THE CONTEMPORARY SIGNIFICANCE OF IMAGE COMPRESSION STANDARDS IN MEDICAL IMAGING

Abstract

The significance of medical image compression is growing steadily as a result of the expanding utilization of health imagery in clinical settings, along with the escalating quantities of data capacities produced by diverse medical imaging modalities. The use of data compression is imperative in facilitating the dissemination, preservation, and administration of digital medical imaging datasets. Over the last several decades, worldwide standardization groups have proposed many picture compression standards. The primary objective of this chapter is to examine image compression standards, encompassing contemporary standards that were previously overlooked, in order to provide an up-to-date overview of the present status of these guidelines within the realm of medical imaging applications. Additionally, this chapter will address the legal and regulatory considerations associated with the utilization of compression techniques in medical contexts.

Keywords: X-Ray, Computed Tomography (CT), Breast Tomosynthesis, Magnetic Resonance Imaging, Ultrasound, Nuclear Imaging, Digital Pathology, JPEG, H.265.

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I. INTRODUCTION

In recent times, significant advancements have been made in the methodologies and frameworks used for the processing of multimedia data. Various approaches have been undertaken to address these enhancements, including advancements in representation, interpretation, and other related aspects. Novel techniques have been developed to diminish the dimensions of multimedia data, representing a noteworthy technological breakthrough. These algorithms have significant use across a diverse range of applications, including but not limited to their implementation as a data storage system for multimedia data. The compression process is a commonly used word that describes the procedure of informally lowering the amount of data. Compression, within the realm of computers, refers to the systematic procedure of representing data in a condensed manner. The word "compression" encompasses several processes involved in reducing the size of data, such as source coding, data compression, bandwidth compression, and signal compression. In the present context, the term "signal" encompasses several forms of media, including images, videos, and audio signals. However, the scope of this chapter is confined to medical imagery.

II. THE MODALITIES OF MEDICAL IMAGING AND ITS CHARACTERISTICS

Medical imaging has become a pivotal and indispensable instrument in contemporary society for the precise and prompt identification of human health-related conditions. Medical imaging investigations have led to a variety of positive results, including the avoidance of several surgical procedures, increased efficiency in the utilisation of hospital beds, and better health outcomes [1, 2]. The use of medical photographs has seen a notable surge in popularity during the last several years. Prior to the 1990s, medical imaging was mostly recorded and stored using radiological film, namely X-ray films. In contemporary times, this process is achieved via the use of digital imaging technology and afterwards stored on computer systems. Moreover, there have been notable breakthroughs in modern image capturing techniques and technology, leading to significant improvements in both the quality and quantity of digital medical information. This trend has been especially evident in recent years. During the early 1990s, a computed tomography (CT) image of the thorax was acquired using film with a thickness of 10 millimetres, resulting in 25 slices. The picture creation process used an estimated 12 megabytes (MB) of data [1]. Currently, the storage of a single picture captured using state-of-the-art CT collection equipment necessitates a data size that varies between 600 megabytes (MB) and several gigabytes (GB). Therefore, it is essential for a medical imaging collection system to possess the ability to efficiently compress substantial volumes of data. Numerous contemporary hospitals have also adopted a Picture Archiving and Communication System (PACS) to facilitate the storage, management, transmission, and analysis of medical data. Data compression methods play a crucial role in these systems and are widely used [1]. The implementation of Picture Archiving and Communication Systems (PACS) has long anticipated the need for compression of medical pictures. In fact, proposals for novel compression techniques were put out prior to the availability of standardised compression methods [3]. Nevertheless, the utilisation of proprietary compression techniques substantially amplifies the expenses and exertion involved in transmitting data across diverse systems, hence compelling the implementation of digital communication standards [4]. It is important to acknowledge that prior assessments of medical image compression techniques have been documented in published literature [5–14].

The term "medical imaging" refers to an all-encompassing concept that includes a wide variety of imaging methods that are applied to the aim of visualising the human body for the purposes of diagnosing, monitoring, or treating various medical diseases. There are many different imaging techniques, each of which is predicated on a unique combination of physical principles and offers varying degrees of information regarding the structure, morphology, and function of the human body. The field of medical imaging is characterised by its dynamic nature, as it continuously witnesses the emergence of novel imaging modalities and the enhancement and expansion of existing ones. Due to the extensive scope and diverse nature of the field of medical imaging, it is unfeasible to attempt a thorough elucidation of all methodologies used in medical imaging within the confines of this section. As a consequence of this, the scope of our discussion will be restricted to the medical imaging modalities that are typically utilised in clinical settings as well as the essential properties that pertain to data compression [15]. In Table 1, we give the standard picture dimensions as well as the sizes of the uncompressed files for the various medical imaging modalities. Consequently, this part presents details on some medical imaging technologies often used in practical applications. The medical imaging methods that are often used include X-rays, Magnetic Resonance Imaging (MRI), Computed Tomography (CT), and Ultrasound [16].

Table 1: Medical Imaging Modalities and its Image Dimensions and Uncompressed File Sizes [22, 108]

Modality	Anatomy	Image Dimensions (x, y, z, t)	Bit Depth	Uncompressed File Size
Radiography	Chest	(2000, 2500, -, -)	10–16 bits	10 MB
Computed Tomography (CT)	Abdomen	(512, 512, 500, -)	12–16 bits	250 MB
	Brain	(512, 512, 300, -)		150 MB
	Heart	(512, 512, 100, 20)		1 GB
Breast Tomosynthesis	Breast	(2457, 1890, 50, -)	10–16 bits	0.4 GB
Magnetic Resonance Imaging (MRI)	Abdomen	(512, 512, 100, -)	12–16 bits	50 MB
	Brain	(512, 512, 200, -)		100 Mb
	Heart	(256, 256, 20, 25)		250 MB
Ultrasound	Heart	(512, 512, -, 50)/s	24 bits (color)	38 MB/s
Positron Emission Tomography (PET)	Brain	(256, 256, 50, -)	16 bits	6 MB
	Heart	(128, 128, 40, 16)		1 MB
Digital Pathology	Cells	(30,000, 30,000, -, -)	24 bits (color)	2.5 GB

In recent times, a plethora of innovative medical imaging techniques have emerged in the market owing to significant progress made in core scientific disciplines such as nuclear physics and optics. The procedure in question is denoted by the phrases Positron Emission Tomography (PET) and endoscopy. These techniques are used to enhance the accuracy of patient diagnosis and optimise therapeutic interventions. Positron emission tomography (PET) scans are used in the diagnostic process of many types of tumours and serve as a valuable tool in guiding cancer treatment strategies. The technique of endoscopy, which was developed in the year 2001, involves the use of optical imaging to capture visual representations of the inside structures within the human body. In the year 2010, General Electronics (Gen. Electronics) devised innovative techniques in the field of medical imaging by integrating computed tomography (CT) and/or magnetic resonance imaging (MRI) scans with positron emission tomography (PET) images. This integration aimed to enhance the accuracy of diagnosing and treating patients.

1. ***X-Ray:*** Hall-Edwards is widely acknowledged as the pioneer behind the development of the first medical imaging technique, which enabled the viewing of internal organs inside the human body. The phrase "X-ray imaging" is used to denote this particular technology. Figure 1 illustrates a collection of X-Ray images. The radiographic examination refers to the picture obtained on X-ray film when X-rays pass through the organ afflicted by the illness inside the patient's body. The cost-effectiveness and transportation convenience of pictures produced by these imaging technologies surpass those of conventional photographic imaging techniques. Nevertheless, the photos generated using this approach exhibit substandard quality, hence posing challenges in extracting valuable insights from them on some occasions.

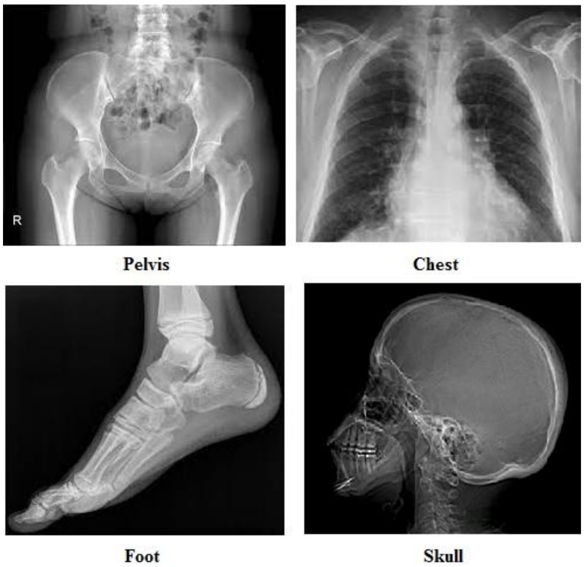

Figure 1: Various X- Ray Images

X-ray radiography involves the use of a collimated X-ray beam to traverse the patient, resulting in modifications to the X-ray's properties such as intensity, energy spectrum, and propagation direction. These alterations occur while the X-ray beam traverses the human body. After assuming the appropriate posture, a series of X-ray detectors is positioned behind the individual, capturing the altered X-ray beam properties and generating the X-ray image. The dimensions of the picture are defined by the size of the detector elements, which typically range from 0.1 mm to 0.2 mm, as well as the field of view. The field of view is set depending on the anatomy of interest and typically ranges from 18 X 20 cm to 35 X 40 cm.

2. ***Computed Tomography (CT)L:*** The invention of this imaging approach in 1972 is attributed to A. Cormack and G. Hounsfield. The technique referred to in academic literature as computed tomography is commonly recognised as computer tomography (CT). Figure 2 displays a collection of Computed Tomography images. The shown picture is generated by the use of X-ray technology, wherein X-rays are sent into the patient's body from many angles during the examination of the organ afflicted by the ailment. In recent times, there has been an increased prevalence of using pictures generated by this particular methodology in the context of addressing health concerns pertaining to neurology, cardiology, and gastrointestinal. In X-ray radiography, the detector plane captures the projection of a specific anatomical region onto a single plane. In contrast, computed tomography (CT) imaging use a technique known as tomography to gather several projections from different angles and then build a three-dimensional representation of the specific anatomical structure of interest [17]. Modern multi-detector row CT scanners have the capability to acquire up to 320 simultaneous slices in each spin of the X-ray tube. A thin-slice computed tomography (CT) dataset typically has more than 500 slices. The latest generation of CT scanners enables dynamic imaging, including cardiac angiography or perfusion imaging. However, the routine clinical application of these studies is limited due to concerns over radiation dose.

