Three millennia of tonewood knowledge in Chinese guqin tradition: science, culture, value, and relevance for Western lutherie

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Abstract—The qin, also called guqin, is the most highly valued musical instrument in the culture of Chinese literati. Chinese people have been making guqin for over three thousand years, accumulating much lutherie knowledge under this uninterrupted tradition. In addition to being rare antiques and symbolic cultural objects, it is also widely believed that the sound of Chinese guqin improves gradually with age, maturing over hundreds of years. As such, the status and value of antique guqin in Chinese culture are comparable to those of antique Italian violins in Western culture. For guqin, the supposed acoustic improvement is generally attributed to the effects of wood aging. Ancient Chinese scholars have long discussed how and why aging improves the tone. When aged tonewood was not available, they resorted to various artificial means to accelerate wood aging, including chemical treatments. The cumulative experience of Chinese guqin makers represent a valuable source of tonewood knowledge, because they give us important clues on how to investigate long-term wood changes using modern research tools. In this review, we translated and annotated tonewood knowledge in ancient Chinese books, comparing them with conventional tonewood knowledge in Europe and recent scientific research. This retrospective analysis hopes to highlight the practical value of Chinese lutherie knowledge for 21st-century instrument makers.

I. INTRODUCTION

In Western musical tradition, the most valuable musical instruments belong to the violin family, especially antique instruments made in Cremona, Italy. The highest public sales record of a violin was set in 2011, when the “Lady Blunt” Stradivarius of 1712 was sold for 16 million USD. This auction attracted global attention due to the popularity of violins and the iconic status of Antonio Stradivari in Western music culture.

By contrast, fewer people have noticed the record sales of a Chinese guqin called Songshi Jianyi (松石間意, 1120 AD), auctioned for 20 million USD in 2010. In 2011, an even older guqin called Dasheng Yiyin (大聖遺音) from the Tang Dynasty (618-907 AD) was sold for 18 million USD. Precious guqins, like precious violins, often have individual nicknames. Very often the names are carved into the back of the instrument (Figure 1). Chinese guqin (古琴) was originally called qin (琴). But the word “qin” gradually became a general term for many string instruments, and hence the word “gu” (古, ancient) was later added to denote the seven-string zither that originated from antiquity. Qin (琴) is a hieroglyphic character depicting a set of strings (top half) strung over a resonator box (bottom half). Formerly, guqin had been translated as “lute,” but today guqin and qin are more commonly used.

The extraordinary prices of antique Italian violins and 1000-year-old Chinese guqins seem to be driven by similar psychological factors and expectations. They are both rare antiques and symbolic cultural objects. Moreover, their acoustic properties also play important roles. Admittedly, the perceived acoustic quality of musical instruments is very difficult to define and measure objectively under current science, and many related opinions originated from anecdotal observations. In both cases, it is often assumed by players and collectors that fine instruments produced by master makers show acoustic improvements slowly over time, continuing over hundreds of years. In addition, musicians and collectors often believe that old masters in the past possessed special knowledge and skills for making the finest sounding instruments, but such know-how has been lost. Therefore, the best works of old masters are often assumed to possess superlative tones that cannot be matched by modern copies. Whether this assumption is true is still a highly debated subject. Some studies have identified acoustic differences between Stradivari violins and modern violins [1-3],

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but others have failed to do so [4-6]. The acoustic differences between old master guqins and modern guqins have yet to be systematically investigated.

There are two major approaches for investigating the unique properties of antique instruments. The first is to investigate them physically to uncover their manufacturing methods and aging-related properties. The second is to search through historical texts for related knowledge or clues. For Cremonese violin research, the second approach has basically come up empty. Luthiers like Stradivari received little education and were unwilling to disclose their trade secrets. Educated scholars around him knew little about instrument making [7]. When the Golden Age of violin making in Cremona (1550-1750) ended, the tradition was quickly lost. By late 1700s, investigations launched by Count Cozio di Salabue to seek the lost knowledge had already come up empty [8].

The relationship between the instrument and the intelligentsia class was much different for Chinese guqin. Guqin is an elongated wooden resonator about 1.2 meters long, mounted with seven strings on a fixed bridge (Figure 1). It is not to be confused with guzheng (古箏), which has a longer body (1.6 m), 16-21 strings, and moveable bridges (Figure 2). The guqin is a relatively quiet instrument, unsuitable for public performances. Instead, it was generally performed in private by the educated, the Chinese literati class, in tight spaces such as a study room or a pavilion. The audience was typically very small, just a few other scholars or close friends. Guqin was originally invented in China about four thousand years ago and has always been associated with the nobility and the educated. According to *Shiji* (史記, Records of the Grand Historian), Confucius (孔子, 551-479 BC) also learned to play the guqin [9].

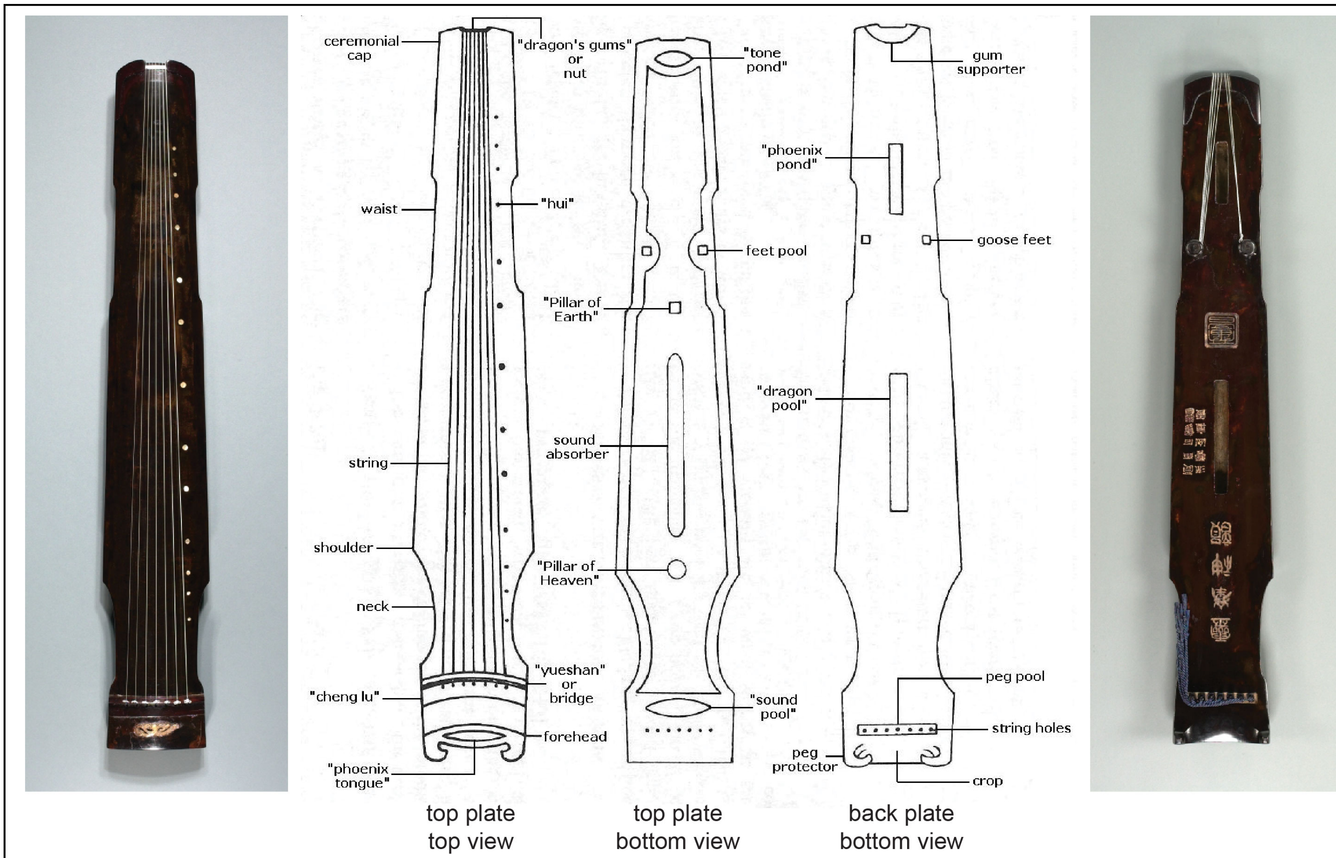

Figure 1. Structure of guqin (qin), the seven-string Chinese zither. This outline of this qin follows the Zhongni (Confucius) style. Images by Charles Tsua (CC-BY SA 3.0 license). The carved characters in the back read “Lingfeng Shenyun” (靈峰神韻, Magical Mountain-Godly Music), the name given to this instrument by one of the past owners.

In ancient China, the recreation of the intelligentsia included the “four arts”—qin, the game of go, calligraphy, and painting. Qin is ranked first, and it represents the music of the educated elite, as opposed to the mundane music enjoyed by common folks in restaurants and festivities. There was tremendous respect for the “four arts.” For instance, papers with calligraphy writings could not be disposed as trash. Instead, they had to be burned in dedicated incinerating towers, following strict rituals. It is therefore easy to imagine that the qin was a sacred object as well. During perilous times such as house fires, wars, or natural disasters, it is said that the Chinese literati would rescue the guqin first, over all other personal belongings. The guqin is very portable (about 1.2 m, 3 kg) and easy to carry on the back. The oldest playable guqins have survived from the Tang Dynasty (618-907 AD)—a strong testament to the dedication of Chinese collectors in preserving the instrument.

Not only did Chinese scholars play the guqin, many of them also knew how to repair it or even make it. For instance, during the Tang Dynasty (the Golden Period of Chinese guqin making), one of the leading makers happened to be the prime minister in the imperial court, Li Mien (李勉) [10]. Chinese scholars have written about various aspects of guqin making for almost three millennia. In particular, they have accumulated a significant body of knowledge about tonewood that still seems very valuable today.

