Keeping in Rhythm

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The most endearing quality of the slide rule is its endless adaptability - from organ pipes to human hearts.

Introduction

To increase their market share or to outshine competitors, many slide rule makers produced "special" models. At the start of the 20th century German maker Faber-Castell (F-C) came up with the ubiquitous *Electro* model, the first specialist slide rule [1]. Later, when rebuilding their slide rule business after WWII, F-C impressively issued 15 new special slide rules [2]. With these post WWII special models F-C, like most makers, targeted particular trades and professions. Moreover many of the F-C post WWII specials had layouts that included non-standard scales or tailor-made ranges of one of the standardised scales [3]. An unusual and rare F-C special slide rule from this period was the **1/44 EKAGNOST**.

Type

The F-C model 1/44 is a wooden 25cm closed frame linear medical slide rule with celluloid veneers. From the blind date stamps in the back, Figure 1 dates from *July 1950*. Stamped in the well of the stock is the company name flanked by the Libra scales and twin Castle company logos, the model number 1/44, the model name EKAGNOST and a system accreditation for *Dr. Sandera*.

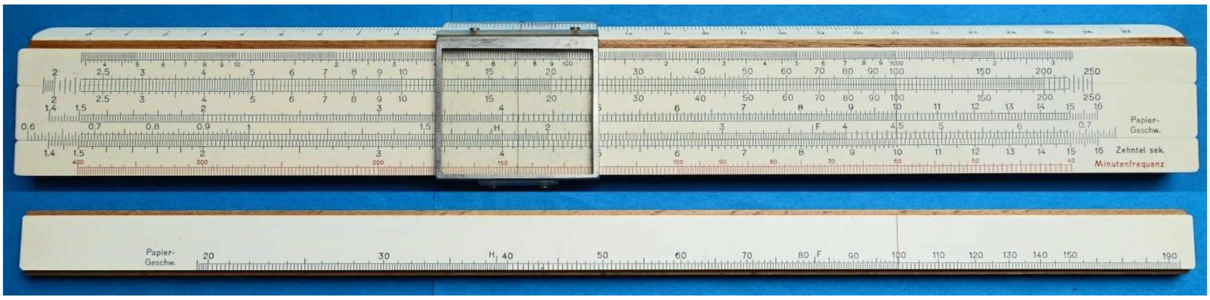

Figure 1: *F-C 1/44 EKAGNOST – System Dr. Sandera*

The EKAGNOST model name is likely a portmanteau of two German words: "**E**lektro**ka**rdio**g**ramm" and "Diag**nost**ik". This fits with the intended trade and profession for this model: *electrocardiography* and *cardiographers*. A "System" accreditation on any F-C slide rule signifies an exceptional design from an external expert. Over the years F-C contracted 20 external designers who were responsible for over 40 models [4].

Especially if protected by a patent or a registered design, F-C would pay such external designers a royalty payment to (re)use their design. However, the royalty paid was usually never more than 8-10% of the unit cost price, possibly supplemented by an extra retainer for a set of instructions [5]. For the model 1/44 the external expert and registered design holder was: **Dr. Robert Sandera**.

Provenance

Despite prolifically publishing in medical journals, being involved in major medical research projects and being a distinguished medic, little is known about Robert Sandera's life. However, by 1926 he was working as a doctor in Vienna, Austria before moving to Germany. In the 1930s he was living in Solingen, North Rhine-Westphalia and working in the local Municipal Hospital. He settled in Solingen because in 1942 he founded *RADPRAX* in his adopted city – the first independent X-ray practice in Germany [6]. The company is still operating but has expanded. It now has multiple medical centres throughout Germany specialising in preventive medicine.

Sometime after founding *RADPRAX* Sandera's focus turned to cardiology. On 12th October 1950 he was granted **German Registered Design 1614435** (DBGM[1]) for: *"inventing a slide rule for evaluating electrocardiograms"* [7]. However, Sandera hedged his bets when making the original application some 18 months earlier in March 1949. He applied for a registered design and also for a full patent. However, Sandera was only ever granted a DBGM for his invention.