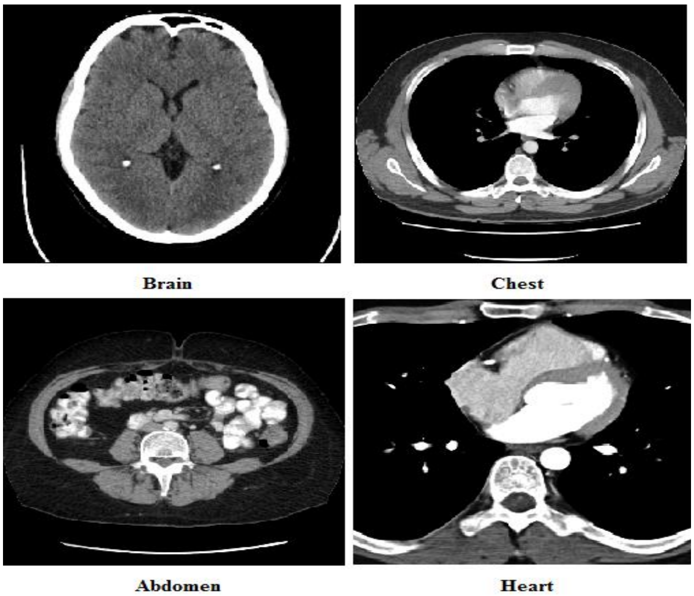

Figure 2: Various Computed Tomography Images

The number of photons that are present in each voxel of a computed tomography (CT) scan is directly related to the contrast resolution of the image. As a consequence of this, there is a compromise that must be made between the contrast resolution, the spatial resolution, and the X-ray dosage. CT pictures are susceptible to being impacted by a variety of noises, including photon noise that is produced by the detector, electrical noise that is present in the detecting system, and the particular image reconstruction approach that is used.

3. ***Breast Tomosynthesis*****:** An new X-ray imaging technology known as digital breast tomosynthesis (3D mammography), which can be shown in Figure 3, was developed with the intention of improving the characterisation of breast lesions [18,19]. Using this method, tiny pieces of breast tissue are reconstructed by first recording multiple projections along a restricted arc angle, and then merging those projections using computer-based stitching methods. This method is used in the treatment of breast cancer. When opposed to more conventional techniques, the use of thin slices that include the whole breast allows for improved visibility and characterisation of masses, which would otherwise be hampered by structures that extend beyond the imaging plane. This is an advantage over other approaches.

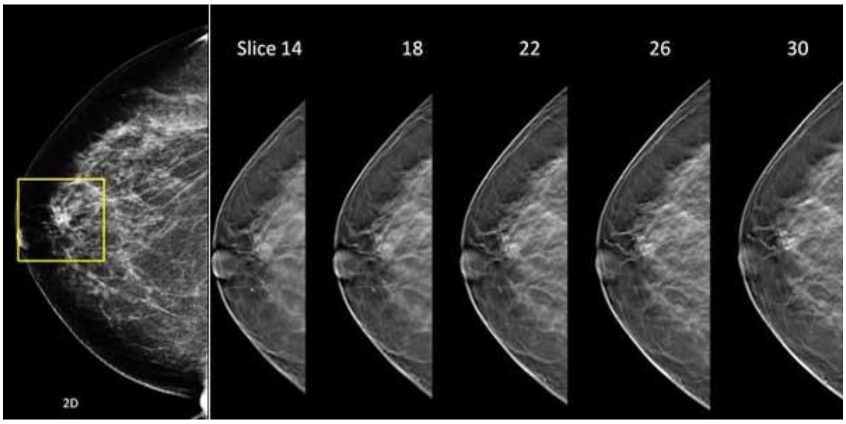

Figure 3: Image of Digital Breast Tomosynthesis (3D Mammography)

4. ***Magnetic Resonance Imaging:*** The magnetic resonance imaging (MRI) technology, invented by P. Lauterbur and P. Mansfield in 1973, was a significant breakthrough in the area. The generation of a picture is achieved by using a magnetic field that is cooled using liquid helium. The use of this imaging technique, which generates a three-dimensional medical picture, is widely employed in the management of neurological, gastroenterological, and angiographic conditions. Figure 4 illustrates a range of Magnetic Resonance Images (MRI). Magnetic Resonance Imaging (MRI) is an imaging technology that operates on the principles of nuclear magnetic resonance [20]. The determination of image contrast in magnetic resonance imaging (MRI) involves consideration of several tissue-dependent parameters and the careful selection of acquisition settings throughout the imaging procedure. The manipulation of MRI scan parameters allows for the acquisition of images exhibiting significant contrast variations. The use of different imaging settings in MRI enables the generation of diverse imaging contrasts, hence enhancing the flexibility of this imaging modality. Consequently, MRI has gained significant clinical utility.

The magnetic resonance imaging (MRI) technique has the capacity to discern between various forms of soft tissue, such as the white matter and grey matter found within the brain, as well as the malignancies and cystic formations found inside the liver. In addition, magnetic resonance imaging (MRI) is often preferred over computed tomography (CT) for the purpose of dynamic imaging since it does not involve the use of potentially harmful ionising radiation, such as X-rays. This choice is due to the exorbitantly expensive expense connected with the excessive radiation dosage that must be absorbed by CT in order to get the dynamic data set. During the course of a routine clinical MRI scan, several images of a specific anatomical structure are generated via the use of a wide variety of imaging parameters. The number of distinct contrasts that may be obtained during a single test normally falls somewhere in the range of five to ten; however, this number can shift depending on the therapeutic application in question. Consequently, even though MRI pictures are often created with a lower spatial resolution when compared to CT datasets, the huge quantity of various contrasts acquired during a normal examination results in a significant augmentation of the data volume. This leads to a significant increase in the amount of information that can be obtained from the scan. The thermal noise that is produced by both the receiver coil and the sample itself is the most significant source of noise in MRI. Rician distributions may be used to provide an accurate description of this noise [21].

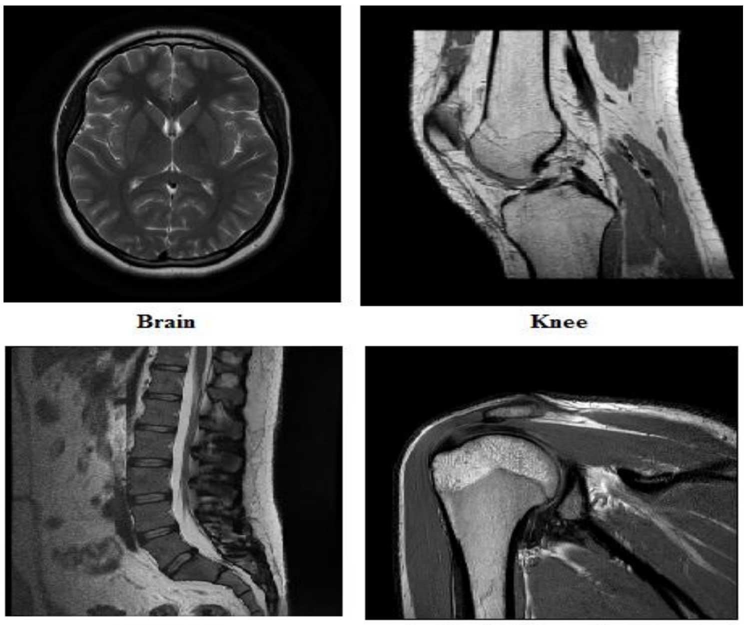

Figure 4: Magnetic Resonance Images

5. ***Ultrasound:*** The concepts of acoustics provide the basis upon which the methods and procedures employed in ultrasonic imaging are built [23]. The transmission of a sound wave is aided by a transducer, which, depending on the exact setting, may be positioned either in direct contact with the skin or placed into a human orifice. Acoustic waves, while travelling through biological tissue, go through a process in which they are partially absorbed by the tissue and partially reflected by it. This happens as the waves go through the tissue. Reconstructing an image of the being inspected tissue requires taking into account both the timing of the echo's arrival and the magnitude of the wave that is reflected back. In ultrasonic imaging technology, axial resolution may be achieved.

This refers to the capacity to differentiate between two reflectors that are positioned successively along the axis of an acoustic wave. In a similar vein, the accomplishment of lateral resolution, which refers to the capacity to discern between two reflectors positioned near to each other and perpendicular to the axis of the ultrasonic wave, is not universally guaranteed to be possible. The axial and lateral resolution of the ultrasonic image may be increased by increasing the frequency of the ultrasonic beam. Because higher frequencies result in greater attenuation, there is a trade-off that must be made between tissue depth and spatial resolution in order to accommodate this connection. Imaging by ultrasound is used extensively in a variety of therapeutic fields, including obstetrics, cardiology, and the imaging of cancer in the abdominal and pelvic areas. This may largely be due to the fact that it is both inexpensive and safe, since it does not entail the use of any ionising radiation. It's possible that different applications may call for different approaches to data collecting and display using ultrasonic technology. Several instances might be given, such as the following: In the amplitude mode, also known as the A-mode, the amplitudes of the echoes are graphed as a function of depth in a single direction. The B-mode, also known as the brightness mode, generates a two-dimensional image using an array of transducers. In this mode, the intensity of each pixel indicates the amplitude of the echoes at a specific direction and depth. The M-mode, also known as the motion mode, takes a sequence of fast pulses to generate images that change over the course of time, which most of the time results in B-mode photographs. Imaging using ultrasound is experiencing a period of tremendous development as a discipline. During the course of the previous several decades, not only have well-established methods of ultrasonic imaging been developed, but also a number of novel, ground-breaking innovations. The creation of a three-dimensional picture with 3D ultrasound requires the digital compositing of a large number of ultrasound images that are planar and two-dimensional. The principles of the Doppler effect are used in Doppler ultrasonography, which determines the direction and velocity of tissue movement in respect to the transducer by using the Doppler effect. Speckle noise, which is signal-dependent and multiplicative in nature, is the predominant source of noise in conventional B-mode ultrasound photographs [24] Speckle noise is signal-dependent and multiplicative in nature.