However, old Chinese books published before the 20th century were written in Classic Chinese—an ancient prose style, making them very difficult to understand even for most native Chinese speakers today. Most of the tonewood knowledge in old Chinese books has never been introduced to the West, except for the translation of *Yuguzhai Qinpu* (與古齋琴譜) by James Binkley [11]. The goal of this review is to translate and discuss tone-wood related knowledge in classical guqin literature and to address its value and relevance for modern instrument makers. From a scientific point of view, such knowledge, although anecdotal in nature, is especially interesting with regard to long-term (hundreds of years) changes in wood properties and instrument acoustics. It is practically impossible to study such phenomena in modern research settings, and therefore we may learn something from the cumulative experience of ancient Chinese luthier-scholars.

Figure 2. (a) A Guqin player, photographed by 夏爱克 (CC-BY 2.0 license). (b) A Guzheng player, photographed by Monika Neumann (CC0 license). Compared to guqin (1.2 m, ~3 kg), guzheng is wider and longer (1.6 m, ~10 kg), with more strings moveable bridges.

II. Research Method

Chinese writings related to guqin are numerous and scattered, spanning across almost three millennia. Fortunately, two useful sources of information have recently become available. The first is *Lidai Qinxue Ziliaoxuan* (歷代琴學資料選, Historical Anthology of Selected Qin Writings), a new book in Simplified Chinese that compiled many historical writings [12]. The second is Qinzhijie (琴之界, Domain of Qin) website, which has scanned the old prints of many qin scores and some related books [13]. In addition to these two sources, we conducted literature surveys using university libraries in Fujian and Taiwan, as well as internet search across Chinese websites.

In Figure 3, we have created a historical timeline that highlights important events in the history of guqin and important texts and books containing tonewood knowledge for guqin. We have taken the opportunity to translate the most important passages on tonewood knowledge into English, to share the traditional Chinese lutherie know-how with the modern world. The original Chinese texts being translated in this review are shown in the Appendix.

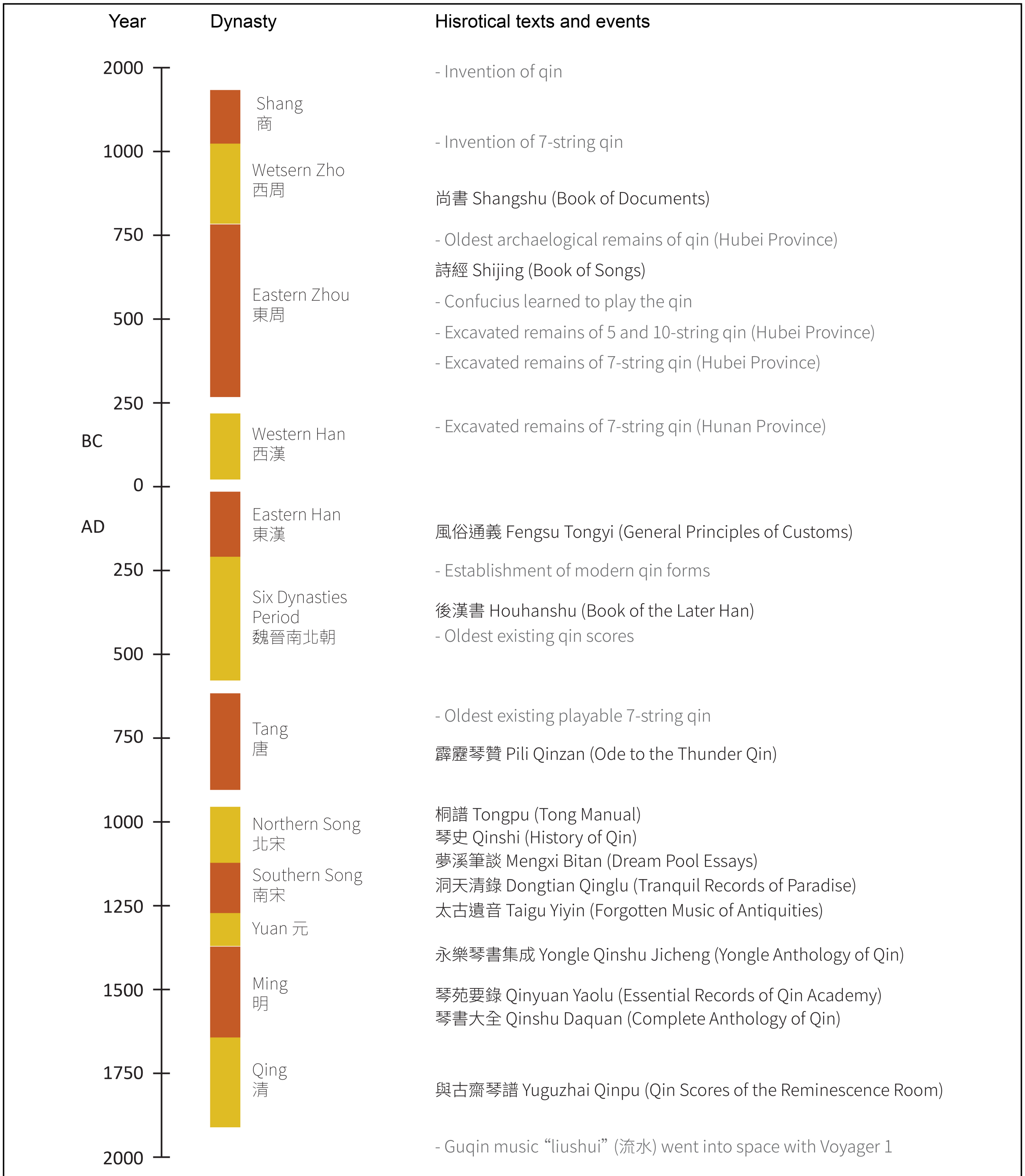

Figure 3. A historical timeline of important texts and books containing guqin tonewood knowledge, as well as key events in the historical development of guqin.

In the following sections, translated excerpts from ancient Chinese writings are presented in a logical order following the topics discussed. Moreover, traditional knowledge on Chinese guqin is compared to conventional knowledge in European violin-making for cross-cultural comparisons. When luthiers across different continents have independently come to similar conclusions, the underlying reasons are discussed. Relevant findings based on modern scientific investigations are also included to further substantiate the observations of traditional luthiers.

III. TREES SPECIES FOR MAKING GUQIN

The modern Chinese character for music, yue (樂), is a hieroglyphic character depicting two strings over a piece of wood, which denotes some kind of zither. The history of this character can be traced back to oracle writings on tortoise shells from the Shang Dynasty (c. 1600-1064 BC). It is generally believed that the invention of Chinese zithers predate the invention of written characters. The history of zither-type instruments dates back at least 4000-5000 years old in China ([14] p.10-15). Over time, different forms of zithers received different names, and the oldest were qin (5-10 strings, narrow-bodied) and se (瑟, 15-50 strings, wide-bodied).

The materials used for building early guqins can be found in *Shijing* (詩經, Book of Songs), an ancient collection of Chinese poetry from the 11th to 6th century BC, and edited by Confucius around 500 BC. Trees for making guqin were mentioned in the poem "Dingzhi Fangzhong" (定之方中) [15]:

Zhen and li were planted. And so were yi, tong, zi, and qi, to be harvested for qin and se. (Appendix Entry 2)

Here, zhen (Asian hazel) and li (chestnut) produced edible nuts. Yi (椅), tong (桐), zi (梓) and qi (漆) were used to make musical instruments—qin and se. In this context, tong is usually interpreted as *Firmiana simplex* (Chinese parasol tree, Figure 4). It is also called wutong (梧桐) or qingtong (青桐, green tong, for its green bark). Another plausible interpretation for tong is a tree from the genus *Paulownia*, which is called paotong (泡桐, Figure 5) nowadays, a popular tonewood material for many instruments including guzheng (古筝), zhongruan (中阮), and pipa (琵琶). Zi means *Catalpa ovata* (Figure 6), which is the back plate material. Its timber was widely useful—furniture, coffins, and woodblocks for printing. Qi means *Toxicodendron vernicifluum*, the Chinese lacquer tree. It produces the lacquer that is applied to guqins for protection. The true identity of the Yi tree is often debated. Some believe it to be a variety of tong or a variety or zi, but it may also represent *Idesia polycarpa*, which produces small red fruits containing high levels of drying oil ([16] p. 218). This drying oil could be mixed with raw lacquer to produce a glossy finish.

This particular poem described a feudal lord building a new capital city in 660 BC, and trees were planted for making guqin. Apparently, instrument making was already an advanced craft with artificial cultivation and long-term planning, consistent with the historical notion that qin and se have been produced for royal courts since ~2000 BC. The basic construction of guqin has remained unchanged for almost 3000 years—using tong for the front plate, zi for the back plate, and lacquer on the outside. The combination of tong and zi has always been the orthodox choice in ancient times, but a few other trees can also work well. Sometimes, the top or even the back can be made from a type of conifer called shan (杉), which usually means *Cunninghamia lanceolata*. The back plate is sometimes made of qiu (楸), which is *Catalpa bungei*, with very similar properties as zi (*Catalpa ovata*). Commercially sold guqins today usually use shan or paotong for tops and catalpa for backs.

There has been a great deal of confusion about the meaning of "tong" in ancient books. Many unrelated types of trees are classified as tong for no apparent reasons, and they have been given various names such as wutong, paotong, qingtong, zitong, youtong, huangtong, baitong and so on. "Tong" may refer to any one of them in different contexts. In the context of guqin, confusions exist between wutong (*Firmiana simplex*) and paotong (several *Paulownia* species). Some luthiers think *Firmiana* is better and more orthodox, while others think *Paulownia* is better because high-quality *Firmiana* tonewood is hard to find these days. In most cases, neither the wood supplier nor the luthier knows the true biological origin of the timber they are buying and selling. It is also challenging to tell if the tong wood in an antique qin or in an old book is *Firmiana* or *Paulownia*. Currently, the best method to distinguish tonewood species in guqin is by microscopic inspection. In the future, DNA testing may be the most reliable method of determining the biological origin of so-called "tong" wood.

