REVIEW

TELEPATHOLOGY: VIRTUALLY A REALITY

ABSTRACT

Telepathology is the practice of pathology at a distance by using video imaging and telecommunications. In most of the developed countries, telepathology has become an important element in the provision of cost-effective medical care. The main application of telepathology is tele-education and remote diagnosis. This paper reviews the history and different types of telepathology. Technical aspects of telepathology including image acquisition, image compression and telecommunication protocols are also explained. Legal aspects, uses and the future of telepathology are discussed.

Key words: telepathology, static, dynamic, digital, CCD, Internet

INTRODUCTION

The dramatic growth of the Internet, telecommunication standards and Information Technology in the last decade has lead to significant changes in how healthcare is delivered. The use of digital images for rendering diagnostic decisions has paved inroads in the field of medicine and dentistry.

Telepathology is the acquisition of histological and or macroscopic images for transmission along telecommunication pathways for diagnosis, consultation or continuing medical education.[3,25,69] Telepathology is the interpretation of transmitted digital histopathologic images while actually being separated from the slides where they were derived from. The word is derived from "*tele*" for far or distance "*pathos*" for disease and "*logos*" for study. The key to this definition is not the distance that separates the viewer from the slide, but the interpretation of histologic data visualised on a computer monitor[22,26]. A pathologist may practice telepathology in another room from the original slide using the hospital intranet; he may practise it if he receives a CD-ROM with a "virtual histologic image" or digital slide. In both of these situations, telecommunications have not played a significant role.

*Professor and Head, Dept. of Oral Pathology, St. Joseph Dental College, Eluru 534 003

Most histopathologists are aware of the concept of transmitting written, numerical, macroscopic and microscopic images via telecommunication technologies, though the majority have yet to see it work in practise. Advances in computer image processing, development of the Internet and telecommunications technology have evolved to a stage where telepathology is now in use in many institutions.

In brief, a telepathology system comprises a conventional microscope; a method of image capture, commonly a camera mounted on a light microscope; telecommunications link between sending and receiving sites; and a workstation at the receiving site with a high-quality monitor to view the images (Figure 1). There may also be mechanical hardware to allow the receiving pathologist to control the microscope from a distance and view the entire slide in 'real-time'. The images are viewed on a computer screen, rather than through microscope oculars.[1,22]

Telepathology in its current form falls short of what pathologists are used to seeing through their conventional microscopes. Despite this, review of literature suggests that telemicroscopy is useful in most cases and an accurate diagnosis can still be made.[1,14,15,29,36,49,61,62,63,65,67,72]The main problem faced by most histopathologists is that image quality is such that diagnosis is unduly difficult and cannot be made with the same level of confidence as with conventional microscopy.

HISTORY

Telepathology has its origins in telemedicine, a generic term encompassing the use of visual telecommunications in health care.[2,4,73] Radiology was one of the earliest medical specialties to utilise this as early as 1959 when Albert Jutra used coaxial cable to transmit videotaped telefluoroscopy examinations between two hospitals in Montreal, some five miles apart (Weinstein et al, 1987).[66] Pathologists came somewhat later to the technology probably because it was not of a sufficient standard. A histological image is exponentially more complex that a black-and-white radiological one and colour television was yet to be mass-produced. One of the earliest instances of telepathology took place in Boston in 1968 when a microwave-based telecommunications system was established, linking Massachusetts General Hospital with a medical station at Logan Airport, outside of downtown Boston (Bird, 1975)[4]. Live black and white images of histological sections and stained blood smears were transmitted from a clinic at the airport to the hospital. The video quality was equivalent to the then current United States commercial television (300-330 lines). A technician at the airport was directed by the pathologist at the hospital and also provided information on stain colours as requested.

In 1974, satellite communication was used to transmit histological images and clinical data from a 17-year-old male on board a hospital ship moored off the coast of Brazil to a hospital in Washington DC (Riggs. 1974)[51]. The system provided the equivalent of two telephone lines, one of which was used for voice communication, the other to transmit images of tissue sections, blood and bone marrow smears from a microscope video camera. In addition, teletype provided textual data communications while facsimiles of drawing and diagrams were sent at a rate of one page every six minutes. An electrocardiogram transmission unit and electronic stethoscope relayed ECGs and heart sounds. While the patient was not actually visualised, the data provided allowed a team of specialist consultants to diagnose 'mediastinal lymphosarcoma with leukemic transformation', initiate a regimen of chemotherapy and irradiation to the mediastinum, and even transmit a relevant journal article to the ship. During follow-up under similar circumstances thirty-five days later, a chest x-ray showed a reduction in tumour size.