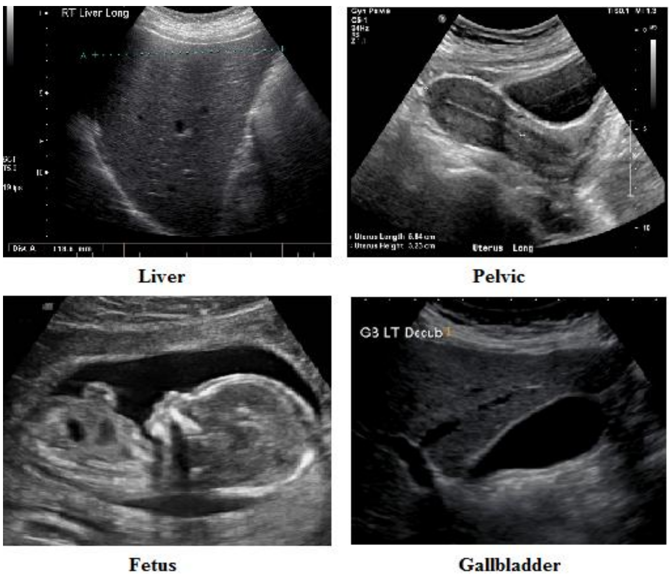

Figure 5: Ultrasound Images

6. ***Nuclear Imaging:*** In nuclear imaging, a tiny quantity of radioactive material, also known as radiopharmaceuticals, is given to the patient in one of two ways: either by injection or by ingestion. This medical procedure is known as nuclear imaging. These radiopharmaceuticals have a chemical connection to compounds that are used by cellular processes. The use of medical imaging methods permits the discovery of spatial and temporal patterns of radioactive chemical buildup inside the human body. This may be accomplished via the use of imaging contrast agents. Nuclear imaging methods such as single photon emission computed tomography (SPECT) and positron emission computed tomography (PET) are used rather often [25]. Positron Emission Tomography (PET) takes use of molecules that have been tagged with an isotope that is capable of generating positrons, while Single Photon Emission Computed Tomography (SPECT) uses a gamma-ray camera to detect the gamma rays that are generated by a radioisotope. During a single diagnostic process, clinical positron emission tomography (PET) and single-photon emission computed tomography (SPECT) scanners are often used in conjunction with other imaging modalities that are complimentary to one another. This allows for the acquisition of information that is both functional and anatomical. In clinical settings, imaging methods such as PET-CT and PET-MRI are used often. The spatial resolution of SPECT is typically restricted to a range of around 1 cm. Because of this, the amount of data that is generated by SPECT imaging is rather low when compared to the volume of data generated by other medical imaging methods that are often used. In a similar vein, it can be observed that the spatial resolution of positron emission tomography (PET) generally varies from 3 to 5 mm. As a consequence of this, PET data sets are known for their very limited scope. There are a variety of causes that might be to blame for the occurrence of noise in SPECT and PET systems. These include the formation of Poisson distributed noise during emission, the electronic noise formed by the detecting system of the scanner, and the modifications in noise that arise from post-processing adjustments and picture reconstruction [26]. In addition, there is a possibility that the noise might be caused by a combination of these three factors. The process of nuclear imaging is shown in figure 6, which may be found here.

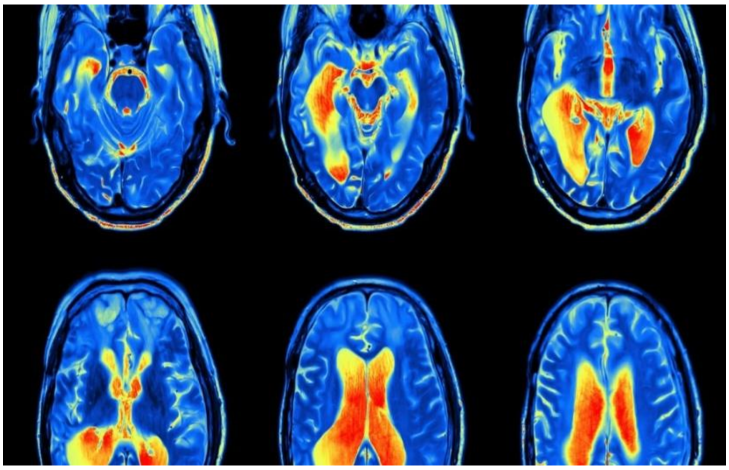

Figure 6: Nuclear Imaging

7. ***Digital Pathology:*** In the field of digital pathology, optical microscopy is used to scan tiny slices of biological tissue, which ultimately results in the production of whole-slide pictures [27]. In the field of digital pathology, optical microscopy is used to scan tiny slices of biological tissue, which ultimately results in the production of whole-slide pictures [27]. In order to highlight the relevant biological qualities that are important to the diagnostic process, tissue samples are stained using one or more dyes, and then they are placed on glass slides. These steps are performed in order to highlight the relevant biological characteristics. In general, a combination of hematoxylin and eosin (H&E) stains is often employed to elicit blue/purple and red/pink colours in the nuclei and cytoplasm, respectively. This is done by staining the nuclei with hematoxylin and then staining the cytoplasm with eosin. Within the slide scanner, the sample is illuminated by a beam of visible white light, and the results are shown. This light is absorbed and dispersed in a manner that is contingent upon the sort of stain that is present at each spatial position as well as the concentration of that stain. Imaging optics are used in order to send an image of the tissue sample that is positioned beneath the objective lens of the microscope to a digital image sensor using said digital image sensor.

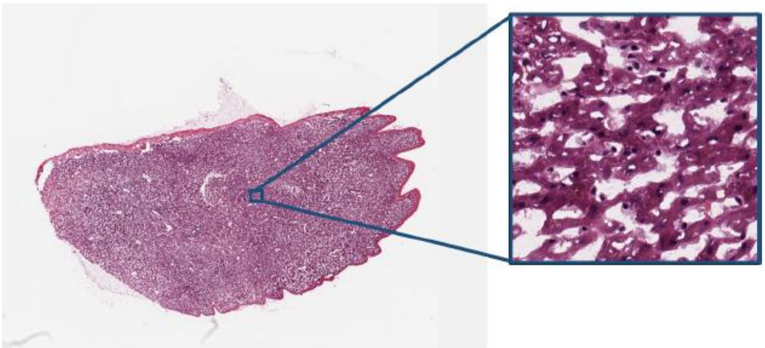

Figure 7: A Pathology Image Depicting H&E-Stained Tissue

In order to generate discrete image segments, an oscillating motion is performed over the glass slide by the objective in a reciprocating fashion. These image segments are then merged to make the overall picture of the slide. It is generally accepted that a magnification of 20 is enough for the identification of essential biological features in the majority of different kinds of tissues and diagnostic processes. On the other hand, larger magnifications, reaching up to 100, may be required in specific kinds of samples, such as those used in cytopathology and haematology. A histological picture of tissue that has been stained with hematoxylin and eosin (H&E) may be seen shown in Figure 7. When doing digital pathology, using a high spatial resolution often results in whole-slide pictures that have a size that is more than 900 million pixels. In addition, because of the importance of colour in differentiating between different biological structures, it is necessary for each pixel to have three separate colour components. Because of this, it is not uncommon for a single uncompressed picture of an entire slide to have a size that is more than 2.5 gigabytes. In digital pathology, the effective structuring of compressed data is essential for facilitating the storage, transmission, and viewing of large-scale pictures, especially in connection to a variety of zoom levels and geographic locations. Therefore, the ability to rearrange compressed data, such as by making use of tiling in BigTIFF [28], utilising tiled Digital Imaging and Communications in Medicine (DICOM) [29], or making use of interactive multi-resolution transmission with JPIP [30], is of the utmost importance in order to guarantee a smooth and uninterrupted viewing experience.

III. IMAGE COMPRESSION STANDARDS

The introduction and widespread use of digital photography in the later decades of the 20th century led to an increase in demand for digital methods of picture transmission and storage. International standardisation organisations such as the International Standards Organisation (ISO), the International Telecommunications Union (ITU), and the International Electro-technical Commission (IEC) have recognised the significance of compatibility and interoperability among various products used for image communications and storage. These organisations acknowledge that compatibility and interoperability among these products is important. As a direct consequence of this, these organisations have launched a variety of initiatives over the last several years to standardise image compression. The acceleration of the development of digital imaging was significantly aided by the aforementioned standards' contributions.

1. ***JPEG:*** JPEG, an abbreviation for "Joint Photographic Experts Group," pertains to the working group WG1 of the ISO/IEC Joint Technical Committee 1, Study Committee 29 (ISO/IEC JTC1/SC29/WG1). Over the course of the last several decades, the WG1 group has successfully formulated a multitude of international standards pertaining to image compression. The process of standardisation starts by forming a technical group, such as the Working Group 1 (WG1), and soliciting input from various stakeholders, including representatives from the business sector and academia. The technical committee is responsible for the development of a preliminary version, sometimes referred to as a working draught, which is then sent to all member countries of the International Organisation for Standardisation (ISO). Once consensus has been reached over the preliminary version, a conclusive version is generated. Upon the completion of voting by national members, the final draught attains the status of an internationally recognised standard.

The Working Group 1 committee started its meetings in the mid-1980s. The first global standard established by the committee is denoted as JPEG, a nomenclature derived from the organisation responsible for its development. The JPEG standard was first released in 1991 [31, 32] and has since gained widespread recognition and utilisation, becoming one of the most prevalent and well-known standards in existence. The first section of the JPEG standard outlines the requirements and recommendations for JPEG compression systems (31). The inclusion of compliance testing is specified in Part 2 [33]. Part 3 of the document addresses the topic of compression system extensions, as referenced by citation [34]. In contrast, Part 4 delves into the subject of profile generation and registration, as shown by citation [35]. The definition of the JPEG File Interchange Format (JFIF) may be found in Part 5 [36]. Part 6 of the study encompasses a comprehensive collection of tools that are specifically designed for the purpose of designing applications for printing systems [37].

