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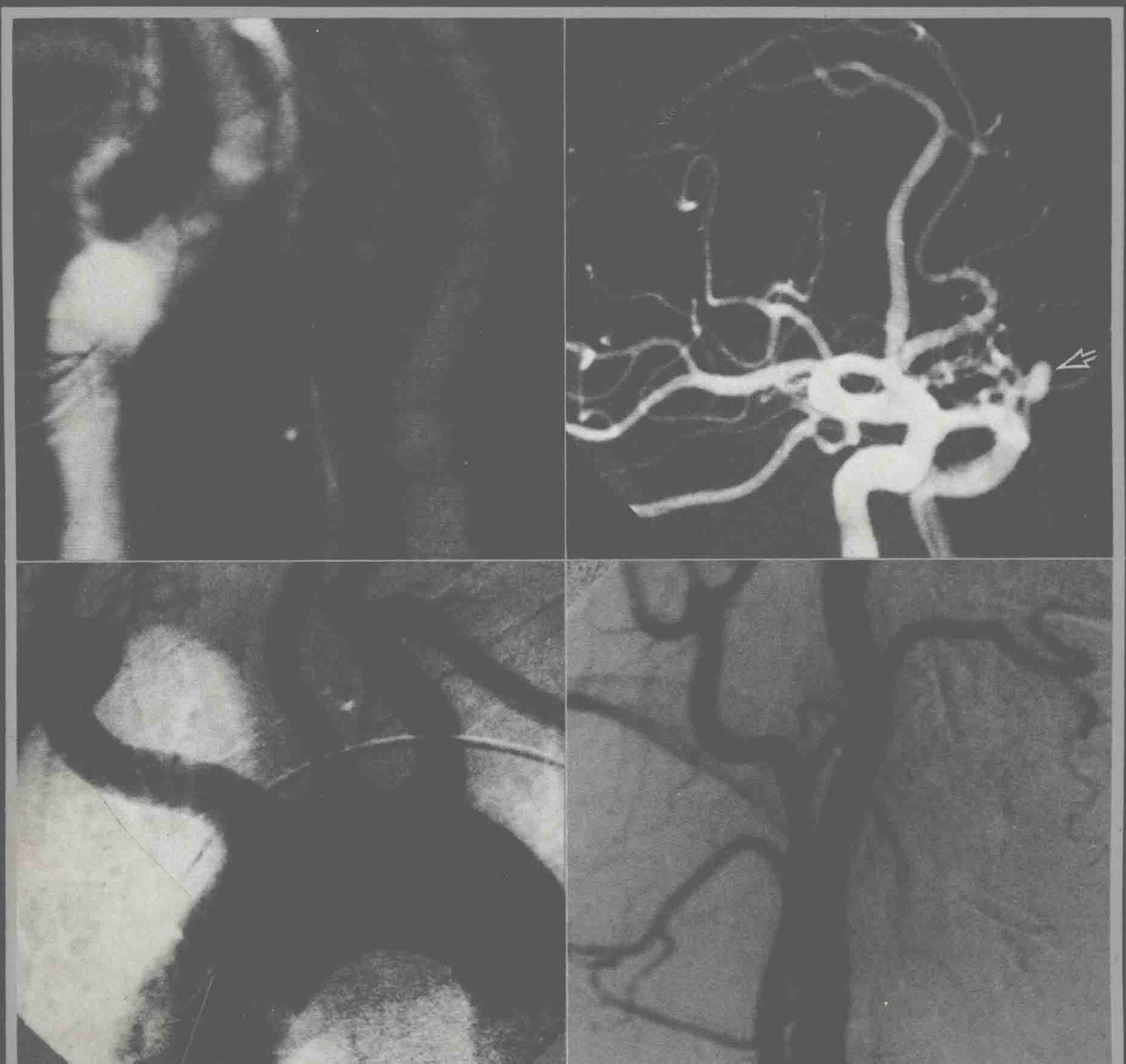
BASIC CONCEPTS OF DIGITAL SUBTRACTION ANGIOGRAPHY



BASIC CONCEPTS OF Digital Subtraction Angiography

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BASIC CONCEPTS OF

Digital Subtraction Angiography

To Ana Maria and Marilyn

PREFACE

Since the time of its development in the mid-1970s, digital subtraction angiography (DSA) has evolved into a widely used clinical imaging technique. Despite this rapid growth, we feel that a detailed description of the scientific principles underlying this method has been unavailable. The intent of this book is to provide such a work. This text is directed principally toward clinical radiologists who will be working with DSA on a routine basis. We hope, however, that the content and style are well suited to other groups as well, particularly research radiologists, medical physicists and engineers, radiology residents, graduate students, and advanced x-ray technologists.

