Textbook of
ORTHOPEDICS AND TRAUMA

4 VOLUMES

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ORTHOPEDICS AND TRAUMA

Third Edition

Under the Aegis of
Indian Orthopedic Association

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Dedicated to

My wife Shashikala
and Children
Milind, Sunil, Rajiv, Vedavati, Ruta and Vidisha, Sujay and Madhura
for their untiring help

— GS Kulkarni

My father Professor Dr Sudhir Babhulkar,
who inculcated in me the art of Orthopedics,
My mother Aruna who created the passionate me,
my loving wife, Dr Nandini, and
lovely daughters Sanskriti and Siddhi
for sparing me for Orthopedic Academics

— Sushrut Babhulkar

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Foreword to the Third Edition

It is a privilege and honor to write a foreword for the third edition of the *Textbook of Orthopedics and Trauma*.

This textbook, which reflects the work and expertise of the Indian orthopedic surgeons, was made possible by the single effort of Dr GS Kulkarni when he brought out the first edition in the year 1999. In the span of merely 16 years, the textbook has become a popular and favored source of reference and learning for orthopedic surgeons and trainees alike around our country. The progress into third edition in a short period reflects the popularity and also the intention of its editor to keep the textbook current and relevant with all recent advances.

The textbook has great relevance as the burden of orthopedic diseases is increasing globally, especially in developing countries like India. People suffering from joint disorders and low back pain include millions resulting in a major socioeconomic problem. Trauma, especially due to road-traffic accidents is also on the rise, and there is one death on the Indian roads every four minutes causing more than seven lakh people undergoing major injuries every year. Orthopedic surgery is also evolving rapidly. The tremendous advances in allied sciences of molecular biology, genetics, biomechanics, and metallurgy that are taking place at a rapid pace have brought a great change in the field. While all this has translated to better patient care and outcome, the trainees and the young surgeons face a challenge to keep up with the current knowledge. The textbook captures the entire spectra of orthopedics in a concise and precise fashion with contributions from many eminent surgeons. It thus fills the need adequately, and I am sure that the demand for the fourth edition will not be far away.

I congratulate Dr Kulkarni for his enthusiasm and persistence towards making this book possible. He is a role model for all of us, and his energy, passion and commitment to a cause is a source of inspiration for many of us.

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Ganga Hospital
Coimbatore, Tamil Nadu, India
President-Elect SICOT
Chair, International Research Commission, AOSpine
Past President, Indian Orthopedic Association
Past President, Association of Spine Surgeons of India

Foreword to the Second Edition

The Herculean task of bringing out the second edition is taken up by the editor Prof Dr GS Kulkarni to update and edit the present knowledge of orthopedics and traumatology. The textbook has an excellent collection of topics written by experienced and knowledgeable orthopedic surgeons. The scholarly work done by the editor is being published by M/s Jaypee Brothers under the aegis of Indian Orthopedic Association as its revised second edition.

All the contributors have taken tremendous efforts to incorporate the present-day knowledge and recent trends of the concerned topics. Many orthopedic problems in developing countries are different from those in the Western country and most of the books, journals and publications are published from the West. The problems associated with osteosynthesis and recent trends in nailing interlocking have been elaborately written. The common problems of neglected fractures and their management which every surgeon encounters in the practice are well covered. The conditions associated with traumatology and their complications are nicely covered in this edition. The textbook has covered almost all the topics and conditions which we face day to day.

This book will be relevant and definitely helpful to orthopedic surgeons and students. Dr GS Kulkarni with his vast experience and dedicated efforts has brought us the new edition of this book with a very high standard which will be helpful to the readers.

Prof (Dr) Sudhir Babhulkar
MS (Orth) D Ortho PhD Orth DSc Orth FAMS
Past President Indian Orthopedic Association

Foreword to the First Edition

The *Textbook of Orthopedics and Trauma* being published by the Indian Orthopedic Association, edited by Dr GS Kulkarni, is the most useful undertaking. This textbook provides the collective experiences in the field of orthopedics and trauma of all the senior and experienced orthopedic surgeons of India.

India is perhaps the foremost amongst the developing countries. The CATCH 22 of the word "developing" fails to reveal that if the whole population of countries like India is taken into account. A certain section may have reached a level of development almost near to that developed by the so-called developed countries, and certain section is plagued by poverty and ignorance.

The orthopedic surgeons practicing in India are familiar and capable of dealing not only with diseases and disabilities that affect the prosperous dominant elite, who expect the same kind of health care as is available in the most developed countries of the world but also to be able to look after and treat adequately such conditions which have almost disappeared from those countries, e.g. paralytic poliomyelitis, pyogenic infections of bones and joints, tuberculous disease of bone and joints, mycotic infections, the neural and osteoarticular damage caused by Hansen's infections especially among young children and infants, including the newborn. These diseases usually affect the poorer section of the society.

The challenge of the orthopedic surgeons in developing countries, therefore, is more comprehensive and varied. They have to handle all these serious conditions with severe financial and infrastructural constraints. Considering these challenges, Dr Kulkarni has done an excellent job of selecting the topics and contributors for the book. Among all the developing countries, India happens to have a fairly well-trained body of orthopedic surgeons, who have had experience in the management of these wide variety of diseases and disabilities of the locomotor system. The contributors have taken great pains and have described in detail these subjects, which I am sure, will be extremely useful to the orthopedists of the developing countries.

Lately, with the introduction of mechanization and high-speed transport facilities, there is increased incidence of high-velocity trauma causing polytrauma, which requires a very well-planned system of casualty care, which does not exist in countries like India. I am pleased to read the chapters on polytrauma written by eminent personalities.

Dr Kulkarni is known to me since long. He is a devoted orthopedic academician. I also know many of the section editors and contributors. They are sincere hard-working group of orthopedic surgeons.

The book points out the wisdom of senior orthopedic surgeons of India and fills the gap that exists in this field. The enterprise that the Indian Orthopedic Association is undertaking, is indeed most gratifying.

I hope that the book will act as a pathfinder and a guide to help orthopedic surgeons, who are practicing in developing countries.

B Mukhopadhyay
Emeritus Professor
Patna

Orthopedics and trauma is the largest specialty of surgery, and especially, with the subspecialties in orthopedics which are now more than 15 in number, it obviously becomes difficult to encompass the total spectrum in its fullness in any textbook. However, I must give credit to Dr GS Kulkarni, who has made tremendous efforts and that too successfully to cover most of the spectrum of this specialty in an adequate manner.

Medical education and training with its threefold commitment to patient care, research and continuing education always presents a difficult challenge. The term "core curriculum" is used widely but seldom defined; therefore, selection and integration of essential information must form the basis for such publications.

A good medical textbook should provide not only information but also a philosophy and approach which makes the knowledge relevant. The authors must have experience, ability and dedication to the mission of teaching. They should be scientifically accurate and capable of projecting their personalized approach. This is amply seen in this textbook.

There are many reasons why prevention is still in its infantile stage. Grants for cancer and heart disease are largely available as this is considered a real science. The life of a cell can be turned round more easily than the mind of a motorcyclist. Looking at the prevention means stepping outside our familiar role as a curative orthopedic surgeon. Road trauma is a great challenge and fills the hospital beds to a great extent.

Intoxication, designing of the roads, playground for children, police protection, bicycle tracks and maintenance of trucks and safe driving are some of the few issues which should be considered very logically for prevention of trauma, and these are the legitimate areas for research, even if they do not have the kudos of molecular biology or so much financial support. "Prevention is wholesale. Treatment is retail".

I am sure that these remarks will be helpful to the future thinking, and the present textbook mainly contributed by the Indian orthopedic surgeons will be a great boon for the orthopedic surgeons practicing not only in developing countries but also will be very informative to all who are devoted to this science and art. I am sure that these volumes must find their place in academic libraries all over the world.

KT Dholakia Hon FRCS (Eng)
Past President SICOT, Past President ASI
Past President IOA, Past President ASSI
Emeritus Professor of Orthopedics
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Breach Candy Hospital and
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The art and science of orthopedics has changed remarkably. There has been an explosion in the orthopedic knowledge in recent years. The success of joint replacement, improvement in implant material with application of improved techniques and the new investigative techniques have made orthopedics a very exciting and rewarding specialty.

Indian Orthopedic Association felt the necessity of a textbook, which can give more importance to commonly observed problems in clinical practice in our specialty as our problems are not similar to those seen in Western countries. The aim of the book is to provide authentic account of common conditions seen in our country more specifically for the young surgeons during and after their training. The newer developments like joint replacement, distraction osteogenesis (Ilizarov and Jess), interlocking intramedullary nailing, spinal instrumentation and arthoscopy have been included. The operative details have been excluded as they are available in many books on operative orthopedics. The commonly prevailing problems of cold orthopedics have also been properly dealt with. There can be no better method of making the future of our specialty brighter than by ensuring that our trainee surgeons have the benefit of the knowledge and experience of their seniors. The contributors deserve full appreciation for doing their best in this regard and for giving their valuable time for this purpose.

Dr Kulkarni is an expert editor, with enormous experience of editing journals and books. It is his dedication and constructive efforts that could provide us *Textbook of Orthopedics and Trauma* of such a high standard and value. He has done a commendable job for the Indian Orthopedic Association.

I am sure that this book will be of tremendous value and help to its readers.

KP Srivastava
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FACS FAMS FAIS FIAMS
President
Indian Orthopedic Association

Preface to the Third Edition

A welcome addition is Sushrut Babhulkar, who is enthusiastic, an outstanding orthopedic surgeon, educator, and innovator. He has joined me as an associate editor.

—GS Kulkarni

The publication of third edition of the *Textbook of Orthopedics and Trauma* in 2016 includes a number of new features, and the most important one is an addition in the list of contributors, many of whom are young, representing newer generation.

Orthopedic discipline is becoming a highly superspecialized branch. Almost every postgraduate resident wants to take up same specialty. However, in India, orthopods at periphery have to be the general orthopedic surgeons. This book is designed for them as well as for the resident who wish to become specialists. All the chapters are fully updated till 2015. Sections on poliomyelitis and leprosy have been deleted and some new chapters like vacuum-assisted closure and Masquelet's membrane techniques have been added.

We are grateful to our contributing authors, whose high level of information; clinical experience and dedication have made this book an excellent reference book for consultants and a must for postgraduate students. We sincerely thank the section editors who have done excellent work to edit the chapters.

We plan to publish the fourth edition of this book in 2019 or 2020. Anybody who wishes to contribute is welcomed and is requested to contact us.

GS Kulkarni
Sushrut Babhulkar

Preface to the First Edition

Orthopedic knowledge is literally exploding at an astounding rate. No other surgical specialty has a greater number of procedures than orthopedics has the orthopedic market is also flooded with bewildering number of implants and instrumentation sets. The practicing orthopedic surgeons as well as the postgraduate students are at a loss to select the clinical material from the vast literature and the implants and instrumentation. This book serves as a quick text refresher and an easy reference to orthopedic surgeons. For postgraduate students, this book should be indispensible.