Telepathology became a newsworthy item on August 20, 1986 with a public demonstration of a satellite-linked colour-video dynamic telepathology system between Fort William Beaumont Army Medical Center in El Paso, Texas and Washington DC.[7] In Texas, a frozen section slide of breast tissue was placed on the stage of a custom-designed, Olympus Vanox motorised microscope equipped with a video camera. The full-colour image was transmitted via the SBS-3 COMSAT satellite (Communications Satellite Corp, Washington, DC) to Washington DC where a pathologist seated at a prototype workstation (Corabi International Telemetrics, Rockville, Md) was able to control stage movements, magnification, focus and illumination, while viewing a real-time image at 525 lines of resolution. A second monitor displayed other parameters such as location of the image in relation to the whole slide, coordinates, and stage speed. Two-way audio communication was also available.

Since then, work by various groups in France,[43,44] Sweden,[49] Norway,[45,46,47,70] other parts of Europe,[21,31-34] the United States[19,64,72] and Japan[29,53] have each made significant contributions to the development and assessment of the clinical utility of telepathology equipment.

TELEPATHOLOGY SYSTEM[5] (see Fig. 1)

1 A high resolution video camera mounted on
2 A microscope to capture images of pathologic specimens and
3 A telecommunication set up (modem and

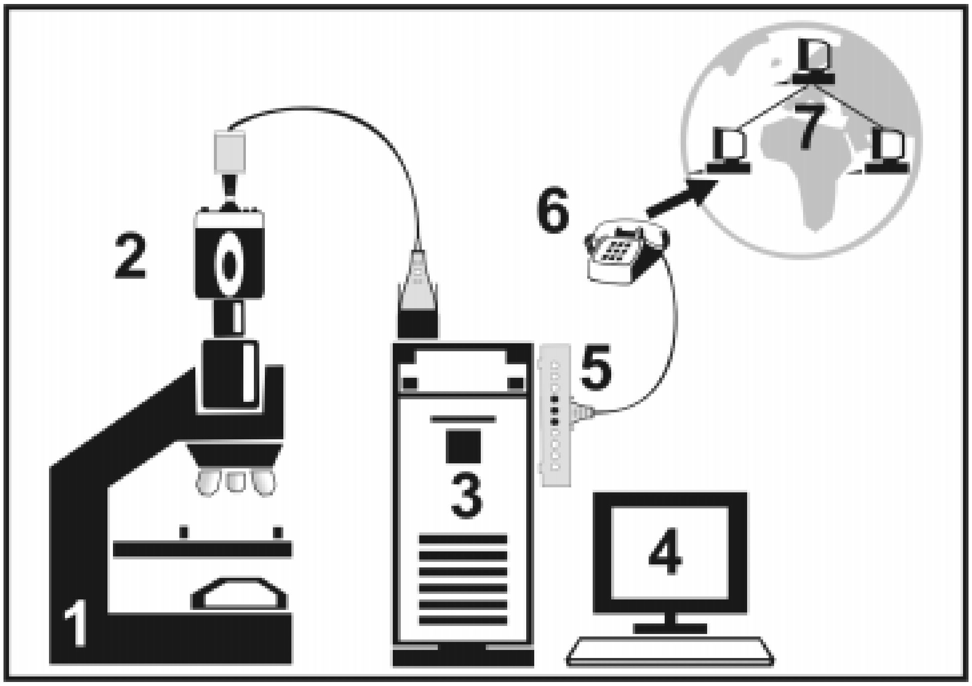


Fig 1: Schematic diagram of telepathology system. 1. Research Microscope 2. CCD / Digital camera 3. Computer CPU 4. High resolution monitor 5. Modem 6. Telephone 7. Internet (Remote work stations)

telephone in Fig. 1) to transmit images to the remote site with

4 A telepathology workstation consisting of computer with graphics card and colour monitor, and software to manage images

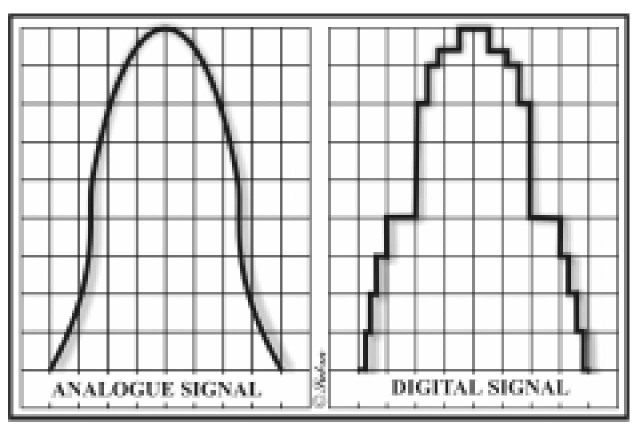
TECHNICAL ASPECTS OF TELEPATHOLOGY[6,8,12,52,54,56-59]

Visible light is commonly represented as a continuous analogue spectrum of waves and is the visible portion of the electromagnetic spectrum, a narrow range of wavelengths between 400-700 nm.

