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Some Misconceptions about the Baroque Violin

Stewart Pollens

Much has been written about the baroque violin, yet many misconceptions remain—most notably that up to around 1750 their necks were universally shorter and not angled back as they are today, that the string angle over the bridge was considerably flatter, and that strings were of narrower gauge and under lower tension.[1] Stradivari's patterns for constructing necks, fingerboards, bridges, and other fittings preserved in the Museo Stradivariano in Cremona provide a wealth of data that refine our understanding of how violins, violas, and cellos were constructed between 1666-1737 (Stradivari's years of activity). String tension measurements made in 1734 by Giuseppe Tartini provide additional insight into the string diameters used at this time.

The Neck

The baroque violin's tapered neck and wedge-shaped fingerboard became increasingly thick as one shifted from the nut to the heel of the neck, which required the player to change the shape of his or her hand while moving up and down the neck. The modern angled-back neck along with a thinner, solid ebony fingerboard, provide a nearly parallel glide path for the left hand. This type of neck and fingerboard was developed around the third quarter of the eighteenth century, and violins made in earlier times (including those of Stradivari and his contemporaries) were modernized to accommodate evolving performance technique and new repertoire, which require quicker shifts and playing in higher positions.

Though a number of Stradivari's viola and cello neck patterns are preserved in the Museo Stadivariano, none of his violin neck patterns survive, and the few original violin necks that are still mounted on his instruments have all been reshaped and extended at the heel so that they could be mortised into the top block. In their 1902 biography of Antonio Stradivari, the Hills state that they knew of seven Stradivari instruments that retained their original necks, though they name only five: the 1715 "Alard," the 1714 "Soil," the 1721 "Blunt," the 1724 "Sarasate," and the 1716 "Messiah."[2] The 1690

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1 David Boyden, *The History of Violin Playing* (Oxford: Oxford UP, 1965), 110, 320; G. Thibault, Jean Jenkins, and Josiane Bran-Ricci, *Eighteenth Century Musical Instruments: France and Britain* (London: Victoria and Albert Museum, 1973), 24. Valerie Walden, *One Hundred Years of Violoncello: a History of Technique and Performance Practice, 1740-1840* (Cambridge: Cambridge UP, 1998), 58-62; Carlo Chiesa, "From the 'Baroque' to the 'Modern' Violoncello," *I violoncelli di Antonio Stradivari* (Cremona: Consorzio Liutai Antonio Stradivari, 2004), 97.

2 W. Henry Hill, Arthur Hill, and Alfred Hill, *Antonio Stradivari: His Life and Work* (London: W.E. Hill & Sons, 1902), 60-61.

"Medici" tenor viola and the 1693 "Harrison" violin are two other Stradivari instruments that retain their original necks—perhaps these were the other two they had in mind. The altered neck of the "Soil" violin is no longer mounted on the instrument, but is preserved in the Museo Stradivariano (MS no. 128). Because the "Soil" and other original Stradivari violin necks all have heel grafts, it is not possible to establish their original lengths with precision. Despite the lack of direct evidence of the original neck lengths of Stradivari's violins, we can deduce their dimensions from original fingerboards and fingerboard patterns (see below), and it would appear that they had virtually the same effective length (as measured from the nut to the upper edge of the instrument's top) as modern necks. The heel grafts on the extant original necks provide just enough extra material to form a dovetailed tenon that was set into the top block. (Stradivari's original violin and viola necks were butted up against the upper rib and held in place with iron nails driven through the top block.) The graft also permitted these re-shaped necks to be angled back several degrees farther than they were originally, though the neck angle was primarily increased to compensate for the non-wedge-shaped fingerboard (see below).

One significant change made in the design of the modern violin and viola neck and fingerboard was the extension of the neck foot beyond the upper surface of the top plate to provide what is termed "overstand."[3] Today, this is generally between 6-8 mm. in violins and violas, and 20-22 mm. in cellos. The Baroque violin and viola neck foot did not project beyond the upper surface of the instrument's top; instead, a wedge-shaped fingerboard provided the requisite height and added a few more degrees of inclination to the slightly angled neck.