Orthopedic problems of the developing countries are different from those in the West, and most of the books and journals on the subject emanate from the Western countries. Incidence of paralytic poliomyelitis, tuberculosis, chronic osteomyelitis, leprosy, etc. are rampant and so are the road-side accidents which are common in the developing countries. Conditions associated with trauma, such as nonunion (with or without infection), malunion, deformity stiff joints, etc. are day-to-day taxing problems. Even the sizes of Indian/Asian bones are smaller than those in the West. This disparity creates problems in inserting implants for the replacement of joints and for the treatment of fractures. Every orthopedic surgeon encounters a large number of cases of neglected trauma, deformities, infections and even tumors of bones and joints. Neglect of orthopedic disease is a common scenario, as also are the poor conditions of the operating rooms, and low quality of implants. Often, the surgical technique is not performed meticulously as described by different methodology. All these add to the complications.

The textbook has been designed to adequately cover all such conditions which are missing from or inadequately described in the Western textbooks. The main aim of the book is to give comprehensive information about diseases and problems peculiar to the developing countries and to provide one source of orthopedic information. Each chapter is written by a surgeon who has a special interest in the subject. I take particular pride in the list of outstanding contributors, many of whom are leading authorities in their fields. An attempt is made to give a complete orthopedic knowledge, including basic and applied sciences and rehabilitation of musculoskeletal system.

In a multiauthor book of this nature, some repetition is unavoidable but is useful. This is mainly addressed to the practicing orthopedic surgeons and postgraduate students in the developing countries. I am very much thankful to the Indian Orthopedic Association for asking me to edit this prestigious book.

GS Kulkarni

Acknowledgments

We are very grateful to Dr MS Ghosh of Kolkata, who convinced the Indian Orthopedic Association to publish the book. We express our gratitude to Milind, Sunil, Ruta, Vidisha, Rajiv Limaye, Sujay, Madhura and all the postgraduate students for their untiring help in completing this book. They have helped us by proofreading, correcting articles and writing a few articles. Our thanks to the stenotypists Arthur Shikhamani and Mr Pravind Sagare, who have tolerated us for the last 15 years. We sincerely thank all the orthopedic patients who are the backbone of the textbook.

We are very much thankful to Shri Jitendar P Vij (Group Chairman), Mr Ankit Vij (Group President), Mr Tarun Duneja (Director-Publishing), Mr KK Raman (Production Manager) of M/s Jaypee Brothers Medical Publishers (P) Ltd, New Delhi, India, who have taken great pains in publishing the book in time, maintaining the international standards. We also sincerely thank to Mr DC Gupta (Senior Editor), Mr Gurnam Singh (Senior Proofreader), Mrs Yashu Kapoor (Senior Typesetter), Mr Manoj Pahuja (Senior Graphic Designer) and the entire production staff of M/s Jaypee Brothers Medical Publishers, for their professional expertise and their active role and cooperation in the production of the book.

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Section 1

Introduction and Clinical Examination

Section Editor: *S Pandey*

1

Chapter

Introduction and Clinical Examination

S Pandey

Introduction

Today in an era of rapid industrialization and mechanization, orthopedics occupies an important place in the field of medical sciences. The examination and management of an osteoarticular problem very much involves assessment of the patient as a whole. However, two factors quite often missed may get their place while examining an orthopedic patient.

Modern orthopedics is concerned with the study of anatomy, function and diseases of the musculoskeletal system, which consists of injuries and disorders of bones, joints, muscles, nerves and ligaments. "Prevention is better than cure." The best example is total immunization of the entire population by polio vaccine, which has wiped out polio from the Western and developed world and now from India too. Early recognition and timely institution of treatment may prevent certain deformities. The example is developmental dysplasia of the hip. The orthopedics is a specialized branch of surgery. Today, it has grown up to such an extent that it is being branched into various sections, such as spine surgery, hand surgery, foot and ankle diseases and injury, joint replacement, arthroscopy, traumatology, pediatric orthopedics, and so on. There is a tremendous scope for research and development of the individual branches.

Documentation

The AO group, rightly, lays great stress on the necessity to carefully document and preserve the clinical and follow-up notes, for research, learning the disease, paper presentation and for planning the treatment. Today, it has become much easier with the help of computers. However, in India, the documentation and follow-up is poor. We have a large number of cases and excellent clinical material. If we meticulously document, we can do high quality clinical research and can contribute to the world of orthopedics in a better way.

Examination of the Patient

Clinical examination of an orthopedic patient is the most important part of the training program. No part of orthopedic training is more important than developing a systematized method of examination. The meticulous history taking and a thorough clinical examination of the patient will almost lead to a successful diagnosis and treatment. Even the most ultramodern investigation will not replace the clinical examination. One is more likely to make mistakes if one relies only on the investigations.

Armamentarium Necessary for Examining an Orthopedic Patient

- A measuring tape.
- Goniometer (large and small).
- A tendon reflex rubber hammer.
- A pocket torch.
- A pin with protected point.
- Skin marker pencil and wax pencil.
- A stethoscope.
- A diagnostic set (tongue depressor, auroscope, ophthalmoscope).
- A plain white paper and impression ink for taking prints.
- A right angled triangle.
- Camera (more important than even a stethoscope for a reconstructive surgeon).
- For neurological cases—cotton wool, tuning fork, test tubes.

Certain Factors Essential for Examining an Orthopedic Case

- Hear the patient with patience, even if he or she is confused, disoriented and annoying.
- Reassure the patient and ensure gentle handling of the affected part.

- Good bedside manners.
- Sympathetic appreciation of the patient's problems.
- An insight into the patient's future rehabilitation program.
- Need for examining the patient as a whole, and not a part, limb or system.
- The patient must be placed in comfortable position.
- The patient is to be fully exposed which guarded covering of genital and at least the corresponding part of other limb for comparison.
- Do not hurt the patient during examination.

The first impression that a keen clinician gets of his or her patient while the patient is entering the examination room, forms the basis for his or her onward assessment.

History Taking

Apley AG[1] calls history—"His"-"story" (or hers). Sit back and patiently hear the development of the orthopedic problems from the very beginning. Start with the question, "When were you completely healthy? How and when the problem had started? Enumerate all the complains. Go into the details of the problem and the progress of the disease".

Chief Orthopedic Complaints

Pain, it is the most common symptom in orthopedics. Throbbing pain indicates acute abscess and burning pain neuralgia. Precise location of pain is important. Ask the patient to point the site of pain, depth of severity (ignorable—trivial, not ignorable as it interferes in activities—moderate, constant even in rest—severe, tossing and incapacitating—very severe), mode of onset, character, diurnal variation, path and site of radiation, relation with activities and rest, relieving/aggravating factors. Reference of pain can be due to same source of sensory supply or cortical confusion between embryologically related areas.

Types of pain:
- *Local:* When pain is felt at the site of pathological processes in superficial structures. It is usually associated with local tenderness to palpation or percussion.
- *Diffuse:* Pain appears to be more characteristic of deeply lying tissue and has a more or less segmental distribution.
- *Radicular:* Radicular pain is due to pressure or inflammation of a nerve root. The example is a disc prolapse in the lumbar spine with radiating pain down the leg.

Referred pain is experienced in other areas, besides that felt in the area of initial stimulation. This is seen when there is injury or disease affecting either somatic or visceral structures, and results from misplaced pain projection because of cortical representation. This occurs because of the convergence of sensory pathways onto a single cell within the cord of higher centers. It is often associated with paresthesias and tenderness along the nerve root.

Specific types of pain:[2]
- *Bone pain* has a deep boring quality usually attributable to the stimulus of internal tension, as seen in osteomyelitis, expanding tumors and vascular lesions of bone such as Paget's disease.
- *Diffuse generalized pain:* The body ache ("my whole body pains") is due to skeletal disease such as osteoporosis and hyperthyroidism, multiple myeloma or metastatic disease, or even in osteomyelitis.
- *Muscle pain* is due to lack of blood supply or due to spasms. Pain of anterior compartment syndrome of leg is an example of muscle pain due to reduced blood supply. Another example is intermittent claudication described above. According to Duthie,[2] the nocturnal cramps in the lower extremities of the elderly are quite characteristic in being relieved or prevented by quinine derivatives.
- *Joint pain (night cries):* Patient suddenly wakes up in the night due to severe pain. This usually occurs in tuberculosis of the joint, e.g. knee, hip and spine. During sleep, the muscles become relaxed, which remain in varying spasm to support the affected painful joint and part. With the relaxation of muscles, the affected ends sag and rub against each other leading to severe pain. Even during sleep, there may be some movements occurring in the joints. When the movements occur in the diseased joint, the articular cartilage rubs against each other causing severe pain and the muscle around the joint go into sudden spasm causing further severe pain, this phenomenon is called as night cries. Joint pain in early stage, i.e. the synovitis stage is usually due to distention of the capsule which is rich in nerve supply.

Deformity: Find out if the mode of onset is progressive or static, any attempt done earlier for correction of deformity and disabilities due to deformity. Deformity may be in the bone, in the joint or in the soft tissues. Deformity is broadly due to abnormal anatomy. It may be angular or rotational. Shortening and lengthening are also included in the deformities. Shortness of stature is a kind of deformity. In the lower limbs, the mechanical axis deviation test,[3] described by Paley, is important to determine whether the deformity is in the bone, in the joint or soft tissue.

Varus and valgus: Varus means the part distal to the joint is displaced towards the midline, whereas valgus means away from it. Genu varus includes bow legs. Genu valgus leads to knock knee. In a case of congenital talipes (clubfoot), the heel shows varus deformity.

Fixed deformity: It means that a part of movement cannot be completed even passively, e.g. 40° of fixed flexion deformity means patient has no movement from zero up to 40°, further flexion movement may be possible.

Causes of joint deformity:
- Destruction due to tuberculous arthritis or septic arthritis
- Joint instability due to ligaments
- Muscle imbalance, for example, in polio paralysis
- Muscle contracture, e.g. Volkmann's ischemic contracture
- Facial contracture, e.g. Dupuytren's contracture
- Skin contractures, e.g. burn contractures
- Injury of growth plate may cause secondary joint deformity later on
- Malunited fractures.

Bowing deformity: It may be due to malunited fractures, diseases like rickets, osteogenesis imperfecta, Paget's disease, fibrous dysplasia, pathological fractures, etc.

Soft tissue contractures may be due to burns, injury or infections, or even idiopathic.

Stiffness: It may be in many joints, e.g. in rheumatoid arthritis, ankylosing spondylitis or in a single joint due to tuberculosis or extra-articular fracture. Morning stiffness of small joints of the hand is one of the cardinal signs of rheumatoid arthritis.

Swelling: It may be in the soft tissues, bone or joint. It is important to carefully localize anatomical plane of the swelling. Carefully examine the swelling for temperature, tenderness, size, shape, any extension in the anatomical compartments, surfaces, edge, consistency, fluctuations, compressibility, pulsatility, fixity of the swelling to muscle, bone or surrounding structures. Consistency can be judged: as muscle is soft like lipoma or cold abscess. Contracted muscle is firm like fibroma. Subcutaneous bone is hard. When one presses hemangioma and releases the pressure, it gradually returns to the original size. False or true aneurysm is pulsatile. It is important to find from which tissue the swelling has arisen and its anatomical plane. If the swelling is in the subcutaneous plane, the skin can be pinched out. If the swelling is subfascial and over the muscle, it becomes more prominent when muscle contracts. When the swelling is in the muscle, and the muscle is made taut by contracting, the swelling becomes comparatively less prominent and can be moved in the direction at right angle to the muscle fibers but not in the direction of fibers. If the swelling is beneath the muscle, it becomes much less prominent, when muscle is taut.