Analogue and Digital Images

An analogue image is represented electronically by continuous wave form as opposed to a digital image which is represented by digital values, derived from sampling the analogue image. Digital values are discrete electronic pulses that have been translated into strings of zeros and ones, the only digits in a binary numbering system. Digital images are electronic snapshots taken from a microscope or scanned from documents, such as photographs, manuscripts, printed texts, and artwork. The digital image is sampled and mapped as a grid of dots or picture elements (pixels). Each pixel is assigned a tonal value (black, white, shades of grey or colour), which is represented in binary code (zeros and ones). The binary digits ("bits") for each pixel are stored in a sequence by a computer and often reduced to a mathematical representation (Fig. 2). As shown in the bitonal image (Fig. 3), each pixel is assigned a tonal value, in this example 0 for black and 1 for white. The bits are then interpreted and read by the computer to produce an analogue version for display or printing. Analogue images are qualitative and comparative rather than quantitative as in the case of digital. Before we take a closer look at the photographic digital im-

Fig. 2: Analogue and Digital signals



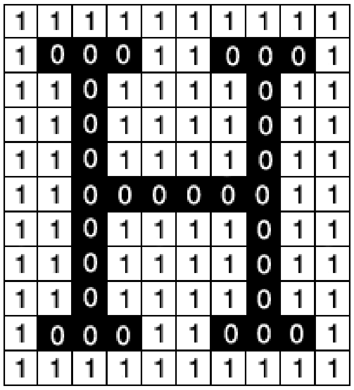


Fig. 3: A bitonal image

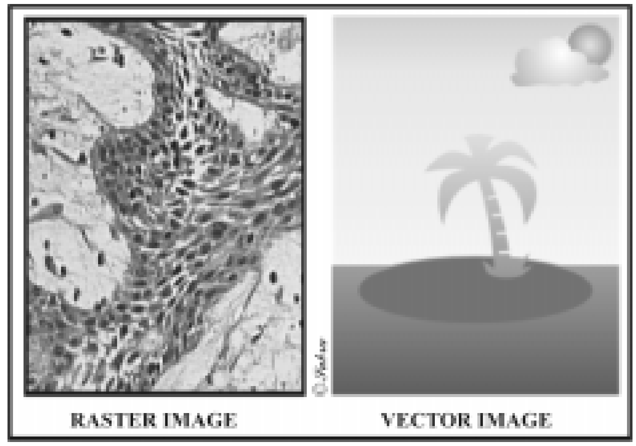


Fig. 4: Rastor and vector images

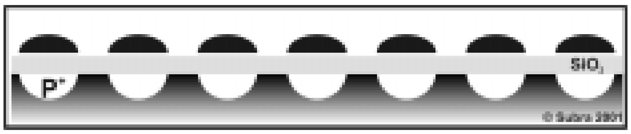


Fig. 5: Schematic diagram of CCD structure

age, we need to understand the difference between two ways the computer stores image data: Vector graphics and Raster graphics (Figs. 4).

Vector graphics, also known as object-oriented graphics, are created in various drawing programs (like CorelDraw, Macromedia Freehand, Adobe Illustrator for example). Vector images are stored as a display list describing the location and properties of the objects making up the image, such as shapes, arcs and lines.

Raster graphics, also known as bit-mapped graphics, on the other hand, are created by scanners and digital cameras. Vector graphics are not much utilized for pathology imaging applications. As we are concerned with the bit-mapped images, the rest of our discussion will be on raster images.

Raster images are “painted” across the computer screen in an array of square elements called pixels. Pixel is short for picture element. Each pixel is stored in an area of memory called a bit-map. Each pixel has a numbered address. Storing the formula for creating a vector image takes only a few kilobytes. Storing the location and value of each pixel in a raster image can take thousands of times more memory.

Image capture[3,18,42,48,52]

Image capture can be performed in a variety of ways. Usually a camera is mounted on the top of a microscope and the image is viewed in a preview window on the computer monitor with the help of software package provided. The user then ‘captures’ the desired fields. The video camera, the digital snapshot camera and optical scanner utilise a solid-state charge-couple device sensor (CCD), to receive and convert images to an electronic form. (Fig. 5). On an area array CCD, a matrix of hundreds of thousands of microscopic photocells creates pixels by sensing the light intensity of small portions of the film image. A CCD consists of a number of polysilicon (P+ in the figure) electrodes embedded on a silicon substrate. The minielectrodes are separated from the silicon substrate by an oxide-insulated layer. Incident photons cause excitation of electrons which are trapped in the depletion layer on the silicon substrate. This charge is transferred (coupled) to adjacent electrodes by altering their relative potentials. The charged pattern (current) is proportional to the corresponding intensity of incident photons. This microchip sensor or CCD usually comes in sizes of 1, 2/3 and 1/3 inch. The image sensor size does not refer to the sensor’s physical dimensions. Rather, format sensors sizes are designations for matching images, sensors and lenses. Their actual physical sizes are smaller. The most popular chips measure 8.8 x 6.6 mm.