The neck, fingerboard, tailpiece, and bridge of the "Medici" tenor viola (1690) are original—this remarkable instrument is the only extant example of Stradivari's work to survive with all its fittings intact.[4] The neck has not been reshaped or reset, though a wedge has been inserted between the neck and the fingerboard, presumably to compensate for the neck pulling forward due to string tension. Though inventory and maintenance records for this instrument extend as far back as 1700 (including a major intervention by the violin maker Giuseppe Scarampella in 1869 that required the removal of the top), there is no mention of the insertion of the wedge between the neck and fingerboard in any of these records.[5] It is conceivable that this repair dates from the eighteenth century or might even have been an adjustment made shortly after the instrument was delivered to the Medici court in Florence. When the

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3 Hans Weisshaar and Margaret Shipman, *Violin Restoration: A Manual for Violin Makers* (Los Angeles: Weisshaar-Shipman, 1988), 155.

4 This instrument is in the collection of the Conservatorio "Cherubini" in Florence.

5 Franca Falletti, Renato Meuci, and Gabriele Rossi Rognoni, *La musica e i suoi strumenti: La Collezione Ganducale del Conservatorio Cherubini* (Florence: Firenze Musei, 2001), 147. According to Gabriele Rossi Rognoni, curator of the musical instrument collection of the Conservatorio Cherubini in Florence, the original decorated bridge of the "Medici" tenor viola was trimmed in recent years to accommodate a musician who was engaged to play the instrument. Personal communication, 2002.

wedge was added, the original fingerboard developed a crack at the top in the process of removing it from the neck.

The "Medici" tenor viola neck is not mounted at a 90º angle relative to the upper rib, but is set at approximately 86º. The wedge-shaped fingerboard produces a composite angle of about 83º, which is within a degree or two of that used in modern viola setup. The neck pattern for this instrument is preserved in the Museo Stradivariano (MS no. 237), but the dimensions and shape of the neck foot are not clearly indicated, and it would appear that the pattern was left oversized to provide extra wood for final fitting. A supplemental pattern for the foot (MS no. 240) also provides a bit of leeway for final trimming (the heel length is 43 mm., whereas the upper rib width of the "Medici" tenor viola is 39.5 mm.), but the bottom of the foot is cut at an angle of 86º, which matches the original neck presently mounted on the viola. This confirms that Stradivari did not mount the neck of this tenor viola in line with the body of the instrument, but tilted it back 4º. The nut-to-heel length of the original neck is 152.5 mm., and the body-stop is 263.3 mm., which indicates that the neck is about 23 mm. short of the 2:3 *mensur* (Ger. measurement; the ratio of neck length to body length). This effectively shortened the string length, undoubtedly to make this rather unwieldy instrument easier to play. The tenor viola was generally played in low positions that did not make extensive use of the neck heel for orienting the hand; thus, it was not as important to maintain the 2:3 *mensur* used with the violin and contralto viola. The string angle over the bridge of the "Medici" tenor viola is presently about 158º, compared to 154º used in typical modern viola setup.[6] This reduction in the string angle over the bridge by 4º results in an 18% increase in downward pressure on an instrument's top by the bridge feet.

Like the neck pattern for the tenor viola, the final dimensions for the foot of the neck pattern for the contralto viola (MS no. 213) are not clearly indicated, though there are a number of reference marks on it. These include two pin holes approximately 4 mm. from the bottom edge of the foot (these pin holes may not be original, but artifacts of an early Museo Stradivariano installation), a short ink mark about 8.5 mm. from the bottom of the foot (which may represent the point where the neck meets the upper edge of the instrument's top), and a line drawn roughly parallel to the bottom edge of the foot and about 15 mm. above it (the function of this line is unclear, as it is too close to the heel to provide a full-size button). The cello-style pegbox cheeks, which originally coincided with the end of the nut and the beginning of the fingerboard, are denoted on the pattern by a series of inked dots. The distance between these dots and the short ink mark on the foot, which may signify the trimmed dimension, indicates a nut-to-heel length of about 147 mm.

The 1690 "Tuscan" contralto viola is believed to have been made for the same Medici commission as the tenor viola discussed above.[7] It has a body-stop of 224.5 mm., and if we multiply the body-stop by 2/3, we arrive at a theoretical nut-to-body length of 149.6 mm., which is close to the

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[6] Henry Strobel, *Useful Measurements for Violin Makers: A Reference for Shop Use* (Aumsville, OR: H.A. Strobel, 2003), 22; Lucien Greilsamer, *The Health of the Violin and the Viola and Cello* (Aumsville, OR: H.A. Strobel, 2002), 16.