Instability: Instability of a joint is usually due to injury to ligaments, malunited intra-articular fractures and laxity of the joints.

Neurodeficit: Neurodeficit may be sensory or motor, or both. It may be due to pressure on the nerve or nerve roots due to prolapse intervertebral disc or tumor, or may be due to nerve entrapment in fibro-osseous tunnel, as in carpal tunnel syndrome.

Laxity of joint: Abnormal degrees of laxity of a joint should be tested. The causes of joint laxity are: Marfan's syndrome, Ehlers-Danlos syndrome, osteogenesis imperfecta and acromegaly. Laxity in joints is also seen after excessive corticosteroid therapy and may be familial as well.

Discharging wound: How it started, type, color and nature of discharge, intermittent or continuous, painful or painless, any history of indigenous applications or cauterization, and any history of bony spicules in the discharge. Ulcers and sinuses must be carefully examined. Colored granules (sulfur granules) indicate Madura foot. Sinogram leads to the exact site of the lesion.

Limb length discrepancy: Limb length discrepancy (LLD) may be due to multiple causes like poliomyelitis, chronic osteomyelitis, malunited fractures, congenital deformities, etc. The best way to measure LLD is to use blocks under the short limb and make anterior superior iliac spines parallel to the ground and measure the height of the block. Long cassettes, i.e. 51" × 14", are now available to take radiographs from hip to ankle.

Constitutional features: Like fever, anorexia, constipation, bodyache, headache, urinary trouble, eye trouble, night pain and swelling.

Cramps: Cramps and cramp-like complaint in both calves are not uncommon. There can be several causes, which may be specific or nonspecific. Claudication should be differentiated from the cramps. In claudication (vascular, e.g. Buerger's phenomenon, neurogenic, e.g. spinal stenotic syndrome), the patient feels gradually ensuing catch in both calf muscles after some walking. The walking distance, before the symptoms start appearing, gradually decreases. The claudication of spinal origin usually disappears after sitting or bending forward in chair, while that of vascular origin requires rest from walking for relief.

In cramps, the patient feels a sudden painful catch in the calf muscles, which almost disappears within a few seconds—either following local massage or rest or itself—leaving behind a dull aching pain lasting for few hours to a day or two. Constipation, overexertion and walking without habit can also induce these cramps. However, symptoms like cramps can also be seen in vague ankylosing spondylitis, thyrotoxicosis, metabolic diseases, myopathies, and depressive syndromes in adults. The nocturnal cramps in the lower extremities of the elderly are quite characteristic in being relieved or prevented by the taking of quinine derivatives.[1]

Any other complaints even unrelated to orthopedics should be noted chronologically.

History of Present Illness

Let the patient narrate the story of his or her ailments in his or her own words from the beginning to the present condition. Pick up the salient points. Dilate on each point with relevant leading questions. Any history of injury or febrile attacks must be explored through leading questions. Treatment received for the present complaints should be noted in detail **(Table 1)**.

In case of injury: Enquire about its mode and nature, and if associated with any abnormal sounds.

Modes of injury

- Direct hit.
- Indirect injuries.
  - Rotational strains (e.g. fracture neck femur).
  - Violent muscle pulls (e.g. fracture of patella).
  - Compression injuries (e.g. compression fracture of vertebra).

TABLE 1: History and record chart

Name	*Age*	*Sex*	*Race*	*Religion*	*Occupation*	*Registration No.* *Complete Postal Address:* *E-mail* *Telephone*
	Marital status and family. *Photographic records with dates*					
Complaints	• Pain • Deformity • Disparity of limb length • Swelling • Any other					

History of present illness—Analysis of relevant points.
History of past illness—Trauma, tuberculosis, syphilis, gonorrhea, bleeding diasthesis.
Personal history—Addiction, immunization, allergy or sensitivity to drugs, education, hobby.
In case of females—Any gynecological disorder, number of children.
Family history and social status—Social status, hereditary disorder, economic status, infectious disease.

In case of fall: Height of fall, surface on which fallen, level of consciousness after falling, if he or she could stand up or walk or even take weight on the affected side of his/her own or not following the injury, immediate posture after injury, any manipulation at the site of injury by himself/herself or anyone else.

After the injury
- Mode of transportation to home or hospital.
- Attempts by bone setters or quacks and/or any other treatment given.

Fever: Onset, any associated, rigor, range of temperature, continuous or intermittent. If only at particular time, e.g. in the evening, sweating, response to treatment and accompanying symptoms.

Enquire about appetite, polyuria, loss of weight.

History of Past Illness

Any earlier injury, history of earlier infections, specially tuberculosis, syphilis, leprosy, pyogenic, average duration of bleeding after any cut, any particular treatment received.

Personal history: Occupation, any tobacco/drug habit, personal hygiene, hobby, sensitivity or allergy to any drug or object.

In case of females—marital status, number of children, any gynecological complaints.

Family history: Any familial incidence related to the recent complaints, tuberculous infection in family, any hereditary disorder **(Figs 1 and 2)**.

Social history
- Economic background, status of living.
- Topographical surroundings.
- Barriers in and around home.
- Education in the family.

Examination

- General examination.
- Regional examination.
- Local examination.

General Examination

- Look, intelligence, built, any special posture, pallor, cyanosis, edema, pulse, temperature, blood pressure, jaundice, lymph glands.
- *Attitude*: While entering the examination room, note the first impression and posture (general, regional, local)
- *Attithude of standing*
  - With full weight.
  - With partial weight.
  - With support.

If patient can stand, also perform Trendelenburg's test.
- *Gait*
  - Limp or lurch.
  - Specific gait.
- Waddling.
- High stepping.
- Hemiplegic (spastic).
- Ataxic.
- Scissors.
- Festinent/short shuffling gait (Parkinsonism).
- Lathyriatic.
- Stamping.
- Knock knee.

Systemic Examination

- *Skull and face:* Contour, swelling, decubitus ulcer, and any stigmata (of syphilis, rickets, etc.).

Fig. 1 A family of five, all having deformities of the limbs due to osteogenesis imperfecta—hereditary familial disorder

Fig. 2 Group photograph of available family members showing multiple exostosis, familial incidence had been followed up to four generations

- *Neck*: Lymph nodes, venous engorgement, any swelling.
- *Cardiovascular system:* Pulse, blood pressure, heart.
- *Respiratory system:* Thoracic cage, rib contour, chest expansion, abnormal shape of chest (flat, barrel, pigeon), rib hump, rachitic rosary, (Harrison's sulcus, scorbutic rosary).
- *Abdomen:* Liver, spleen, kidney, any lump, iliac fossae, any abnormal finding.
- *Central nervous system*
  - Higher mental functions.
  - Cranial nerves.
  - Motor system—power, bulk, tone, reflexes, coordination, involuntary movements.
  - Sensory system.
- Genitourinary system.
- Endocrinal functions.

Regional Examination

The examination of the part complained of only, does not complete the examination, because sometimes the symptoms felt in one part have their origin in another. For example, pain in the leg is often caused by a lesion in the spine, pain in the knee may have its origin in the hip, a pain or tingling and numbness in hand may have its origin in the cervical spine. Hence, regional examination is necessary.

- For lower limb, examine lumbar region to tip of toes.
- For upper limb, examine cervical region to tips of fingers.
- For trunk examine as a whole (and the supply region, if cord is involved).
- Also examine the regional lymph nodes.

Local Examination

Inspection (look for)

- Posture of the patient and position of part/limb—attitude.
- Inspect from different sides.
- Normal anatomical points:
  - Bony.
  - Soft tissue.
- Skin:
  - Color.
  - Texture.
  - Erythematous changes.
  - Puckering.
  - Café-au-lait spots.
  - Tattoo marks.
  - Patch/vaccination scar.
  - Superficial cuts or scars (linear scar with/without suture mark—usually operative scar; irregular scar—injury; broad, adherent puckered scar—old suppuration).
  - Warts or callosities.
- Muscle condition:
  - Swelling.
  - Wasting.
  - Spasm.
  - Contracture.
  - Fasciculations.
- Vascular:
  - Venous prominence.
  - Pulsation.
  - Varicosities.
- Abnormal findings, e.g. swelling, sinus.

Palpation

- *Superficial (touch):* Skin condition, temperature, sensation, superficial tenderness, anatomical points—bony, soft tissue; induration (edema)—regional/local, arterial pulsation, crepitus (may be due to entrapped gas, e.g. in surgical emphysema, gas gangrene **(Fig. 3)**, fracture, tenosynovitis).
- *Deep palpation (feel):* It can be tested by direct pressure, indirect twist, and deep thrust.

Deep tenderness: Tenderness of a bone, joint or soft tissue can be classified in four grades according to the reaction (facial and verbal) of the patient during examination for tenderness:

Grade I—the patient says that part is painful on pressure.
Grade II—the patient winces.
Grade III—the patient winces and withdraws the affected part.
Grade IV—the patient will not allow the part to be touched.

Deep palpation of the bone: Bone should be palpated for surface, alignment, deep tenderness, abnormal prominence, disturbed relationship of the normal bony landmarks, any crepitus (fracture) or gas/air in tissues.

Deep palpation of a joint:
Palpate for:

- Synovial thickening—soft/boggy/doughy feel—any tenderness.
- Joint line—a slit all around or available side in between the articular ends—feel for any tenderness, any abnormal mass.
- Fluid in the joint—yielding/cystic/fluctuant/tense feel.
- Articular ends—for any tenderness, roughness, crepitus.
- Adjoining bones—for any thickening, expansion, crepitus irregularity, tenderness.
  - *Palpation of fossae* (if any).
  - *Palpation of muscles:* Girth, feel, tone and pliability of muscles.

Fig. 3 Extensive linear gas along muscles and soft tissue planes—in gas gangrene

- *Examination of any swelling* should be in details—skin over the swelling, size, margin, shape, vascularity, tenderness, consistency, fixity, deeper relations, mobility, fluctuation test, transillumination test (if cystic).

Examination of any sinus:
- Number, site, relation with deeper tissues, relation with skin, margin discharge—intermittent/continuous, color, relation with pain, possible source, any bony spicule discharge or projecting through sinus, nature of scar (if healed).
- Sinus tract—feel, traceability to parent site, fixed to bone or mobile. Probing should be avoided.

Springing: To elicit pain at the site of lesion by intermittently compressing the distant part of the parallel bones, e.g. in fracture of the neck of radius pain can be elicited by compression of the forearm bones in lower regions.

Transmitted movement: In case of fractures, feel for transmitted movements across the fracture site.

Percussion (tap): Especially over the bone in suspected crack fracture, over the spinous processes to elicit tenderness in spine.

Auscultation (hear):
- If needed, e.g. for systolic bruit (hemangioma).
- May be of value in localizing crepitations, snaps, mild frictional rubs in joints.

Measurements:
- Linear measurements.
- Circumferential measurements.

Linear measurements:
- Apparent measurement.
- True measurement.

Apparent measurement:
- Make the limbs parallel to each other and to the trunk.
- Handle the unaffected limb to make the limbs parallel.
- Measure from any fixed central point to the most distal sharp bony point of the long limb bone.

Therefore, in the lower limb, measure from:
- Manubrium sternum, xiphisternum or umbilicus to the tip of the medial malleolus.