Although the JPEG standard contains a number of lossy encoding modes in addition to a lossless encoding mode, the majority of implementations only provide a fundamental lossy coding technique with a limited number of functions. This is because the JPEG standard also includes a lossless encoding mode. This technique is often referred to as "baseline JPEG." An instance of the JPEG sequential mode is employed whenever the default technique is called into play. In addition to the choices that are preset by default, the JPEG standard provides users with a wide selection of extra options. For illustration purposes, the default JPEG file format places a limit of eight bits per pixel on the image's depth of colour. JPEG compression is frequently inadequate for compressing medical pictures since the majority of medical imaging modalities employ bit depths ranging from 10 to 16. This makes JPEG compression an unsatisfactory option. Thankfully, the JPEG standard provides alternatives for imaging with a bit depth of up to 12 bits, which is adequate for some kinds of medical pictures such as ultrasound, computed tomography, and digital pathology. These kind of images are suited for use in digital pathology. On the other hand, it is possible that it is not appropriate for other kinds of medical imaging, such as certain MRI scans. There are a total of three further modes of operation that are explained, in addition to the sequential mode. There are three unique modes: progressive, hierarchical, and lossless. The progressive mode is the default option. The latter makes use of Differential Pulse Code Modulation (DPCM), which is then followed by Huffman entropy coding, and it can accept bit lengths of up to 16 bits. In spite of the inherent restrictions of the JPEG mode, it has emerged as the most popular choice for lossless compression in applications related to the medical industry. The software version of the JPEG standard was first made available in 1991 [38] by The Independent JPEG Group, and the organisation has been responsible for its upkeep and development ever since then.

2. ***JPEG 2000:*** The WG1 group initiated a standardisation effort in the late 1990s with the objective of enhancing the very effective JPEG compression standard. The targeted attributes were improved performance in bit-rate, especially at lower bitrates, compatibility with samples up to 16 bits in depth, the ability to transmit progressively, and the capability to provide both lossless and lossy compression within a unified architecture. Furthermore, it was necessary to include features such as random access, fault tolerance, and support for low-memory implementations. The standardisation of JPEG2000 was achieved in December 2000, resulting from the efforts outlined in reference [39]. The first section of this standard pertains to the basic coding system, including the syntax of the JPEG2000 code stream and the structure of the JP2 file format. The second installment, which was made available in November 2001, delineates improvements to the fundamental framework. Several other parts have been formulated, such as Part 9, which outlines the definition of JPIP, a protocol used for interactive image transmission [30], and Part 10, which provides a description of JP3D, a technique employed for volumetric imaging [40]. Figure 8 depicts the primary stages involved in the compression process of JPEG2000 [41].

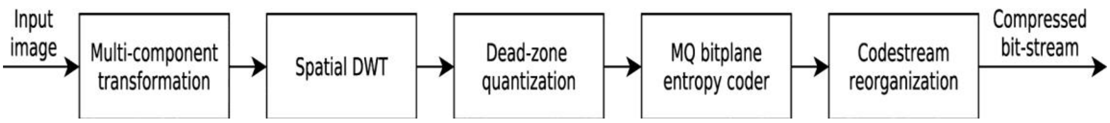

Figure 8: JPEG2000 Compression Pipeline

The use of the multi-component transform (MCT) stage enables the elimination of spectral redundancy across various image components, such as colour channels, spectral bands, or temporal frames. This is achieved by performing individual pixel conversions. The process of component decorrelation may be achieved in Part 1 of the standard by the use of a reversible or irreversible colour transformation. This transformation effectively turns RGB images into distinct luminance and chrominance components. In the second part of the study, it is possible to decorrelate several components by using various MCTs, leading to significant improvements in compression performance under certain circumstances [42–45].

To make a clear distinction between JPEG2000 Parts 2 and 10, this distinction is of the highest significance. The use of an MCT stage in relation to volumetric data sets is particularly outlined in Part 2, while the establishment of a 3D extension of the standard for the purpose of volumetric imaging applications is outlined in Part 10. According to reference [46], Part 2 of the DICOM standard is coupled with its very unique transfer syntax. Having said that, it is essential to keep in mind that DICOM does not provide support for Part 10. In the succeeding step, a two-dimensional discrete wavelet transform (DWT) is used in order to eliminate the spatial decorrelation that was introduced in the previous step for each individual component. The Discrete Wavelet Transform (DWT) begins its process of decomposition by partitioning the N x M picture into four subbands: LL, HL, LH, and HH. This is the initial stage of decomposition. Every sub-band has the same dimensions, which are N/2 by M/2. The first three sub-bands display features that are typified by high frequencies, while the LL sub-band is a depiction of the original picture that has been shrunk down to a smaller size. It is common practise to carry out the procedure of decomposition five times, with each successive iteration using the lower-low (LL) sub band that was acquired from the preceding iteration as the input for the subsequent iteration. The discrete wavelet transform, often known as the DWT, is able to successfully capture a multi-scale representation of the picture. This is in addition to the spatial correlation that it displays. During the phase of the encoding process known as lossy coding, the DWT coefficients are quantized using a uniform dead-zone scheme, in which the values v are assigned to the same quantization interval as 0. In the mode of lossless compression, the modified coefficients keep their integer status and are not subjected to quantization in any way. The generated coefficients are automatically segmented into 64 x 64-square blocks, regardless of the mode being used. An adaptive arithmetic coder known as MQ is used in order to individually encode each block. In conclusion, the compressed blocks are ordered in a way that enables the transmission of the final bit stream in a progressive manner, while simultaneously retaining resolution, spatial, quality, and component scalability. This is made possible by the organisation of the compressed blocks in a manner that allows for such transmission. JPEG2000 additionally offers support for region-of-interest coding, often known as ROI coding [47]. This kind of coding includes assigning a higher priority to certain geographic locations during the encoding process. There are additional versions of JPEG2000 that have been produced, such as open-source software solutions such as OpenJPEG, JasPer, and JJ2000, in addition to commercial software such as Kakadu [48-52]. These other versions of JPEG2000 are available.

3. ***JPEG-LS:*** [53] The JPEG-LS standard specifies ways for compressing pictures containing bi-level, gray-scale, and colour components while keeping a high degree of accuracy and with minimum loss of data. These methods may be found in the JPEG-LS standard. The JPEG-LS technique was adapted from the HP LOCO codec [54,55], and the uncomplicated design of the algorithm was a significant factor in its selection for use in the Mars Spirit Rover mission [56]. The standard is broken up into two parts that are completely separate from one another. In Part 1, the fundamental method is broken down [53], and in Part 2, further extensions are provided [57]. An image's pixels are examined one at a time by the Baseline JPEG-LS algorithm, which does so in a sequential fashion and in accordance with a raster-scan sequence. After that, it begins the process of encoding each pixel by using either the run mode or the regular method.

   The JPEG-LS standard takes care of the issue by computing the conditional mean for each circumstance. This is how it addresses the problem. The aforementioned estimations are then used in a process referred to as bias cancellation, which is utilised in order to improve the accuracy of the forecasts. The encoding of bias-canceled prediction errors [58] makes use of Golomb codes as a method of data representation. JPEG-LS has a number of major benefits, including the fact that its procedures are straightforward and simple to put into action, that it makes very little use of memory, and that it simplifies the complexity of computation. Although the coding operations that are involved in JPEG-LS are fairly basic, the compression performance of this approach is quite comparable to that of systems that depend on coding techniques that are more computationally expensive, such as arithmetic coding. JPEG-LS is a lossy image compression format. Because of its cutting-edge capabilities in lossless compression, JPEG-LS is an excellent choice for certain medical applications that call for lossless compression. JPEG-LS's applicability for certain applications is extraordinary. There are a number of open-source implementations of JPEG-LS, including libjpeg [60] and CharLS [59], amongst others. HP [61], Dr. David Clunie [62], and the University of British Columbia [63] were the ones responsible for the development of the LOCO-I/JPEG-LS algorithm.

4. ***JPEG-XR:*** JPEG-XR was created with the main intention of achieving effective compression of continuous-tone still pictures, namely those of a photographic type [64]. The HD Photo technology, which was first created by Microsoft Corporation in 2007 [65], served as the basis for the standard, which was then released in five separate components: The framework of the system architecture is outlined in the first part [64] of the standard, and the succeeding section [66] of the standard defines the precise requirements that must be met in order to perform image coding. The Motion JPEG XR standard [67], conformity testing [68], and reference software [69] are the following sections.

   The JPEG-XR format was designed with the main intention of integrating higher compression efficiency with encoding and decoding procedures that need a minimum amount of complexity. The JPEG-XR image compression method, like JPEG, is a technique for reducing the size of digital photographs by making use of "block-transforms." JPEG-XR, on the other hand, uses a two-stage hierarchical lapped biorthogonal transform (LBT) that is carried out via lifting stages. This is in contrast to JPEG's use of the discrete cosine transform (DCT). The LBT (Local Binary Transform) is able to effectively reduce the appearance of block-boundary artefacts, which are often seen in JPEG-compressed pictures with high compression ratios. The transform bands that are acquired are compressed independently, which makes it possible to create a hierarchical structure with many degrees of resolution, up to a maximum of three layers deep. This structure may be further refined. The user is given the option to choose the size of the quantization step during the quantization stage of the JPEG-quantization XR compression format. It is possible to alter the quantization step size in a geographical sense, in relation to the various frequency bands, and in relation to the various colour channels. Following the quantization phase comes the inter-block coefficient prediction stage, which is used to reduce the impact of interdependencies among the quantized transform coefficients that are present across several blocks.