Video cameras usually have a standard CCD format of 768 (H) x 492 (V) pixels and measure 8.8 mm x 6.6 mm. The parallel register (2-dimensional array of pixels) is interlaced with alternate rows used for sensing and storage. High performance arrays, on the other hand, come in a variety of shapes and sizes with active arrays as big as 2048 x 2048 or 4096 x 4096 pixels. The pixel (device sensors) sizes are in the range of 6-25 micra. These larger CCD sensors are more expensive and are used in large scanners and high-end digital cameras.
Different manufacturing techniques and specifications result in different performances of CCD microchips. These performance parameters are:

1. Spatial resolution
2. Brightness resolution
3. Noise
4. Dynamic range
5. Quantum efficiency
6. Photometric accuracy (linearity) and
7. Image processing flexibility

Each of these factors will be considered below.

1. Spatial Resolution

Basically resolution means the 'quality' of the image. The higher the resolution, the finer detail in the image. Spatial Resolution is the ability to distinguish fine spatial detail. The spatial frequency at which a digital image is sampled (the sampling frequency) is often a good indicator of resolution. This is why dots per inch (dpi) or pixels per inch (ppi) are common and synonymous terms used to express resolution for digital images. Generally, but within limits, increasing the sampling frequency also helps to increase resolution (Fig. 6).
However, if one is working on screen only the resolution does not need to be any higher than 72 dpi. Monitor displays are set at 72 dpi resolution so one really does not require to use higher resolutions. Higher resolutions make file sizes much larger.

2. Brightness Resolution

The brightness or colour value of each pixel is defined by one bit or by a group of bits. The more bits used, the higher the brightness resolution.

Bit depth is determined by the number of bits used to define each pixel. The greater the bit depth, the greater the number of tones (greyscale or colour) that can be represented. Digital images may be produced in black and white (bitonal), greyscale, or colour. A bitonal image is represented by pixels consisting of 1 bit each, which can represent two tones, using the values 0 for black and 1 for white. A greyscale image is composed of pixels represented by multiple bits of information, typically ranging from 2 to 8 bits or more. For example, in a 2-bit image, there are four possible combinations: 00, 01, 10, and 11. If "00" represents black, and "11" represents white, then "01" equals dark grey and "10" equals light grey. The bit depth is two, but the number of tones that can be represented is 22 or 4. At 8 bits, 256 different tones can be assigned to each pixel.

A colour image is typically represented by a bit depth ranging from 8 to 24 or higher. With a 24-bit image, the bits are often divided into three groupings: 8 for red, 8 for green, and 8 for blue. Combinations of those bits are used to represent other colours. A 24-bit image offers 16.7 million colour values. Increasingly scanners are capturing 10 bits or more per colour channel and often outputting 8 bits to compensate for "noise" in the scanner and to present an image that more closely mimics human perception. Binary calculations for the number of tones represented by common bit depths:

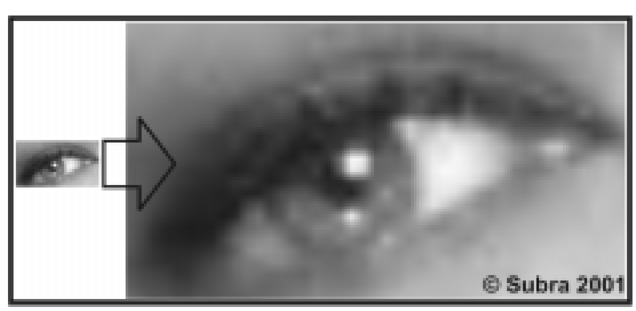


Fig. 6: Spatial resolution: Loss of image resolution on increasing the dimensions of the image on the left.

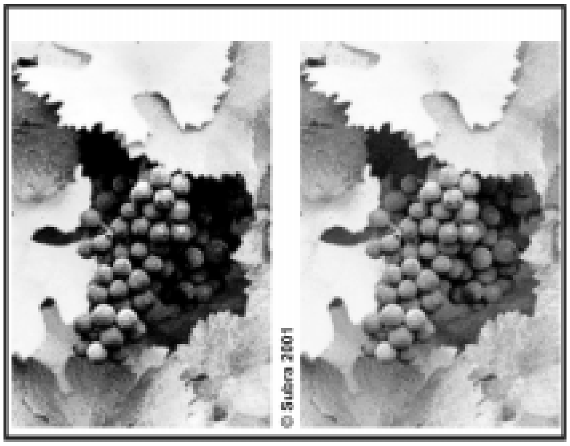


Fig. 7: Grapes in the image on the right (which has a greater dynamic range) are better visualized than image on the left.

1 bit = 2 tones
2 bits = 4 tones
3 bits = 8 tones
4 bits = 16 tones
8 bits = 256 tones
16 bits = 65,536 tones
24 bits = 16.7 million tones

3. Noise

Noise appears as small, random variations in brightness or colour. Sensor sites with low signal-to-noise ratio, introduce noise. Sensor sites with high signal-to-noise ratio represent the image accurately.