In the upper limb from vertebra prominence (C_7) to radial styloid.

True measurement:
- Reveal the concealed deformity by handling the affected limb.
- Limbs to be kept in identical position.
- Measurement is ipsilateral and then compare with the other side.

Lower limb:
- Total length—from anterosuperior iliac spine to medial malleolus.
- Segmental length:
  - Anterior superior iliac spine to knee joint line (thigh length).
  - Medial knee joint line to medial malleolus (leg length).
  - The components of thigh length are measured as:
    - Infratrochanteric—tip of greater trochanter to knee joint line.
    - Supratrochanteric—indirect measurement, e.g. Bryant's triangle.

Upper limb:
- Total length—from acromial angle to radial styloid process tip.
- Segmental length:
  - From acromial angle to lateral epicondylar tip (arm length).
  - From lateral epicondylar tip to radial styloid process tip (forearm length).

Circumferential measurements:
- At affected point—for any swelling.
- At fixed distances, proximal and distal, from the affected part:
  - for muscular wasting.
  - for muscular hypertrophy.
- For disorganized joint.

Across measurements (for cross check-up of measurement): In identical position of the limbs:
- From left anterosuperior iliac spine to right medial malleolus tip.
- From right anterosuperior iliac spine to left medial malleolus tip.

Movements: (Ask to perform—active, performed by others—passive).

Always compare with the opposite joint. In general, the range of movements at any joint is more in females than males. First look for ankylosis or stiffness of the joint.

Ankylosis (no apparent movement in a joint).

Types of ankylosis:
- Bony—no movement even on using force (true ankylosis):
  - No pain on using force.
  - Bony trabeculation across the joint in radiograph.
- Fibrous (jog of movement):
  - Pain on using force (false ankylosis).
  - Slight yield on using force.
  - Joint line visible in radiograph.

Stiffness in the joint (i.e. joint in which complete movements cannot be obtained—either active or passive)—Limitation of movements can be:
- In all directions due to arthritis.
- Not in all directions due to synovitis and/or spasm of muscles.
- Fixed position in one or more direction due to fixed deformity.

Limitations of movements are painful in active arthritis and painless in healed ones due to short fibers (fibrous bondage).

Types of Joint Stiffness (Table 2)

- Extra-articular
- *Intra-articular:*
  If no ankylosis, assess the movements in various planes:
  - Sagittal plane—flexion/extension.
  - Coronal plane—abduction/adduction.
  - Rotational plane—external/internal, supination/pronation.

For Each Movement

- Fix the zero position.
- Mark lag of movement (usually extensor lag).

TABLE 2: Types of joint stiffness

	Extra-articular	*Intra-articular*
1.	Obvious evidences of extra-articular tightness or adhesion like scars subcutaneous fixity, musculotendinous contracture, sinus tract in vicinity	No obvious scar, adhesion, sinus or contracted tissues
2.	Joint line is usually nontender, except when any inflammatory process lies over the joint line	Joint line tender
3.	Painless range of free movements active and/or passive	Possible movements are usually painful, especially at the extremes
4.	On radiography joint space sharply defined and clearly visible, articular ends nearly normal	Joint margins fluffy, joint space reduced. Articulating bony ends usually osteoporotic with or without evidences of underlying pathology
5.	Dealing with the contracted extra-articular tissues, releases the stiffness	Dealing with the extra-articular tissues does not release the stiffness
6.	Manipulation under general anesthesia is not helpful in mobilizing the joint	Manipulation mobilizes the joint in early or moderate stiffness. Arthroplasties of different types are usually required for mobilizing the joint in severe cases

- Assess angle of fixity of any movement (e.g. fixed flexion deformity).
- Range of active movement.
- Range of passive movement.
- Range of utility or activity—free active movement.
- Range of possibility—free active movement and free passive movement.
- Any pain during the movement—if painful focus is in the vicinity of the joint (not in the joint), patient will still be reluctant to initiate active movement. Taking the patient in confidence, passive movement can be demonstrated to variable range, in such cases.
- Limitation of terminal range.
- Achievement of "critical arc".
- Achievement of activities of daily living (ADL).
- Any abnormal movement (e.g. hypermobility in neuropathic joint, e.g. Charcot's joint).
- Any abnormal sound during the movement (heard/felt).
- Assess the power of controlling muscles.

Active movement at a joint: Movement produced by patient himself or herself without any assistance.

Passive movement: Movement produced at a joint either by patient's other limb and/or examiner.

Fixed Deformity

It is a fixed position of a joint from where the limb cannot be brought back to neutral position, but further movement in the same axis (direction) may be possible.

Normally active and passive ranges are equal.

Passive range is more than active in:

- Paralyzed joint.
- Lax/torn:
  - Capsule.
  - Ligament.
  - Tendon.
  - Muscle.
- Subchondral/condylar fracture.

  Test for any laxity or tear of the aforesaid components.

Critical Arc

For any joint, the minimum range of active movement, which is necessary for the important functions of the joint is its critical arc.

Activities of daily living: The bare minimum necessary for daily living, like—eating, clothing, cleaning the private parts and minimum necessary mobility.

Power of Controlling Muscles (Table 3)

The assessment should be accurate from prognostic point of view. According to Medical Research Council (MRC) scale, muscle power is grouped under five grades. We feel that each grade is further divisible into four quadrants, depending upon lag of completion of full range, the deficit can be assessed as, e.g. "2---", "2--", "2-", "2".

Special tests: Pertaining to individual joints.

Heel Walking/Toe Walking

If the patient can walk, quick inferences can be drawn by making him or her walk on heels and toes alternately.

If he or she can walk swiftly in both positions without any complaints, probably there is no serious affection in the lower limbs including its neuromuscular control.

Erect posture along with integrity of the hip, knee, ankle, and foot are essential for painless, quick, heel/toe walking.

Any limb length disparity will obviously affect these walking and any inequality will be apparent.

If patient cannot walk swiftly, there are two broad probabilities.

- If there is inability/difficulty in walking on heels, it may be due to:
  - *Weakness of muscles* and/or abnormal joint condition/pain:
    - Weakness of dorsiflexors of ankle, stiffness of the ankle joint.
    - Probable weakness in quadriceps femoris and erector spinae, unstable hip.
  - *Pain*: This may be felt due to any of the following pathologies:
    - Pain in back of thigh, knee and leg—due to sciatic stretch.

TABLE 3: Power of controlling muscles

MRC scale	*Suggested subgrouping*
0—Not even flicker of contraction	0
1—Flicker of contraction	1
2—Contraction of muscles with no assistance and gravity eliminated, but moving the joint to full range	Depending upon lag of completion of full range 2 ---, 2--, 2-, 2
3—Contraction of muscles against gravity but with no resistance moving the joint to full range	Depending upon lag of completion of full range 3---, 3--, 3-, 3
4—Contraction of muscles against gravity and with moderate resistance	Depending upon lag of completion of full range 4---, 4--, 4-, 4
5—Normal	Depending upon lag of completion of full range 5---, 5--, 5-, 5 (While "5" is normal, the rest are subnormal in that order)

1– : 1st quadrant
2– : 1st and 2nd quadrant
3– : 1st, 2nd and 3rd quadrant

    - Pain in sacroiliac region, in hip region—(affection of the joint line, e.g. trauma, tuberculosis).
    - Back of the knee, e.g. in cases of trauma—posterior cruciate lesion, condylar fracture/crush of tibia (upper end).
    - Pain at ankle—in any traumatic, inflammatory, degenerative or neoplastic condition.
    - Pain at heel—any cause of painful heel syndrome.
- *If there is inability/difficulty in walking on toes, it may be due to*:
  - *Weakness of muscles* and/or abnormal joint condition:
    - Weakness of plantar flexors, stiffness of ankle (except where in equinus), genu recurvatum, unstable hip.
  - *Pain:* Pain in the forefoot—trauma, metatarsalgia, inflammatory lesion. Usually pain in ankle is not complained of in early affections because the gravity line falls forwards:
    - If pain is in knee region—in case of trauma—probably anterior cruciate involvement, involvement of anterior horn of semilunar cartilage, affection of quadriceps apparatus.

Peripheral Circulation

Impaired peripheral arterial circulation may produce symptoms in a limb, especially in lower limb. So, a thorough examination should be done to assess the state of circulation, which is done by examination of the color and temperature of skin, the texture of skin and nails and by palpating for arterial pulsation, which must always be compared with opposite side.

Peripheral Nerves (e.g. Lateral Popliteal Nerve, Ulnar Nerve, etc.)

- Tenderness.
- Thickening.
- Beading.
- Irritability.
- Detailed muscular and sensory charting.

Investigations

- Usually required for orthopedic patients.
- General investigations.
- Special investigations.
- Electrical investigations.
- Radiological and allied investigations.

General Investigations

- Routine hemogram.
- Erythrocyte sedimentation rate (ESR).
- Routine urine examination.
- Stool examination.
- Grouping and cross-matching of blood (also for human immunodeficiency virus (HIV)/acquired immune deficiency syndrome (AIDS) and hepatitis B).

Special Investigations

Serum biochemistry, e.g. sugar, urea, calcium, phosphorus, alkaline and acid phosphatase, fluorine, creatinine.

- Serology—Washerman's reaction (WR), Kahn, Venereal Disease Research Laboratory (VDRL), rheumatoid factor (Rose-Waaler test).
- Aspiration of any collection and its examination—physical, chemical, cytological, serological, culture and sensitivity, inoculation test.
- Footprint/handprint.
- Arthroscopy [diagnostic/therapeutic—knee, shoulder, ankle, elbow, and even interphalangeal (IP) joints].

Arthroscopy: Nowadays, arthroscopy is being widely used to diagnose and variably deal the pathology (mainly traumatic) affecting the interior of the joints. It is particularly useful for the knee:

- Biopsy
  - Fine-needle aspiration cytology (FNAC).
  - Needle biopsy.
  - Open biopsy.

Electrical Investigations

- Electrocardiography (ECG).
- Electroencephalography (EEG).
- Electromyography (EMG).
- Strength duration curve.
- Nerve conduction test.

- Electrophoresis.

Radiological and Allied Investigations

Plain radiography, xeroradiography (by photoelectric process, the conventional radiograph exposure is recorded as positive image):

- Routine projections.
  - Anteroposterior view/posteroanterior view.
  - Lateral view.
  - Oblique view.
- Special projections:
  - Axial view.
  - Stress radiography.

Contrast radiography:

- Air contrast radiography.
- Radiopaque dye contrast radiography [water soluble (metrazimide), oil soluble].
- Myelography.
- Radiculography.
- Diskography.
- Arthrography.
- Sinography.
- Venography.
- Arteriography.
- Cystography.
- Lymphangiography.

Tomography: Radiograph taken after being focused at a desired depth.

Stereoscopic: Bidimensional picture studies.

Cine-radiography.

Scintigraphy (radioactive isotope studies or radionuclide studies). Ultrasonic scanning.

Computer-assisted tomography—CT scanning, PET-CT (positron emission tomography).

Computerized tomography and intrathecal low osmolarity contrast media studies.

Nuclear magnetic resonance (NMR) imaging or magnetic resonance imaging (MRI)—in order to avoid using the word nuclear, which induces fear, the changed terminology is MRI.

Spinal cord monitoring—recording of somatosensory-evoked potentials (SEP).