In the framework of multilayer coding, JPEG-XR makes use of a method that partitions the high-frequency data into two different components. This process takes place during the compression stage. The information that is thought to be important is encoded using entropy, and the rest of the information is sent using codes of a predetermined length. The JPEG-XR compression technology makes use of variable-length coding (VLC) tables that may adapt to their environment. The statistical features of the local coefficients are used in these tables to determine which table would be the most appropriate to use for entropy coding. These tables have been developed in this way. When it comes to the compression of medical photographs, JPEG-XR has two key characteristics that are absolutely necessary: JPEG-XR is able to handle images with an input bit depth of up to 32 bits, which is the maximum allowed by the format. In addition, JPEG-XR is capable of compressing data using both lossy and lossless compression techniques while still making use of the same signal flow route in both of these modes.

5. ***H.265:*** The Joint Collaborative Team on Video Coding (JCT-VC), which is a collaboration between the Video Coding Experts Group (VCEG) of the International Telecommunication Union (ITU-T) and the Moving Picture Expert Group (MPEG) of the International Organisation for Standardisation (ISO/IEC), is proposing the adoption of the H.265 video coding standard, which is also known as High Efficiency Video Coding (HEVC) [70]. HEVC/H.265 has demonstrated considerable gains in coding efficiency for camera-captured data when compared to earlier video coding standards. These advancements have resulted in a drop of around 50 percent in bit-rate while keeping equal perceptual quality [70].

The H.265/HEVC standard uses an encoding method that is quite similar to that of its predecessor, the H.264/AVC standard [71]. Previous research [72–83] demonstrates that the HEVC/H.265 standard has a lossless coding mode that makes it possible to reconstruct signals with no information being lost. This was made possible by the fact that the standard does not compress the signals in any way. The aforementioned goal may be accomplished by skipping the transform and quantization phases, as well as any other following processing stages (such sample adaptive offset and deblocking filters), which have an effect on the image that has been decoded. Instead, the residual signal that was acquired using either inter or intra prediction is sent straight into the entropy coder. As a direct result of this, there is no longer a need for additional lossless coding techniques. Figure 7 is a simplified block diagram that demonstrates an encoder that is capable of producing a compressed bitstream in accordance with the HEVC/H.265 standard [70].

According to the information presented in the source [70], the HEVC/H.265 intra-prediction process is comprised of a great deal of essential components. These include a set of prediction modes, which consists of 33 angular modes, one DC mode, and one planar mode. Also included is one planar mode. In addition, the procedure includes adaptively smoothing the reference samples, as well as filtering the border samples of the prediction blocks. According to the research that has been done, the inter-prediction method that is used in the HEVC/H.265 standard is made up of a great deal of very important components [70]. Enhanced motion compensation approaches are presented in this paper. These techniques include using 7-tap or 8-tap filters for interpolating fractional sample locations and including quarter-sample accuracy for motion vectors (MVs). The presence of several reference photographs makes it possible to send either one or two MVs for each block, which, depending on the situation, facilitates either unpredictive or predictive coding. In addition to this, an improved method for predicting motion vectors is shown, and this method requires the derivation of sev.

The HEVC/H.265 video coding standard introduces the concept of slices as its foundational component. A decoding process may be carried out in an independent fashion for each individual slice included inside a particular frame. Either the whole of a frame or a section contained inside a frame may be referred to as a slice. In the case that data is lost, the process of resynchronization is made easier by the use of slices. The HEVC/H.265 standard is now the subject of ongoing research and development in order to further improve and broaden its capabilities. These efforts intend to assist the coding of high-bit-depth photos and films in a variety of colour formats, allow scalable coding, and ease the coding of multi-view and 3D video. The aforementioned improvements are what are meant when people talk about "Range Extensions (RExt)" [84]. In the end, even if the major goal of HEVC was to cater to applications for video coding, it is important to note that the standard's intra-coding techniques may also be utilised for the compression of still photographs. This is something that should be kept in mind. Because of its lossless mode and its capacity to support images with substantial bit depths, the High Efficiency Video Coding (HEVC) standard has the potential to become an attractive option for use in applications that need medical image compression.

IV. MEDICAL IMAGE COMMUNICATION STANDARDS

The beginning of the 1980s saw a tremendous boom in the digital medical imaging business, which led to the unmistakable realisation that there was a pressing need for the establishment of standards for the transmission of digital medical pictures. The American College of Radiology (ACR) and the National Electrical Manufacturers Association (NEMA) worked together in 1983 to form the Digital Imaging and Communications Society (DICOM). This was made possible as a consequence of their shared commitment to the advancement of digital imaging and communications technology. The American College of Radiology (ACR) operates as a trade group for producers of electronic equipment, while the National Electrical producers group (NEMA) represents professionals working in the disciplines of radiology, radiation oncology, and clinical medical physics in the United States. Following the first publication of the standard (ACR-NEMA 300-1985) in the year 1985 [85], the committee subsequently made modifications to the standard in the year 1988 [86]. In response to the shift towards networked operations in the medical imaging sector, the standardisation effort evolved as worldwide participation increased. Additionally, engagement from medical specialties other than radiology grew at the same time. The committee's name was changed to Digital Imaging and Communications in Medicine (DICOM) in 1993, and shortly afterwards, a considerably updated standard was published under the name DICOM [87].

The Digital Imaging and Communications in Medicine (DICOM) standard, which outlines the preexisting file formats for the exchange of medical pictures, has emerged as the dominant standard for the transmission of medical images throughout the industry. Since its inception in 1993, it has seen widespread usage in the healthcare sector and is acknowledged for its substantial role in accelerating the transition from conventional film-based radiology practises to a totally digital workflow. This role has earned it recognition as one of the most important roles in this transition. The Digital Imaging and Communications in Medicine (DICOM) standard specifies a protocol for the transfer of medical images, which may take place via a network or on a physical media such as a CD ROM or DVD. This protocol can also be referred to as the DICOM standard. The objective of the standard is to accommodate the unique characteristics of each imaging modality while simultaneously preserving a common basis for the data components.

DICOM is continuing to advance in its development. The DICOM Standards Committee is responsible for ensuring that the standard is kept up to date and under constant review. Frequent updates are required in order to guarantee continuing compatibility with earlier versions of the software. This is because some functionalities may be removed during the maintenance phase of the project. It is recommended that while developing new applications, developers stay away from including features that are now considered to be outdated. The most recent revision of the standard [88] specifies a wide variety of transfer syntaxes for the purpose of encapsulating encoded pixel data. These syntaxes include compressed data format specifications [89]. ACR-NEMA has developed their very own standardised method for the assembly of compression pipeline components [90], which they have recommended. However, the remedy that was presented was not accepted by those who were responsible for its execution, which led to its abandonment for a large amount of time after it had already been tried.

The standard incorporates a wide variety of compressed data formats, including Run Length Encoding (RLE), JPEG, JPEG-LS, JPEG-2000, JPIP, MPEG2, and MPEG-4 AVC/H.264, amongst others. It is important to note that the process of designing innovative transfer syntaxes for the purpose of integrating High Efficiency Video Coding (HEVC)/H.265 in the Digital Imaging and Communications in Medicine (DICOM) format has only recently begun. This is something that should be brought to your attention. Publication of the DICOM work item proposal to add HEVC/H.265 (often referred to as [93]) has been place at this time. In addition, the draughts of the necessary supplement (Sup 195) have been made available for public inspection and comments (they are referred to as [94]). The project is divided into two sections that are completely separate from one another. The first phase of the project is designated as Sup 195, and its primary objective is to improve the compatibility of the High Efficiency Video Coding (HEVC) standard with devices used by the general public. This involves improving its usage in a variety of applications such as mobile phones used for the capture of medical video. In the succeeding phase, we will investigate the implementation of algorithms for lossless scalable intra-frame compression. A prior research [95] made a suggestion on the possible integration of JPEG-XR into DICOM.

Despite this, the progress that had been made on this issue came to a stop when Microsoft decided to withdraw its engagement, which ultimately led to the linked work item being abandoned. Our assessment does, however, take into account JPEG-XR as a means of ensuring that it is as exhaustive as possible.

V. LEGALITY & REGULATORY STANDARDS

There have been several technology advancements and establishment of industry standards to enable the transmission and storage of compressed medical pictures. Nevertheless, the incorporation of these procedures into mainstream practises is important in order to fulfil the specific criteria established by regulatory bodies on a worldwide scale. The use of compression methods for medical images may be subject to limitations imposed by government bodies and professional associations [96, 97]. The commercial distribution of medical equipment in the United States is regulated by the Food and Drug Administration (FDA). The Food and Drug Administration (FDA) exercises regulatory authority over Picture Archiving and Communication Systems (PACS), which include systems that possess the capability to transport, display, process, and store medical pictures. In 1993, the Food and Drug Administration (FDA) released a recommendation statement about the appropriateness of using lossy compression for various medical applications, such as primary diagnosis, referral, and archiving [98]. The guidelines provided by the FDA did not impose any mandatory requirements on manufacturers to restrict the indications for use of PACS devices using lossy compression. However, it was acknowledged that manufacturers had the option to implement such limitations voluntarily. Furthermore, it is stipulated by these regulations that "video and hard copy images that have undergone compression through lossy techniques must be accompanied by a printed declaration stating the utilisation of lossy compression and providing an estimate of the compression ratio."

The ongoing discourse around the choice between lossy and lossless compression has been a subject of extensive deliberation among governmental organisations, professional associations, and legal entities for many decades. There is an allegation that the degradation of picture quality due to lossy compression might potentially lead to physical harm to a patient, hence establishing potential liability for the maker of the equipment [99]. Moreover, it has been argued that the lack of legislative mandates pertaining to the compression of radiological images poses challenges for courts when adjudicating malpractice lawsuits related to medical devices that use lossy compression techniques [100].

In 2006, two independent legal examinations were carried out with the purpose of determining the legal ramifications of using lossy compression. According to the findings of these studies, judicial investigation into lossy compression has not yet been carried out in either the Commonwealth or the United States [101]. In addition, there have been legal initiatives taken to control the use of compression in certain settings. As an example, the United States Congress [102] passed a law known as the Mammography Quality Standards Act (MQSA) with the intention of establishing national requirements for film-based and digital mammography.