4. Quantum Efficiency

Quantum efficiency (QE) is defined as the ability of a CCD in generating electrons from the incident light reaching the CCD; it is a function of the wavelength of the incident light. QE measures detection efficiency. CCD cameras, in theory, have a maximum efficiency of 100%. This value is never reached in practice. The latest high performance cameras operate at 80% efficiency which is about 3 times higher than the typical video camera.

5. Dynamic Range or Density Range

The ability of discerning minute differences in low light levels is known as the dynamic range or intensity resolution. Dynamic range indicates how well the camera can differentiate between light levels. It is the range of tonal difference between the lightest light and darkest dark of an image. The higher the dynamic range, the more potential shades can be represented (Fig. 7).

Dynamic range also describes a digital system's ability to reproduce tonal information. Film excels at distinguishing small changes in light level, while digital capture systems have limited brightness range. The dynamic range of an imaging system is usually expressed as a grey scale digital resolution: 8-bit, 12-bit, 16-bit, etc. The dynamic range of a CCD chip is very important in scientific applications and it is often a critical factor in choosing a camera system for an imaging application, particularly for quantitative image analysis. With low dynamic range, shadows lose detail and saturated areas are washed out.

6. Accuracy And Linearity

Ideally, each pixel acts a high fidelity photometric device producing an electronic signal that is exactly proportional to the intensity of the incident light level. A typical linearity reading on a high performance camera deviates less than 0.1% over the entire dynamic range. Also, these cameras have excellent pixel-to-pixel response uniformity with deviations less than 0.1% in the best cases. Both of these factors are important in quantitative digital imaging analysis. CCD cameras should be linear over their entire dynamic range.

7. Readout Flexibility

Most video cameras can only operate at video rates, 30 frames per second. The exposure time can be varied continuously between an open shutter and the fastest scan rate possible. When a low light image situation is encountered, it is often necessary to average many captured frames (oversampling), in order to improve the rather poor signal-to-noise ratio inherent in this type of system. However, with high performance CCD cameras, the image can be "integrated" on the CCD sensor thus providing a superior signal-to-noise ratio in each captured frame and eliminating the need to compute frame averaging.

File Sizes

There are various units of measurement for file size listed below in order of size:

- A Bit - smallest measurement, 1 or 0, on or off.
- A Byte contain 8 Bits
- A Kilobyte (Kb) contains 1024 Bytes
- A Megabyte (MB) contains 1000 Kilobytes
- A Gigabyte (GB) contains 1000 Megabytes
- A Terrabyte (TB) contains 1000 Gigabytes

The units you will use most frequently are Kilobytes (Kb) and Megabytes (MB). The higher the colour depth and the higher the resolution, the higher the file size will be.

Types of Image Compression and Image Formats[17,18,40,42,48]

Generating digital images results in big digital image files. Photo realistic images of 24- or 32-bit depth present commonly in desktop microcomputers with 640 x 480 resolution require one or more megabytes of storage space each. Image archival requirements have resulted in bigger and faster hard or optical drives (storage devices) and data-compression techniques. There are many image-compression formats capable of storing 24-bit images. Some of them operate with "lossless" compression algorithms; others operate with "lossy" compression algorithms. Lossless compression achieves only about a 2:1 compression ratio, but the reconstructed image is mathematically and visually identical to the original. Lossy compression provides much higher compression rates, but the reconstructed image shows some loss of data compared to the original image. This loss can be visible to the eye or visually lossless. Visually lossless compression is based on knowledge about colour images and human perception. Visually lossless compression algorithms sort image data into "important data" and "unimportant data," then discard the unimportant. Popular image formats currently available for personal computers are as follows:

BMP (BitMapped Picture): This is Microsoft-based bitmapped file format. It can handle "lossless" 32-bit graphics and is used frequently in Windows and McIntosh software programs.

GIF (Graphic Interchange Format): This format is widely used in bulletin board systems (BBS) and Web pages. GIF software display programs are available in multiple platforms. It supports only up to 256 colours. GIF offers efficient file size at the expense of image quality. It is a proprietary format.

JPEG (Joint Photographic Expert's Group): Presently it is one of the most popular compression formats for still images. This popularity exists because JPEG is available for many platforms and throughout most popular software programs and hardware devices. It is a "lossy" format although the degree of image degradation is controllable and, in many cases, undetectable. The data is compressed to remove information not easily detectable by the human eye. Compression efficiency is excellent. The compressed files are often only about 1/20th or 1/30th of the original file size. This makes storage and transmission of the images much more efficient. JFIF, the JPEG File Interchange Format, is a minimal implementation for image transfer among different computer platforms. Too much compression will result in a blocky image and a decrease in the number of colours.

PCX: It is supported by DOS paint programs. It is a bitmapped format and supports up to 32-bit files.

PNG (Portable Network Graphics): This new format retains and enhances GIF's strength. It is an open format for storing bitmapped graphics images. The compression method is free from patent problems. It supports true colour up to 48 bits including alpha channel storage.