Meterecom [a three-dimensional (3-D) skeletal analyzer]—A precise, computer-based, noninvasive, 3-D digitizer designed to access bony landmarks, at any point on the body for various patient's positions.

Clinical Diagnosis

Thorough clinical examination leads to more or less accurate clinical diagnosis. However, in certain situations, this may not be possible. In such conditions, provisional diagnosis with immediate differential diagnosis should be mentioned. The most probable provisional diagnosis should be reached by the process of elimination, starting from the common to rare conditions.

In expressing the diagnosis of the disease, it is essential to make it a complete expression under the following headings:

- Duration.
- Anatomical site affected.
- Causative pathology with its stage of advancement.
- Any obvious complication.
- Any particular treatment given.
- Affection of the patient's routine life, especially the ADL, e.g.:
  - 5-month-old, untreated, advanced tuberculous arthritis of right hip joint with discharging sinus and patient not able to perform ADL, or
  - 7-week-old conservatively managed traumatic ununited fracture of neck of left femur with 2 cm of supratrochanteric shortening and patient not able to perform ADL.

Examination of Child Patients

All too often children are examined but not looked at (Aieard, 1998) while the basic methodology of examination remains the same as in adults, one should not expect to get same degree of cooperation as even in average adults. Try to derive as much information as possible in the same short period when the child cooperates with. The child gets irritated by repeated examinations and gets frightened seeing the white coats, examining tools and heavy environments. Younger children are always comfortable in mother's lap. Some toys and toffees will help you to make familiar with child. Before touching the child, watch the general built, expression and behavior of child, any obvious abnormality(ies) and movements of the limbs, while the child is in mother's lap.

Assessment of Elderly

Besides the chronological count, the old age requires a broad assessment. Comorbidity is the hallmark of the elderlies. Multiple systems involvement at a time, symptoms varying from 6 to 12 months and diagnosis around two or three at a time usually characterize the clinical profile of elderly patients. Usually there is overlay of depression and/or anxiety and/or insecurity while examining an elderly person, besides keeping above factors in mind; one must exclude Alzheimer's disease, which results due to deposits of amyloidal substances and several other inflammatory proteins in the brain.

Clinical Audit in Orthopedics

Ernest Codman was perhaps the first true medical auditor following his work in 1912, on monitoring surgical outcomes.

Clinical audit compares the current practice to the standard practice. The clinical audit is essential to assess one's performance. The audit guides us if we are doing the things in right direction. Of course, the knowledge about the thing to do comes from research.

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2

Chapter

Damage Control Orthopedics

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Introduction

Polytrauma has been defined as a multisystem, multiorgan, post-traumatic insult with profound pathophysiological and metabolic changes. The management of polytrauma patients has changed considerably during the past century. Advances in fields of fracture fixation techniques and intensive care have all contributed to better treatment of a polytraumatized patient.

Prior to the 1970, early surgical fracture stabilization of long bone fractures after multiple traumas was not routinely advocated. It was believed that the multiply injured patients did not have the physiological reserve to withstand the prolonged operations. The introduction of standardized, definitive surgical protocols, led to the concept of early total care (ETC) in the 1980s. This concept was subsequently applied universally, in all patient groups, regardless of injury severity and distribution. In the following decade, it was recognized that early stabilization of skeletal injuries produced poor results in certain critically ill patients. This particularly applied for patients with significant thoracic, abdominal and head injuries and those with high injury severity scores (ISS). In response, the concept of damage control orthopedics (DCO) was developed in the 1990s. DCO methodology is characterized by primary, rapid and temporary fracture stabilization. Secondary definitive management follows, once the acute phase of systemic disbalance has passed. In the current chapter, we outline the evolution of treatment strategies for major fractures in polytrauma and the current trends towards staged management of these patients.

Historical Perspectives

There has been a consistent change in the management protocol of multiply injured patient over the last century. This has followed the advances in prehospital care, resuscitation, implants and intensive care medicine.

Before the 1950s, the surgical stabilization of fractures of the long bones was not routinely performed. The polytraumatized patient was not considered physiologically stable to undergo any surgical procedure—too sick to operate on. Many surgeons cited fat embolism following manipulation of fractures as one of the justifications for nonintervention.[1] At the same time, surgical techniques available for fracture fixation were few. Moreover, there were reports by some surgeons that fracture fixation performed late up to 14 days yielded better results,[2,3] operations were therefore delayed or avoided.

The management of femoral fractures with a Thomas splint illustrated the importance and benefits of skeletal stabilization resulting in the improved survival of the patients.[4] The routine introduction of immediate Thomas splinting of soldiers with gunshot wounds of the femur, during the First World War, reduced mortality from this injury from 80% to about 20%.[5]

In the latter half of the 1960s and early 1970s, there were several reports that early skeletal stabilization had a beneficial effect on pulmonary function and postoperative complications.[6,7] Johnson et al. demonstrated that a delay of more than 24 hours in the stabilization of a major femoral fracture was associated with a five-fold increase in the incidence of adult respiratory distress syndrome (ARDS).[8] They also noted a significant relationship between the incidence of ARDS and mortality reflecting evidence that patients with higher ISS scores tended to develop ARDS.

Bone et al. performed the first prospective randomized trial on 178 patients with an femoral shaft fracture for assessing the effect of early fracture stabilization.[9] He allotted femoral fractures into two groups—those early (within 24 hours of injury) or late stabilized (more than 48 hours after injury). The patients in the early treatment group had their fractures stabilized immediately, whereas those in the delayed treatment group were placed in traction. The study showed conclusive evidence in favor of early fracture stabilization with decreased pulmonary morbidity, ARDS, fat embolism, pulmonary embolism and pneumonia in the early stabilized groups. The length of hospital stay was also reduced in the early osteosynthesis group of patients.

This new philosophy in the management of the patients with multiple injuries was named early total care. ETC became accepted as an important element in injured patient's care. A new view now prevailed in surgeons—too sick not to operate on. Improvements in intensive care and newer fracture fixation techniques facilitated the concept of ETC.[8]

The exact mechanism by which early stabilization contributes to decreased mortality and better pulmonary function is unknown, but reduction in the fat embolism syndrome, decreased analgesic need and an ambulatory patient participating in active rehabilitation are thought to play a part.[10] Other important benefits of ETC are pain relief, and the fact that the procedures are being performed when the patient is still in optimal nutritional state resisting any hospital acquired infection.[8] The optimal time, therefore, for any surgical intervention is in the first 24 hours post-injury.[10]

In the early 1990s, a variety of unexpected complications related to the early stabilization of fractures were described.[11,12] The term "borderline" patient was first used by Pape et al.[11] They conducted a retrospective study of a series of polytrauma patients with an ISS greater than 18, and femoral shaft fractures treated by reamed intramedullary nailing. They found that early intramedullary nailing in patients without thoracic injury was associated with lower rates of pulmonary complications. By contrast, patients with severe thoracic trauma had poor outcomes after primary intramedullary nailing, with development of ARDS. Similar findings of a multicenter study by the AO (Arbeitsgemeinschaft für Osteosynthesefragen) Foundation or the Association of the Study of Internal Fixation (ASIF) reinforced this concern.[13] This led to the conclusion that the method of fracture stabilization and timing of surgery may have contributed in the pathogenesis of such complications.

With further reports substantiating above data[14,15] and on the basis of laboratory findings, "patient at risk" or "borderline" patients were identified which have potential to do particularly badly with ETC **(Table 1)**.[16] Thus, patients with a high ISS and significant thoracic, abdominal and head injuries formed a subgroup in whom ETC approach was detrimental.

This borderline phenomenon has been explained on the basis of a two hit theory.[17] The type and severity of injury, the first hit phenomenon, may predispose the borderline patient to deteriorate after surgery. Furthermore, the type of surgery, the second hit phenomenon, poses a varying burden on the biological reserve of the patient, and may predispose to an adverse outcome. Numerous publications were able to show that surgery caused a variety of subclinical changes in the inflammatory system which could become clinically relevant with a cumulative effect of several impacts were added.[18-20] Massive amounts of transfused blood commonly used in the polytrauma patients have also been implicated as a cause of depression of immune system.[21] In response to these observations, the concept of DCO for the management of the polytraumatized patient was developed. This approach is based on the principle of damage limitation and is an attempt to minimize the magnitude of the second hit or the inflammatory reaction induced by the any major operative procedure.

TABLE 1: "Borderline" patient or "patient at risk"[16]

• Multiple injuries with injury severity score > 20 with additional thoracic trauma AIS > 2
• Multiple injuries with abdominal/pelvic trauma and initial systolic blood pressure < 90 mm Hg
• Injury severity score > 40
• Radiographic evidence of bilateral pulmonary contusion
• Initial mean pulmonary arterial pressure > 24 mm Hg
• Pulmonary artery pressure increase during intramedullary nailing > 6 mm Hg

Abbreviation: AIS, Abbreviated Injury Scale

Concept of Damage Control Surgery

The term "damage control" was originally coined by the US Navy in reference to the "capacity of a ship to absorb damage and maintain mission integrity". Rotondo et al. first applied the term "damage control surgery" to the management of patients with penetrating abdominal trauma.[22] They found that in a small subset of patients with major vascular injury and at least two visceral injuries survival was improved by an initial laparotomy to deal only with hemorrhage and contamination, followed by intraperitoneal packing and rapid closure, resuscitation to normal physiology, and subsequent definitive surgery. This practice resulted in improved survival rates after penetrating abdominal injury. Based on the concept of damage control surgery, the application of the same principles to the management of the multiply-injured patients with associated fractures of the long bones and pelvic fractures was termed "damage control orthopedics".

Damage control orthopedics consists of three stages **(Table 2)**, the first stage involves early temporary stabilization of fractures and hemorrhage control. Intracranial lesions, if indicated, can be decompressed at the same time. The second stage involves resuscitation of the patient to stable physiological state in the intensive care unit and optimization of his condition. In the third stage, delayed definitive management of fractures is undertaken and is postponed until the second stage is complete.[23]

The favored technique for temporary stabilization of fractures is usually an external fixator. This can be rapidly applied for stabilizing of fractures and avoids any additional stress on the patient. There are several criteria on which the stable physiological state of the patient is determined in the second stage. The patient is considered optimized when there is stable hemodynamics, stable oxygen saturation, the serum lactate level is less than 2 mmol/L, there are no coagulation disturbances, the patient is afebrile, and there is adequate urinary output.[24] The third stage of definite fracture fixation, usually entails intramedullary nailing (especially for fracture femur) and is carried out when the patient condition is optimized.