In accordance with the Mammography Quality Standards Act (MQSA), the U.S. Food and Drug Administration (FDA) has been tasked with developing and enforcing the associated rules. Certain limits for the compression of mammography pictures are outlined as being defined by the recommendations that have been established by the Food and Drug Administration (FDA) [103]. For the sake of long-term storage, it is essential that the data obtained from full-field digital mammography be stored either in its original uncompressed format or in a format that supports lossless compression. When archiving data for the long-term, you are not allowed to utilise compression methods that result in data loss. Recent months have seen a large number of professional organisations publish recommendations and guidelines relating to the use of compression in various medical imaging applications.

An updated version of the technical standard that was first published by the American College of Radiology (ACR) in 2007 went through the revision process in 2014 [97]. The ACR standard does not contain any claims on the specific type or amount of compression that is suitable for a particular modality, disease, or therapeutic application in order to obtain a diagnostically acceptable result. This is because the ACR standard does not include any claims on the precise kind or amount of compression that is appropriate. In order to achieve the highest level of compression possible, it is advised by the ACR standard to make use of only compression methods that are DICOM-compliant, such as JPEG, JPEG-LS, JPEG-2000, or MPEG. This is because images compressed using proprietary or non-standard compression techniques may result in lower interoperability [97]. The reason for this is due to the fact that JPEG is the de facto standard for image compression. It is important to note that the Royal College of Radiologists (RCR) published some recommendations on the use of lossy compression for clinical interpretation in 2008 [103]. Compression is supported by the position statement of the RCR, which indicates that the RCR is in favour of using it in the national PACS solution known as Connecting for Health. In addition to this, it recommends certain compression ratios for the primary diagnostic aims of the various modalities, as can be seen in Table 2.

Table 2: Recommendations on Lossy Compression Ratio by RCR [104]

Modality	**Compression Ratio**
Mammography	20:1
Chest Radiography	10:1
Skeletal Radiography	10:1
Ultrasound	10:1
Digital Angiography	10:1
CT (all areas)	5:1
Magnetic Resonance	5 1
Radiotherapy CT	No lossy compression

An exhaustive investigation of previously conducted research served as the basis for the RCR's proposed recommendations, which may be seen below. These studies investigated the effect that varying degrees of lossy compression had on the precision of diagnostic results. Additionally, they investigated the concept of Just Noticeable Difference (JND), which refers to an individual's capacity to differentiate between a compressed image and its original version [103]. In addition, the Research Committee on Radiology (RCR) suggested doing more research to determine the impact that compression has on thin-slice computed tomography (CT) data as well as radiation CT planning. The Canadian Association of

Radiologists (CAR) developed a standard in 2011 to authenticate the use of lossy compression in certain sorts of situations and tests [105]. The standard set by CAR is based on previous research that was carried out throughout Canada and was funded by CAR [106]. This study was done with the intention of ensuring that the highest possible level of protection is provided.

Table 3: Recommendations on Maximum Lossy Compression Ratio by CAR [105]

Anatomical	Computed Radiography/ Digital Radiography		Computed Tomography with a Slice Thickness ≥5 mm		Computed Tomography with a Slice Thickness <5 mm		Ultrasound		Magnetic Resonance		Nuclear Medicine	
Region	**JPEG**	**J2K**	**JPEG**	**J2K**	**JPEG**	**J2K**	**JPEG**	**J2K**	**JPEG**	**J2K**	**JPEG**	**J2K**
Angio	-	-	15:1	15:1	-	-	-	-	24:1	24:1	11:1	11:1
Body	30:1	30:1	15:1	10:1	12:1	12:1	12:1	12:1	24:1	24:1	11:1	11:1
Breast	25:1	25:1	-	-	-	-	12:1	12:1	24:1	24:1	11:1	11:1
Chest	30:1	30:1	15:1	15:1	12:1	12:1	-	-	24:1	24:1	11:1	11:1
Musculoskeletal	30:1	20:1	15:1	15:1	12:1	12:1	12:1	12:1	24:1	24:1	11:1	11:1
Neuro	-	-	12:1	8:1	12:1	12:1	-	-	24:1	24:1	11:1	11:1
Pediatrics	30:1	30:1	15:1	15:1	-	-	12:1	12:1	24:1	24:1	11:1	11:1

The compression rates of JPEG and JPEG2000 for different modalities and anatomical locations are provided. In accordance with Table 3. In order to minimise perceptible distortions in the specific modalities, it is recommended that the compression ratios specified in Table 3 be used. The findings of a comprehensive study including a sample size of 100 participants have yielded a set of recommendations that are derived from the data collected during the research endeavour. In their analysis, the researchers used both an objective evaluation strategy, which relied on diagnostic accuracy, and a subjective assessment method, which was based on the concept of Just Noticeable Difference [106]. Due to its advantages in progressive transmission and bit depth support, the CAR standard promotes the utilisation of JPEG2000 instead of JPEG. Additionally, it is necessary for display systems to provide visual indications that lossy compression techniques have been used, together with information on the specific kind of compression utilised and the corresponding compression ratio. It is noteworthy to mention that the CAR standard explicitly specifies its exclusion of image compression techniques intended for utilisation in Computer Aided Diagnosis (CAD) or image post-processing applications, including but not limited to 3D reformatting, multi-planar reconstruction, and maximum intensity projection.

Research on the issue has also been performed by professional bodies throughout Europe. The publication of standards for lossy compression of digital radiological pictures in 2009 was documented by the German Röntgen Society (DRG) [107]. An agreement on the proposals was reached by a group of over 80 experts who convened during the discussion. The conference attendees conducted a comprehensive evaluation of several research studies conducted over the last twenty years. The purpose of this study was to determine recommended compression ratios that would not lead to a decline in the quality of diagnostic images, contrary to earlier expectations. Table 4 presents the recommended compression ratios for different applications.

Table 4: Recommendations on Lossy Compression Ratio by GRS [107]

Modality	Compression Ratio
CR/DR (mammography)	15:1
CR/DR (all areas except mammography)	10:1
CT (all areas except brain)	8:1
CT (brain)	5:1
Magnetic Resonance	7:1
X-ray Angiography	6:1
Radio Fluoroscopy	6:1

In the present year, the European Society for Radiography (ESR) released a position statement that elucidated the outcomes of an international expert discussion about unresolved issues pertaining to the utilisation of image compression in radiology, which was initiated by the ESR [96]. The position paper of the ESR included suggestions on several issues; however, it did not incorporate compression ratios, which had already been addressed by professional associations via the establishment of standards and guidelines. According to the ESR's recommendation, in order to achieve Diagnostically Acceptable Image Compression (DAIC), radiologists are urged to follow the recommendations provided by the CAR, DRG, or RCR [96], rather than depending only on their own subjective evaluation.

VI. CONCLUSION

Medical imaging has become a crucial tool for diagnosis, but the increasing amount of data produced by imaging techniques necessitates a new strategy for managing this data. Efficient distribution, storage, and management solutions are needed for the successful integration of digital medical picture data into clinical processes. Data compression methods are essential for enhancing storage and transmission efficiency without compromising diagnostic precision. International standardization groups have introduced numerous image compression standards to address individual requirements and maintain diagnostic accuracy. These standards have increased effectiveness in medical data administration and stimulated greater cooperation among healthcare professionals, facilitating prompt diagnosis and informed treatment choices. However, the use of image compression in medical settings requires a comprehensive examination of legal and regulatory aspects. The safeguarding of patient data, ethical implications for maintaining diagnostic precision, and adherence to data protection regulations are crucial factors that need careful scrutiny.

In conclusion, the complex interaction between increasing demands for medical imaging and the need for effective data management has resulted in the incorporation of image compression standards within medical environments. These standards have significantly transformed the processes involved in the distribution, storage, and administration of digital medical picture collections, leading to notable improvements in healthcare service delivery. However, a holistic strategy incorporating technical proficiency, ethical considerations, and adherence to regulatory standards is necessary to fully exploit the benefits of picture compression while maintaining patient care integrity and data privacy.