The principal goal of this work is to provide an understanding of the basic instrumentation and physical concepts of DSA. In addition, we have included a set of clinical images indicating some of the present applications of DSA in intravenous and intraarterial studies. Several topics of DSA research, such as temporal filtering, also are presented. It is hoped that the information in this book will enable the practicing radiologist to use DSA more effectively and efficiently, with DSA equipment appropriate to these needs.

In preparing this book we have attempted to maintain a quantitative style, but with as little mathematics as possible. We hope this approach is suited to those who are allergic to equations while still being satisfactorily concise to those with more rigorous mathematical backgrounds. Whenever possible we have illustrated concepts with experimental DSA phantom or clinical examples. We also wish to stress that since neither of us has a medical degree, we are in no way attempting to teach medicine. We show clinical results either as practical illustrations of technical principles, or simply as indications of present DSA capabilities that we have observed in many DSA studies.

The structure of the book is as follows: after an historical overview of DSA development in chapter 1, chapters 2 to 6 cover the basic principles and instrumentation underlying digital fluorographic imaging, including the imaging chain, video signals, and digital processing. Chapters 7 and 8 present the physical concepts and the actual implementation of DSA. Chapter 9 is a discussion of temporal filtering. Finally, chapter 10 is a collection of clinical results, gathered from a number of sources, illustrating present applications. Two newer DSA techniques, hybrid subtraction and tomographic DSA, are also discussed briefly at the end of chapter 10.

We strongly recommend that all 10 chapters be read in order. For readers, however, who may wish to concentrate immediately on clinical applicability, we suggest reading chapters 1, 7, 8, and 10 sequentially.

ACKNOWLEDGMENTS

Preparation of a book involves the efforts of many more people than the authors. This is particularly true in this case since an attempt was made to demonstrate many of the technical aspects of DSA with clinical examples provided to us by clinical colleagues. Of course, the responsibility for all the material presented here lies with the two authors.

At the outset we wish to acknowledge the support provided to us by the Department of Radiology of the University of Utah (Robert A. Kruger) and General Electric Company Medical Systems (Stephen J. Riederer). One of us (Riederer) also acknowledges the support of the Department of Radiology of Stanford University during the period of his appointment there in 1982 as a visiting scientist.

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CONTENTS

CHAPTER 1

Introduction to Digital Fluorography

HISTORICAL OVERVIEW

The history of diagnostic x-ray imaging has been linked closely with fluoroscopic methods. The very discovery of x-rays by Roentgen in 1895 was made using a fluorescent screen. Since Roentgen's time, the application of fluorescent materials to x-ray detection has undergone major changes, so that several dozen commercial manufacturers now offer modern digital fluorographic imaging equipment.

The evolution of fluoroscopic imaging equipment is shown in figure 1.1. The first systems to be used clinically resembled figure 1.1A. A fluorescent screen was placed behind the patient being studied. Of the x-rays striking the screen, less than 15% were absorbed, and of these only 30% were converted into visible light. A dim light image resulted and could be viewed directly by a radiologist, but only in a darkened room after a period of dark adaptation. The main limitation to this system was the poor efficiency of the screen in converting x-rays into visible light.

A direct way of increasing the image brightness was to increase the x-ray exposure rate to the patient. High x-ray exposure was, in fact, a necessary side effect of these early systems. Even so, light levels were still low, and an increase in brightness by a factor of 100 or more was still desired.

In some landmark research performed in the 1940s independently by Langmuir (1940), Coltman (1948), Morgan and Sturm (1951), and others, the x-ray image intensifier evolved, resulting in the system shown schematically in figure 1.1B. In this case, x-rays were absorbed and converted to visible light as in figure 1.1A; however, this light then was converted to electrons that were accelerated within the image intensifier (II) tube before striking the output phosphor, where the high energy electrons were reconverted to visible light and viewed. Because of the large increase in electron energy and because of the minified image, the final image was about 500 times brighter than the image produced by the fluorescent screen alone.

Although the II represented a tremendous advance, the approach described in figure 1.1B still had some inconveniences: an image could be observed only during the exposure itself, and unless a mirror system was used it was awkward for more than one observer to view the image. The next step was to couple the output of the II to a television camera, as shown in figure 1.1C. This combination was achieved in the late 1950s and early 1960s, when IIs of even higher brightness amplification were developed. There have been numerous refinements in II technology since then; perhaps the most important improvement was the development in the late 1960s of cesium iodide (CsI) as the input phosphor. Use of CsI increased the quantum detection efficiency to 50% to 60%. It is with the basic framework shown in figure 1.1C that investigators in the mid-1970s began applying digital technology to fluoroscopic imaging.