TABLE 2: Damage control principles algorithm

Borderline patient or patient at risk
Stage 1: Early temporary stabilization of fracture and hemorrhage control intracranial decompression, if necessary
Stage 2: Resuscitation and patient optimization
Stage 3: Definitive stabilization (after day 4) of fractures

Several studies have supported the success of this approach in multiple injured patients. Scalea et al.[25] reviewed patients who had femoral fractures treated with either primary intramedullary nailing, or an external fixation. They found that the patients treated with external fixators tended to be more severely injured. The operative time and average blood loss was less with external fixation than with nailing. Most of the cases in the external fixation group had subsequent conversion to intramedullary nailing. They concluded that external fixation of femoral fractures in patients with multiple injuries followed by early intramedullary nailing was a viable method of treatment and afforded all the benefits of early fracture stabilization with none of the potential complications. In another study, Nowotarski et al.[26] echoed the advantageous effect of delayed definitive fixation for managing fractures of the shaft of the femur in appropriately selected cases. Taeger et al. conducted a trial in 409 patients to prospectively evaluate the concept of damage control by immediate external fracture fixation and consecutive conversion osteosynthesis with regard to time savings, effectiveness, and safety. They found that DCO appears to provide a major reduction of operation time and blood loss in the primary treatment period in severely injured patients compared with hypothetical ETC.[27]

There is some concern regarding the increased risk of infection and optimal time for conversion of external fixation to intramedullary nailing. Rates of infection after conversion of external fixation of the femur to intramedullary nailing range between 1.7% and 3%[25,26] and are comparable to those for several series for primary intramedullary nailing of the femur.[28-30] Bhandari et al.[31] after analyzing several studies examining conversion of external fixation to intramedullary nailing in the lower limb, found that the rate of infection decreased significantly when the interval between the two procedures was less than 14 days. Pape et al.[32] assessed the levels of the proinflammatory cytokine interleukin-6 (IL-6) to predict for development of multiple organ dysfunction. They showed that patients who underwent definitive surgery at 2–4 days post-injury developed a significantly increased inflammatory response compared with those who were operated on 5–8 days post-injury. They report a high association between the combination of high initial IL-6 measurements and the secondary surgery on days 2–4 and the development of multiple organ failure. It was concluded that the definitive operation should be delayed until after the 4th day from initial surgery. In a more recent prospective, randomized, multicenter intervention study, Pape et al. measured levels of proinflammatory cytokines interleukin (IL-1, IL-6, and IL-8) in patients undergoing primary femoral nailing, DCO external stabilization and during secondary osteosynthesis.[33] The study concluded that a primary (< 24 hours) intramedullary femoral instrumentation evokes a sustained inflammatory response but during DCO external fixation or the secondary conversion to an intramedullary implant, these responses were minimal. The study also reaffirmed that damage control orthopedic surgery minimized the additional surgical impact induced by acute stabilization of the femur. Harwood et al. has proposed to use systemic inflammatory response syndrome (SIRS) score as an adjuvant in clinical decision making regarding the timing of conversion to an intramedullary device since DCO patients undergoing conversion while their SIRS score was raised suffered the most pronounced subsequent inflammatory response and organ failure.[34]

These studies indicate that conversion of external fixation to intramedullary nailing can be performed safely within the first 2 weeks and has a very low rate of infection.

Algorithm of Damage Control Sequence

Most fracture surgeons now agree that there are certain severely injured patients in whom definitive early skeletal fixation is contraindicated.[35] The severity of the injuries sustained and the clinical condition of the patient dictate the major factors governing the line of treatment in polytraumatized patients. The "borderline", **(Table 1)** condition as described above is a useful guiding tool. Other parameters which predispose to adverse outcome in polytraumatized patients are hypothermia, coagulopathy, multiple fractures in long bones, fractured femur and patients presenting with lung or chest pathology,[36,37] several biochemical markers can now be used to determine patients at risk of physiological decompensation. These are serum lactate, IL-1, IL-6, IL-10 and procalcitonin and can be used to aid in the decision to carry out DCO and subsequent secondary conversion.[38]

The concept of DCO has gradually been extended to orthopedic indications other than extremities.[39-41] Stahel et al. tested a standardized "spine damage-control" (SDC) protocol for the acute management of unstable thoracic and lumbar spine fractures in 112 severely injured patients. The SDC cohort fared better in terms of a reduced mean length of operative time, length of hospital stay, and number of ventilator-dependent days and the complication rates (wound complications, urinary tract infections, pulmonary complications, and pressure sores).[39] Mooney described use of DCO in open, segmental pediatric femur fractures complicated by severe soft tissue injury and bone loss which were managed definitively by submuscular bridge plates.[42]

Damage control orthopedics gives a stepwise approach to the management of patients with multiple injuries and is designed to take account of the difficulties encountered in dealing with patients who are hemodynamically unstable. Thus, the concept of DCO entails performing initially the least morbid procedures that preserve life and prevent death whilst avoiding potentially lethal complications, such as ARDS and multiple organ failure.

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Section 2

Basic Sciences

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3
Chapter

Functional and Anatomy of Joints

Nagesh P Naik, Manish Chadha, Arun Pal Singh

3.1 Joints: Structure and Function

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Introduction

The joint is a structural component of the skeleton where two or more skeletal elements meet including the supporting structures within and surrounding it. In simpler words it is the point of articulation between two or more bones.

There are approximately 200 bones in the human skeleton that are connected by joints. The basic purpose of a joint is to provide mobility and stability. The structure of a joint varies from simple to complex. While more simple joints have stability as primary function, the more complex joints have mobility as primary function.

Types of Joints

The joints are broadly classified into three categories. Each category has further subcategories.

1. Fibrous joints (synarthroses—immovable articulations)
   a. Sutures
   b. Syndesmoses
   c. Gomphoses
2. Cartilaginous joints (amphiarthroses or slightly movable articulations)
   a. Symphyses (fibrocartilage)
   b. Synchondroses (hyaline cartilage)
3. Synovial joints (diarthroses)
   a. Uniaxial
      i. Ginglymus (hinge)
      ii. Trochoid (pivot)
   b. Biaxial
      i. Condyloid
      ii. Saddle
   c. Triaxial
      i. Plane or gliding joint
      ii. Ball and socket.

Table 1 summarizes joints and their examples.

Synarthroses or Fibrous Joints

Synarthroses include all those articulations in which the surfaces of the bones are in almost direct contact, fastened together by intervening connective tissue, and in which there is no appreciable motion as in the joints between the bones of the skull, excepting those of the mandible. There are three varieties of synarthrosis: *sutura, gomphosis* and *syndesmosis.*

Sutura

Sutura is that form of articulation where the contiguous margins of the bones are united by a thin layer of fibrous tissue. This kind of joint is found in the skull only. When the margins of the bones are connected by a series of processes and indentations interlocked together, the articulation is termed a *true suture* (sutura vera). Sutura vera is of three types: sutura dentata, serrata and limbosa. The *sutura dentata* is so called from the tooth-like form of the projecting processes as in the suture between the parietal bones. In the *sutura serrate*, the edges of the bones are serrated like the teeth

TABLE 1: Joint types and their examples

Types of joint	*Subcategories and examples*		
Fibrous joints (Synarthroses or immovable articulations)	*Sutures:* The contiguous margins of the bones are united by a thin layer of fibrous tissue. 1. True suture (*sutura vera*) a. *Sutura dentata*: Suture between the parietal bones b. *Sutura serrata* between two frontal bone c. *Sutura limbosa*: Suture between the parietal and frontal bones 2. *False suture* (*sutura notha*) a. *Sutura squamosa*: Between the temporal and parietal b. *Sutura harmonia*: Between the maxillae, or between the horizontal parts of the palatine bones	*Syndesmoses*: Two bony components are joined directly by a ligament, cord or aponeurotic membrane, e.g. inferior tibiofibular articulation	*Gomphoses* Gomphosis is articulation in which the surfaces of a bony components are adapted to each other like a peg in a hole, e.g. the articulations of the roots of the teeth with the alveoli of the mandible and maxillae
Cartilaginous joints (Amphiarthroses or slightly movable articulations)	*Symphyses*: The intervening cartilage which connects the two bones is fibrocartilage, e.g. symphysis pubis, articulation of adjacent vertebral bodies	*Synchondroses*: The connecting material between two bones is hyaline growth cartilage, e.g. between the epiphyses and bodies of long bones	
Synovial joints (Diarthroses or freely movable joints)	*Uniaxial* 1. Ginglymus (Hinge)—Articular surfaces are molded to each other in such a manner as to permit motion only in one plane, e.g. interphalangeal joints, the joint between the humerus and ulna 2. Trochoid (Pivot)—Joint where the movement is limited to rotation, e.g. proximal radioulnar articulation, articulation of the odontoid process of the axis	*Biaxial* 1. *Condyloid*: An ovoid articular surface, or condyle, is received into an elliptical cavity, e.g. wrist joint, metacarpophalangeal joint 2. *Saddle*: Opposing surfaces are reciprocally concavo-convex, e.g. carpometacarpal joint of the thumb	*Triaxial* 1. *Plane or gliding joint:* Formed by the apposition of plane surfaces, or one slightly concave, the other slightly convex, e.g. the articular processes of the vertebrae, the carpal joints, the tarsal joints 2. *Ball and socket:* The distal bone is capable of motion around an indefinite number of axes—the hip and the shoulder

of a fine saw as between the two portions of the frontal bone. In the *sutura limbosa*, there is besides the interlocking, a certain degree of beveling of the articular surfaces, so that the bones overlap one another as in the suture between the parietal and frontal bones.

When the articulation is formed by roughened surfaces placed in apposition with one another, it is termed a *false suture* (*sutura notha*). Of which there are two kinds: (1) the *sutura squamosa*, formed by the overlapping of contiguous bones by broad beveled margins as in the squamosal suture between the temporal and parietal, and (2) the *sutura harmonia*, where there is simple apposition of contiguous rough surfaces as in the articulation between the maxillae, or between the horizontal parts of the palatine bones.

Figure 1 shows section across the sagittal suture.

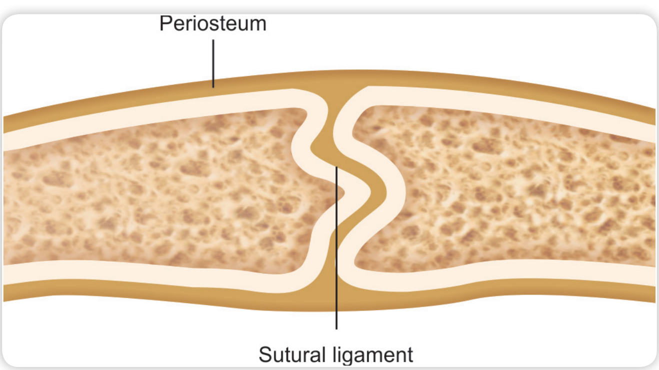

Fig. 1 Section across the sagittal suture

Syndesmosis

A type of joint in which two bony components are joined directly by a ligament, cord or aponeurotic membrane.

Examples: The shaft of tibia joins shaft of fibula by a membrane. This syndesmosis allows slight amount of motion with movements of knee and ankle joints. Another example of syndesmotic joint is inferior tibiofibular articulation **(Fig. 2)**. Here the bones are connected by an interosseous ligament.

Gomphosis

Gomphosis is articulation in which the surfaces of a bony components are adapted to each other like a peg in a hole. This is illustrated by the articulations of the roots of the teeth with the alveoli of the mandible and maxillae.

Amphiarthroses or Cartilaginous Joints

In these articulations, the contiguous bony surfaces are either connected by broad flattened disks of fibrocartilage or hyaline growth cartilages. In this kind of joint, the cartilage directly unites one bony structure to another (bone—cartilage-bone). Cartilaginous joints are of two types.