In a recent book chapter on guqin acoustics, Waltham et al. [17] consider Paulownia as the primary wood for guqin tops. *Paulownia* is called kiri in Japan and is often used as tonewood there. They also noted that *Firmiana simplex* (420-550 kg/m^3) sometimes may have higher density than *Catalpa ovata* (410-490 kg/m^3). However, the density readings given by a Taiwanese guqin maker are different for the former (*F. simplex* 286 kg/m^3; *Catalpa fargesii* 472 kg/m^3) ([18] p. 157). It is unclear if there is a low-density variety of *F. simplex* specifically chosen for tonewood. As for Paulownia species, both sources agree that they average around 300 kg/m^3, which represents a very light wood. In comparison, the density of violin spruce top (*Picea abies*) is about 400 kg/m^3, and for the maple back (*Acer* species) around 600-700 kg/m^3 ([19] p. 96-97). Please refer to Table 1 for density data of guqin tonewoods.

Figure 4. Firmiana simplex, or Chinese wutong (梧桐) tree. Also called qingtong (青桐) for its green bark. (a-c) A wutong tree on the campus National Taiwan University, Taipei, Taiwan, photographed by H.-C. Tai. (d) A wutong tree showing “forked-stem” growth in North Carolina, USA (courtesy of Will Cook).

Most ancient Chinese authors referred to the best wood for guqin tops as “tong” or “wutong,” The latter term is clearly referring to *Firmiana simplex*, the tree associated with the mythical phoenix. They also stated that tong for guqin is low in density but not too soft. The botanical origin of tong top plates in antique guqins cannot be directly confirmed by visual inspection or computed tomography (CT) scans. Because DNA tests have yet to be applied to antique guqin samples, we have adopted the traditional view that the standard tong wood incorporated into antique guqins was *F. simplex*. More scientific investigation is required to differentiate the tree species actually used in antique guqins to validate this conventional hypothesis.

Chinese name	Scientific name	Common name	Density (kg/m^3)	
			ref. [12] p. 157	ref. [11]
wutong (梧桐) qingtong (青桐)	*Firmiana simplex*	Chinese parasol tree	286 (*F. simplex*)	420-550 (*F. simplex*)
paotong (泡桐)	*Paulownia* species		310 (*P. fortunei*)	252-317 (several species)
zi (梓) qiu (楸)	*Catalpa* species	catalpa	472 (*C. fargesii*)	410-490 (*C. ovata*)
shan (杉)	*Cunninghamia lanceolata*	Chinese fir	380 (*C. lanceolata*)	390

Table 1. Common tonewoods for guqin.

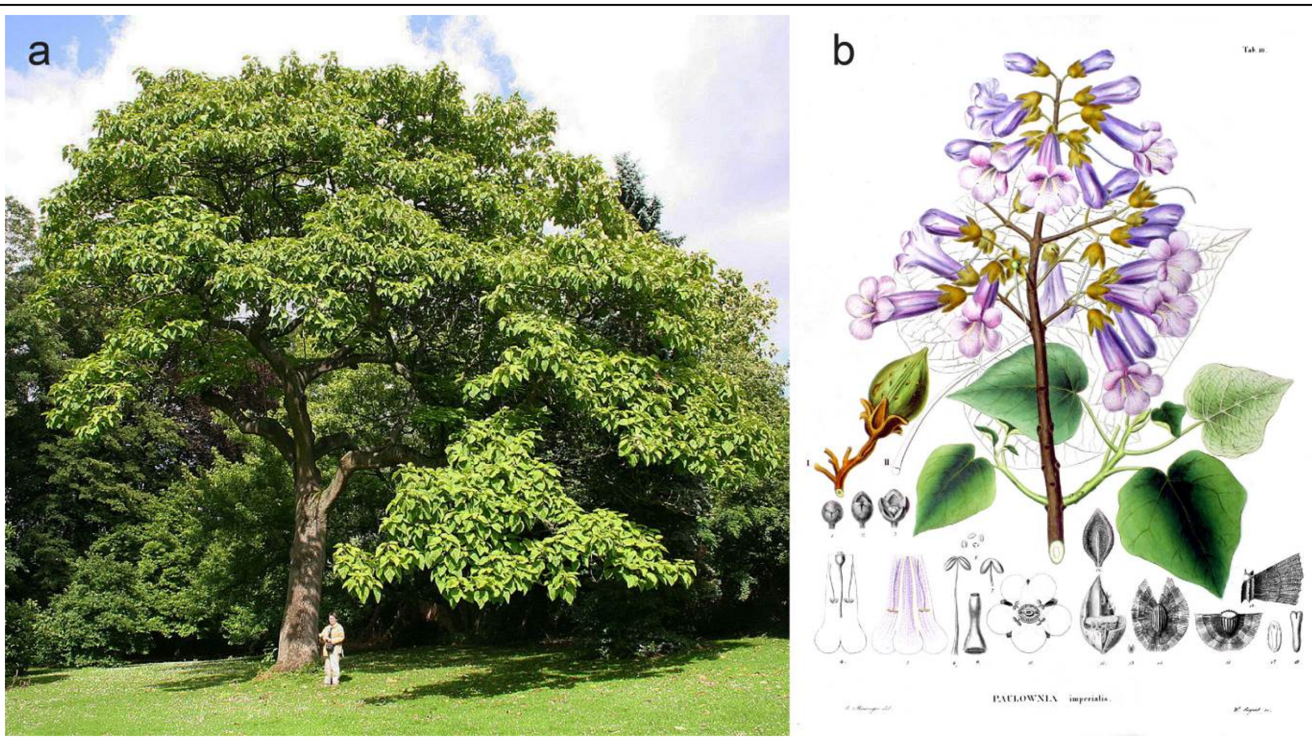

Figure 5. Paotong (泡桐) refers to several *Paulownia* species growing in China. It is a fast-growing tree with low wood density. Shown in (a) is *Paulownia tomentosa*, the empress tree, also called maopaotong (毛泡桐) or zihuatong (紫花桐). Photographed by Jean-Pol Grandmont (CC BY-SA 3.0) (b) An illustration of its leaves and flowers, from Siebold & Zuccarini, Flora Japonica, 1870 (public domain image).

IV. Construction principles

Why Chinese luthiers settled on the combination of tong and zi for guqin is a very interesting question. It probably resulted from trial an error, being the optimal solution based on common timbers available in China. But Chinese scholars also offered an explanation for this wood combination, recorded in *Taigu Yiyin* (太古遺音), a book from the Southern Song Dynasty (1127-1279) [20]:

The lightness of tong encounters the firmness of zi, as the hard matches the soft. (Appendix Entry 9-1)

Another book from the same era, *Dongtian Qinglu* (洞天清錄), offered an explanation for the softer top and harder back [21]:

The top is used to generate the sound, and the back is able to store the sound. If the back is not hard enough, the sound will certainly escape. (Appendix Entry 8-4)

According to Yoshikawa [22], woods suitable for soundboard and frame board (back and/or ribs) have rather different physical characteristics. Two factors appear to be important here: (1) the transmission factor cQ (c is speed of sound and Q is narrowness of resonant bandwidth, historically referred to as "quality" factor); (2) the anti-vibration factor ρ/c (ρ is wood density). Moreover, $c = \sqrt{(E/\rho)}$, where E is the Young's modulus (along the grain). Ideal soundboard materials should have greater transmission factor and smaller anti-vibration factor, which means that E and c should be high and ρ should be low. The quality factor Q, which is lower for more damped oscillators, should be high for good soundboards. In other words, tonewoods for soundboard should be stiff along the grain, low in density, and underdamped [22]. Moreover, greater anisotropy also helps improve sound transmission and frequency response [23]. This explains why wood with very straight grains are desirable for soundboards.

Tong is a very light wood with straight grains, and has been used as soundboards in many Chinese and Japanese instruments. Take *Paulownia* wood, for example, the speed of sound along the gain is 5300 m/s, basically identical to *Picea abies* [23], and almost approaching that of the steel. *Paulownia* has even lower density than *Picea abies*, resulting in a greater transmission factor. Ancient Chinese were indeed correct in stating that lighter soundboards can lead to more efficient sound generation.

Figure 6. Catalpa ovata, called zi (梓) tree in China. (a) Photo by Peter Coxhead (CC0 1.0 license). (b) Photo by Brandon Castellano (CC-By 3.0 license).

On the other hand, suitable woods for the back plate should have greater anti-vibration factor and lower transmission factor [22, 23]. This may explain why back plate materials (zi) is required to have higher density than soundboard materials (tong). The tong top and zi back are connected by two soundposts (pillar of heaven and pillar or earth, Figure 1), and the harder back will reflect energy back to the top. In a more complex sense, the soundpost alters the acoustic impedance of the vibrating plates and also affects the excitation efficiency of different modes. But the exact acoustic functions of soundposts are still difficult to predict using current computational methods.

The principle of choosing materials for guqin plates is quite similar to that of violin plates. The spruce for the violin top is light and straight, a highly resonant tonewood also used in guitars and pianos. The maple back is harder and reflects back the acoustic energy via the soundpost ([24] p. 223). Although viols and violins are invented 2000 years after the guqin, the underlying acoustic principles remain similar. The key is to achieve greater acoustic transmission efficiency, but luthiers also have to consider the matching of top and back plates to achieve a pleasant frequency response [23].