[7] The "Tuscan" contralto viola is presently in the collection of the Smithsonian Institution in Washington, D.C.

distance between the inked marks on the neck pattern.[8] This indicates that Stradivari employed a 2:3 *mensur* in designing this viola (the neck is not foreshortened as in the tenor viola). The "Tuscan" viola does not have its original neck, and the new one is presently fitted with a nut mounted on line with the bottom of the pegbox (well below the cello-style pegbox cheeks). This suits violists and violinists who find it comfortable to use the chin of the pegbox to orient their hand in first position. Thus, the *mensur* of the "Tuscan" is not presently set at a 2:3 ratio, as it was originally designed. Again, the final dimensions and shape of the heel are not indicated on MS no. 213, but the supplemental pattern for the foot MS no. 216 provides a neck angle of 86º, just like that of Stradivari's tenor viola.

Several of Stradivari's cello neck patterns are preserved, and from these we can clearly see that his cello necks were also angled back. The length of the neck feet and the presence of scribe lines parallel to the bottom of the feet suggest that the necks may have been mortised into the top blocks, though they were apparently reinforced with nails like those of the violins and violas, while in the case of cellos, generally six nails were used rather than three. From the patterns, it appears that the neck feet extended beyond the top of the instrument, very much like the modern cello neck. As with the violin and viola, a wedge-shaped fingerboard was used. The "Batta" Stradivari cello of 1714 appears to have been made on the B form because the B form f-hole positioning template preserved in the Museo Stradivariano (MS no. 272 recto) matches that cello's C-bouts, corners, and f-hole placement.[9] A cello-neck pattern also marked letter "B" (presumably used to make B-form cellos) has a nut-to-heel length of 286 mm., which forms a 7:10 ratio with the "Batta's" body-stop of 406 mm. This 7:10 *mensur* is also used today in setting up most cellos.[10]

Three cello neck patterns in the Museo Stradivariano, as well as a supplementary cello neck foot pattern marked *B* (MS no. 279), all provide an 84º angle relative to the upper rib. Though the overall length of the foot of the neck pattern in MS no. 276 is 158 mm., there is an inked line that indicates it was intended to be trimmed back to 134 mm. The trimmed length would provide an overstand of about 6 mm. with cellos having an upper rib depth of 128 mm., which is very likely close to the uncut dimension of a B-form cello upper rib.[11] Though this is considerably less than the 20-22 mm. overstand that is used today, a wedge-shaped fingerboard 29 mm. thick at the neck heel (see discussion of cello fingerboard

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8 Measurements of the "Tuscan" viola are from Charles Beare, *Antonio Stradivari: The Cremona Exhibition of 1987* (London: J. & A. Beare, 1993), 316.

9 An f-hole positioning pattern (MS no. 272) is inscribed *musura per la forma B/ Per far gli occhi del violoncello* (measure for the B form/ for the eyes of the violoncello). This pattern consists of a tracing of the rib structure of the right C-bout region of a cello, upon which are drafted geometric construction marks for locating the eyes and tracing of an f-hole (see Chapter 3). The author made a rubbing of the 1714 "Batta" Stradivari cello's f-hole and c-bout region and confirmed that the positions of the corners and f-hole matched Stradivari's B-form f-hole positioning pattern. This suggests that the "Batta" was made on the B-form.

10 Weisshaar and Shipman, *Violin Restoration*, 144.

11 Cinzia Manfredini, *I violoncello di Antonio Stradivari*, 188-89.

pattern MS no. 280, below) would have increased the distance between the playing surface of the fingerboard and the upper edge of the top plate to about 35 mm., which is close to that used today. The wedge-shaped fingerboard would have increased the effective neck/fingerboard angle to within a degree or two of that used in modern cello setup.[12]

The Fingerboard

The fingerboards used in the Baroque were quite different from those used today. The modern fingerboard is made out of a relatively thin slab of solid ebony, a hard and extremely dense wood that creates a rigid platform for the stopped string. As indicated above, Stradivari's violin and viola necks were not angled back to the same extent as modern necks, nor did they extend beyond the edge of the top as do modern necks. Instead, the final angle and elevation of the strings were provided by wedge-shaped fingerboards. Stradivari's violin fingerboards ranged from about 15-18 mm. thick at the neck foot (the modern violin fingerboard is about 8 or 9 mm. thick at that point), and his viola fingerboard patterns in MSS nos. 217 and 241 have markings indicating a thickness of 23 mm. at the neck foot; his cello fingerboard pattern in MS no. 280 has inscribed markings indicating a thickness of 29 mm. at the neck foot.