Symphyses

It is a type of joint where the intervening cartilage which connects the two bones is fibrocartilage. This intervening cartilage could be

Fig. 2 An example of syndesmosis

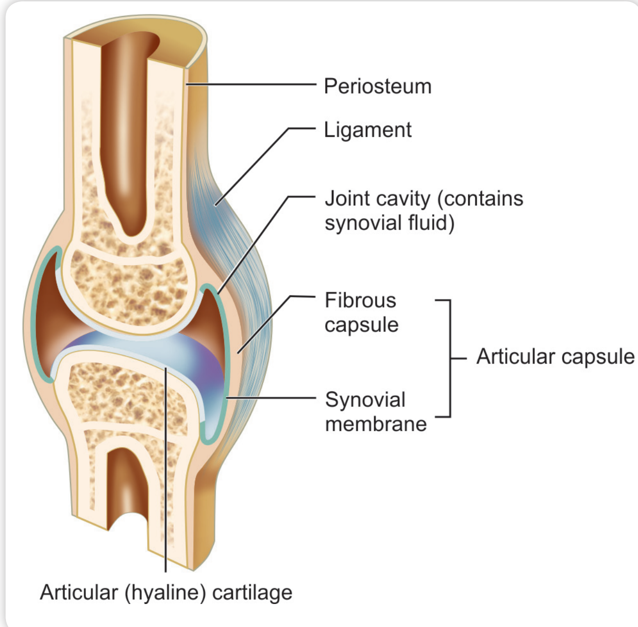

Fig. 3 Structure of a typical synovial joint

either in form of disk or plate. The symphysis pubis is one such joint where two pubic bones are joined by fibrocartilage. As the joint is a weight-bearing joint, therefore, under normal conditions very little motion occurs. It is primarily a stability joint. But during pregnancy slight widening of the joint occurs to ease the passage of the baby through the canal.

Another example of symphysis joint is articulation of adjacent vertebral bodies connected by intervertebral disks.

Synchondrosis

It is a type of joint where the connecting material between two bones is hyaline growth cartilage. The cartilage forms a bond between two ossifying centers of long bone. This is a temporary form of joint, where the cartilage is converted into bone before adult life. The function of this joint is to permit bone growth, provide stability and allow a small amount of mobility. Such joints are found between the epiphyses and bodies of long bones and skull bones.

Diarthroses or Synovial Joints

This class includes majority of the joints in the body. In a diarthrodial joint the ends of the bones are free to move in relation to each other because there is no cartilaginous tissue to connect the adjacent bony surfaces. However, the bone ends are indirectly connected to each other by joint capsule that covers and encloses the joint.

All synovial joints have following features:

- A joint capsule formed by fibrous tissue. A joint cavity enclosed by a joint capsule. Inner surface of the capsule is lined by synovial membrane.
- Synovial fluid which forms a thin film over the joint surfaces.
- Hyaline cartilage covering the joint surface.

Additionally, the synovial joints may have accessory structures. The joints may be divided, completely or incompletely, by an *articular disk* or *meniscus* or *labrum along with fat pads*, the periphery of which is continuous with the fibrous capsule while its free surfaces are covered by synovial membrane. The joints may also have tendons and ligaments within the joint capsule or immediately adjacent to the joint. Menisci or disks and synovial fluid help to prevent excessive compression of opposing joint surfaces. Ligaments and tendons assist in guiding motion and also have an important role in keeping joint surfaces together.

Structure of a Typical Synovial Joint

A typical synovial joint is depicted in the **Figure 3**.

Joint Capsule

The joint capsule encloses the joint. It is composed of two layers. The outer layer is called the stratum fibrosum and inner layer is called the stratum synovium. Stratum fibrosum is composed of dense fibrous tissue and completely encircles the ends of bony components. It is attached to the periosteum of either bone by Sharpey's fibers and is reinforced by ligamentous and musculo-tendinous structures that cross the joint. It has poor vascularity but is rich in innervation by joint receptors.

In contrast, the inner layer is highly vascularized but poorly innervated. Thus, it is insensitive to pain but undergoes vasodilation and vasoconstriction when subjected to heat or cold. Stratum synovium contains synoviocytes, specialized cells which can synthesize hyaluronic acid which is found in the synovial fluid. Stratum synovium also produces matrix collagen and is also involved in transfer of nutrition and waste products. Joint receptors are present in the outer layer and they are involved in detection of rate and direction of motion, compression, tension, vibration and pain. Different types of joint receptors are presented in **Table 2**. These receptors act as messengers to the central nervous system about the status of the joint. This information is essential to provide protection for joint structures, to produce controlled movements at the joint, and to provide proprioception in static or dynamic state.

TABLE 2: Different types of joint receptors

Receptor	*Location*	*Sensitivity*	*Distribution*
Group I, Golgi ligament endings	Ligaments	Stretch of ligaments	Found in most joints except in vertebral column
Group I–II, Ruffini endings	Outer layer of joint capsule	Stretch of joint capsule; change in joint fluid pressure; and changes in joint position	Found in highest concentrations in proximal joints
Group II, Pacinian corpuscles	Outer layer of joint capsule	High frequency vibration; acceleration; and high velocity changes in joint position	Found in highest concentrations in distal joints
Group II–III, Golgi-Mazzoni corpuscles	Inner layer of joint capsule	Compression of joint capsule	Found in knee joint and most likely in other joints
Group IV–V, Free nerve endings	Throughout capsule and in ligaments	Mechanical stress or biochemical stimuli	Found in many joints and ligaments

TABLE 3: Analysis of synovial fluid

Analysis	*Normal results*	*Noninflammatory effusion*	*Inflammatory effusion*	*Septic effusion*
Gross Examination				
Volume	1–4 mL	Increased	Increased	Increased
Clarity	Transparent	Transparent	Transparent	Opaque
Color	Clear/pale yellow	Yellow	Yellow/white	Yellow/white/gray
Viscosity	High	High	Low	Low
Mucin clotting	Good	Good/fair	Fair/poor	Poor
Microscopic Examination				
Leukocytes	<300	<2,000	2,000–80,000	>80,000
Neutrophils	<25%	<25%	25–75%	>75%
Bacterial smear	Negative	Negative	Negative	Positive
Serum glucose ratio	0.8–1.0	0.8–1.0	0.5–0.8	<0.5
Protein (g/dL)	<3	<3	≤8	≤8
Culture	Negative	Negative	Negative	Positive

Neurovascular Supply

The source of nerve supply to a joint conforms well to Hilton's law, i.e. the nerves supplying the muscles acting across a joint give branches to that joint called articular branches as well as to the skin over the area of action of these muscles.

Thus, the knee joint is supplied by branches from the femoral, sciatic and obturator nerves. The arteries in the vicinity of a synovial joint anastomose freely on its outer surface. From the network of vessels so formed, branches lead to the fibrous capsule and ligaments, and to the synovial membrane. Blood vessels to the synovial membrane are accompanied by nerves.

Synovial Fluid

Composition of the synovial fluid is almost similar to the plasma except that the synovial fluid contains hyaluronic acid and a glycoprotein called *lubricin*. The hyaluronic acid component of synovial fluid is responsible for its viscosity and is essential for lubrication of the synovium. It reduces the friction between the synovial folds of the capsule and the joint surfaces. Lubricin on the other hand is responsible for cartilage on cartilage lubrication. Changes in the concentration of the either component will affect overall lubrication and the amount of friction.

To the naked eye, the normal synovial fluid appears as clear, pale yellow, viscous fluid. It shows good mucin clotting. A joint pathology will alter the color and other properties of the synovial fluid as well as its composition. A comparison of joint fluid in normal and pathological state is shown in **Table 3**. Study of synovial fluid changes is helpful in making a diagnosis.

Types of Diarthrodial or Synovial Joints

The varieties of joints in this class have been determined by the kind of motion permitted in each, i.e. number of axes about which the gross visible motion occurs. A further subdivision of the joints is made on the basis of shape and configuration of the ends of the bony components. Diarthrodial joints are mainly of three types:

Uniaxial Joint

In this joint, the visible motion occurs only in one plane of the body around a single axis. The axis of the motion usually located near or at center of the joint. As the uniaxial joints allow movement only in a single axis, they are said to have 1° of freedom of motion.

Two types of uniaxial diarthrodial joints are found in the human body. Hinge joint or ginglymus joint and pivot joint or trochoid joint.

Ginglymus or Hinge Joint

This joint is called so because it resembles a door hinge. In this form the articular surfaces are molded to each other in such a manner as to permit motion only in one plane, forward and backward, the extent of motion at the same time being considerable. The direction which the distal bone takes in this motion is seldom in the same plane as that of the axis of the proximal bone; there is usually a certain amount of deviation from the straight line during flexion. The articular surfaces are connected together by strong collateral ligaments, which form their chief bond of union. The best examples of ginglymus are the interphalangeal joints and the joint between the humerus and ulna. Knee and ankle joints are less typical, as they allow a slight degree of rotation or of side-to-side movement in certain positions of the limb.

Trochoid or Pivot Joint

It is a type of joint where the movement is limited to rotation. The joint is formed by a pivot-like process turning within a ring, or a ring on a pivot, the ring being formed partly of bone, partly of ligament. In the proximal radioulnar articulation, the ring is formed by the radial notch of the ulna and the annular ligament and the head of the radius rotates within the ring. In the articulation of the odontoid process of the axis with the atlas, the ring is formed in front by the anterior arch, and behind by the transverse ligament of the atlas; here, the ring rotates around the odontoid process.

Biaxial Diarthrodial Joints

A biaxial diarthrodial joint permits the motion in two planes around two axes. These joints have 2° of freedom. Condyloid and saddle joints represent biaxial joints.

Condyloid Joints

In this form of joint, an ovoid articular surface, or condyle, is received into an elliptical cavity in such a manner as to permit flexion, extension, adduction, abduction and circumduction, but no axial rotation. The joint surfaces are shaped in such a manner that the concave surface of one bony component is allowed to slide over the convex surface of another component in two directions. The wrist joint is an example of this form of articulation. Another example is metacarpophalangeal joint.

Saddle Joints

In this variety the opposing surfaces are reciprocally concavo-convex. The movements are the same as in the preceding form; that is to say, flexion, extension, adduction, abduction and circumduction are allowed; but, no axial rotation. The best example of this form is the carpometacarpal joint of the thumb.

Triaxial or Multiaxial Joints

These joints permit movement in three planes around three axes. Thus, these joints have 3° of freedom of motion. Motion at these joints may also occur in oblique planes. The two types of joints in this category are plane joints and ball and socket joints.

Plane or Gliding Joints

These joints permit gliding movement only it is formed by the apposition of plane surfaces, or one slightly concave, the other slightly convex, the amount of motion between them being limited by the ligaments or osseous processes surrounding the articulation. It is the form present in the joints between the articular processes of the vertebrae, the carpal joints, except that of the capitate with the navicular and lunate, and the tarsal joints with the exception of that between the talus and the navicular.

Ball and Socket Joints

These are the joints in which the distal bone is capable of motion around an indefinite number of axes, which have one common center. It is formed by the reception of a globular head into a cup-like cavity, hence the name ball- and-socket. Examples of this form of articulation are found in the hip and shoulder.

Function of the Joints

The structure of joints of human body reflects the function that they will serve.

Synarthrodial joints are simple joints and basically serve as stability joints though some degree of motion may occur. Basic purpose of diarthrodial joints is mobility although many of them also provide stability. Together with their integrated action they provide an effective functioning to the body

Kinematic Chains

These are a series of rigid links that are interconnected by a series of pin-centered joints. They can be
- *Open*: One joint can move independent of other
- *Closed*: One end of chain remains fixed.