In the aesthetics system of guqin, acoustics plays a critical role. This was summarized in *Qinshi*, (琴史, *History of Qin*), written in 1084 [25]:

> *The qin has four beautiful qualities. The first is good materials, the second is skilled carving, the third is sophisticated fingering, and the fourth is a righteous heart. (Appendix Entry 6)*

Here, good materials refer to high-quality tonewood, which ranks first on the list. With the skills of the luthier, good wood is turned into an instrument with superior acoustics. The skill of the player ranks third, and the heart-felt emotion is last on the list. In general, Chinese philosophy valued human spirit much more highly than mundane materials. For their beloved guqin, however, they readily acknowledged that finding the best tonewood was the number one priority. For Chinese scholars, wutong is no ordinary tree. The great philosopher *Zhuangzi* (莊子, 369-286 BC) once wrote that the phoenix only rested on wutong trees [26]. The sacredness of wutong is almost certainly associated with its tonewood applications. For recent investigations on the acoustics of guqin, please refer to Waltham et al. [17].

There is another important similarity between guqins and violins—they both appear to improve acoustically over long periods of time, according to many leading players and collectors. In contrast, some wooden string instruments appear to show sound degradation over time, such as Chinese guzheng. Although there is little objective data on the acoustic improvement or degradation of string instruments, antique guqins and violins have fetched extraordinary prices in market auctions, but not guzheng or erhu (two-stringed Chinese fiddle). Ancient Chinese had a saying: “it is easy to see a 1000-year-old guqin, but rare to hear a 100-year-old guzheng.”

The primary causes of string instrument degradation are probably dimensional changes and high string tensions. Firstly, dimensional change is induced by moisture and temperature variations. Both violins and guqins have curved soundboards to prevent excessive deformation as wood expands and contracts. Secondly, for modern performances, many instruments have been fitted with higher-tension strings for greater playing volume. On violins, the gut strings were replaced by synthetic polymer and metal strings. On guqins, silk strings were also replaced by steel stings. The worst consequence of instrument degradation is the cracking of the plates. In terms of anti-cracking designs, the violin has purflings; Guqin is covered with several millimeters of highly durable lacquer coating, sometimes with thin cloth covered under the lacquer to cushion against bumping. The sister instrument of guqin, the guzheng (Figure 2), has an unvarnished paotong soundboard which has to withstand much higher bridge tensions from its 21 strings. Guzheng can play much louder than guqin, but its soundboard shows acoustic degradation after 20-30 years of regular playing. The thick plates and thick lacquer of guqins ensure their longevity.

V. Criteria for tonewood selection

In violins, it is generally believed that the front plate (soundboard) has a greater influence on the sound quality than the back plate. Although this concept is difficult to quantify, it is reflected in the very narrow choice of front plate material for master violins—a single tree species (*Picea abies*) from the southern side of Alps ([27] p. 60). In comparison, the back plate can be several species of *Acer* from different countries, with or without wide flames, even for the best Cremonese instruments [7, 28]. Similarly, the knowledge of tonewood selection in ancient texts is mostly concerned with tong rather than zi, emphasizing the importance of the soundboard. The earliest knowledge of tonewood selection can be found in *Shangshu* (尚書, *Book of Documents*), an anthology of ancient Chinese writings (2000-700 BC), edited by Confucius around 500 BC. When it discussed the geography of China in the Xia Dynasty (2000-1600 BC), a special type of tong wood was mentioned as a tribute to the emperor [29]:

Solitary tong tree from the southern slope of Mount Yi. (Appendix Entry 1)

Although guqin is not mentioned here, scholars have always interpreted this tong tree as precious materials for making musical instruments. Mount Yi (嶧山), which is 582 m high with rocky cliffs, provides a lookout point over the hometown of Confucius, about 30 km away. Confucius is said to have climbed this mountain, and, as a guqin player himself, might have known something about its tong trees.

In the Eastern Han Dynasty (25-220 AD), the "harvesting of tong branches (孫枝)" for guqin was first mentioned in Qinfu (琴賦, Ode to Qin) by Fu Yi (傅毅), and later in *Fengsu Tongyi* (風俗通義) [30]:

Wutong grows on the rocks on the southern slope of Mount Yi. Taking the branch facing southeast to make qin will produce a clear and elegant sound. (Appendix Entry 3)

The advice to harvest the branch is rather puzzling, but it has been repeatedly mentioned in many old books. For most tree types, the tonewood is taken from the straightest part of the trunk without any branch. The existence of a branch creates a knot in the wood which weakens the structure. Here we propose a plausible explanation for the branch tonewood. It is known that *Firmiana simplex* has a tendency to branch early in growth [31], resulting in three or so branches which grow like vertical trunks, giving the impression of multi-stem growth. The photo in Figure 4d shows this kind of "forked-stem" tree shape. The advice to cut the branch for tonewood may have meant to harvesting such "forked" trees in wild growth. We also know that Chinese luthiers were already using cultivated tongs trees back in 660 BC [15]. In *Tongpu* (桐譜, *Tong Manual*), the renowned forestry expert Chen Zhu (陳翥, 982-1061) recommended pruning tong tree branches within the first two or three years, in order to grow straight trunks with only high branches [32].

Like instrument makers everywhere, ancient Chinese luthiers were confronted with the challenge of picking one or two excellent trees out of a thousand to make a superior instrument. Luthiers or wood harvesters looking for supreme tonewood would have naturally examined the growth conditions of trees, including tree shape, branch direction, soil condition, exposure to the sun, and so on. It is difficult to validate if the recommendations given by the ancients were correct or still applicable today, but their writings suggest that they were very picky. Moreover, they have developed certain methods for grading tonewood according to physical properties, as summarized in these writings from the Song Dynasty:

Wood that feels solid and shows narrow grains like silk threads, which run tight and straight without crookedness, represents the finest materials. Even more marvelous are the ones that fingernails cannot sink into. (Dongtian Qinglu [21], Appendix Entry 8-6)

The qin material should be light, unhindered, crisp, and smooth, and these are the four virtues. (Mengxi Bitan [33], Appendix Entry 7-2)

It seems light when lifted; it vibration is unhindered when tapped; it breaks crisply when bent; it feels smooth to the touch. These are the four virtues. (Taigu Yiyin [20], Appendix Entry 9-1)

According to the above passages, in addition to visual inspection, ancient luthiers conducted various physical tests including density measurement, tapping, scratching, and bending. Tong for guqin is a low-density wood, and the luthiers were looking for straight grains with enhanced hardness and stiffness.

By understanding the desirable mechanical properties, we may better interpret why ancients recommended tong trees under specific growth conditions. First, open standing trees grow wider and faster than those in forests, due to more sunlight, and the latter generally produces better timber [34]. It appeared that ancients were looking for tong wood that grew very slowly—growing on rocks with poor soil support, with forked stems. They were probably also looking for wood that could resist bending. A solitary tree on a mountain rock is susceptible to strong winds. Among the forked stems, the one facing southeast will face stronger winds (based on weather data around Mount Yi [35]) and receive more sunlight to grow bigger. So the southeast branch-stem may be wider and more resistant to bending—resulting in better soundboard materials. One of the major complaints from modern luthiers working with *Firmiana simplex* is that they crack easily during sawing. Perhaps ancient Chinese were looking for particular trees that could provide a more workable wood. Because there lack systematic studies on the wood properties of *F. simplex* branch-stems, it is unclear if it is realistic to harvest them as tonewood.

It appears that ancient Chinese already understood that the sun and the wind could affect wood growth and mechanical properties, and modern research has also investigated such influences. For instance, wind can lead to greater microfibril angle ([36] p. 40) as well as greater density and ring width in the back side (away from the wind) of the trunk [37]. A single incident of strong wind can severely suppress tree growth for decades [38]. The side of the trunk facing the sun has wider ring, higher density and shorter fibers [39]. The specific effects of wind and sunlight on tong trees have not been scientifically examined yet, but evidently Chinese luthiers have paid close attention to such factors more than 2000 years ago.

The sunny and shaded side of the tree fits with the Chinese concept of yin (dark) and yang (bright). In *Dongtian Qinglu* (13th century), a clear explanation was given on how sunlight affects wood density, based on the concept of yin and yang [21]:

Guqin tonewood can be classified into yin and yang materials. Tong wood on the sun-facing side is yang, and the opposite side is yin. If you do not believe me, just take new or old tong wood and float it on water. The yang side will float and yin side will sink. (Appendix Entry 8-1)

Yin and yang properties had also been considered for selecting zi wood, and *Yongle Qinshu Jicheng* (永樂琴書集成, 13th century) had the following suggestion [40]:

Zi trees growing by the river is used for the bottom, but the pith should be avoided…… Wood that grows very straight, with yin and yang on opposing sides, and without any knot at the bottom face, are most appropriate for making qin. (Appendix Entry 10)

It may be inferred from the description that zi wood was cut on the slab, avoiding the pith, which allowed the yang (sunny side) and yin (shaded side) to be on opposing ends (see Figure 7). But ancient books did not specify where the yin side was placed, either under the low-pitch or high-pitch strings. In comparison, violin tonewood sellers do not appear to label the yin and yang side of their maple boards. Computed tomography (CT) examinations of guqins collected in the Palace Museum of Beijing have confirmed that most guqins had top and back plates built with slab-cut boards [14]. It was difficult to identify the tree species by CT alone, however.

