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Anatomical investigation of pernambuco wood sticks used to manufacture bows for strings instruments

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Aims

“The luthier is an artist who uses specific tools and techniques to give each instrument unique aesthetic and functional characteristics” (1). This also applies to the bow maker or archetier. The first reference about the use and the development of the bows comes from Arabic and Byzantine culture since the 10th century. After 1800, following the evolution with a more sophisticated music, more often written for bigger orchestra and a bigger audience the instruments were “upgraded” in their shapes and materials. Following this evolution the bows stopped to be considered as a mere accessories. Bow makers developed stronger and more responsive bows, and players realized that bows were just as important as instruments in producing a better sound (2,3).
Before the middle of the 18th century, bow makers used various tropical hardwoods including pernambuco that was established as the ideal material for the manufacturing of bows by François Xavier Tourte (1747–1835). Tourte, in collaboration with the violin virtuoso G.B. Viotti, made important changes in the shape and characteristics of the bow in the Classical period between 1785 and 1790. They lengthened them slightly, to 74 – 75 centimetres, and used more wood in the tip and a heavier nut. Tourte's bows was made from pernambuco wood, the most common kind of wood used on professional bows today, bent by being exposed to heat. Tourte's bows tended to be heavier than previous models, with more wood in their tip counterbalanced by a heavier frog (the device connecting the hair to the stick at the end nearest the player's hand).
The concept of quality of a bow is relative, but usually it is related with the timbre (sonority of the emitted sounds) and the way it can be controlled, this characteristic may be correlated with the physical properties of the bow wood. For a player, the choice of bow is as important as the choice of instrument. Indeed, the bow is considered as a prolongation of the arm, like an artificial limb (4). Moreover, there is a constant interaction between musician, violin and bow.
Pernambuco (*Caesalpinia Echinata Lam*. – *Leguminosae Caesalpinioideae*) wood combines, among others, ideal characteristics of resonance, density, durability and beauty (5) for those reasons it has been considered for centuries and it's still considered the best wood for bows. “Nevertheless, practice shows that pernambuco wood sticks processed in the same way by the same bow maker can result in bows with very distinct qualities. This variation is due to a series of factors that probably

involve the anatomy of the wood and its physical, mechanical, acoustic and chemical properties" (6). Many bow makers use their experience to estimate the modulus of elasticity (MOE) which is the measure of resistance of the wood to deflection. Very often this is the only empiric criteria they use to make a prior selection of the sticks before they begin the process of manufacturing the bows themselves (7,8,9). Nevertheless, some objective parameters such as wood density and the speed of sound propagation reduce the guesswork involved in evaluating the potential tonal properties of a stick. In particular, on the basis of the studies and experience of the bow maker Mo. Giovanni Lucchi from Cremona, an high sound speed propagation in the wood stick bow means that the stick is able to vibrate regularly with an high frequency and small amplitude. This feature permits a perfect contact between the hair bow and the resonant strings of the instrument, whereby the bow results ready and handy to follow the intention of the player. The main purpose of the present paper is to correlate the speed sound propagation in pernambuco wood sticks with their anatomical characteristics studied by x-ray microtomography analysis.

Method

The X-ray microtography analysis were performed on sixteen pernambuco blocks cutted from the end of different bow sticks. The longitudinal speed sound propagation in every sticks had been measured with the Lucchimeter. This is an ultrasonic tester designed by Giovanni Lucchi to measure the time needed for ultrasonic waves to travel through the material.

Old version of the Lucchimeter applied on some wood sticks suitable for strings instrument bow

We collected µ-CT data using a Skyscan 1172 high-resolution MicroCT system at the University of Firenze (Crist). This system has a sealed, microfocus tungsten X-ray tube with a 5 µm focal spotsize. The X-rays were produced by exposing the anode to an electron beam at 59 kV at 167 µA. Every wooden block was placed on the pedestal between the X-ray source and the CCD detector and the 2D X-ray images were captured over 180° rotating the sample with a slice-to-slice rotation angle of 0.3°, each 2D image represents one slice. The total acquisition time was approximately 40 min. Spatial resolution of the images was kept in a range of 7-10 micron in terms of pixel size.