The feet of baroque violin and viola necks were rabbeted to clear the top plates of the instruments where the tops overlapped the ribs. Baroque fingerboards were notched at their juncture with this rabbet and were undercut to follow the arching of the top. Stradivari's fingerboard patterns generally mark the position of this notch and provide a pair of compass arcs that indicate the thickness of the fingerboard at that point.[13] Because this notch aligns precisely with the upper edge of the instrument's top plate, it provides a definitive point for determining the neck-stop, which is needed to calculate the string length of the instrument for which the fingerboard was intended. Fingerboard patterns in MSS nos. 131, 132, 133, and 134 are marked with the form letters P, G, G, and PG, respectively. A number of violins have been matched with these forms, and by comparing the nut-to-body lengths in Table 2 with the body stops of these instruments, it becomes evident that Stradivari employed a 2:3 *mensur* in his violins. For example, the "Soil" Stradivari violin has a body-stop of 198 mm., which requires a neck having a nut-to-body length of 132 mm. to provide a 2:3 *mensur*. We know that this instrument was made on the G form because the original neck of this instrument, MS no. 128, has a pegbox inscription *G.* The G-form fingerboard patterns MSS nos. 132 and 133 have a nut-to-body length of 129 mm., which is just 3 mm. short of the theoretical length calculated using the 2:3 ratio and the "Soil" violin's body-stop. Today, full-size violin necks are generally set at 130 mm., which is only one millimeter longer than the neck length calculated from fingerboard patterns made for use with

12 Weisshaar and Shipman, *Violin Restoration*, unpaged cello-neck template.

13 Simone Sacconi refers to this as the "line of excavation" in *The Secrets of Stradivari: with the Catalogue of the Stradivarian Relics Contained in the Civic Museum Ala Ponzone of Cremona* (Cremona: Libreria Del Convegno, 1979), 201.

Stradivari's full-size violin forms P and G. This contradicts current dogma that the "modern" violin neck is significantly longer than those originally fitted by makers in the Baroque.[14]

An original Stradivari violin fingerboard, MS no. 129, has a core of willow edged with figured maple and faced with ebony on the playing surface. It is 213 mm. long and has a nut-to-body length of 120 mm., so it was presumably fitted to a small violin having a body-stop of about 180 mm. The fingerboard is 26 mm. wide at the nut and 40 mm. wide at the bottom; it is 5 mm. thick just beyond the nut and 15 mm. thick where it meets the violin's top plate, producing a 4½° angle. The ebony facing is bordered by an inlay of ivory and ebony, a decorative touch that contrasts with today's solid ebony fingerboards. The figured maple facing on the sides bears traces of varnish along the entire length, indicating that Stradivari varnished the necks of his instruments. Willow is very light and was undoubtedly used as the core to reduce weight. Though facing and inlaying were labor-intensive processes, it conserved ebony, which was a precious commodity. Baroque tailpieces were constructed in the same manner.

An important distinction between Baroque and modern fingerboards is the difference in their lengths. The modern violin fingerboard is about 270 mm. long, whereas Stradivari's patterns and original fingerboards are between 190 and 213 mm. long, 207-213 mm. being the apparent range for full-size violins made on the P, PG, and G forms. This length represents the uppermost note that can be stopped on the fingerboard, which in the case of full-size violins is shy of an octave and a fifth above e^2, or b^3 (stopping a string a full octave and a fifth above a typical string length of 327 mm. would require a fingerboard of 218 mm.). Stradivari's fingerboard pattern for the B form cello (MS no. 280) has an overall length of just 424 mm., which would have been adequate for playing up to the fifth position, which is the uppermost one given in Michel Corrette's cello tutor of 1741.[15] Thus, the fingerboards fitted in Stradivari's day were too short to accommodate music written just a few decades later (for example, Mozart's fifth violin concerto, composed in 1775, extends up to $c\sharp^4$), so it is little wonder that no Stradivari violins, violas (with the exception of the "Medici" tenor), and cellos are still equipped with their original necks and fingerboards.

Strings

Strings are the most ephemeral of the violin's fittings, and very few survive from Stradivari's time. Two partial sets of strings for a contralto viola and a cello are preserved in the Museo Stradivariano in Cremona. Three viola strings (MS no. 222) are sewn onto a sheet of heavy paper that is inscribed *Adi agosto 1727 queste Quattro corde sono la grosezza per finire la viola a Quattro corde ciovè il contraldo* ("In the year of our Lord, August 1727, these four sounding strings of a size to finish

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14 *The New Grove Dictionary of Music and Musicians*, ed., Stanley Sadie (London: Macmillan Publishers, 1980), s.v. "Violin."