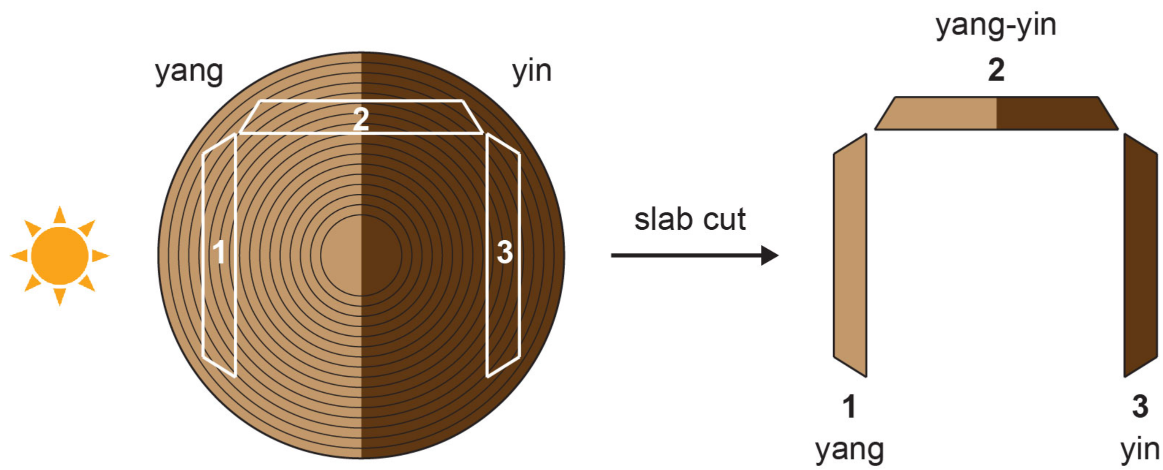

Figure 7. Yin and yang timber material. The shaded side is yin, and the sunny side is yang. The boards cut on the slab may be yin (#3), yang (#1), or yin-yang combination (#2).

VI. THE IMPORTANCE OF WOOD AGING

The golden age of Chinese guqin making was the Tang Dynasty (618-907 AD). The most famous makers of the Tang Dynasty were the Lei family (雷氏) in Sichuan Province, producing nine famous makers over several generations. The Lei family may be seen as the Chinese equivalent of the Amati or Guarneri family, and the few surviving examples of their instruments are legendary for their tone qualities. Regarding the acoustics of guqin, the Lei family made the following comment [41]:

Choose the finest materials and invest serious intentions, and the proper sound will develop after five hundred years. (Appendix Entry 11)

It is possible that the Lei family had played 500-year-old guqins or acquired very old wood for making guqin. But many modern luthiers simply consider this as ancient myth. We became interested in this particular statement because we have recently measured the half-life of hemicellulose decay in Stradivari's maple wood, and it turned out to be around 400 years [42], lending some support to the claims of the Lei family. Other studies have suggested that spruce aged for 390 years has significantly lower sound velocity ([43] p. 198-201).

The opinion of Lei family was further supported by Shen Kuo (沈括, 1031-1095), one of the most famous scientist in ancient China. In *Mengxi Bitan* (夢溪筆談, *Dream Pool Essays*), he wrote [33]:

The qin is made of tong, but many years must go by to remove the woodiness, and the sound will become more resonant. (Appendix Entry 7-1)

Unfortunately, Shen Kuo did not further explain what woodiness meant. About 200 years later, Zhao Xihu (趙希鵠), a member of the Song royal family and a renowned collector of antiques, offered more detailed explanations about tonewood aging in his book, *Dongtian Qinglu* [21]:

In general, tong wood with great hardness and over one thousand years old has already lost most of its liquid. (Appendix Entry 8-3)

The suitable zi wood are five to seven hundred years old. After sawing it open, only those hard enough to resist the scratching fingernail can qualify. (Appendix Entry 8-5)

Guqin is more difficult to acquire than fine gold or beautiful jade. If old tonewood is available, order a fine craftsman to make a qin without hesitation. Those who deliberated over tonewood selection in the past used to say: "paper steamers, wash basins, wood fish, drum shells, broken coffins, old beams, pillars, and rafters." But pillars and beams may have their wood grain damaged by heavy loading. Broken coffins are rarely made of tong wood. Steamers and basins may be too thin and absorbed too much moisture. Only wood fish and drum shells that are close to bells and drums day and night, penetrated by the sound of the metal, qualify as the finest material, but they may also suffer from mechanical damage. (Appendix Entry 8-2)

Zhao explained that old wood loses its internal liquids, and the drying process could continue for 500-1000 years. Even in the Song Dynasty, it was very difficult to find old tong wood for guqin, to the extent that even old coffins were considered. Zhao believed that weight loading and vibrations could damage the wood, but sometimes favorable vibrations can improve wood quality. The Buddhist temples used to sound the bells and drums daily, and the wood fish is a kind of large wooden drum without skin. But is there any objective basis for his claims?

Much to our surprise, our recent data on Italian violin research appear to lend some support for Zhao's claims. The loss of "liquids" in old wood may be interpreted in two ways. First, it may refer to the decomposition of sap residues, the soluble components of tree saps being left behind after initial drying, becoming a part of the extractives. Secondly, it may refer to the reduction of equilibrium moisture content, as the wood becomes less hygroscopic. Our recent study on Stradivari's maple wood suggests both may be happening [42]. We observed by ^{13}C nuclear magnetic resonance that hemicellulose gradually decomposes in the maple wood. Some of the carbons in hemicellulose sugars may be lost from the wood by turning into volatile organic compounds [44]. Similarly, some sap residues could also oxidize and decompose, sometimes turning into volatile organic compounds and eventually vanish. Hemicellulose is the most hygroscopic component of wood fiber, and hence its decomposition reduces the equilibrium moisture content of wood.

Stradivari's maple absorbs about 25% less moisture compared to modern maple [42]. Most studies on aged wood have also reported lower moisture content [45], in good agreement with ancient Chinese texts.

Furthermore, we have observed that the combustion thermograms of maples are different for Stradivari violins versus Stradivari cellos. In these experiments, wood flakes were gradually heated in atmospheric air to 600 ^{o}C. The heat released at different combustion temperatures was recorded by a calorimeter. Normal maple and Strad cello maples showed two stages of combustion (two heat-releasing peaks). Maples from Strad violins exhibited three combustion stages, which corresponded to the three major components of cell wall—hemicellulose, cellulose, and lignin. This implies that the molecular adhesion between these three components have been reduced in Strad violins [42]. One plausible explanation is that 300 years of high-frequency vibration is sufficient to cause molecular rearrangement, and this appears to corroborate Zhao's statement that constant vibrations may alter acoustic qualities.

European luthiers have long experimented with taking spruce beams and pillars from old buildings to build violins. The general consensus is that the results are mediocre at best [7]. We have recently analyzed 300-year-old spruce from old European buildings by X-ray diffraction. The diffraction signals from two out of three samples were severely attenuated, indicating that crystalline cellulose had partially transformed into amorphous cellulose (unpublished data). The reason for such changes remains unclear, but no sign of structural damage was apparent to the eye. The loss of crystalline cellulose, the main structural support of wood cell wall, would have softened and weakened the wood, reducing the axial stiffness [46]. It is impossible to check every part of the old spruce board for crystallinity loss, and hence it is a risky material to use for violin plates. Ancient Chinese luthiers already understood such risks and offered their warnings in writing. Such internal degradation could have been detected by wood workers through tapping, scratching, or the dulling of knives. On the other hand, 300 years of vibration does not seem to affect cellulose crystallinity in Cremonese instruments. We have tested a dozen Cremonese spruce and maple samples and all showed normal diffraction patterns ([42] and unpublished data).

Even in the Song Dynasty, when China was much more forested than today, finding old wood suitable for making instruments was a very difficult task. It is often said that, for newly harvested spruce wood, only one tree in a hundred or a thousand may qualify as tonewood, and only certain parts of the tree are suitable. To encounter a random piece of old tong or zi wood that happens to possess tonewood quality is a very rare event. Therefore, *Taigu Yiyin* recommended old woods other than tong and zi for making guqin, as long as they were old enough [20]:

> *The qin does not necessarily require tong and zi. One may choose any wood of which the liquid is exhausted and the muddiness is removed. (Appendix Entry 9-3)*

In practice, however, only a few trees seem suitable for guqin acoustics. Shan, the Chinese fir, is often used as an alternative for the top plate and occasionally for the back. Today, tong wood aged over 200 years is very hard to find, and most luthiers could only find aged shan wood instead. Aged shan wood was highly recommended in *Yuguzhai Qinpu*, which also gave some general precautions about decay issues [47]:

> *Shan wood over several hundred years old will also qualify. (Appendix Entry 13-1)*

> *Tonewood for qin should be transformed. Transformation does not equal decay. Decay causes the wood material to rot, which crumbles to dust when rubbed. Transformation preserves the wood material but removes the turbid liquid, giving a light feel when lifted. The fingernail does not easily sink into it. If hit by a heavy object or dropped abruptly, it breaks crisply. (Appendix Entry 13-2)*

Aging has been shown to affect the mechanical properties of wood mainly due to molecular decomposition and cell wall disruption (reviewed in [19], p. 308-344). However, the changes appear to be quite specific to each wood species, without a general way of prediction. There has not been any scientific study on the aging of tong or zi yet, but there is little doubt that their mechanical properties will also be affected by aging just like other wood species already investigated.

VII. DRYING AND ACCELERATED AGING

The importance of wood aging proposed by the Lei family in the Tang Dynasty was widely accepted by luthiers of the Song Dynasty. However, tonewood seasoned for hundreds of years has always been difficult to find, and it was natural for luthiers to experiment with artificial wood aging.

The wood is composed of cell walls left behind by dead wood cells. The cell wall contains three types of biopolymers—cellulose (straight-chain polymer of glucose), hemicellulose (branched polymer of mix saccharides), and lignin (polyphenolic compound) [48]. As wood ages, there are two prominent chemical changes—decomposition of hemicellulose and oxidation of lignin. These chemical reactions can also be accelerated by heating [49]. Lignin oxidation is easily manifested as the yellowing or browning of wood, but hemicellulose degradation requires spectroscopic techniques to detect, such as ^{13}C nuclear magnetic resonance spectroscopy or infrared absorption spectroscopy. Some researchers hypothesize that heating can approximate the process of wood aging [50], but we consider this as an oversimplification.

