive-only, the number of receive channels varies between eight and 18, with a trend to higher channel counts. Higher receive channel counts will provide higher SNR closer to the surface and enable higher acceleration factors with parallel imaging. However, the drawback with higher channels is the need for intensity correction due to intense signal closer to the surface coils.
- Most TR knee coils have rigid enclosures, with a split-top design, making patient positioning relatively straightforward. Some receive-only coils may require additional fixation structures to support the patient's knee and the coil. As such, positioning of the patient's knee typically consists of centering the knee within the superior/inferior extent of the coil. Most often, this is best accomplished by centering the tibial plateau with the patient lying supine. Some flexible coils will be able to accommodate larger patients who might not fit within rigid coils.

Immobilization

- Patients will almost always be positioned supine, with the knee to be imaged located as close to right/left isocenter as possible, though this will be limited by the size of the nonimaged knee. Wedge pads will often be placed within the coil to keep the knee immobilized, with a slight bend for comfort, though some radiologists may prefer a straighter knee. Depending on the MR system, either a feet first or head first orientation can be used, though most patients will prefer feet first.

Basic Pulse Sequences

FSE

- The most commonly used sequence for musculoskeletal imaging is fast spin-echo or turbo spin-echo. Most vendors have versions for 2D and 3D acquisitions, but multiplanar 2D is primarily used, though there is an increasing trend toward 3D. FSE provides spin-echo type contrast with faster scan times by acquiring multiple echoes in each shot. PD, T1, or T2 image contrast can be obtained, determined by the TR, echo time (TE), and echo train length (ETL) parameters. FSE protocols typically focus on controlling echo spacing (time between echoes) to avoid blurring and flow artifacts. The minimum TE is an indicator of echo spacing, and shorter values are desired to provide good image quality.

Parameter selections for decreasing Echo Spacing:			
↑↑ Field of view (FOV)	↓↓ Matrix	↑↑ Slice thickness	↑↑ Bandwidth

FRFSE

- The fast recovery fast spin-echo (FRFSE) sequence produces images with more T2 contribution with the same TR as FSE. It is a modified FSE sequence using additional RF pulses after the acquisition window to hasten recovery of longitudinal magnetization from signal with long T2.
- FRFSE is commonly used to reduce scan time by using a shorter TR, while maintaining T2 contrast.

Recommended TR, TE, and ETL values for FSE and FRFSE:

Pulse Sequence	TR	TE	ETL
FRFSE PD	2000–3000ms	30–60ms	6–10
FRFSE T2	2000–3000ms	85ms	12–14
FSE T1	500–900ms	Min.	2–4

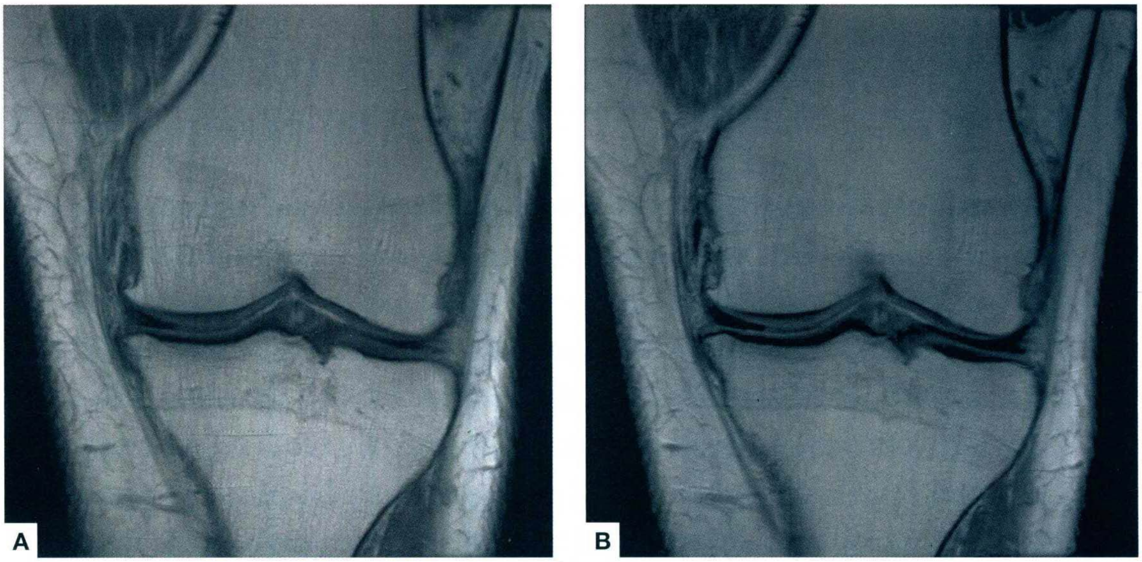


FIGURE 1.1 (**A**, **B**) Image on the left with an echo spacing of 8ms compared to an echo spacing of 16ms resulting in image blurring.