The 3D image of the objects internal structure has been reconstructed using modified Feldkamp algorithm for cone-beam acquisition geometry realized in Nrecon v.1.6.3.3 software. The alignment, beam-hardening and ring artifacts corrections were made before starting reconstruction process. A rough estimation of the porosity was calculated with CTAn software. CtVox program was used for 3D visualization.

The density was determined from the relation between the sample weight and the volume of water displaced from the wood immersed. The volume was measured with a suitable graduated cylinder.(Archimede's principle).
The number of pores was estimated either optically, from clean wood surfaces, or using the micro-CT reconstructions.

Results

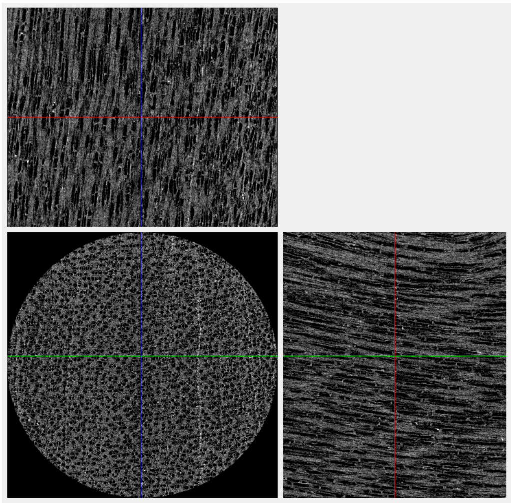
In the table 1 has been reported the speed sound propagation in the 16 analysed samples.

Table1

Sample	Speed (m/s^2)
1	5500
2	5300
3	5500
4	5650
5	5100
6	5800
7	**5000**
8	5400
9	**4800**
10	**5700**
11	**6000**
12	5300
13	5300
14	5600
15	5600

Although the anatomical analysis was done for all 16 samples, we report in the present communication the results for just four samples (in red in table 1). Sample n°7 and n°9 were chosen for the their low speed sound propagation, on the contrary sample n°10 and n°11 for their high speed propagation.

Sample	Lucchi speed of sound (m/s)	Density (kg/m^3)	Vessels / mm^2	Grain
7	5000	870	22,05	7°



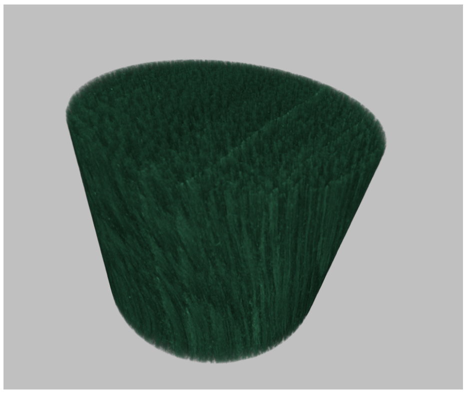
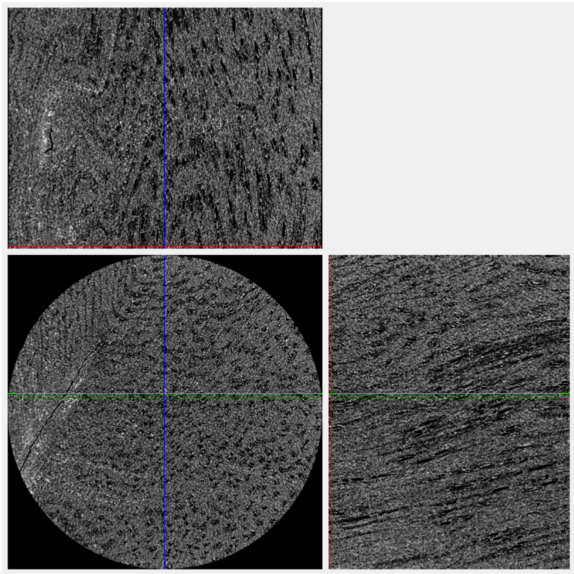


