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Medical Color Imaging
- Present Status and Future-

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Reliability of the diagnosis based on digital images

- They are stable against preservation, transfer and duplication.
- We can get identical digital images anytime and anywhere.
- Therefore, physicians can make diagnosis observing the same medical images anytime and anywhere... Is that true?

Anatomical pathology and cytology

- Diagnoses on microscopic pathology, in which most colors observed are made of various stains, seem to be less affected by shifting into digital filing than diagnoses on macroscopic pathology, in which fine variations of natural colors are important.
- Although when consultations on pathological diagnoses over the network become generalized some demands for standardization will surely arise, current commercial products for telepathology are considered to be satisfactorily used in practice.
- Commercial products for computerized screening in cytology require some improvement to be used effectively.

Clinical pathology and laboratory medicine

- Because laboratory information systems encourage the spread of digital imaging, early investigations on diagnostic quality of digital color images have been progressed in this field.
- Problems with digital imaging in this field include inaccurate color reproduction, rough gradations of color and insufficient density of pixels, with varying degrees of relevance as regards their seriousness in various sub-fields.
- In hematological diagnosis, the colors of stained dyes themselves, as well as their change in color caused by various chemical reactions with the components of each blood cell, are considered extremely important.

Gastrointestinal endoscopy

- Diagnoses on mucosal lesions require proper expertize, especially on distinguishing cancer from benign lesions.
- Introduction of digital imaging with electronic endoscopy is expected to realize
  - Computerized endoscopic diagnosis based on digitized images.
  - Computerized laser cauterization on the basis of automatic detection and targeting of early cancer.
  - Real time superimposition of various referential information on endoscopic images.
- In a study, primary wavelength of light which comes from diseased mucosa, no statistically significant difference in color was shown among them.
- In only few cases, the affected area of mucosa could be detected and made visible by computerized image.

Dermatology

- Because skin color directly reflects every pathological change of skin that causes modification of its optical characteristics, it is vital information in dermatological diagnosis.
- But the quality of skin color images reproduced by any currently available imaging system does not meet the requirement for dermatological diagnosis; therefore, they are not yet considered a substitute for the observation of the real objects.
- If advanced digital imaging technologies can reproduce images equally used as real objects, revolutionary changes are expected.
- If not, a huge investment in electronic patient records and tele-medicine would run the risk of having been made in vain.

Plastic surgery

- In plastic surgery, color matching between graft and skin has vital importance.
- Conventional instruments used for measuring skin color have some problems:
  - they are affected by pores and wrinkles in the skin
  - they are affected by various illuminant conditions
  - they have the edge loss error caused by the semitransparency of skin.
- A new measuring system for the color of skin based on a noncontact-type spectrocolorimeter equipped with a globe for light integration is under development.

Forensic medicine

- Color is one of the most important findings because it reflects critically the cause of death in certain cases such as carbon monoxide intoxication or suggests aging of subcutaneous hemorrhage.
- Digitized images are increasingly used in the fields and strict device calibration is a prerequisite for utilizing digitized images instead of photographs for storage of autopsy findings.

Neurosurgery

- In neurosurgery, the essential elements to realize minimally invasive surgery are (1) substitution of human hands, (2) substitution of human eyes, (3) visual information such as the 3-D maps superimposed on the image of the real object which provides navigation to assist the surgeon in the operation.
- Stereoscopic video microscope systems equipped with a flat panel display and a video camera are substituting ordinary microscopes for microsurgery.
- They must have high-fidelity color because erroneous color appearance of blood and tissue may directly affect operations.

Otorhinolaryngology

- Although various visual data are recorded for later reference using digital still cameras, video cameras, stroboscopes, electronic endoscopes and so on, such recorded images usually have differences depending on the preference of the physician and the characteristics of the equipment used to record them, and they may not be compared properly to each other.
- There is an effective and practical solution, in which a color chart taken simultaneously with the object is used to calibrate color values of the displayed images.
- But uniform input and compatible output of still and video images should be pursued as fundamental techniques.

Nursing

- With expanding needs for nursing services provided at home, easily understood nursing information including visual information should be supplied to patients and their families to maintain the quality and effectiveness of the service.
- In nursing information, the color of visual data is one of the most important factors in all contexts mentioned above, and nursing professionals should have opportunities to actively join in the discussion on clinical applications of digital imaging, especially accurate reproduction of color.

Process of the diagnosis based on conventional analog images

1. The subject emanates light waves.
2. The light waves pass through an iris, a lens and reach to a retina.
3. The retina converts the light waves to the pulse signals.
    1. The rod cells sense and convert the brightness.
    2. The cone cells sense and convert only three kinds of colors.
4. The visual area of the brain converts the pulse signals into images.
5. The memory area gives the images some concepts.
6. The brain uses the concepts to make a diagnosis.