REFERENCES

[1] Sayood, K. (2017). Introduction to data compression. Morgan Kaufmann, USA.
[2] Duszak, R. Medical imaging: Is the growth boom over? In the Neiman Report; Harvey L. Neiman Health Policy Institute: Reston, VA, USA, 2012.
[3] Van Aken, I.W.; Reijns, G.L.; De Valk, J.P.J.; Nijhof, J.A.M.; Dwyer, S.J., III; Schneider, R.H. Compressed Medical Images and Enhanced Fault Detection within an ARC-NEMA Compatible Picture Archiving and Communications System. In Medical imaging International Society for Optics and Photonics. 1987. Vol. 767, pp. 290–298
[4] Clunie, D.A. What is Different About Medical Image Compression. IEEE COMSOC MMTC E-Lett. 2011, 6, 31–37.
[5] Koff, D.A.; Shulman, H. An overview of digital compression of medical images: Can we use lossy image compression in radiology? Can. Assoc. Radiol. J. 2006, 57, 211.
[6] Erickson, B.J. Irreversible compression of medical images. J. Digit. Imaging 2002, 15, 5–14.
[7] Menegaz, G. Trends in medical image compression. Curr. Med. Imaging Rev. 2006, 2, 165–185.
[8] Bhavani, S.; Thanushkodi, K. A survey on coding algorithms in medical image compression. Int. J. Comput. Sci. Eng. 2010, 2, 1429–1434.
[9] Sridevi, S.; Vijayakuymar, V.R.; Anuja, R. A survey on various compression methods for medical images. Int. J. Intell. Syst. Appl. 2012, 4, 13.
[10] Banu, N.M.M.; Sujatha, S. 3D Medical Image Compression: A Review. Indian J. Sci. Technol. 2015, 8, 1.
[11] Sahu, N.K.; Kamargaonkar, C. A survey on various medical image compression techniques. Int. J. Sci. Eng. Technol. Res. 2012, 2, 501–506.
[12] Ukrit, M.F.; Umamageswari, A.; Suresh, G.R. A survey on lossless compression for medical images. Int. J. Comput. Appl. 2011, 31, 47–50.
[13] Sridhar, V. A Review of the Effective Techniques of Compression in Medical Image Processing. Int. J. Comput. Appl. 2014, 97, doi:10.5120/17012-7291.
[14] Nait-Ali, A.; Cavaro-Ménard, C. Compression of Biomedical Images and Signals, 1st ed.;Wiley-ISTE: London, UK, 2008.
[15] Cavaro-MéNard, C.; NaïT-Ali, A.; Tanguy, J.Y.; Angelini, E.; Bozec, C.L.; Jeune, J.J.L. Specificities of Physiological Signals and Medical Images. In Compression of Biomedical Images and Signals; Nait-Ali, A., Cavaro-MéNard, C., Eds.;Wiley-ISTE: London, UK, 2008; Chapter 4, pp. 266–290.
[16] Thanki, R., & Borra, S. (2018). Medical imaging and its security in telemedicine applications. Springer, Germany.
[17] Kak, A.C.; Slaney, M. Principles of Computerized Tomography; IEEE Press: Piscataway, NJ, USA, 1988.
[18] Helvie, M.A. Digital Mammography Imaging: Breast Tomosynthesis and Advanced Applications. Radiol. Clin. N. Am. 2010, 48, 917–929.
[19] Clunie, D.A. Lossless Compression of Breast Tomosynthesis: Objects to Maximize DICOM Transmission Speed and Review Performance and Minimize Storage Space; Radiological Society of North America 2012 Sicentific Assembly and Annual Meeting: Chicago, IL, USA, 2012.
[20] Liang, Z.P.; Lauterbur, P.C. Principles of Magnetic Resonance Imaging: A Signal Processing Perspective;Wiley-IEEE Press: New York, NY, USA, 1999.
[21] Gudbjartsson, H.; Patz, S. The Rician distribution of noisy MRI data. Magn. Reson. Med. 1995, 34, 910–914.
[22] F. Liu, M. Hernandez-Cabronero, V. Sanchez, M. Marcellin, and A. Bilgin, “The Current Role of Image Compression Standards in Medical Imaging,” Information, vol. 8, no. 4, p. 131, Oct. 2017.
[23] Hill, C.R.; Bamber, J.C.; ter Haar, G.R. Physical Principles of Medical Ultrasonics; JohnWiley and Sons, Ltd.: Hoboken, NJ, USA, 2004.
[24] Wagner, R.F.; Smith, S.W.; Sandrik, J.M.; Lopez, H. Statistics of Speckle in Ultrasound B-Scans. IEEE Trans. Sonics Ultrason. 1983, 30, 156–163.
[25] Cherry, S.R.; Sorenson, J.A.; Phelps, M.E. Physics in Nuclear Medicine, 4th ed.; Elsevier/Saunders: Philadelphia, PA, USA, 2012.
[26] Teymurazyan, A.; Riauka, T.; Jans, H.S.; Robinson, D. Properties of Noise in Positron Emission Tomography Images Reconstructed with Filtered-Backprojection and Row-Action Maximum Likelihood Algorithm. J. Digit. Imaging 2013, 26, 447–456.
[27] May, M. A better lens on disease. Sci. Am. 2010, 302, 74–77.

[28] BigTIFF. Available online: http://bigtiff.org/ (accessed on 20 July 2023).
[29] Supplement 145: Whole Slide Microscopic Image IOD and SOP Classes. Available online: ftp://medical.nema.org MEDICAL/ Dicom/Final/sup145_ft.pdf (accessed on 20 July 2023)
[30] JPEG 2000 Image Coding System: Interactivity Tools, APIs and Protocols; ISO/IEC IS 15444-9; ISO: Geneva, Switzerland, 2005.
[31] Digital Compression and Coding of Continuous-Tone Still Images, Part I: Requirements and Guidelines; ISO/IEC IS 10918-1; ISO: Geneva, Switzerland, 1994.
[32] Pennebaker, W.B.; Mitchell, J.L. JPEG Still Image Data Compression Standard, 1st ed.; Kluwer Academic Publishers: Norwell, MA, USA, 1992.
[33] Digital Compression and Coding of Continuous-Tone Still Images: Compliance Testing; ISO/IEC IS 109182; ISO: Geneva, Switzerland, 1995.
[34] Digital Compression and Coding of Continuous-Tone Still Images: Extensions; ISO/IEC IS 10918-3; ISO: Geneva, Switzerland, 1997.
[35] Digital Compression and Coding of Continuous-Tone Still Images: Registration Of JPEG Profiles, SPIFF Profiles, SPIFF Tags, SPIFF Colour Spaces, APPn Markers, SPIFF Compression Types and Registration Authorities (REGAUT); ISO/IEC IS 10918-4; ISO: Geneva, Switzerland, 1999.
[36] Digital Compression and Coding of Continuous-Tone Still Images: JPEG File Interchange Format (JFIF); ISO/IEC IS 10918-5; ISO: Geneva, Switzerland, 2013.
[37] Digital Compression and Coding of Continuous-Tone Still Images: Application to Printing Systems; ISO/IEC IS 10918-6; ISO: Geneva, Switzerland, 2013.
[38] Independent JPEG Group. Available online: http://www.ijg.org (accessed on 20 May 2023).
[39] JPEG 2000 Image Coding System: Core Coding System; ISO/IEC IS 15444-1; ISO: Geneva, Switzerland, 2004.
[40] JPEG 2000 Image Coding System: Extensions for Three-Dimensional Data; ISO/IEC IS 15444-10; ISO: Geneva, Switzerland, 2011.
[41] Taubman, D.S.; Marcellin, M.W. JPEG 2000: Image Compression Fundamentals, Standards and Practice; Kluwer Academic Publishers: Norwell, MA, USA, 2001.
[42] Tzannes, A. Compression of 3-Dimensional Medical Image Data Using Part 2 of JPEG 2000. Available online: http://dicom.nema.org/ dicom/minutes/WG-04/2004/2004-02- 18/3D_compression_RSNA_2003_ver2.pdf (accessed on 28 July 2023).
[43] Siegel, E.; Siddiqui, K.; Johnson, J.; Crave, O.; Wu, Z.; Dagher, J.; Bilgin, A.; Marcellin, M.; Nadar, M.; Reiner, B. Compression of multislice CT: 2D vs. 3D JPEG2000 and effects of slice thickness. Proc. SPIE 2005, 5748, 162–170.
[44] Lee, H. Advantage in image fidelity and additional computing time of JPEG2000 3D in comparison to JPEG2000 in compressing abdomen CT image datasets of different section thicknesses. Med. Phys. 2010, 37, 4238–4248.
[45] Kim, K.J. JPEG2000 2D and 3D Reversible Compressions of Thin-Section Chest CT Images: Improving Compressibility by Increasing Data Redundancy Outside the Body Region. Radiology 2011, 259, 271–277.
[46] JPEG 2000 Part 2 Multi-Component Transfer Syntaxes. Available online: ftp://medical.nema.org/medical/dicom/final/sup105_ft.pdf (accessed on 25 August 2023)
[47] Askelöf, J.; Carlander, M.L.; Christopoulos, C. Region of interest coding in {JPEG} 2000. Signal Proc. Image Commun. 2002, 17, 105–111.
[48] Reference JPEG2000 Implementations. Available online: https://jpeg.org/jpeg2000/software.html (accessed on 30 July 2023).
[49] Open JPEG JPEG2000 Implementation. Available online: http://www.openjpeg.org/ (accessed on 30 July 2023).
[50] Jasper JPEG2000 Implementation. Available online: https://www.ece.uvic.ca/~frodo/jasper/ (accessed on 30 July 2023).
[51] JPEG2000 Implementation. Available online: https://code.google.com/p/jj2000/ (accessed on 30 July 2023).
[52] Kakadu JPEG2000 Implementation. Available online: http://www.kakadusoftware.com/ (accessed on 30 July 2023).
[53] Lossless and Near-Lossless Compression of Continuous-Tone Still Images—Baseline; ISO/IEC IS 14495-1; ISO: Geneva, Switzerland, 1999.