The potential benefit of heating tonewood was already well recognized in the 2nd century AD, due to the story of the "Burnt-Tail Qin." This renowned instrument was owned by Cai Yong (蔡邕, 132-192), a famous scholar, artist, and musician. The birth story of this serendipitous instrument could be found in official historical records [51]:

A person from Suzhou region was burning tong wood for cooking. Yong heard it crack in the fire and recognized a fine piece of wood. He asked to have it carved into qin, and the tone was beautiful indeed. Its tail still carried burning marks, and hence people named it the "Burnt-Tail Qin." (Appendix Entry 4)

The Burnt-Tail Qin was arguably the most famous guqin in Chinese history due to its superlative tone qualities, and it inspired luthiers to seek naturally burnt wood. Liu Zongyuan (柳宗元, 773-819), a famous scholar and qin player, also gave high praises to instruments made with lightning-struck wood. He therefore composed "Pili Qinzan" (霹靂琴贊, Ode to Thunder Qin), and in the introduction he said [52]:

The best material for guqin is tong tree. The best tong tree grows on the rock. A dead tong tree on the rock is even better. If it was burned by fire, even more superior. If the fire was caused by lightning strike, the properties would be unique. A qin made from such wood is both superior and unique, combining two beautiful qualities. (Appendix Entry 5)

Not only has Liu noticed the benefit of slightly burned wood, he also recommended harvesting "standing dead trees"—dead trees that remain upright, not falling got the ground. Tonewoods baked by natural or accidental fires to just the right degree for instrument building are rare at best, and ancient luthiers have attempted to replicate this process under controlled conditions. This process has been described in detail by a monk musician called Juyue (僧居月) from the Song Dynasty [53]:

Cut the trees in December and place timber at a shaded spot in a spacious house with good air circulation for drying. Then it will be ready for carving into guqin. For both tong and qiu, the yin side is removed and the yang side is preserved. Prepare a hot stove, take the yang side, and bake it with charcoal fire. The hot stove, also called an earthen stove, should be next to the wall. The wood is placed one meter above, sitting on an iron rack on the wall, and turned frequently during heating. If husks are burned for fire, the sound will be muddy. Between five and ten days, the wood will gain a smoky color. The wood is weighed to determine the degree of drying. When the weight remains constant without further decrease, the wood is fully dried, reaching the ideal state of baking. After the wood is removed, listen to its tap sound, and the ideal response should be firm, forceful, clear, and resonant. (Appendix Entry 12-1)

This relative brief description by Juyue demonstrates a clear understanding of wood drying know-how, still valid after almost 1000 years. First, his recommended to cut the tree in the winter. Living trees contain a lot of water and sap, and after cutting they are lost rapidly from the large vessels in wood. At this stage, it is important to prevent microbial growth and shrinkage damage due to rapid water loss. The cold temperature in winter can reduce both risks. The water content of wood is also lower in winter [54], which makes it lighter and easier to handle. It is often said that the best resonant spruce for violins were traditionally cut in December and January ([55] p. 128, [56] p. 198-199). After a few days or weeks, the liquids in larger vessels are mostly lost, but there is still water retained by capillaries and surface adsorption. The tonewood then needs to enter a second phase of drying, which is best carried out by the natural circulation of air in a very slow manner. Juyue did not explain how long this period should be. Violin tonewoods are generally air-dried for 3-10 years before use, but sometimes extending to decades ([43] p. 198-201, [55] p. 129). A rule of thumb given by wood workers is that every millimeter of board thickness requires one year to fully dry. For guqin, this could equate to 20-30 years.

The moisture content of wood affects its acoustic properties. Higher moisture leads to lower Young's modulus, lower shear modulus, slower speed of sound, and increased damping ([43], p. 241-245). Therefore, wood that is not fully dried is unsuitable for making string instruments. Although wood materials will eventually become fully dried over the years and reach a state of equilibrium with its environment, the process of reaching that dried state is very crucial. Violin makers have always known that rapid drying of wood by heating (kiln dry) is inferior to the slower process of air drying. Air-dried wood has better dimensional stability and less internal tension ([43] p. 199-200, [56] p.216). Ancient Chinese luthiers had the same experience, as reported in *Qinshu Daquan* (琴書大全, Complete Anthology of Qin) from the 16th century [57]:

> *The best qin tonewood is dry and light, having been stored for long periods after cutting the tree. If the wood material still contains excessive moisture, the sound will lack clarity. Upon acquiring new tonewood, some are impatient and apply baking to quickly drive out the moisture. Even if complete drying is achieved this way, the quality of wood will be compromised. (Appendix Entry 12-2)*

For the purpose of instrument making, the aging of wood is only counted after the tree is cut or dead, as water is lost and the air (with oxygen) enters. Wood harvested from very old living trees is still considered fresh wood, not aged wood. Standing dead trees, as recommended by Liu, will naturally dry out and start to age on its own [58]. However, dead trees falling to the ground are easily subjected to biological attacks and decay too quickly. In modern times, if luthiers wish to experiment with wood aging by heating, one would start with wood that has been air-dried for years, and this is exactly what Juyue had recommended ten centuries ago.

Another interesting recommendation by Juyue is to use only the yang material in tonewood. We could not find any research comparing the vibrational properties of yang and yin materials from the same tree, but some violin makers also believe that the sunny side of the tree is better ([55] p. 128). Some have proposed that, because trees often lean to toward the sun as they grow, the sunny side (yang) is under constant compression and that such material can better cope with the string tension applied to it [59].

In modern timber industry, the temperature applied to dry wood is kept below 120 ^{o}C to avoid chemical changes [60], and the temperature required to accelerate wood aging by promoting chemical changes is around 180-220 ^{o}C [61]. The humidity condition during and after heating can also affect the chemical properties of wood [50], and Juyue also noticed that charcoal fire (low moisture) and husk fire (high moisture) would lead to different results. While some researchers [62] believe that heating can approximate the effects of aging by promoting hemicellulose degradation and lignin oxidation (browning), we are quite skeptical about this. In our opinion, chemical reactions occurring slowly over hundreds of years will not be the same as those forcibly accelerated by heating over just a few hours or days. Recently, we have compared the infrared absorption spectra of maples from 18th-century instruments to maples that underwent artificial aging—boiling, steaming, baking, and UV exposure. None of these four methods reproduced the spectral changes found in old instruments (unpublished data). Obviously, some of the chemical reactions caused by natural aging are not fully recapitulated by artificial aging. In fact, we are not the only skeptics here—Zhao Xihu had expressed similar concerns nine centuries ago [21]:

> *Ancient people immersed tong and zi in water for long periods, or hung them above the stove, or sometimes exposed them to the sun and wind. Despite a myriad of artificial means, the results are inferior to natural aging. (Appendix Entry 8-7)*

On a side note, the soaking of tonewood in the past was sometimes intentional and sometimes out of necessity. Heavy logs were often transported by floating down a river before trucks were invented. Sometimes logs were ponded for months or years for extended storage. Recently, it has been reported that soaking tonewood in distilled water is sufficient to reduce the damping efficiency [63]. It has been proposed that wood storage in ponds or lagoons may also bring biological attacks that alter wood porosity [64].

VIII. Chemical treatments

After experimenting with various artificial methods for wood aging, Chinese luthiers did not overlook the possibility of chemical treatments. The history of wood chemical treatments is very ancient both in Europe and China. In ancient Rome, alum was soaked into wood for flame retardation purposes ([65], p. 541). In the 4th century AD, copper acetate was used as a wood preservative by chemical impregnation in China [66]. More recently, chemical analyses of wood shavings removed from Cremonese violins during restoration have revealed that Stradivari and Guarneri used chemically treated wood. The chemical they applied may have included alum borax, zinc sulfate, copper sulfate, and table salt [42, 67]. In violin making, the use of chemically treated wood by Cremonese masters may be considered a secret, because no one knew about it until chemists started to analyze their instruments [67, 68]. In the 19th century, some violin makers experimented with chemical treatments of wood, but it was never accepted by the mainstream ([55] p.130-131). By contrast, Chinese luthiers have clearly stated that chemical treatment could be applied to tonewood for artificial aging. This was recorded by Zhu Fengjie (祝鳳喈), a leading authority on guqin, in *Yuguzhai Qinpu* (與古齋琴譜, 1855) [47]:

Concerning the sap in tong wood, it is easy to let it dry out, but difficult to remove completely. If the sap is not removed, the sound is muddy and lacks clarity and brilliance. The method of sap removal: take a tong board about 4 cm thick and make its top somewhat rounded, and slightly hollow the bottom face, so the final dimensions are similar to those of the qin. Place this board in the paper pulp pool (a pool of lime solution for soaking bamboos in papermaking), and immerse for one to two months to gain the lime-ness which will remove the sap. Retrieve and place it in a clear creek or under a waterfall to remove the lime-ness for approximately three to four months. Retrieve it and hang it at a place exposed to hot winds and strong sun (but under a cover to avoid rain), and let it dry completely. Knock on the wood every day for testing—wait for the sound to become clangorous before carving it into an instrument. Although it still lacks the marvels of aged materials, the beauty of the new material can at least be enhanced. (Appendix Entry 13-3)

From the perspective of modern science, the alkalinity of lime water (calcium hydroxide) may help dissolve wood extractives with acidic groups (resin acids, phenols, fatty acids, etc.) [69]. The reason for soaking bamboo for papermaking is to hydrolyze hemicellulose in order to isolate cellulose in the end. While too little alkalinity may do nothing to the wood, too much of it may cause excessive wood damage. In our preliminary tests, a very thin slice of wood wutong or maple shows moderate hemicellulose degradation at around pH 11.5-12 after one or two days (unpublished data). An alkaline solution continues to absorb CO_2 from the atmosphere, and we could observe an obvious drop in pH after just one day. How ancient craftsmen had tried to control the pH of the lime pool remains unclear.