PS/EPS (PostScript and Encapsulated PostScript): It supports bitmapped and vector graphics up to and beyond 36-bits. Compression is minimal. EPS files are primarily used for printing purposes. Encapsulated PostScript is a limited version of PS for single pictures to be included, "encapsulated" in PS program files. Display PS is an implementation of PS for controlling video hardware. It was first used in the NEXT computer and more recently in UNIX computers.

TIFF (Tagged Image File Format): This popular format has been used for some time on many platforms. It supports up to 32-bit bitmapped images, uncompressed or compressed with Run Length Encoding (RLE) or LZW compression. TIFF formatted files are considered "lossless".

WMF (Windows MetaFile): It supports both bitmapped and vector graphics up to 32-bits; a fairly popular format among Windows users.

Flashpix (FPX): This relatively recent format, developed by a consortium called the Digital Imaging Group, has the advantage of multilayering of image resolutions and may have application in image digitisation, although it has yet to gain widespread acceptance.

Wavelet (WSQ): Wavelet scalar quantisation is a method originally developed for storing and transmitting fingerprint data. It is a lossy compression technique that will most likely supercede JPEG due to its better compression ratios and preservation of image detail. There are multiple vendors offering wavelet compression software but unfortunately no industry standard or compatibility between different companies. Until a particular format is recognised by a major software company or the ISO, it would be unwise to store images solely with this method.

DICOM (Digital Imaging and Communication in Medicine)[24]: An effort from the American College of Radiology (ACR) and the National Electrical Manufacturers Association (NEMA) to create a Standard for Medical Data and Image Communication. DICOM 3.0 addresses both protocol language issues and data content issues. It is based on an object-oriented architecture. It is more than an image format. It is a document format where the Objects (entities defined by the DICOM model) have attributes and the models and tables of attributes that defined them are known as Information Object Definitions (IODs).

Image storage

The hard drive offers the fastest access and greatest convenience for storage of images. Alternatively, images can also be stored on external hard disks, or compact disks (CDs) using a CD writer.

Telecommunication protocols

Knowledge of telecommunication protocols and line speeds is necessary in order to structure the most cost-efficient way of communicating between local and remote stations.

Phone Line and modem

This is the cheapest but slowest method of data transmission and is impractical for dynamic telepathology. Under optimum circumstances the maximum speed of this analogue service between two 33.3 Kbps modems is 4.2 KB/sec (33000 bits / 8 = 4200 bytes). 56 Kb/s modems (V.90) have now been standardised and are widely available.

Integrated Services Digital Network (ISDN)

Integrated Services Digital Network (ISDN) is an international communications standard for sending voice, video and data over digital phone lines at speeds up to 64 Kbps. It is common for two ISDN lines to be employed, allowing for simultaneous voice and data or pure data transmission at 128 Kbps. Requiring special metal wiring, early ISDN uses **baseband** transmission, in which one wire carries one signal at a time. A recent technology, **broadband** ISDN (B-ISDN), uses broadband transmission, in which a single wire may carry multiple signals simultaneously. Requiring fibre-optic cables, this offers speeds of up to 1.5 Mbps, roughly 23 times the capacity of ISDN.

Asynchronous Transfer Mode (ATM)
Asynchronous Transfer Mode (ATM) is a network technology that overlaps with B-ISDN and is capable of speeds from 25-622 Mbps. Suitable for both local and wide area networks it transmits data in packets of fixed size at variable speeds determined by the nature of the data and the type of service subscribed to by the user. It is however, extremely expensive and currently limited in its use.

T-1/T-3
A T-1 carrier (also referred to as DS-1 line) is a dedicated phone connection supporting data transmission rates of up to 1.544 Mbps. It actually consists of 24 individual channels, each supporting 64 Kbps. A T-3 carrier (or DS-3 line) consists of 672 channels and can provide speeds of around 44.736 Mbps. The internet is based upon a T-3 carrier. Even a T-1 carrier does not come cheaply and telephone companies will often offer fractional T-1 access in multiples of 56 Kbps.

Cable modems/Digital subscriber lines
These technologies are a superior alternative to ISDN. Cable modems use a computer network interface card and operate via cable television. Working speeds are very much manufacturer and service provider specific. Realistic figures vary between 3-10 MB/s for downloading and 200Kb/s-2Mb/s uploading. xDSL refers collectively to all types of digital subscriber lines, a transmission protocol which utilises unused frequencies in normal copper telephone wires. xDSL offers up to 32 Mb/s for downstream traffic, and from 32 Kb/s to over 1 Mb/s for upstream traffic.

TYPES OF TELEPATHOLOGY
There are two main types of telepathology. The first one is called **Dynamic Imaging Telepathology**, which is also known as "**Real Time Video Imaging**" or "**Robotic Telepathology**". The second type of telepathology is the **Static Imaging Telepathology** or **"Store and Forward telepathology"**. There is also a **hybrid system** that combines the efficient bandwidth utilization and transmission of static system with the real time control and imaging of the dynamic system.

