

MDCT EVALUATION OF THE RAREST ITALIAN VIOLINS FROM THE 17th AND 18th CENTURY

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Figure 8A. MDCT Volume rendered

violin (referred to as the Mona Lisa

luthier Giuseppe Guarneri Del Gesù.

It is possible to appreciate the gen-

eral construction and aesthetics of

Figure 8B. The violin box of the same

instrument as in 8A is made trans-

dering parameters. This allows ob-

sound post and bass bar inside the

violin, as well as their relationship

with the bridge, without disassem-

Figure 8C. By changing the volume

rendering parameters, some fea-

tures of the violin can be demon-

strated. Here it is possible to appre-

plate, which run parallel to the long

tudinal axis of the violin. The charac-

teristics of the wood grain determine

the regional stiffness of the front

and back plates, and consequently

its vibrating properties.

bling the instrument.

servation of the position of the

parent by adjusting the volume ren-

(VR) image of the "Vieuxtemps"

of violins) made by the famous

HISTORY

The violin first emerged in northern Italy in the early 16th century. The earliest explicit description of the instrument was in the Epitome musical by Jambe de Fer, published in Lyon in 1556. Andrea Amati (1505 – 1578), from the town of Cremona, is the earliest known luthier and is the maker of the earliest surviving violin, built in 1564 (currently at the Metropolitan Museum of Art in New York). The modern-day violin has changed little from Amati's original model.

In the 16th century nearly all of the region's luthiers died of the Bubonic Plague. The sole known survivor to carry on the tradition of violin making was Nicolò Amati (1596 – 1684), the grandson of Andrea, who improved on the model adopted by the Amati family. Having no sons to carry on the family tradition, Nicolò Amati was one of the first known makers to take apprentices from outside his family into his workshop. According to most current sources, apprentices in Nicolò Amati's workshop included some of the most famous luthiers in history: Andrea Guarneri (1626 – 1698), who eventually founded the Guarneri Family of violin makers, was one of them. There is some controversy as to whether Antonio Stradivari (1644 – 1737), probably the most well known luthier of all time, was also his pupil, but current research indicates this is unlikely.

The violins made by these masters have a long and revered history, with a sound quality that is deemed unparalleled by many. The names Stradivari and Guarneri are practically synonymous with violins of unsurpassed beauty, quality, and tone. The richness of sound produced by these instruments, the responsiveness, and their expressive potential are just a few of the reasons they are so venerated. Stradivari made approximately 1,100 instruments in his life, but less than 650 remain. Bartolomeo Giuseppe Guarneri (1698 – 1744), also called "del Gesù", became the most famous member of the Guarneri family, and his instruments are regarded as some of the finest made in the 18th century although they are quite a bit rarer than Stradivari instruments with approximately 150 extant examples.

The violin became immensely popular and soon eclipsed the Viola da Gamba and Viola D'Amore family of instruments that were played by the aristocracy. This had a tremendous impact on music literature - as better quality instruments emerged and the violins' popularity soared, com-

fingerboard

Figure 1. Volume rendered MDCT images of a Stradivarius violin.

posers such as Bach, Tartini, and Vivaldi (amongst others) began writing more music for this instrument, ranging from music intended for amateurs to virtuoso solo literature. The art of Cremonese violin making declined after the death of Carlo Bergonzi in 1747, the last of the "great" Cremonese makers. Due to economic demands, the luthiers were forced to produce instruments faster, leading to degradation in the quality of the instruments. The fact that northern Italy changed political regime quite often at that time was probably another contributing factor to the decline of Cremona as the center for violin making.

The violins of Stradivari and Guarneri del Gesu have become the gold standard to which all modern violins are compared. Many different construction variables have been studied, including the arching design and contours, plate thickness, varnish layers, and various aspects of construction such as the angle of the neck and bridge. The grain of the wood, the treatment of the wood by water or minerals, and the infiltration of the wood by fungus are just a few of the topics of study. Despite extensive research, most musicians believe that no modern luthier has been able to recreate the characteristics of Stradivari or Guarneri violins.

Many of these violins are owned by foundations, who often loan them to famous violinists or young new artists. These may be loaned out for only one concert, or for an extended period of time. Other violins are privately owned, either by collectors or prominent musicians. For example, Itzhak Perlman owns and plays the "Soil" Stradivari made in 1714, and Yo Yo Ma performs on the "Davidov" Stradivari cello; however, the era of private ownership of these instruments is most likely nearing the end as even the most highly respected musicians rarely earn enough to afford them.