15 Michel Corrette, *Méthode théorique et pratique pour apprendre en peu de temps le violoncello dans sa perfection* (Paris, 1741), C.

the viola of four strings, namely the contralto"). Three cello strings (MS no. 309) are mounted onto a sheet of paper that reads *Queste sono le mostre del tre corde grosse quella mostra che sono di budelo va filata è vidalba* ("These are examples of three thick strings of gut that are overspun and polished").[16] Overspun strings came into use around 1660 (see below). Like the cello and viola, violins in Stradivari's day most likely used an overspun lowest string. The earliest overspun strings employed a thin wire filament (copper, tinned or silvered copper, or silver) spun directly over a plain gut core (without the "silking" that is commonly inserted between the core and the wire filament in the manufacture of most of today's overspun strings).

No original Stradivari violin strings survive, but a number of attempts have been made to reconstruct their diameters from various documentary and iconographic sources.[17] The diameters of violin strings used in Stradivari's day can be deduced from experiments made in 1734 by the violinist Giuseppe Tartini, which were recounted by the music historian François-Joseph Fétis (1784-1871) in 1856. According to Fétis:

> "Tartini found, by experiments made in 1734 that the pressure of the four strings on the instrument was equal to 63 pounds [63 *livres* is given in the original 1856 French edition; *l'ancienne livre* was equivalent to 489.5 grams, whereas the modern pound is equivalent to 453.6 grams].[18] It must be observed that the strings of Tartini were smaller than those with which violins are now mounted, and that his bridge was lower, so that the angle formed by the strings was considerably less. Twenty years ago, the first string required a weight of 22 pounds in order to bridge it up to pitch, and the other strings a little less; so that the total pressure was, then, about 80 pounds. After 1734, the pitch was raised a semitone, the instruments were mounted with thicker strings, and the angle which they formed on the bridge was more acute: hence the necessity of re-barring the violins. Since then, so excessive has been the rise in pitch, through the craving for a brilliant sonority, that there is nearly a difference of a semitone between the pitch of 1830 and that of 1856. If a new experiment were now made to ascertain the pressure of the four strings on the belly of a violin, no doubt it would be found greatly augmented. This enormous weight incessantly tends to effect the destruction of the old instruments, and demands increased power of resistance in the bar underneath the bridge. Such is the real cause of the necessity of substituting for the old, weak bar, in the violins of Stradivarius, one of stronger proportions."[19]

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[16] On several visits to the Museo Stradivariano, I requested permission to measure the gut core and metal winding diameters of these strings with a micrometer, but permission was denied. The catalog gives overall diameters of both sets of strings, but it does not indicate which diameters go with which instrument: 1.1 mm, 1.23 mm, and 1.65 mm (presumably the viola strings), 1.5 mm, 1.55 mm, 1.95 mm (presumably the cello strings).

[17] Mimmo Peruffo, "Italian Violin Strings in the Eighteenth and Nineteenth Centuries: Typologies, Manufacturing Techniques and Principles of Stringing," aquilacorde.com (2004), 1-34. This website is an updated version of an article that first appeared in *Recercare* (1997), 155-203. Page citations that follow are from the website version.

[18] Ronald Edward Zupko, *French Weights and Measures before the Revolution; a Dictionary of Provincial and Local Units* (Bloomington: Indiana UP, 1978), 99.

[19] F. J. Fétis, *Notice of Anthony Stradivari, the Celebrated Violin Maker*, trans. John Bishop (London: R. Cocks and co., 1864), 88-89. F. J. Fétis, *Antoine Stradivari, Luthier Célèbre* (Paris: Vuillaume, 1856), 92-93.

Fétis was himself a violinist, and in the preface to his published account he acknowledges the technical assistance provided by the violinmaker J. B. Vuillaume. Though doubts have been cast upon the reliability of Tartini's measurements of string tension and their conversion to modern units of weight, the 63-pound (or *livre*) figure has not been disputed.[20] Oddly, 63 pounds (28.6 kg) or 63 *livres* (30.8 kg) is considerably greater than used today at higher pitch (a set of Dominant strings are strung at a total of 22.1 kg, or 48.6 pounds); the 80 pounds cited by Fétis would be excessive by today's standards.