Static Imaging Telepathology[9,19,41]
In this form, pathologist selects images, stores them on a computer, and either uploads the images or copies them on a CD-ROM and sends it across for other pathologists to see. By definition, the images are static, i.e., there is no facility for recipient control. There are two types:

- **Simple store-and-forward telepathology:** Images captured manually by the base pathologist beforehand. Transmission of images via email attachment, file transfer protocol (FTP), website etc.
- **Interactive store-and-forward telepathology:** The remote pathologist receives a set of pre-selected images. Specialised software is used to show the relationship between these images. The key feature is the ability to show the relationship of the individual images with the original slide. "total slide digitisation" or "virtual histologic imaging".

Although static telepathology may seem practical, there are disadvantages of static telepathology. The consulting telepathologist will see images that the transmitting pathologist has selected, leading to sampling error. Sampling error has been well-demonstrated in various studies.[14,19,29,65] Attempts to overcome this have included use of a trained pathologist to select the images[19,65]. However few pathologists are completely happy with relinquishing control to another person. Halliday et al[19] pointed out that referring pathologists would often selected images that supported their own diagnosis and that ambiguous fields were often ignored. The limited number of images could under-represent the complexity of the case and lead to a false sense of security as to the ease of the diagnosis. Sampling error or bias remains a serious flaw as it precludes the pathologist being consulted from applying his skills in identifying significant regions of the slide while scanning at low-power.

Assessing the accuracy of telepathology is difficult. Involving multiple pathologists is the best option as the results from a single pathologist is influenced by his degree of skill and experience in viewing static images. Eusebi et al[15] used the Pathmaker image acquisition software[27] to package thirty-six diagnostically difficult cases from a quality assurance program over the course of a year. Images included immunohistochemistry and were digitised at 640 x 480 x 24 bit colour resolution before being sent as email attachment to Dr Juan Rosai, in the Memorial Sloan-Kettering Center, New York. Of the thirty-six cases, thirty-five were also sent for final diagnosis based upon actual histological slides and/or further stains. Dr Rosai deferred a telepathology diagnosis in eight cases. In three of these cases, his final diagnosis concurred with the referring pathologists. While a telepathology diagnosis was provided in only 77% of the cases (27/35) the concordance with the final diagnosis in those 77% was 100%. It is difficult to ascertain whether this is due to the accuracy of the technique or the skill of the histopathologist.

Shimosato et al[53] reported a diagnostic accuracy of 88.1%, Weinberg et al[61] showed an overall diagnostic accuracy was 88.5% though marked inter-observer variability was noted. Lisa Weinstein et al[62] found 100% concordance in discriminating benign from malignant lesions, with minor discrepancies relating to precise characterisation of the lesion. Work published from the Arizona-International Telemedicine Network (AITN)[64] showed an 88.2% concordance (127/144) between telepathology and glass slide diagnosis on a variety of referred cases, with 96.5% concordance (139/144) for clinically important diagnoses.

The above studies indicate the skill of several individual pathologists in interpreting 'bitmapped' histological images. It is difficult to make comparisons between studies however due to the lack of standardisation in hardware, image resolution, storage format and colour-depth. This, combined with the narrow range of pathologists and wide range of cases, is a limitation preventing the extrapolation of results. The future of this technique may lie in teaching and external quality assessment rather than as a diagnostic tool.

Image quality may be compromised because of the file size. Hence, in practise, only a small number of images can be transmitted, varying between one and forty[19,15]. However it has its advantages of being cheap and simple (needs only a standard telephone line or internet connection) and being much more convenient.

Dynamic Imaging Telepathology[13,68,69]

This method allows the receiving pathologist to control the movement of the slide on the stage, and to see the image in 'real-time' on a high-resolution monitor. The limiting factor in dynamic telepathology is transmission time and understanding of the various type of telecommunications protocols is essential knowledge in assessing the viability of a dynamic system in your particular area.

The dynamic telepathology system consists essentially of a automated microscope with a triple charge-couple device sensor (CCD) video camera transmitting images to a remote station. At this station the user is able to control all the functions of the microscope, including the scanning stage, magnification and light intensity. Manual focussing may also be exercised in preference to the autofocus. Designed to be used with low-bandwidth networks, eg. Integrated Services Digital Network (ISDN), compression algorithms are employed to minimise the data transmitted. Transmission along multiple ISDN channels is also possible. The system also conforms to Transmission Control Protocol/Internet Protocol (TCP/IP), the *de facto* standard for data transmission over networks to ensure compatibility with current network systems. The remote station is designed for ease of use with two monitors, one displaying current position relative to the whole slide, the other providing the current view at 768 x 576 x 24-bit colour. Stage movement is controlled via a joystick or through mouse control. The images are transmitted in compressed JPEG format. The software at the receiving station 'stitches' the images together, thus simulating a moving image. The degree of JPEG compression employed is proportional to the speed of movement, with the image quality improving when the slide is at rest. Images and position on the slide can be marked and saved. An example of such a system is the **HISTKOM** system[28] which is a joint project of the Institut für Physikalische Elektronik of the University of Stuttgart and Deutsche Telekom. In this case, the time required for reviewing a slide in under ten minutes.