Process of the diagnosis based on digital images

1. The subject emanates light waves.
2. The light waves converted into digital images of the RGB system.
3. The digital images are stored or transferred.
4. The display equipment reproduces the images from the digital data.
5. The light waves pass through an iris, a lens and reach to a retina.
6. The retina converts the light waves to the pulse signals.
    1. The rod cells sense and convert the brightness
    2. The cone cells sense and convert only three kinds of colors
7. The visual area of a brain converts the pulse signals into images.
8. The memory area gives the images some concepts.
9. The brain uses the concepts to makes a diagnosis.

Diagnoses based on digitized images may be affected by :

- Color data lost in the A-D conversion process.
- Difference among digitized images according to
  - various physical specifications of digitizing processes.
  - various physical specifications of display equipment.
- Difference of illumination causes
  - various spectra of light waves emanated from the subject.
  - various degree of adaptation of observers' eyes.
- Therefore they may incidentally cause erroneous diagnoses.

Problems in accurate reproduction of colors

- Color calibrators for CRT displays and flat panel displays are available, but not for other output devices.
- The color management technology is optimized for making printed images equal to the original ones, but it is required that displayed images are made equal to the standard images acquired in the brain of experienced physicians.
- A color chart taken simultaneously with the object is used to adjust color values of displayed images so as to reproduce the same color as the original chart, but can neither reproduce the same colors under different illumination nor compensate the brightness and color adaptation of observers' eyes.

The quality of color reproduction required for medical diagnosis

- The diagnostic qualities of most of digitized medical images properly prepared are almost the same as slidefilms.
- However, the medical findings which should be detected in an image may greatly affect the required degree of digitizing precision to maintain the same diagnosis that is made by observing the original.
  - One study showed particular combinations of medical images and displays may incidentally cause erroneous diagnoses.
  - Another study suggested that the artificial lesion recorded as a digital image might be diagnosed differently according to the spatial densities of pixels composing the image.
- The process of visual recognition and medical diagnosis is still unclear, but it was clearly shown that the poor reproduction of color information possibly interferes the proper diagnoses.

Solutions (1) : Verification of diagnostic equivalence

- Because it will take still a more time to establish a comprehensive theory to manage the color in medical imaging, a novel concept for simple and inexpensive methods to calibrate common displays, 'diagnostic equivalence', was introduced.
- Two displays reproducing colors differently are considered as medically equivalent if the same diagnosis is gotten observing the two medical images reproduced with each of them.
- To verify this kind of equivalence, a set of typical medical images with their diagnoses decided by authorities in advance are proposed to be used as a practical calibrator.
  - In medical application, physical differences between a digitized image and original one can be allowed as far as they do not affect the medical diagnosis.
  - Medical professionals can evaluate and adjust their displays by comparing the diagnoses made observing the images using their displays with authorized ones.

Solutions (2) : Multispectral imaging

- There is the possibility that the conventional RGB systems, which records colorimetric values of only three primary colors, red, green and blue, cannot reproduce precise colors required for reliable diagnosis.
- Multispectral imaging, which makes it possible to record the spectral reflectance of objects for accurate color reproduction, will give an important solution.
  - One of its unique advantages is the ability to reproduce the precise colors under various illuminations.
  - The photometric stereo technique can reproduce multiple images of the object viewed from different directions.
  - Its techniques will clarify 1) the enough number of principal components to represent required colors of medical images and 2) the boundary between digitized medical images used properly and ones causing erroneous diagnoses.
- The realization of these expectations requires improvement of its costs, its sensitivity and its speed of data acquisition and affordable multispectral displays

Prevailing superstitions about color

- Every color can be represented by the RGB system because we have only three kinds of color sensors. [Truth : Original RGB values calculated by color matching functions for some light wavelengths become negative numbers and they actually cannot be displayed.]
- Complete color reproduction is impossible because no display equipment is free from theoretical limitations. [Truth : Even approximated reproduction of spectrum reflectance is very effective because human color sensation are not so precise.]
- Effects of improvement in accuracy of reproduced colors will be limited because human color sensation is not so precise. [Truth : Human visual recognition of vital information is highly-developed by means of real-time combined analysis of various kinds of signals.]
- It is not realistic to replace present infrastructures based on the RGB color system. [Truth : Approximated reproduction of spectrum reflectance can be realized using conventional input and output hardware with particular software attached.]

Conclusions

- A large potential risk of erroneous diagnoses caused by inaccurately reproduced colors has been left in medical imaging.
- Interdisciplinary collaboration of medicine and engineering science has identified many problems and solutions.
- To proceed further, strategies to eliminate some superstitions about color should be one of the most important targets.

Other sources of information on this research

- Textbook : Digital Color Imaging in Biomedicine, ID Corporation, Tokyo, 2001
- Academic Society : Digital Biocolor Society
- Web site : http://biocolor.umin.ac.jp/ (Full contents of the textbook and the society are also available here)