In this passage, Zhu mentioned lime-ness (灰氣) twice, but they carry different meanings. In the first case, calcium oxide (lime, 石灰) is dissolved in water to generate calcium hydroxide solution:

$$CaO_{(s)} + H_2O_{(l)} \rightarrow Ca(OH)_{2\,(aq)}$$

Zhu believed that it takes 1-2 months for lime-ness, the basicity of calcium hydroxide, to completely transform the wood. This is limited by the rate of liquid penetration and diffusion in thick wooden boards. Afterward, Zhu recommended removing the lime-ness by washing with running water for 3-4 month. In this case, lime-ness is referring to calcium carbonate that precipitates in the wood, as carbon dioxide is continuously absorbed from the air:

$$Ca(OH)_{2\,(aq)} + CO_{2\,(g)} \rightarrow CaCO_{3\,(s)} + H_2O_{(l)}$$

Calcium hydroxide is sparingly soluble in water, and therefore soaking it in still water is insufficient for its removal. Once the water is saturated by tiny amounts of dissolved calcium carbonate, an equilibrium is reached and the following reaction does not move to the right anymore.

$$CaCO_{3\,(s)} + H_2O_{(l)} \rightarrow Ca^{2+}_{(aq)} + CO_3^{2-}{}_{(aq)}$$

To keep driving the above reaction to the right, one needs to continuously remove the product ions, and this can be achieved by washing in running water. This is called Le Chatelier's Principle in modern chemistry textbooks. Deep in the wood, the diffusion is slow and the removal of calcium carbonate takes a long time. Zhu noticed that residual calcium carbonate can negatively affect the acoustics. In the end, Zhu still believes that artificial aging using alkaline treatment is not as good as natural aging, echoing the opinion by Zhao Xihu.

Based on our literature search, *Yuguzhai Qinpu* appears to be the only old book to have mentioned the chemical treatment of guqin tonewood, and its publication date was 1855. However, it remains plausible that chemical treatment had already been attempted centuries before that. Some lutherie techniques were never recorded in writing, while many published texts have been lost. In fact, there was never any record or even conjectures about soaking maple tonewood in mineral solutions, but the analytical evidence clearly indicates such practices in Cremona during the early 1700s [42, 67, 68]. With the gradual evolution of lutherie in both the Europe and China, many makers and players have come to believe in the acoustic benefits of aging, whether correctly or incorrectly. This eventually led to experiments in the chemical treatment of wood to achieve some sort of uniqueness or competitive edge.

IX. Cultural value considerations

In 2012, "Traditional violin craftsmanship in Cremona" was listed as an Intangible Cultural Heritage with the United Nations Educational, Scientific, and Cultural Organization (UNESCO). Similarly, "Guqin and its music" was listed even earlier in 2008. Compared to Cremonese violins, guqin culture was much more endangered in the 20th century. In the 1960s, the cultural turmoil in China had almost completely halted guqin education and manufacturing, and the number of serious guqin players dropped below 300 worldwide, most of whom were over 60, born under the imperial period. Guqin heritage received a great boost with the launch of Voyager 1 Space Probe by NASA in 1977. The Voyager carried a Golden Record containing music meant to represent the human civilization, which included a guqin piece called "liushui" (流水, flowing streams). A renaissance of guqin soon followed, and today there is a vibrant guqin culture flourishing in China again.

Somewhere along the history of guqin, it was transformed from an ordinary musical instrument to a valuable collectible. In "Ode to Qin" (琴賦), Fu Xuan (傅玄, 217-278) described four famous named instrument and their respective owners [70]. The oldest was named Haozhong (號鐘, Sounding Bell), owned by Duke Huan of Qi (齊桓公, ?-643 BC). The youngest on the list was the "Burnt-Tail Qin," which has been discussed earlier. Giving instruments individual names and associating them with famous owners was a sign that a collection system for guqin had already formed. This collection system appears to date back to the 7th century BC. The oldest guqins we can play today date back to the 8th century AD, comparable with the oldest wooden building in the world—Horyu-ji Temple in Nara, Japan, built in 711 AD.

In addition to being beautiful antiques and cultural symbols, guqins made before the Qing Dynasty are believed to sound warmer and more rounded. Ancient luthiers generally attributed this gradual acoustic improvement to wood aging. However, some modern makers believe the aging of lacquer coating may also play a role. Scientific examination of lacquer aging is very difficult because instruments are frequently re-lacquered. It is difficult to tell which layer belongs to the original coating. In contrast, the interior of the instrument is not lacquered, and, during restoration, it is sometimes necessary to remove some wood (similar situations occur during violin restoration). This allows research samples to be collected without causing harm to antique guqins.

In most cases, ancient guqin makers did not leave their names or personal marks on the instrument. When they did, their name and year of making were generally written in black ink with a brush over the bare wood in the interior. But this signature could be easily forged when the instrument was opened for repairs. To determine the maker or the era, experts mostly rely on instrument geometry, the peeling and fracturing pattern of lacquers, and other visual cues. In the future, ^{14}C radiocarbon dating may provide some assistance to instrument authentication. With current technology, 5-10 milligrams of wood over 500 years old can be routinely dated. Considering the thickness of guqin plates, the removal of such small wood quantity is basically harmless. Radiocarbon can only tell us when the tree was growing, not when it was carved into an instrument. It is useful for establishing the upper limit of age, but not the lower limit. On the other hand, antique violins are generally too young for radiocarbon dating, but dendrochronology dating may be possible if the spruce originated from certain Alpine forests with good database records [71, 72]. In guqin, however, the wood sources are too variable to establish useful dendrochronology tests.

In the past, many guqin players knew how to repair guqin and some of them also made guqin. Therefore, guqin players not only collected the instrument, but they often collected old tonewood as well. For instance, when the library attic of a Tang-Dynasty temple collapsed some years ago, a guqin collector acquainted with the author rushed to buy its remaining wood materials. It is unclear the library attic was still the original Tang-Dynasty structure, or had been rebuilt during later periods. Radiocarbon dating will be very helpful in this regard. With the increasing rarity of very old tonewood, especially *Firmiana simplex*, there may be a new trend for guqin players to become proactive in collecting tonewood, who will then commission skilled makers to build custom instruments. From the cultivation of tong an zi trees in 660 BC [15] to the present day, tonewood procurement has always been a pivotal issue in guqin culture.

X. Opportunities for future investigation

Wood is an enigmatic material. On one hand, it is the most abundant organic substance on earth, due to its structural and chemical stability. On the other hand, its molecular composition and architecture are so complex that investigations are still ongoing, even after a century of wood research. Aging of wood and chemical treatments of wood can only make the problem even more complex.

In modern laboratory settings, it is very difficult to study the process of wood aging. Methods that accelerate wood degradation in the lab are not equivalent to actual aging processes. So far, the scientific study on the acoustic changes during aging has been limited to three years on the violin, and the result was negative [73]. But many players still believe that instruments over 200 years old seem to respond and sound differently compare to instruments under 50 years old. Nonetheless, such anecdotal observations have never been verified by controlled studies. To the naked eye, the color of the wood can show progressive color changes after 50-500 years of aging. To see beyond that, scientific instruments are required.

So far there has only been one scientific study that carefully examined wood aging in antique violins [42], and it clearly demonstrated that hemicellulose decomposition reduces the equilibrium moisture constant of maple wood in Stradivari instruments. In fact, there are distinct advantages for studying wood aging in antique violins compared to aged wood from old furniture, old buildings, or archaeological sites. First, spruce woods used to build violins are relatively similar in initial properties and of more consistent quality compared to spruce woods for other purposes; the same can also be said for maple woods. Secondly, spruce and maple tonewoods have been carefully preserved inside musical instruments, much more shielded from environmental stresses and biological attacks.

The oldest violins are only about 450 years old. This corresponds to the Ming Dynasty (1368-1644) in China, and in the guqin world that is not very old. There are still hundreds of well-preserved guqin over 500 years old, some even going back to the 8th century. Hence, guqins offer exciting new opportunities for studying wood aging and its impacts on instrument acoustics. According to ancient Chinese, the effects of wood aging become more obvious after 500 years. In guqins, such degrees of wood aging are believed by many to bring favorable acoustic effects. But we do not know if it will be the same for violins, because no violin has reached this age yet. By studying how wood ages in guqin over a millennium, we will better understand how to preserve antique Italian violins and other wooden instruments for future generations. Another important advantage of studying wood aging in guqin is that ancient luthiers and scholars have offered plenty of observations and tips, which can be useful guidelines for future scientific experiments. For instance, we can test if calcium hydroxide treatment produces the same molecular changes as long-term aging.

Subject of inquiry	Instrument/method
Thermal properties	Thermogravimetric analysis Differential scanning calorimetry
Age	Radiocarbon dating
Anatomical structure	Scanning electron microscope Optical microscope X-ray tomography
Molecular structure	Small-angle X-ray scattering Wide-angle X-ray diffraction Second and third harmonic generation spectroscopy
Organic composition	^{13}C & ^{1}H solid-state nuclear magnetic resonance spectroscopy Infrared spectroscopy Raman spectroscopy Ultraviolet-visible light spectroscopy
Inorganic composition	Inductively coupled plasma-mass spectrometry X-ray absorption spectroscopy and fluorescence microscopy ^{27}Al & ^{11}B solid-state nuclear magnetic resonance spectroscopy

Table 2. Analytical methods used by our laboratory for investigating tonewood alterations

By contrast, European luthiers have been less outspoken about the issue of wood aging and artificial treatments. Although Cremonese masters clearly applied chemical treatments to their wood, for reasons not yet entirely clear, they did not leave any trail of evidence. Just one generation later, Count Cozio and his luthier partners (Guadagnini and Mantegazza) already appeared to be unaware of such secret techniques [8]. The French luthiers and bow makers appeared to be more openly interested in wood aging. It is often said that J. B. Vuillaume had conducted experiments with wood baking and chemical treatments, often with poor results in the long run, but he was unwilling to admit to such tricks in his lifetime [55, 56, 74]. Jacques Français believed that aged pernambuco becomes drier and harder, which makes it difficult to replicate the superior quality of antique French bows ([75] p. 45).