In lower limbs, the joints remain in closed chain when functioning that is weight bearing because the feet are fixed on the ground while in nonweight-bearing position, the joints are in open chain. For example, in weight bearing position with knee flexion automatic flexion at hip and dorsiflexion at ankle occurs to maintain upright position while in nonweight-bearing position knee can flex independently.

In upper extremity as the ends are not fixed open linked chain exist where motion does not occur in predictable manner because joints may either function independently or in unison. For example while waving a hand movement can occur in wrist or in shoulder rotation or both.

Osteokinematics and arthrokinematics:
- Movements of bone in space is osteokinematics like flexion of forearm.
- The joint surface movements are termed arthrokinematics and are subclassified into:
  - *Roll*: Rolling of one surface on other like rolling of tire on road as in knee joint
  - *Slide*: Translatory motion by gliding of one surface over other like braked wheel skids as in proximal phalanx over metacarpal.
  - *Spinning*: Rotation like top spins as in head spins on capitellum.
- Combination of rolling and sliding movements occur depending on whether a concave surface moves over convex or vice versa
- Joints are divided into ovoid (one surface is concave and other convex) and sellar (Both surfaces are concavoconvex)
- General changes with immobilization, exercise and overuse.

Immobilization:

- *Ligaments and tendons*: Collagen content and crosslinking decrease although size remain same ligaments and tendons decrease their tensile strength and stiffness
- Proliferation of fibrofatty connective tissue within joint
- Adhesions between folds of synovium
- Atrophy of cartilage
- Regional osteoporosis
- Weakening of ligaments at their insertion sites due to osteoclastic resorption of bone and Sharpey's fibers
- Decrease in proteoglycan content and increase in water content of the articular cartilage
- Inhibits and weakens muscles surrounding joint, loss of sarcomeres in series, decreased contractile proteins
- *Capsule*: Shrinking, increased resistance to movement
- These changes occur in 8 weeks but recovery may take 18 months or longer

Effects of loading:

- Connective tissues become weaker and lose their tensile strength if they are not loaded
- Changes with decreased load occur rapidly
- Recovery of normal structure and function requires gradual progressive loading
- Loads should be tailored to connective tissue.

Exercise:

- Low frequency compressive loading will increase cartilage formation while higher frequencies can enhance bone synthesis
- Higher magnitude or sustained loading will produce fibrocartilage formation
- Tensile loads result tissue formation resembling that in ligament and tendon
- Maintenance of normal state of connective tissue appear to require repetitive loading beyond a threshold level, below this level immobilization changes rapidly occur.

Overuse

Changes resulting from repetitive tensile loading of connective tissues may be called overuse injury or syndrome, repetitive motion disorder or strain injury. These appear to affect athletes, dancers, farmers, musicians, office and factory workers; more in men. The role of systemic influence (hormones and nutrition) and neurophysiologic influences (referred pain, focal dystonia) in repetitive injuries remain to be explored.

Tissues have a movable threshold below which they atrophy and above which they get injured. Progressive loading involves gradually moving this threshold is essential. Therapist must skillfully load the tissues with appropriate direction, magnitude, and frequency of loading to prevent weakening and to induce adaptation.

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3.2 Synovium Structure and Function

Nagesh P Naik

Introduction

Synovial membrane differentiates from the mesenchymal tissue around articular disk, clearing the articular surface by the fifth month in utero.

Histology

Synovial tissue may be fatty, fibrofatty or fibrous and contains types I and III collagen. Two types of cells are found.

Type A macrophage-like phagocytic cells.

Type B resembles fibroblast and is responsible for the secretion of hyaluronic acid and protein. The subsynovial tissue contains macrophages and fibroblasts and precursors of the synovial cells which give rise to the membrane after synovectomy. A small number of mast cells whose function is unknown are also found. There is a rich vascular plexus accompanied by lymphatic channels extending up to the synovial membrane itself which is formed by a layer of two to three cell thicknesses with no basement membrane. This arrangement is presumably to allow ready passage of fluid from the capillaries through synovial membrane into the cavity. However, the combined effect of the overlapping processes, the hyaluronate in the intercellular matrix and the capillary wall, restricts entry or exit to substances with molecular weight above 150,000. The surface area is increased by numerous villous folds which increase the area for secretion and resorption.

Synovial Fluid

- It is an ultradialysate of blood plasma to which proteoglycans has been added by local synthesis by the joint tissues.
- It is clear viscous yellow fluid and does not clot due to not containing fibrinogen.
- It contains 96% water and 4% solutes with a specific gravity of 1.010 and a pH of 7.3–7.6.
- Normal synovial fluid contains very few cells.
- Proteins are present in lower concentration and most of it is albumin (approximately two-third).

The viscosity is lowered in osteoarthritis, aging and trauma. The specific gravity is reduced in osteoarthritis and after trauma. In inflamed joints, the protein contents are high and may clot.

Joint Lubrication[1]

Boundary Lubrication

In synovial joints, a specific glycoprotein 'lubricin' appears to be absorbed to each articulating surface and prevents direct surface to surface contact, significantly reducing surface wear. It depends exclusively on the chemical properties of the lubricant.

Fluid Film Lubrication

Fluid film lubrication is by a layer of fluid between the sliding bearing surfaces. The efficiency of the lubricant film depends on its viscosity which is resistant to the flow and is defined as the sheer stress in the fluid divided by the rate of sheer strain. Viscosity is constant for ideal Newtonian fluids, but in the most biological fluids it varies with flow rate. A lubricant with low viscosity produces less viscous drag in the bearing but is more likely to be expelled from the joint to allow the articulating surfaces to come into direct contact. In human joints, the oscillating nature of the joint movements, the flow of synovial fluid into and out of the articulating region and the local deformation of articulating cartilage under load contribute to a variety of mechanisms by which the fluid separates and lubricates the articular surfaces. Hyaluronate is essential for lubrication of the joint surfaces and its removal by hyaluronidase leads to erosion of the surfaces. The mode of action of hyaluronate is complex and the mode of joint movement and load. The lubricating action of synovial fluid is not viscosity dependent and the molecules during movements without loss of its lubricating properties. Two classic forms of fluid film lubrication are seen in engineering practice.

Hydrodynamic Lubrication

It takes place by virtue of relative motion of the bearing surfaces. When two nonparallel rigid bearing surfaces lubricated by a thin film move tangentially on one another, a converging wedge of fluid is formed which tends to loft the bearing surfaces apart, as the motion of the surfaces drags the fluid into the gap between the surfaces.

Squeeze Film Lubrication

It occurs when the rigid bearing surfaces move perpendicularly towards each other. There is a tendency for the fluid to squeeze out from between the surfaces which is resisted by the viscous forces. Very high fluid pressures are generated which can support heavy loads transiently. However, eventually the fluid film becomes so thin that contact between the bearing surfaces occurs.

Elastohydrodynamic Lubrication

When the bearing surfaces are not rigid, the soft material deforms under load, and the deformations tend to increase the bearing contact area and prevent escape of lubricant fluid.

Boosted Lubrication

It depends on the ability of the solvent component of synovial fluid to pass into the articular cartilage using squeeze film action, leaving behind it a concentrated pool of hyaluronic acid protein complex to lubricate the surfaces.

As the two articular surfaces approach each other, pools of lubrication fluid are trapped between asperaties on the surface of the articular cartilage. The trapped pool of fluid becomes progressively more viscous, so boosting the lubrication. This mechanism may also operate in the presence of a sliding load.

Mechanism of Joint Lubrication[2]

The lubrication mechanisms operating in animal joints have not been completely elucidated. Boundary lubrication appears to be most important when the joint is stationary and under conditions of severe loading. As movement commences and loading is reduced, there is a transition to a mixture of boundary and fluid film lubrication. Under these conditions boundary lubrication occurs between asperaties, while fluid film lubrication occurs at other regions. In this mixed lubrication, it is probable that most of the friction is generated in the boundary lubricated areas, while most of the load is carried by the fluid film. As speed increases, a conversion to elastohydrodynamic lubrication occurs. During slowing, squeeze film lubrication begins to operate once again and this continues until the limb is at rest. After a period of immobility, boundary and elastohydrodynamic lubrication, the weeping and the trapped pools systems are operating to an extent as yet undetermined.

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4

Chapter

Growth Factors and Fracture Healing

Anil Agarwal, Anil Arora

Introduction

Fracture healing is a complex physiological process of bone regeneration. The process involves integration of hematopoietic, immune cells, vessels, periosteum and surrounding mesenchymal tissue.

Although, to a great extent, the cascade of molecular events remains unknown, various signaling molecules, including growth and differentiation factors (GDFs), hormones and cytokines, participate in this fine orchestra of events. Ongoing research in cellular and molecular biology has helped us in better understanding of the fracture healing process.

Growth Factors: General Concepts

Growth factors are proteins secreted by cells that act on the appropriate target cell or cells to carry out a specific action. Three types of action are possible: (1) *autocrine,* in which the growth factor influences the cell of its origin or other cells identical in phenotype to that cell (e.g. a growth factor produced by an osteoblast influences the activity of another osteoblast), (2) *paracrine,* in which the growth factor influences an adjacent or neighboring cell that is different in phenotype from its cell of origin (e.g. a growth factor produced by an osteoblast stimulates differentiation of an undifferentiated cell) and (3) *endocrine,* in which the growth factor influences a cell that is different in phenotype from its cell of origin and located at a remote anatomical site (e.g. a growth factor produced by neural tissue in the central nervous system stimulates osteoblast activity). Thus, a growth factor may have effects on multiple cell types and may induce an array of cellular functions in a variety of tissues.[1,2]

The binding of a growth factor to its receptor is known as a ligand-receptor interaction. These interactions are very specific and can range from simple, with a specific growth factor (ligand) binding to a single cellular receptor, to complex, with one or more ligands binding to one or more receptors in order to produce a desired ligand-receptor effect.[3,4] Once the ligand-receptor interaction is established, the receptor is activated and ultimately leads to activation of signal transduction system. Part of this signal transduction system involves a so-called transcription factor, an intracellular protein that is activated as part of the signaling pathways initiated by the intracellular domain of a receptor. The activated transcription factor travels to the nucleus, binds to the nuclear DNA, and induces the expression of a new gene or set of genes. It is the expression of these new genes by a cell that ultimately changes the characteristics of that cell.[3,4] The type of activation as well as the specific transcription factor varies with the target cell, the growth factor-receptor combination, and the biological competency of the cell.

Molecular Aspects of Fracture Healing (Table 1)

There are basically three categories of growth factors:[5]

1. *The acute phase reactants:* The group includes interleukin (IL)-1, IL-6 and tumor necrosis factor-alpha (TNF-α) and other cytokines
2. Growth and differentiating factors
3. Angiogenic factors.

Acute Phase Reactants

Interleukin-1, IL-6 and TNF-α play a significant role in initiating and then regulating the osteogenesis process.[6]

Interleukin-1

Interleukin-1 is a predominantly macrophage-produced IL which mediates the host inflammatory response in innate immunity; two principal forms exist, designated α and β, with apparently identical biological activity. Their main cellular sources are mononuclear phagocytes, fibroblasts, keratinocytes, and T and B lymphocytes. Both IL-1α and IL-1β act at preosteoblast and osteoblast level