The diameters, and hence the distribution of tension among the strings, remains a subject of debate that has been clouded rather than clarified by several seventeenth- and eighteenth-century writers, who indicated that the relative thicknesses of strings should be in proportion to their relative pitches and that tension should be equal from string to string.[21] Marin Mersenne, for example, wrote in 1636 that the violin E string was equivalent in thickness to the fourth string of a lute, which he indicated was equal to one-third of a *ligne* (in the old *pied d' roi*).[22] This is equivalent to about .75 mm. He further indicated that "the strings will be perfectly proportioned among themselves when they follow the ratios of the said notes."[23] Taken literally, impractical sequences of string diameters would result: for example, starting with a violin E string of .75 mm, it then follows that the A string would be 1.12 mm, D would be 1.68 mm, and G would be 2.53 mm (much too thick); working backwards from a more reasonably proportioned gut G string of 1.9 mm, D would be 1.27 mm, A .84 mm, and E .56 mm (much too thin). Leopold Mozart, however, advocated the same principal of proportionality in his *Versuch einer gründlichen Violinschule* (1756):

> "The violin is strung with four strings, each of which must be of the right thickness in relation to the other. I say 'right thickness,' for if one string be a little too thick in proportion to another it is impossible to obtain an even or a good tone. It is true that violinists and violinmakers frequently judge these thicknesses by the eye, but it cannot be denied that the result is often very bad. Indeed, one must go to work with the greatest patience and care if one wishes to string the violin properly and in such fashion that the strings have their intervals in the right proportion to each other, and the right notes lie therefore opposite each other. He who is willing to take the trouble, can test them according to mathematical principles. He can take two well-stretched strings, an A and E, a D and A, or a D and G, each of which is as exactly as possible of the same thickness throughout. That is: the diameter or cross-section must be uniform. To each of the two strings equal weights can be attached. Now, if the two strings have been well chosen, they should, on being struck, give forth the interval of a perfect fifth, but if one string sounds too sharp and oversteps the fifth, this is a sign that it is too weak and a thicker string is then selected; or the string which sounds

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20 Peruffo, "Italian Violin Strings," 18.

21 Ibid., 15-21.

22 Marin Mersenne, *Harmonie universelle; traité des instrumens a chordes* (Paris, 1636), 51,189. Marin Mersenne, *Harmonie Universelle; the Books on Instruments*, trans. Roger E. Chapman (The Hague: M. Nijhoff, 1957), 79, 244.

23 Mersenne, *Harmonie universelle* (1636), p. 51. Mersenne, *Harmonie Universelle* (1957), 79.

> flat and is therefore too thick may be exchanged for a thinner string. One must proceed thus until the perfect fifth is attained and the strings are in proportion and truly chosen. But how difficult it is to find evenly made thick strings! Are they not mostly thicker at one end than at the other? How can one make a sure test with an uneven string? I would therefore remind you that the choice of strings must be made with the greatest care and not merely at random."[24]

Despite Leopold Mozart's explicit directions for suspending weights from strings when selecting gauges, many of today's violinists involved in period-performance practice, as well as historians and makers of gut strings, reject the idea of equal tension and advocate a system of so-called "progressive scaling."[25] Mimo Peruffo's research into the diameters of holes drilled in early lute bridges does in fact confirm that Mersenne's and Mozart's rule of employing string diameters in strict proportion to pitch, which is equivalent to equal tension from string to string, was not strictly adhered to, as bass strings calculated from the pitch relationships between the strings would result in rather large diameters that could not have passed through the holes found in early lute bridges.[26] It should be pointed out, however, that lutes are tuned over a greater pitch range than the violin, so string gauges could not have been increased or decreased in strict proportion to the pitch.

Regarding the use of overspun strings for the lowest pitched strings of members of the violin family, it is generally believed that gut strings overspun with thin metal wire first came into use around 1664, the year an advertisement for them appeared in John Playford's *Introduction to the Skill of Music*. Mimmo Peruffo cites a slightly earlier manuscript of Samuel Hartlib dated 1659 that refers to Goretsky's invention of lute strings covered with silver wire.[27] Overspun strings, however, may have been in use at a much earlier date, as Michael Praetorius's S*yntagma Musicum* (1619) refers to twisted or spun strings used in a *d'amore* variant of the *viola bastarda* made in England: *Jetzo ist in Engelland noch etwas sonderbares darzu erfunden dass unter den rechten gemeinen sechs Säitten noch acht andere Stälen und gedrehere Messings-Säitten uff ein Messingen Steige gleich die uff den Pandorren gegraucht werden liegen* ("Presently something curious has been invented in England, that under the ordinary six strings there are in addition eight other steel and spun brass strings on a brass bridge, just as they would lie on the Pandora").[28] Praetorius then goes on to explain how sympathetic strings worked,

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24 Leopold Mozart, *A Treatise on the Fundamental Principles of Violin Playing* trans., Editha Knocker (Oxford: Oxford UP, 1990), 13-14.