One disadvantage of using video conferencing technology is susceptibility of the system to blurring or interruptions in image display. The use of a T-1 line greatly improves transmission speeds compared with ISDN. Moreover, such systems are very expensive.

Dunn et al[13] reported that in using this system they achieved an overall concordance with consensus 'truth' diagnoses of 97.5% based upon a test set of 100 consecutive routine surgical pathology cases. Quality of the video images was cited as the reason for diagnostic error in two cases. The rest were attributed to diagnostic difficulty. The time spent on each case varied between 2.8 and 4.7 minutes.

LEGAL ASPECTS OF TELEPATHOLOGY[38,71]

In some legal surroundings telepathology is considered a breach of registrational barriers. Under today's conditions in private international law it must be considered essential to agree upon a choice of law and stipulate a court of jurisdiction when doing telepathology. It is crucial that the principles of minimum data exchange, anonymity, pseudonymity and cryptography must be established as a basis for all telepathology procedures. Moreover, it is advised to obtain written consent of the patient. Data protection and data security are other crucial topics that require attention. Finally, reimbursement questions must be answered to establish a sound economical basis for telepathology. The spatial distance between the participants may yield the question, whether the service has been rendered to an extent necessary and sufficient for reimbursement. If reimbursement takes place on a cross-border or cross-regional level, severe disturbances of the health systems can occur (Dierks & Bohle, 2000).

USES OF TELEPATHOLOGY[1,2,4,8,10,15,16,20,29,31,32,35,39,60]

Although pathology would be especially suitable for being practised at a distance by transporting digital image information, the spread of telepathology into everyday work still is relatively slow (Mairinger, 2000)[39].

Diagnostic accuracy of telepathology is comparable with that of conventional light microscopy for most diagnoses. Current telepathology applications include intraoperative frozen sections services, routine surgical pathology services, second opinions, and subspecialty consultations (Weinstein et al, 2001)[69].

The initial impetus in the development of telepathology was the provision of the best possible diagnostic opinion to all patients irrespective of geographical locale and social/economic circumstances. One of the main applications of telepathology is to provide urgent services at sites either without a pathologist or with a pathologist requiring back- up. Secondly, telepathology can, provide immediate access to subspecialty pathology consultants. For example, if a primary care physician in a rural area needs a pathologist to diagnose a disease, and the nearest pathologist is over an hour away, telemedicine can be an excellent alternative. Thirdly, and probably the one most often used, is to generate second opinions. Often times, physicians are not sure if their diagnosis is correct and in order to confirm their decision, they can contact another telepathologist. Additionally, it can assist pathologists in completing or refining a differential diagnosis. And finally, telepathology can be used for continuing medical education, proficiency, testing, and recertification of pathologists as well as other laboratory personnel. This can be extremely beneficial to students in rural areas. This way, they do not have to travel far to receive their education or take exams.

THE FUTURE

In its current form, telepathology is far from being an alternative to conventional reporting. However, it offers a new approach to diagnostic services. The technological advances will result in improvement of the quality of digitised histological images to equal that which is seen through the standard microscope. To most pathologists, the idea of working without a microscope is inconceivable.

To date, 12 classes of telepathology systems have been engineered. Rapid and ultrarapid virtual slide processors may further expand the range of telepathology applications. Next-generation digital imaging light microscopes, such as miniaturized microscope arrays (MMA), may make virtual slide processing a routine laboratory tool (Weinstein et al , 2001)[69]. We would like to think that progress in the will continue and this will be true up to a point. However what is more likely and perhaps more feasible, is that pathologists' skill in interpreting digitised images will improve until it matches their skill with conventional images. To nearly all pathologists, and to question that paradigm almost blasphemous. Could a possible future exist however, where not only has all optical equipment moved from the office into the laboratory, the use of glass slides is obsolete? Consider a future where a section need not leave the laboratory if it could be completely digitised then transmitted via local area network to the pathologist in his office. The microscope, would be moved to the laboratory and reduced to its optics, which would be integrated within the digitisation equipment. It is possible that the pathologists' workstation would comprise an A3-size flatscreen monitor (employing a technology superior to the cathode ray tube), with links to information resources and automated reporting. Pyramidal layering of image resolution will show the image at various magnifications and focussing planes, effectively reproducing the views at each microscope objective magnification. However, it is how we view technology as much as the technological developments themselves that will determine whether the Oral Pathology specialty takes advantage of and develops existing tools; or disregards them, letting others be the innovators while we are left behind.

Telepathology is not a science of the future but of the present and is here to stay, to the point that today's pathologists are more and more required to have at least some knowledge of telepathology. Once most of its limitations are corrected, it will become a common diagnostic tool (Mairinger, 2000)[39].

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Address for communication
Dr R V Subramanyam
Professor and Head
Dept. of Oral Pathology
St. Joseph Dental College
Eluru 534 003
Email: subra@oralpath.org