Fig. 1A Three spatial planes of sample n°7 Fig. 1B

Typical microCT slices for sample n° 7 are shown in Fig 1A, in Fig. 1B a 3D view of the wood stick is reported. Visual inspection of the microCT images of sample n° 7 reveals the following features:

Growth ring boundaries distinct. Wood diffuse-porous. Pores mainly in more or less long radial files, rarely sparse. Very abundant axial parenchyma, vasicentric, either aliform or confluent. The slope of the grain is around 7°.

Sample	Lucchi speed of sound (m/s)	Density (kg/m^3)	Vessels / mm^2	Grain
9	4800	1160	17.6	Distorted



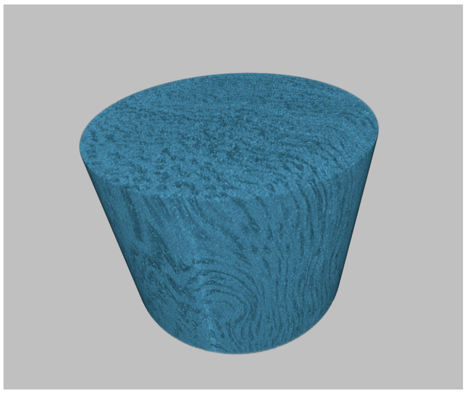
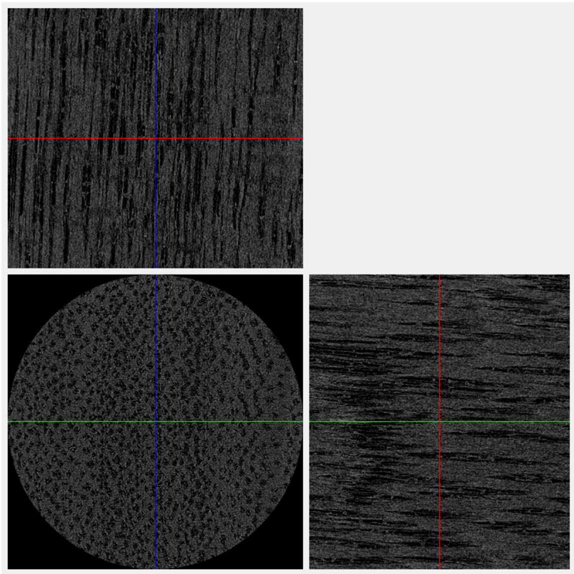


Fig. 2A Three spatial planes of sample n°9 Fig. 2B

Typical microCT slices for sample n° 9 are shown in Fig 2A, in Fig. 2B a 3D view of the wood stick is reported. Visual inspection of the microCT images of sample n° 9 reveals the following features:
Growth ring boundaries indistinct. Wood diffuse-porous. Pores mainly sparse but also in more or less long radial files. Axial parenchyma vasicentric, either aliform or confluent. Distorted grain due to the presence of a knot.

Sample	Lucchi speed of sound (m/s)	Density (kg/m^3)	Vessels / mm^2	Grain
10	5700	980	14,7	Straight