[54] Weinberger, M.J.; Seroussi, G.; Sapiro, G. LOCO-I: A low complexity, context-based, lossless image compression algorithm. In Proceedings of the Data Compression Conference (DCC'96), Snowbird, UT, USA, 31 March–3 April 1996; pp. 140–149.
[55] Weinberger, M.J.; Seroussi, G.; Sapiro, G. The LOCO-I lossless image compression algorithm: Principles and standardization into JPEG-LS. IEEE Trans. Image Process. 2000, 9, 1309–1324.
[56] HP on Mars: Labs Technology Used to Send Images. Available online: http://www.hpl.hp.com/news/2004/jan-mar/hp_mars.html (accessed on 25 July 2023).
[57] Lossless and Near-Lossless Compression of Continuous-Tone Still Images: Extensions; ISO/IEC IS 14495-2; ISO:Geneva, Switzerland, 2003.
[58] Pountain, D. Run-length encodings. IEEE Trans. Inf. Theory 1966, 12, 399–401.
[59] CharLS, A JPEG-LS Library. Available online: https://github.com/team-charls/charls (accessed on 30 July 2023).
[60] Libjpeg. Available online: https://github.com/thorfdbg/libjpeg (accessed 30 July 2023).
[61] LOCO-I/JPEG-LS Download Area. Available online: http://www.hpl.hp.com/research/info_theory/loco/locodown.htm (accessed on 30 July 2023).
[62] JPEG-LS Software. Available online: http://www.dclunie.com/jpegls.html (accessed on 30 July 2023).
[63] JPEG-LS Public Domain Code. Available online: http://www.stat.columbia.edu/jakulin/jpeg-ls/mirror.htm (accessed on 30 July 2023).
[64] JPEG XR Image Coding System—System Architecture; ISO/IEC IS 29199-1; ISO: Geneva, Switzerland, 2011.
[65] Srinivasan, S.; Tu, C.; Regunathan, S.L.; Sullivan, G.J. HD Photo: A new image coding technology for digital photography. Proc. SPIE 2007, 6696, 66960A.
[66] JPEG XR Image Coding System—Image Coding Specification; ISO/IEC IS 29199-2; ISO: Geneva, Switzerland, 2012.
[67] JPEG XR Image Coding System—Motion JPEG XR; ISO/IEC IS 29199-3; ISO: Geneva, Switzerland, 2010.
[68] JPEG XR Image Coding System—Conformance Testing; ISO/IEC IS 29199-4; ISO: Geneva, Switzerland, 2010.
[69] JPEG XR Image Coding System—Reference Software; ISO/IEC IS 29199-5; ISO: Geneva, Switzerland, 2012.
[70] Ohm, J.R.; Sullivan, G.J.; Schwarz, H.; Tan, T.K.; Wiegand, T. Comparison of the Coding Efficiency of Video Coding Standards—Including High Efficiency Video Coding (HEVC). IEEE Trans. Circuits Syst. Video Technol. 2012, 22, 1669–1684.
[71] Sullivan, G.J.; Topiwala, P.N.; Luthra, A. The H.264/AVC advanced video coding standard: Overview and introduction to the fidelity range extensions. In Proceedings of the SPIE 49th Annual Meeting on Optical Science and Technology, Denver, CO, USA, 2–6 August 2004; pp. 454–474.
[72] Barroux, G. Lossless Coding for Still Pictures with HEVC. 2016. Available online: http://dicom.nema.org/Dicom/News/March2016/docs/sups/sup195-slides.pdf (accessed on 30 July 2023).
[73] Cai, Q.; Song, L.; Li, G.; Ling, N. Lossy and lossless intra coding performance evaluation: HEVC, H.264/AVC, JPEG 2000 and JPEG LS. In Proceedings of the 2012 Asia Pacific Signal and Information Processing Association Annual Summit and Conference, Hollywood, CA, USA, 3–6 December 2012; pp. 1–9.
[74] Zhou, M.; Gao,W.; Jiang, M.; Yu, H. HEVC Lossless Coding and Improvements. IEEE Trans. Circuits Syst.Video Technol. 2012, 22, 1839–1843.
[75] Chen, H.; Braeckman, G.; Satti, S.M.; Schelkens, P.; Munteanu, A. HEVC-based video coding with lossless region of interest for telemedicine applications. In Proceedings of the 20th International Conference on Systems, Signals and Image Processing (IWSSIP), Bucharest, Romania, 7–9 July 2013; pp. 129–132.
[76] Gao,W.; Jiang, M.; Yu, H. On lossless coding for HEVC. SPIE 2013, 8666, 866609.
[77] Choi, J.; Ho, Y. Differential Pixel Value Coding for HEVC Lossless Compression. Adv. Video Coding Next-Gener. Multimed. Serv. 2012, 3–19, doi:10.5772/52878.
[78] Tan, Y.H.; Yeo, C.; Li, Z. Residual DPCM for lossless coding in HEVC. In Proceedings of the IEEE International Conference on Acoustics, Speech and Signal Processing, Vancouver, BC, Canada, 26–31 May 2013; pp. 2021–2025.
[79] Sanchez, V.; Aulí-Llinàs, F.; Bartrina-Rapesta, J.; Serra-Sagristà, J. HEVC-based lossless compression of Whole Slide pathology images. In Proceedings of the IEEE Global Conference on Signal and Information Processing (GlobalSIP), Atlanta, GA, USA, 3–5 December 2014; pp. 297–301.

[80] Sanchez, V.; Llinàs, F.A.; Rapesta, J.B.; Sagristà, J.S. Improvements to HEVC Intra Coding for Lossless Medical Image Compression. In Proceedings of the 2014 Data Compression Conference, Snowbird, UT, USA, 26–28 March 2014; pp. 423–423.
[81] Sanchez, V.; Bartrina-Rapesta, J. Lossless compression of medical images based on HEVC intra coding. In Proceedings of the IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP), Florence, Italy, 4–9 May 2014; pp. 6622–6626.
[82] Sanchez, V.; Aulí-Llinàs, F.; Vanam, R.; Bartrina-Rapesta, J. Rate control for lossless region of interest coding in HEVC intra-coding with applications to digital pathology images. In Proceedings of the 2015 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP), South Brisbane, Australia, 19–24 April 2015; pp. 1250–1254.
[83] Sanchez, V. Sample-based edge prediction based on gradients for lossless screen content coding in HEVC. In Proceedings of the 2015 Picture Coding Symposium (PCS), Cairns, Australia, 31 May–3 June 2015; pp. 134–138.
[84] Flynn, D.; Marpe, D.; Naccari, M.; Nguyen, T.; Rosewarne, C.; Sharman, K.; Sole, J.; Xu, J. Overview of the Range Extensions for the HEVC Standard: Tools, Profiles, and Performance. IEEE Trans. Circuits Syst. Video Tech. 2016, 26, 4–19.
[85] ACR-NEMA Standards Publication No. 300-1985-DICOM-Digital Imaging and Communications. 1985. Available online: ftp://medical.nema.org/medical/dicom/1985/ACR-NEMA_300-1985.pdf (accessed on 20 May 2016).
[86] ACR-NEMA Standards Publication No. 300-1988-DICOM-Digital Imaging and Communications. 1988. Available online: ftp://medical.nema.org/medical/dicom/1988/ACR-NEMA_300-1988.pdf (accessed on 20 May 2016).
[87] ACR/NEMA Standards Publication No. PS 3.1. 1993. Available online: ftp://medical.nema.org/medical/dicom/1992-1995/ (accessed on 20 May 2016).
[88] DICOM PS3.1 2016b. 2016. Available online: http://dicom.nema.org/MEDICAL/Dicom/current/output/chtml/part01/PS3.1.html (accessed on 20 May 2016).
[89] DICOM PS3.5 2016b—Data Structures and Encoding. 2016. Available online:http://dicom.nema.org/medical/Dicom/current/output/chtml/part05/PS3.5.html (accessed on 20 May 2016).
[90] PS2-1989 ACR-NEMA Data Compression Standard. 1989. Available online: ftp://medical.nema.org/MEDICAL/Dicom/1989/PS2_1989.pdf (accessed on 20 February 2017).
[91] Information Technology—Generic Coding of Moving Pictures and Associated Audio Information: Systems; ISO/IECIS 13818-1; ISO: Geneva, Switzerland, 2000.
[92] Information Technology—Coding of Audio-Visual Objects—Part 10: Advanced Video Coding; ISO/IEC IS 14496-10; ISO: Geneva, Switzerland, 2003.
[93] Proposal for New Work Item from WG13 on HEVC / H.265 Video Coding. Available online: ftp://medical.nema.org/MEDICAL/Dicom/Overviews-CPs-Sups-WIs/Work-Items/2015-12-A-HEVC-H265-v.2.docx (accessed on 30 July 2023).
[94] Digital Imaging and Communications in Medicine (DICOM) Supplement 195: HEVC/H.265 Transfer Syntax. Available online: ftp://medical.nema.org/medical/dicom/supps/PC/sup195_pc2.pdf (accessed on 30 July 2023).
[95] MINUTES of DICOM STANDARDS COMMITTEE on December 2, 2010. Available online: http://dicom. nema.org/dicom/minutes/committee /2010/2010-12-02/DICOM_2010-12-02_Min-Rev1.doc (accessed on 30 July 2023).
[96] Usability of irreversible image compression in radiological imaging. A position paper by the European Society of Radiology (ESR). Insights Imaging 2011, 2, 103–115.
[97] ACR–AAPM–SIIM Technical Standard for Electronic Practice of Medical Imaging—Resolution 39. 2014. Available online: http://www.acr.org/~/media/AF1480B0F95842E7B163F09F1CE00977.pdf (accessed on 30 July 2023).
[98] Guidance for the content and review of 510(K) Notifications for Picture Archiving and Communications Systems (PACS) and Related Devices; Food and Drug Administration: Rockville, MD, USA, 1983.
[99] Wong, S.; Zaremba, L.; Gooden, D.; Huang, H.K. Radiologic image compression—A review. Proc. IEEE 1995, 83, 194–219.
[100] Gooden, D.S. Legal Aspects of Image Compression. In Proceedings of the American Association of Physicists in Medicine (AAPM) 35th Annual Meeting, Washington, DC, USA, 8–12 August 1993.

[101] Bak, P.R.G. Will the Use of Irreversible Compression become a Standard of Practice? Newsl. Soc. Comput. Appl. Radiol. 2006, 18, 10–11.
[102] Mammography Quality Standards Act (MQSA). 2004. Available online: https://www.fda.gov/RadiationiEmittingProducts/MammographyQualityStandardsActandProgram/Regulations/ucm110823.htm (accessed on 30 July 2023).
[103] Mammography Quality Standards Act (MQSA) Policy Guidance Help System—Recordkeeping. 2014. Available online: http://www.fda.gov/Radiation-Emitting Products / Mammography Quality StandardsActandProgram/Guidance/PolicyGuidanceHelpSystem/ucm052108.htm (accessed on 30 July 2023).
[104] The Adoption of Lossy Image Data Compression for the Purpose of Clinical Interpretation. Available online: https://www.rcr.ac.uk/sites/default/files/docs/radiology/pdf/IT_guidance_LossyApr08.pdf. (accessed on 30 July 2023)
[105] CAR Standards for Irreversible Compression in Digital Diagnostic Imaging within Radiology. 2011. Available online: http://www.car.ca/uploads/standards%20guidelines/Standard_Lossy_Compression_EN.pdf (accessed on 30 July 2023).
[106] Koff, D.; Bak, P.; Brownrigg, P.; Hosseinzadeh, D.; Khademi, A.; Kiss, A.; Lepanto, L.; Michalak, T.; Shulman, H.; Volkening, A. Pan-Canadian Evaluation of Irreversible Compression Ratios ("Lossy" Compression) for Development of National Guidelines. J. Digit. Imaging 2008, 22, 569–578.
[107] Loose, R.; Braunschweig, R.; Kotter, E.; Mildenberger, P.; Simmler, R.; Wucherer, M. Compression of Digital Images in Radiology—Results of a Consensus Conference. Fortschr. Röntgenstr. 2009, 181, 32–37.
[108] Thanki R.M., Kothari A. (2019) Data Compression and Its Application in Medical Imaging. In: Hybrid and Advanced Compression Techniques for Medical Images. Springer, Cham. https://doi.org/10.1007/978-3-030-12575-2_1