GRE

- **Gradient echo (GRE) sequences are used to provide T1 and T2* contrast, which can complement spin-echo based acquisitions. Most practical uses in the knee are with 3D sequences, such as spoiled gradient echo (SPGR) for assessing physes. Generally, the key parameter for managing contrast with GRE sequences is flip angle:**

Sequence	Contrast	Flip Angle
2D GRE/SPGR	T1 T2*	40–60 20–30
3D GRE/SPGR	T1 T2*	25–45 5–8

An increase in flip angle:	
↑↑ T1 contrast	↑↑ SNR

Inversion Recovery

- **Inversion recovery sequences are frequently used for uniform suppression of fat signal by acquiring data at the null point of the T1 recovery, with the key parameter being the TI (inversion time).**

Scan Parameters

Spatial Resolution

- Determined by voxel size, which depends on the FOV, acquisition matrix, and slice thickness

Calculating Voxel Size

$$\frac{\textit{Phase FOV}}{\textit{\# Phase matrix}} = \text{Phase dimension}$$

$$\frac{\textit{Frequency FOV}}{\textit{\# Frequency matrix}} = \text{Frequency dimension}$$

Phase dimension × Frequency dimension × Slice thickness = Voxel volume

- High resolution may add valuable information for musculoskeletal imaging.

Parameter selections to increase resolution (i.e., reduce voxel volume):		
↓↓ FOV	↑↑ Matrix	↓↓ Slice thickness

Acquisition Time

- Typically, the SNR is proportional to the acquisition time. However, longer scans are more prone to motion artifacts. The primary parameters that impact acquisition times are TR, phase matrix, and the number of excitations (NEX) or averages. For 3D sequences, phase matrix includes both the in-plane and slice direction, which is typically the number of slices.

Calculating acquisition time:
2D TR × phase matrix × NEX 3D TR × in-plane phase matrix × NEX × # slices

SNR

- Noise is the nondiagnostic signal that is generated from the patient, the environment, and the system electronics. The goal of sequence parameter optimization is to increase signal, which is proportional to field strength, voxel volume, and the time spent acquiring the signal.
- Parameter selection to increase SNR:

Time		
TR ↑↑	NEX ↑↑	
Resolution		
FOV ↑↑	↓↓ Matrix	Slice Thickness ↑↑

Trade-Offs

- In the clinical environment, the imaging protocol parameters will be determined according to many different goals. Understanding the parameter trade-offs is the only way to achieve good image quality, whether there is patient motion or anxiety, positioning limitations, anatomic variations, time restrictions, or any other challenges.
- The table below is designed to provide guidance to adjust protocols without compromising the exam objectives.

Parameters	Resolution	Time	SNR
↑↑ TR	–	↑↑	↑↑
↑↑ TE	–	–	↓↓
↑↑ NEX	–	↑↑	↑↑
↑↑ Slice Thickness	↓↓	–	↑↑
↑↑ FOV	↓↓	–	↑↑
↑↑ Bandwidth	–	–	↓↓
↑↑ Frequency	↑↑	–	↓↓
↑↑ Phase	↑↑	↑↑	↓↓

↑↑ ETL	–	↓↓	–

- **ETL and bandwidth are parameters that affect protocols in a wider manner and deserve special mention.**

Increasing ETL allows:				
↑↑ TE/T2 Contrast	↓↓ # of slices	↓↓ Scan time	↑↑ Motion Artifacts	↑↑ Blurring

Increasing Bandwidth:				
↓↓ SNR	↑↑ # of slices	↓↓ Echo Space	↓↓ Motion Artifacts	↓↓ Chemical Shift

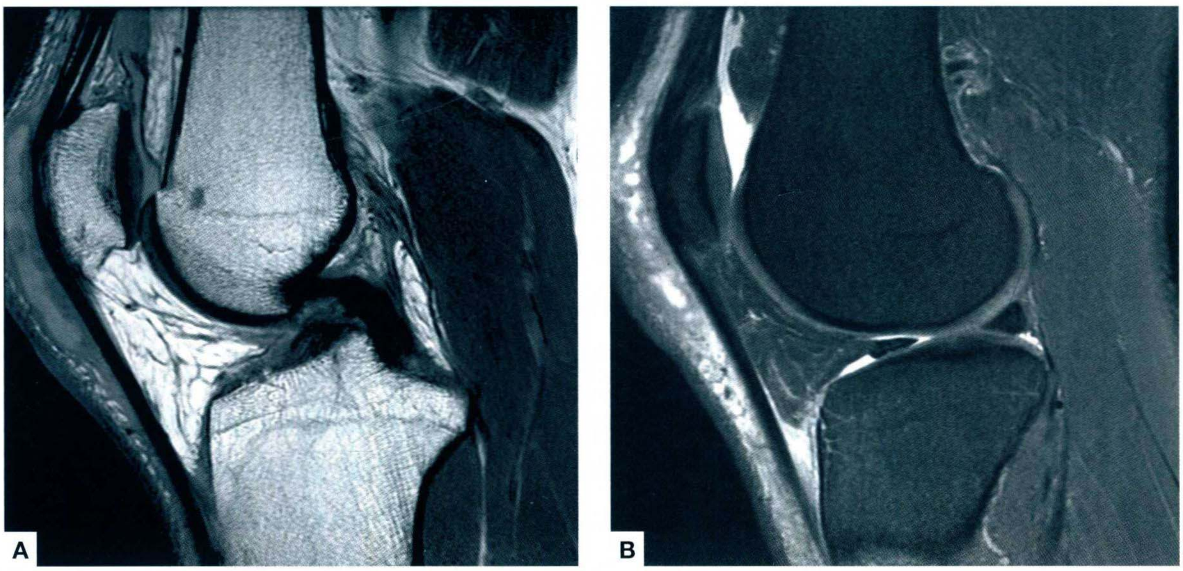


FIGURE 1.2 (**A**) Sagittal FR FSE PD and (**B**) sagittal FR FSE PD fat saturation images.