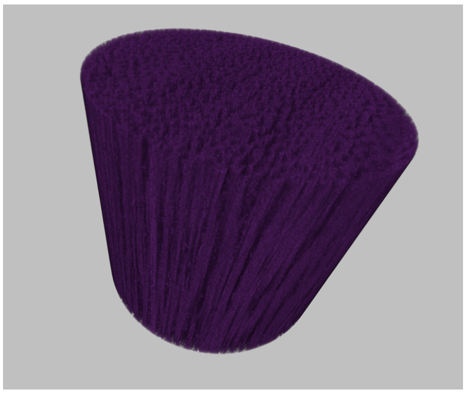
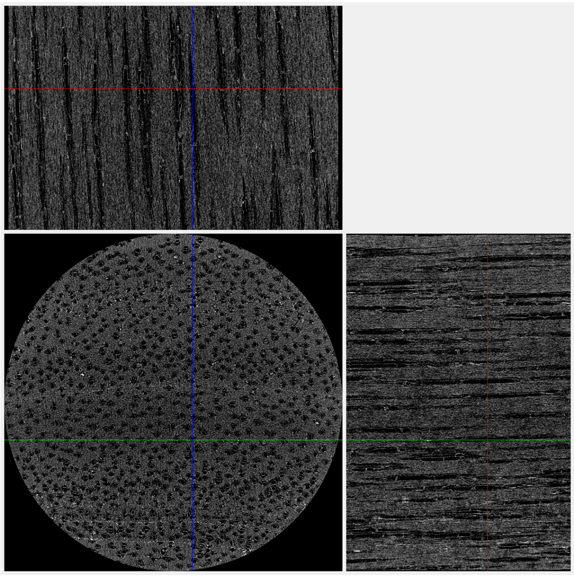


Fig. 3A Three spatial planes of sample n°10   Fig. 3B

Typical microCT slices for sample n° 10 are shown in Fig 3A, in Fig. 3B a 3D view of the wood stick is reported. Visual inspection of the microCT images of sample n° 10 reveals the following features:
Growth ring boundaries indistinct. Wood diffuse-porous. Pores either sparse or in more or less long radial files. Abundant vasicentric axial parenchyma, either aliform or confluent. Straight grain.

Sample	Lucchi speed of sound (m/s)	Density (kg/m^3)	Vessels / mm^2	Grain
11	6000	1000	13,2	Straight



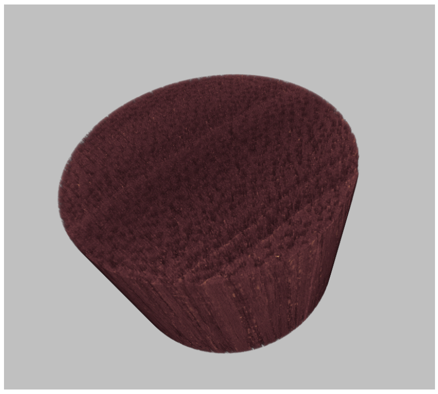


Fig. 4A Three spatial planes of sample n°11 Fig. 4B

Typical microCT slices for sample n° 11 are shown in Fig 4A, in Fig. 4B a 3D view of the wood stick is reported. Visual inspection of the microCT images of sample n° 11 reveals the following features:
Growth ring boundaries distinct. Wood diffuse-porous. Pores mainly sparse. Axial parenchyma vasicentric, mainly aliform. Straight grain.

In the table 2 the speed of sound propagation, the wood density, the number of vessel for mm^2 and the grains direction in relation to the longitudinal direction of the sticks has been reported .

Sample	Lucchi speed of sound (m/s)	Density (kg/m^3)	Vessels / mm^2	Grain
7	5000	870	22,05	7°
9	4800	1160	17.6	Distorted
10	5700	980	14,7	Straight
11	6000	1000	13,2	Straight

Table 2

Conclusion

Samples n°11 and n°10, that had the highest speed of sound, were characterised by straight grain and higher density. Sample n°9 showed the highest density but a very poor speed of sound due to the distorted grain. Sample n°7 showed very regular growth rings. Moreover its speed is poor because its grain is oriented with an angle of 7° from the longitudinal direction of the stick and its density is the lowest. Therefore, many factors affect the speed of sound on wood, not only the anatomical features that influence wood density, like the frequency of vessels and the amount of parenchyma, but also macroscopic features like the deviation of the grain, which is the main medium for the sound propagation.

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