25 Peruffo,"Italian Violin Strings," 15-20.

26 Mimmo Peruffo, "The Mystery of Gut Bass Strings in the 16th and 17th Centuries: the Role of Loaded Weighted Gut," *The Lute Society of America Quarterly* 29/2 (May, 1994), 5-14. Though the author applauds Peruffo's historical research, he does not subscribe to Peruffo's theory that historical bass gut strings were weighted by chemical means.

27 Peruffo, "Italian Violin Strings," 2.

28 Praetorius, *Syntagma Musicum* 2, 47.

which leads one to conclude that the addition of sympathetic strings to the *viola bastarda* was the "curiosity" and not the fact that they were made of steel and overspun with brass. The pandora (or bandora) was a bass, plucked wire-strung instrument with scalloped ribs invented by John Rose in England in 1562. The earliest examples are believed to have had twisted (rather than overspun) metal strings; however, the German term *gedrehere* suggests spinning, turning, as well as twisting, thus it is possible that Praetorius is referring to steel core strings overspun with brass wire.

For equally tensioned strings pulled to a total of 63 pounds or *livres* (the total tension measured by Tartini in 1734), we can use Mersenne's law to calculate the diameters of each of the gut strings where A=420 Hz, which is an estimate of the pitch used in Padua, where Tartini lived when he conducted his string tension experiment (A=420 Hz is about 81 cents below A=440 Hz):[29]

$$D = \sqrt{}T/F^2L^2\rho\pi$$

Where D is the diameter in meters

T is the tension in Newtons, in this case (63 lb./4) x 4.44822 Newtons per pound,

or 70.06 Newtons per string

F is the frequency in Hz, in this case 187 Hz for g, 280 Hz for d^1, 420 Hz for a^1,

and 629 Hz for e^2

L is the length of the strings in meters, in this case .327 m

ρ is the density of gut in kg per cubic meter, in this case 1,300 kg/m^3

The following gut string diameters were calculated:

e^2 = .64 mm.

a^1 = .95 mm.

d^1 = 1.43 mm.

g = 2.14 mm.

[29] Bruce Haynes, *A History of Performing Pitch* (Lanham: Scarecrow Press, 2002), 271.

The G-string of the violin would not have been plain gut but rather gut overspun with fine metal wire. According to Francesco Galeazzi's *Elementi teorico-pratici di musica* (1791), the core of the G-string was made with *una seconda non molto grossa* ("a second [string] not too large") and overspun with: *L'argento, che comunemente si adopera a questo uso è rame inargentato, e deve esser sottilissimo. Si adopera con egual successo il rame semplice, ed anche l'acciajo: ho fatto a bella posta filare dell' argento fino, ma non vi ho conosciuta differenza dall' argento falso commune, se non che ei non diventa rosso, ma resta sempre bianco, rilucente, come fosse sempre nuovo* ("The silver normally used for this purpose is silver-plated copper, and must be very thin. One can use with equal success copper and even iron. I purposefully wound some thin pure silver, but saw no difference from the use of common false silver, except that it does not become red, but stays white and shiny, as if always new").[30] Peruffo suggests that wire having a diameter of .12-.13 mm. was used for overspinning, but wire of such fineness was not readily available in Stradivari's day, or even in the late eighteenth century when Galeazzi wrote his account of string making. Patrizio Barbieri has attempted to reconstruct the diameters of strings found on a harpsichord made in 1559 by Vito Trasuntino based upon the weights of the strings Giordano Riccati published in 1767 (though he did not specify the material from which the strings were made, which is essential for calculating the string diameters if only the total weight of the string is known). According to Barbieri's calculations, the finest strings found on this harpsichord had a diameter of .15 mm.[31] The finest gauge of wire generally employed in musical instrument making was used in the top strings of the 4' choir of harpsichords. Original wire fragments found in the 4' of a harpsichord by François Blanchet dated 1733 are .17-.18 mm. in diameter, which is probably a more accurate figure than those suggested by Peruffo and calculated by Barbieri.[32]