To truly understand the effects of artificial treatment and natural aging in the wood of violins, violin bows, and guqin, it is important to collect wood shavings for chemical analyses. As little as 30 mg of wood can give some useful analytical results. The best opportunity to remove wood samples from violin plates, which are only 3-4 mm in thickness, is during crack repair. During repairs, damaged wood is sometimes removed and replaced by new wood. Wood may be similarly removed from guqins during restoration. Moreover, guqin plates may be thicker than 20 mm in some places, and the intentional removal of wood for research purposes is possible without affecting its acoustic performance.

We are currently collaborating with multiple laboratories around the world to examine antique instrument wood samples (violins and guqins) using a wide range of techniques, as listed in Table 2. There are many additional testing methods that could be applied to the study of tonewood properties, especially mechanical and vibrational measurements. Frankly, the study of tonewood by scientific means is still an immature and underexplored field. It should be further noted that studying the vibration of individual plates does not give full insights into the structural acoustics of assembled instruments under actual playing conditions. Important discoveries in the structural acoustics of violin has been summarized by Bissinger [76], but similar investigations have not been conducted for guqins.

XI. Conclusion

Chinese people invented the prototype zither more than 4000 years ago and have been fascinated by it ever since. These zithers were plucked string instruments with silk strings and wooden resonators. From historical texts, we know that the basic combination of lacquered tong and zi plates have been used to build guqin for 2700 years. This gave ancient Chinese luthiers plenty of opportunities to experiment with instrument forms and wood selection and to observe the effects of long-term aging on tonewood and instruments.

The modern form of guqin was probably invented around the 3rd to 5th century AD, and the oldest surviving playable instruments date back to the Tang Dynasty (618-907). The Tang Dynasty has always been considered as the Golden Age of guqin making in Chinese history. Famous luthiers of the Tang Dynasty proposed that 500 years of aging is required for superlative acoustics, and this has become a doctrine adopted by later luthiers until the present day. Luthiers of the Song Dynasty (960-1279) had already experimented with various ways of artificial aging, including soaking, baking, and weathering. Alkaline treatments to promote wood aging was later proposed as well.

Today, it is generally believed that the finest guqins in terms of acoustic performance are from the Ming Dynasty (1358-1644) or earlier ([16], p. 252). Is it really because the luthiers of the Qing Dynasty (1644-1912) were inferior in talents, skills, or techniques? Or is it because the instruments of the Qing Dynasty have not aged long enough for optimal performance? There is no general consensus among the guqin players and collectors on this issue. We need to analyze actual wood samples taken from antique instruments to figure out the real effects of aging. Just like previous research on antique violins, wood shavings removed during guqin restoration are valuable research samples. A close collaboration between guqin restorers and scientists will bring real progress to the field.

The general principles of tonewood harvesting and selection mentioned in ancient Chinese texts are quite similar to those in Western traditions. These represent the collective wisdom of ancient woodworkers and luthiers across different cultures. The ancient Chinese knowledge on wood aging and artificial aging is particularly valuable because related experiments are difficult to conduct in modern laboratories. The importance of wood aging on violin acoustics is gaining recognition as recent research identified age-related wood changes in Stradivari violins. It has never been difficult to apply some kind of harsh treatment on wood to alter its mechanical properties, but it is difficult to ensure that a particular treatment method will bring long-term acoustic benefits instead of compromising structural integrity. Chinese luthiers have conducted many experiments along this direction and their cumulative experience may bring new inspirations for 21st-century luthiers. In fact, there is much room for further development, especially along the direction of material property-acoustics relationships.

Artificial aging and chemical treatments of wood are challenging processes because it is difficult to achieve homogeneity, both between and within samples. The treatment could be easily overdone or underdone in the absence of quality assurance assays. Modern science can provide many tools to monitor the progress of wood treatments to ensure reproducibility. From the experience of Italian and Chinese master luthiers, it appears that chemical treatment is the final frontier of tonewood knowledge. Even before the era of modern science, old masters in China and Italy were already using their rudimentary chemical knowledge to modify wood properties. 21st-century luthiers should be possible to surpass the achievements of the old masters, given the fact that we have so much better understanding of wood chemistry and acoustical physics.

However, there is no simple way to reproduce the effects of aging through physical and chemical manipulations. It is possible that the finest guqins made in the 21st century will also have to wait for several centuries to reach their peaks in terms of acoustic performance. In ancient Chinese paintings, calligraphy, and literature, the artists were interested in long-lasting values left for posterity, and the same applied to guqin as well. Great masters of the past have taught us to be patient with the wood and wait for 500 years, and this is perhaps the greatest lesson we can learn from the traditional culture of guqin—it's a transcendent experience, beyond just “us and now.” A single tree can live up to five thousand years, and a single guqin can still sound mesmerizing after 1300 years. Much of the complexity of wood, guqin, and music perception are still beyond the analytical capability of modern science. There is much more to learn.

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XII. Appendix

The following entries are book passages that have been translated into English by the author. The books are arranged in chronological order (see Figure 3).

1. *Shangshu* (尚書・禹貢) [29]

嶧陽孤桐。

2. *Shijing* (詩經・定之方中) [15]

樹之榛栗，椅桐梓漆，爰伐琴瑟。

3. *Fengsu Tongyi* (風俗通義) [30]

梧桐生於嶧山陽巖石之上，採東南孫枝為琴，聲甚清雅。

4. *Houhanshu* (後漢書・蔡邕列傳) [51]

吳人有燒桐以爨者，邕聞火烈之聲，知其良木，因請而裁為琴，果有美音，而其尾猶焦，故時人名曰焦尾琴焉。

5. Pili Qinzan Bingxu (霹靂琴贊並序) [52]

琴莫良於桐，桐之良，莫良於生石上，石上之枯，又加良焉，火之餘，又加良焉，震之於火為異。是琴也，既良且異，合為二美。

6. *Qinshi* (琴史) [25]

琴有四美，一曰良質，二月善斫，三曰妙指，四曰正心。

7. *Mengxi Bitan* (夢溪筆談) [33]

7-1. 琴雖用桐，然須多年木性都盡，聲始發越。

7-2. 琴材欲輕、鬆、滑、脆，謂之四善。

8. *Dongtian Qinglu* (洞天清錄) [21]

8-1. 古琴陰陽材者：蓋桐木面陽日照者為陽，不面日者為陰。如不信，但取新舊桐木置之水上，陽面浮之陰必沈。

8-2. 古琴最難得於精金美玉。得古材者，命良工旋製之斯可矣。自昔論擇材者曰：「紙甑、水槽、木魚、鼓腔、敗棺、

古樑柱、榱桷」。然樑柱恐為重物壓損紋理，敗棺少用桐木，紙甑水槽患其薄而受濕氣太多，惟木魚鼓腔晨夕近鐘鼓，為金聲所入，最為良材。然亦敲損之患。

8-3. 大抵桐材既堅而又歷千餘年，木液已盡。

8-4. 面以取聲，底能匱聲，底木不堅，聲必散逸。

8-5. 當取五七百年舊梓木，鋸開以指甲掐之，堅不可入者方是。

8-6. 宜擇緊實而紋理條條如絲線，細密條達不邪曲者，此十分良材，亦以掐不入為奇。

8-7. 古人以桐梓久浸水中，又取以懸竈上，或吹曝以風日。百種用意，終不如自然者。

9. Taigu Yiyin (太古遺音) [20]

9-1. 舉則輕、敲則鬆、折則脆，撫則滑，謂之四善。

9-2. 以桐之虛，合梓之實，剛柔相配。

9-3. 琴不必桐梓，惟木液既竭，濁性去盡，皆可選用。

10. *Yongle Qinshu Jicheng* (永樂琴書集成) [40]

底中河梓須避其心……，木性條直，陰陽相向，底面無節者，視為斫之妙也。

11. *Qinyuan Yaolu (*琴苑要錄) [41]

選材良，用意深，五百年，有正音。（唐代雷氏語）

12. *Qinshu Daquan* (琴書大全)

12-1. 十一月斬之，安高屋陰處，令其風乾，然後剖斵。桐楸並剖除陰面，取向陽者。乃作熱竈，除陰面，取向陽者，以炭火焙之。熱竈，土竈也，近壁為之，高三尺闊狹，隨時以橫鐵扶置其木，翻覆焙之。若燒糠火，木聲必濁。五日以上，十日以下，其木自有煙色。乃秤其木輕重以定乾濕，候其斤兩已定，不減，其木則乾，乃上爆焉。木既已出，擊而聽之，其聲堅勁清響為妙。(宋代、僧居月琴製 [53])

12-2. 凡琴材惟以采伐，日久輕乾者為上，若材木稍潤，則聲不透徹。或得新材，急於速成，以火烘熁，津脉遽盡，雖便乾然，終失其性也。[57]

13. *Yuguzhai Qinpu* (與古齋琴譜) [47]

13-1. 若有數百年者，即杉木亦可。

13-2. 凡琴材木，取其化，化與朽不同，朽則木質腐爛，撥之多成灰屑，化則木質猶存，濁液去淨，舉之甚輕，以指甲掐之，不甚能入，若用重物敲擊，或致崩跌，則脆折而已。

13-3. 故桐液，使之乾燥則易，使之去盡則難。液若未盡，其音必濁滯而不清亮。去液之法，將桐木厚寸餘者，略圓其面，稍刨其中，長短廣挾之制略若琴式，置於紙料池中(凡做紙必以竹浸石灰池中)，令其浸一二月，得其灰氣，將木液去盡。復取起，投之清流之中，或瀑布之下，漂去灰氣，約三四月久。再取出，懸諸炎風烈日之衝（須要避雨之處），任其吹曝極乾。日擊其木而驗之，待其鏗然有聲，然後裁製成器。雖不能如古木舊材之奇妙，亦可稍盡新材之美矣。

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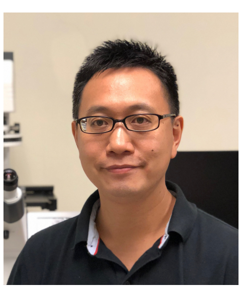

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