MOTIVATION FOR SUBTRACTION

Because of the superimposition of a variety of anatomic structures (bone, soft tissue, fat, blood, air cavities, etc.) in a radiographic image, the detection

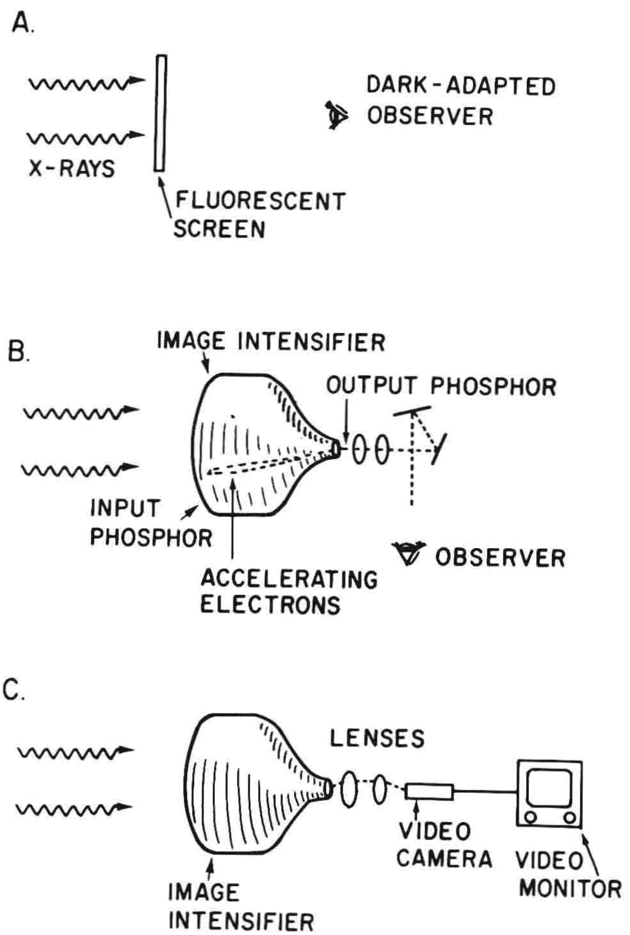

FIGURE 1.1.
The evolution of fluoroscopic x-ray imaging. *A,* The earliest fluoroscopic imaging systems. Radiation continuously struck the fluorescent screen and was converted to visible light, but with an overall efficiency only of about 5%. Because of very low light levels, the radiologist was forced to observe the screen in a darkened room and only after minutes of dark adaptation. *B,* The image intensifier converted x-rays into electrons, which were accelerated within the intensifier and in turn converted into visible light at the output phosphor. The output was substantially brighter than the fluorescent screen case *(A)* and could be viewed via lenses and mirrors. *C,* The next step in system development coupled the output of the image intensifier in *(B)* to a video camera. The resultant electronic image could be viewed remotely on a television monitor.

and delineation of a particular structure within an image is potentially a difficult perceptual problem. A number of methods have been used to reduce the complexity of the radiographic image without degrading the appearance of structures of interest. Such techniques include "optimizing" the kVp in order to maximize radiographic sensitivity to a particular substance, choosing a projection to obtain a best view of a structure of interest, or choosing an x-ray film that emphasizes low contrast detail.

The ideal image to analyze would be one in which all regions not containing a desired structure, X, had a background level of "zero," while those corresponding to X ideally would have a signal substantially different from zero. The goal of subtraction is to provide a result as close to this ideal as possible.

In general, this is done by acquiring two (or more) images of the anatomy suspected of containing X. Ideally, the contrast (or signal) caused by X changes from the first image to the second, while the contrast from all non-X structures remains the same. Upon subtraction, all non-X structures are canceled, thereby isolating X, as desired. This situation occurs during angiography, in which case X corresponds to iodinated blood flowing through the arteries being studied. The iodinated blood creates a change in radiographic image contrast from one film to the next as the contrast bolus (iodine) passes through.

The concept of subtracting one image from another to highlight the differences between them is not new. Early radiographic image subtraction was performed by Ziedses des Plantes (1934, 1962). Since that time and well before the advent of digital fluorography, film subtraction has been performed routinely in neuroangiographic studies.

Although the subtraction concept has been exploited in imaging for a long time, not until the development of digital subtraction angiography (DSA) has subtraction accuracy been sufficient to isolate less than 1% image contrast within complex images. In addition, the flexibility of DSA equipment has made a wide variety of subtraction techniques available that until now might have been hopelessly complex to implement.

The subtraction concept can be carried further. A subtraction image, at least one regarded in a very generalized fashion, need not be the result of merely subtracting one image from another. Instead, subtraction can be the result of combining or processing a