The formula for string tension of overspun strings is:

$$T = \frac{F^2 L^2 \pi}{10^{12}}\left[d_c^2\,\rho_c + d_w^2\rho_w\sqrt{1+\frac{\pi^2}{W^2}\,(d_c + d_w)^2}\,\right]$$

Where:

T = tension in Newtons (1 Newton = .10197 Kilogram-force or .2248 pound-force)

ρ_c = density of the core in kg/m^3

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[30] Francesco Galeazzi, *Elementi teorico-pratici di musica* (Rome, 1791), 75, footnote a. Peruffo, "Italian Violin Strings," 20-21.

[31] Patrizio Barbieri, "Giordano Riccati on the Diameters of Strings and Pipes," *The Galpin Society Journal* XXXVIII (1985), 20-34.

[32] William Dowd, "The Surviving Instruments of the Blanchet Workshop," *The Historical Harpsichord* 1 (New York: Pendragon, 1984), 100.

ρ_w = density of the winding in kg/m^3

d_c = diameter of core in millimeters

d_w = diameter of winding in millimeters

W = winding pitch in millimeters (for close-wound strings, W = d_w)

L = string length in millimeters

F = frequency in Hz

If we substitute a plain gut A-string of .95 mm. diameter for the gut G of 2.14 mm. diameter, it alone would require a tension of only 13.78 Newtons to bring it to 187 Hz (the pitch of G at A-420 Hz), which would be insufficient to produce a good quality sound. A 2.14 mm. diameter gut string 327 mm. in length would have a mass of about 1.53 grams, whereas a .95 mm. string of equal length would have a mass of about .30 grams. Therefore, a mass of 1.23 grams would have to be added to the .95 mm. string to bring it up to the requisite tension of 70.06 Newtons. A winding of copper wire .17 mm. in diameter (having a density of 8944 kg/m^3) would provide a mass of about 1.35 grams, yielding a total string mass of 1.65 grams, very close and only marginally greater than the calculated ideal mass.

Up until the mid-nineteenth century, violins strings were made of whole rather than split sheep gut, and from documentary sources we know that E and D strings were typically made of 3 and 7 whole guts wound together (presumably A-strings were made of 5 whole guts).[33] Furthermore, gut strings were not ground down to smooth and regular size, and thus only a rather limited selection of gauges was then available. A set of early-nineteenth century strings made by the highly regarded Ruffini firm in Naples was measured by William Huggins in 1883. He reported the following:

1st .0265” [.67 mm.]

2nd .0355” [.90 mm.]

3rd .0460” [1.17 mm.]

4th 1.41 grams [presumably an overspun string, no diameter given][34]

Surprisingly, this tallies almost perfectly with the string diameters calculated from Tartini’s tension measurements. Strings of these diameters, with the 4th, or G-string, perhaps made up of a .90

33 Peruffo, “Italian Violin Strings,” 13.

34 William Huggins, “On the Function of the Sound-post and on the Proportional Thickness of the Strings of the Violin,” *Proceedings of the Royal Society* (1883), 241.

mm. gut core wound with .17 mm. copper or silver wire would be an appropriate set of strings for a Stradivari violin with original fittings, were one ever to be found! Needless to say, they would also be appropriate for an "authentic" performance of Paganini's *Caprices* and Brahms' violin concerto![35]

In conclusion, from Stradivari's patterns, we see that he mounted the necks of his instruments at a slight angle, and that wedge-shaped fingerboards contributed several more degrees that brought the total angle of the strings over the bridge very close to that used in modern violin setup. The 2:3 neck-length to stop-length ratio was a precept of Cremonese violin-making, and thus necks and string lengths were not increased when they were adapted from Baroque to modern configuration. From Tartini's measurements, we learn that violin-string gauges and tensions may have been considerably greater than used today. As many Stradivaris, Guarneris, and other fine instruments from the Baroque were re-graduated (thinned) in later periods, stringing re-graduated violins with the original, heavier gauges of strings would be an empty exercise and potentially disastrous, as plate stiffness is proportional to the cube of its thickness.

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35 Philippe Borer, "Le Corde di Paganini," *Atti del Convegno Internazionale di Liuteria: Recupero e conservazione del violino Guarneri 'del Gesù' (1743) detto 'Cannone'* (Genoa: Civica Biblioteca Berio, 2006), 85-98.