The usual price paid for Stradivari violins is several million US dollars. The "Kochanski" made by Guarneri and formerly owned by violinist Aaron Rosand was sold for \$10 million in 2009. Of note, these instruments are usually named after their most well known previous owner.

ART & SCIENCE

The basic parts of a violin include the body, neck, and scroll (**Figure 1**). The body is the portion which resonates and is therefore responsible for sound production. It consists of

the front, back, and ribs. The front of the violin is made of two pieces of spruce which are joined at the midline and connected by glue. The remainder of the violin body, in cluding the back, is made of maple. The front and back plates are joined together along the periphery by ribs, which are thin strips of wood built up on a mould and glued together. Inside the violin body, the front and back plates are connected by the sound post, a short and narrow cylinder of wood which supports the pressure of the strings bearing down on the treble side of the bridge. The bass side of the bridge is supported by a long strip of wood that is glued parallel to the length of the instrument on the underside and which is called the bass bar.

Wood is a complex material, with different mechanical properties in different directions. Material selection is very important, as the sound quality of the violin is significantly affected by the quality of wood. The spruce used for the front plate is believed to have the most impact on sound quality. Several different aspects of the wood affect the sound quality, including wood density, stiffness, and damping properties.

The front and back plates of a violin must be thin enough to resonate easily and yet sturdy enough to support the violin neck and the tension of the strings. The plates are carved, their thickness varying in different locations. Every piece of wood is different, and therefore no two violins have identical plate thicknesses; determining the ideal thickness of each plate is a skill mastered by the maker. The plate thickness as well as wood density affects sound quality and can be measured by CT.

MDCT OF RARE VIOLINS CURRENT APPLICATIONS:

In 1997, Dr. Stephen Sirr imaged his own violin with a single detector helical CT scan, and subsequently scanned several violins of varying quality, ranging from student instruments to Stradivari and Guarneri violins. Since then, CT scan has been used to evaluate the design and structure of these instruments. The physical design of the Stradivari violins has been found to vary from student violins. For example, it has been shown that a Stradivari had thinner plates with more pronounced arching than student violins, which allows better plate vibration and resonation, producing a superior sound.

Today, isotropic voxels obtained by state of the art MDCT scanners provide additional information about the design and construction of these rare Italian violins. Luthiers have used this information to alter the construction of newer violins to mimic that of the Cremonese instruments, with favorable results. Especially useful is the virtual "slicing" of an instrument to view the arching and thickness of the front and back plates at any location.

Many other parameters can be evaluated with a MDCT scan besides the design of a violin. For example, a map of wood density for the top and back can be generated (Figure 2). Stoel and Borman used this technique to study density differentials in Cremonese and modern violins by measuring wood density and then quantitatively analyzing ROI histograms to evaluate the degree of variation in the density of the wood. They found no significant difference between the median densities of Cremonese and modern violins, but did find that the wood density differential between the early and late growth of the spruce used was significantly less in the Cremonese violins than in the modern violins (Figure 3).

Another application of quantitative MDCT data analysis is to generate an elevation profile, or topographic maps of instruments, which can show arching styles as well as deformations due to age (Figure 4).

Plate thickness measurements have proven very useful to luthiers. Quantitative analysis of high resolution MDCT acquired data, makes it possible to generate thickness maps (Figure 5). It is also possible to analyze the relationship between thickness and modes of vibration. This is done by overlaying the thickness map with a map of the vibration characteristics of the violin at various frequencies (Figure 6). Most recently, integration of MDCT results with Modal Analysis provides virtual real time analysis.

Another use of the MDCT is the characterization of repairs and prior damage (worms, cracks etc.) to the instrument. This can be very helpful when advising a client about a potential acquisition as well as in insurance claim resolution.

IMAGE ACQUISITION TECHNIQUE:

The following is the MDCT protocol used at Northwestern University and is adapted from Stoel and Borman (Reference 1) for imaging of these rare violins.

1. Scan performed on 64-row single or dual source/dual energy MDCT scanner.

- 2. Removal of steel strings and replacement with nylon strings by master luthiers.
- 3. Long axis of the violin along the z-axis.
- 4. 64-row acquisition:
 Collimation: 0.6 mm (reconstructed at 0.6 x 0.3 mm)
 80 kV
 53 mAs/ref
 Kernel B50S
- 5. Dual-source/Dual Energy acquisition:

Source 1
Collimation: 0.6 mm (reconstructed at 1.25 x 0.3 mm)
140 kV

Source 2

34 mAs/ref

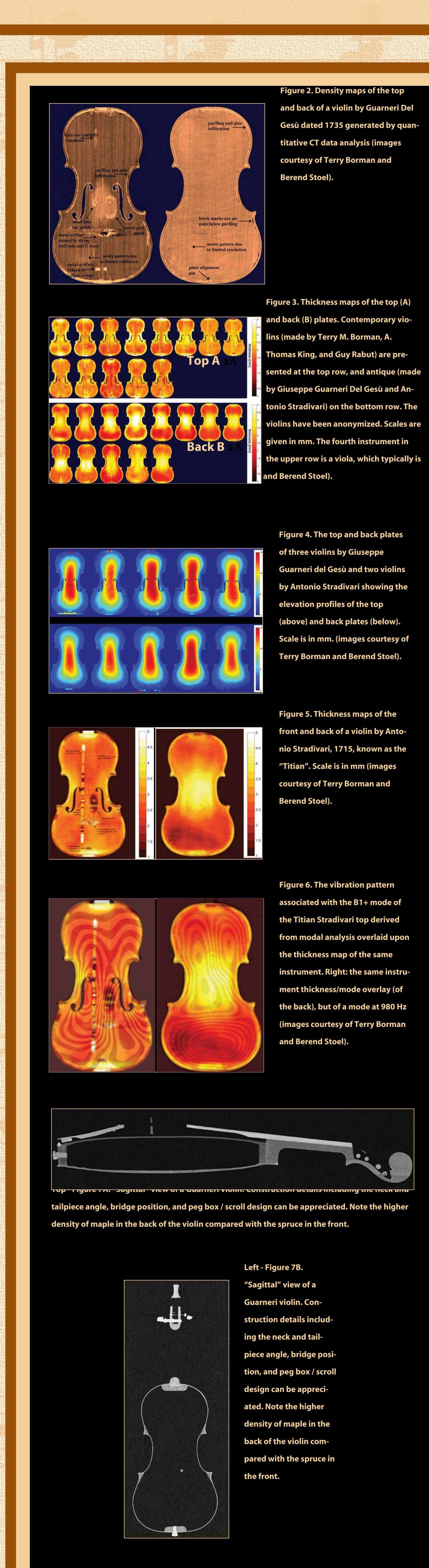
Collimation: 0.6 mm (reconstructed at 1.25 x 0.3 mm) 80 kV 134 mAs/ref

6. Post-processing using volume rendering and density map analysis using both commercial and non-commercial software.

EXAMPLE OF A CREMONESE VIOLIN ANALYZED BY MDCT:

MDCT images of a Cremonese violin built by Giuseppe Guarneri "Del Gesù" in 1741 that was scanned using a 64-row MDCT scanner are shown. This violin was evaluated in collaboration with the Stradivari Society.

The usual orthogonal views can be used to characterize the design and construction details of the instrument (**Figure** 7a-b). Three-dimensional (3D) volume rendering (VR) images were generated, and the general construction and geometry of



the instrument could be appreciated (Figure 8B). By changing opacity settings, it is possible to generate "transparency" in the box, thereby examining the internal features such as the sound post and the bass bar withoudisassembling the violin (Figure 8B). The VR parameters can also be changed to better demonstrate other characteristics of the instrument, such as the wood grain (Figure 8C).

Using the technique of virtual navigation it is possible to analyze the sound post and bass bar locations as if one were inside the box (**Figure 9**). The internal architecture can, therefore, be analyzed non-invasively by master luthiers.

FUTURE APPLICATION: DUAL ENERGY

The role of dual-energy scanning is still under investigation. Dual-energy CT refers to the use of CT data representing two different energy spectra in differentiating and classifying material composition. After the development of spectra tables for different types of materials commonly used in the construction and restoration of violins, dual-energy CT may aid in finding repairs and restoration work previously done on an instrument, making it potentially easier to determine a violin's origin and condition (Figure 10).

CONCLUSION

The sound of a Stradivari and Guarneri violin is an elusive property. MDCT of these violins provides valuable information regarding the structure and design of the instrument. The wood thickness, density, and internal grain structure can be analyzed by MDCT and dual energy CT. This information can be used to improve on current construction models of the violin, as well as to help characterizing prior repairs or damage to valuable instruments.

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Figure 9. Virtual navigation: one is "inside" a Guarneri violin box. It is possible to characterize the sound post (S), the bass bar (B) and one of the "f" holes (F).



Figure 10. Dual-energy acquisition of a Cremonese violin presented as a 3D volume rendered image, using the standard dual-energy protocol normally used for assessing gout. The regions with different composition than the rest of the violin are mapped in green (white arrows indicating regionally higher concentrations of calcium in the wood of the fingerboard). Dedicated dual-energy protocols to assess the materials used in violin construction may further help in the analysis of these historic instruments.