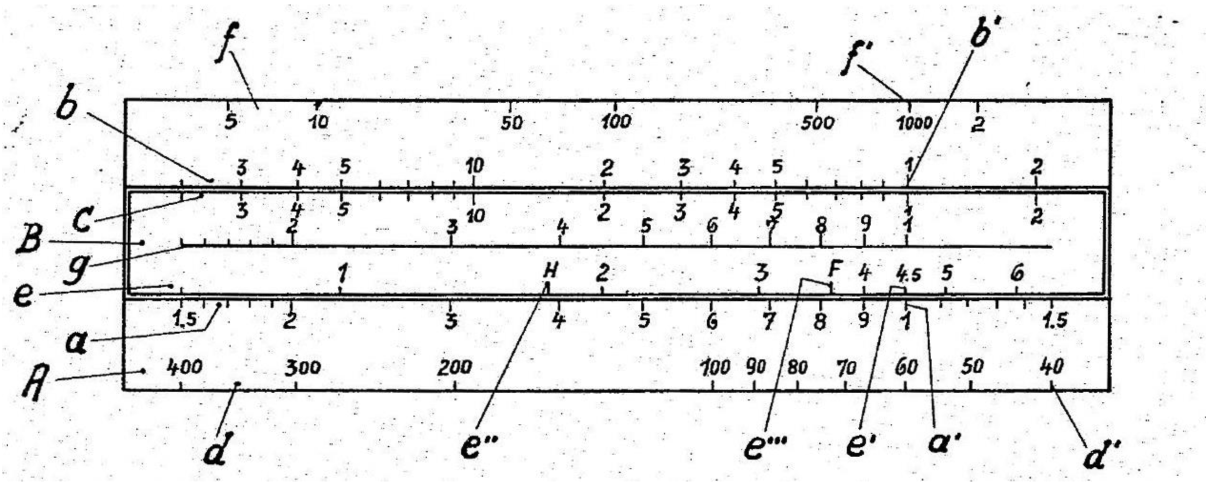

Figure 2: *Mosaic drawing from DBGM 1614435*

The Mosaic in Figure 2 has a recognisable slide rule layout. However, Sandera had been collaborating with F-C long before the DBGM was

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[1] **D**eutsches **B**undes **G**ebrauchs**m**uster (German Federal Utility Model).

granted because in May 1950 he published a paper in the journal for the German Society for Internal Medicine: *"Zur quantitativen Auswertung des Elektrokardiogramms - Der Rechenstab Ekagnost"*[2] [8]. In this paper Sandera argues that the currently available aids too often meant that cardiologists had to use imprecise values and base too much of their analysis on approximations. So he invented a special slide rule to do the needed calculations much more quickly and accurately. Significantly Sandera included an image of the finished F-C model 1/44 in his paper and explains how easy it is to use.

The projected and achieved sales volumes for the 1/44 are unknown. But some insights can be drawn from how the model was marketed and the years it was in production. This special was only produced from 1950 to 1955 [4]. The construction and packaging was standard for that era of production. So it has celluloid veneers on top of a pearwood base, a metal framed cursor (single hairline but with extensions for the top and bottom side edge scales), a paper table of medical constants/conversion factors on the back and a black two-part stiff cardboard box emblazed with the F-C company name and the 1/44 model number. However, the annotations on the front face (see Figure 1) are in German. Whether F-C later scrapped plans for an export version is unknown. But F-C saw strong potential for the home market, retailing the 1/44 for 27 German Marks (DM)[3] and going to the expense of publishing a 4-page German language marketing flyer [9].

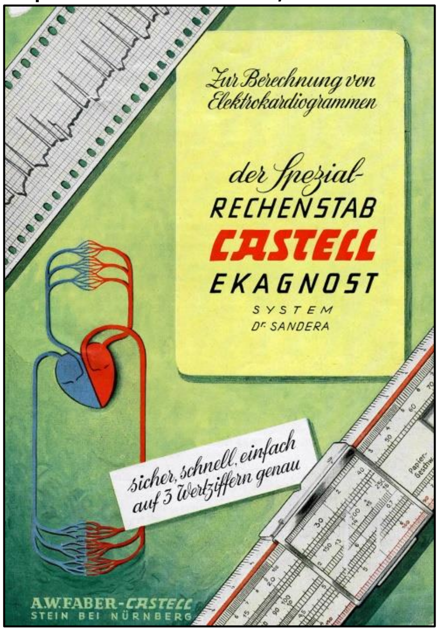

Figure 3: Flyer front cover

Electrocardiography & Cardiographers

To understand how and why the 1/44 works it is necessary to explain in layman's terms[4] the medical context. Electrocardiography is the medical term for taking an electrocardiogram (ECG or EKG[5]) of the human heart. The first practical ECG[6] machine was invented by Dutchman **Willem Einthoven** (1860-1927) in 1895. This was a diagnostic tool for ascertaining how the heart is performing and for showing up any

[2] Or: "*Quantitative Evaluation of the Electrocardiogram; the Ekagnost Slide Rule*".
[3] Allowing for inflation (consumer price index) = 146 DM or 74 Euro in 2021.
[4] A more technical explanation is out of scope and beyond the author's knowledge.
[5] Is an abbreviation of the German "Elektrokardiogramm".
[6] The first ECG is accredited to Waller, Beyliss and Starling at a congress in 1892.

heartbeat related irregularities. When beating, human hearts continuously polarise and depolarise much in the same way an electric motor attracts and repels a magnetic field. When electrodes from an ECG machine[7] are placed next to the skin at strategic points around the body, the leads can detect the small electrical changes in each element of a heartbeat.
Grossly oversimplified, analysing an analogue ECG plot involves comparing the metered heart performance over time against the profile expected with a comparable healthy heart. Despite sounding complex and technical, it was remarkably easy to capture the data needed from an ECG.

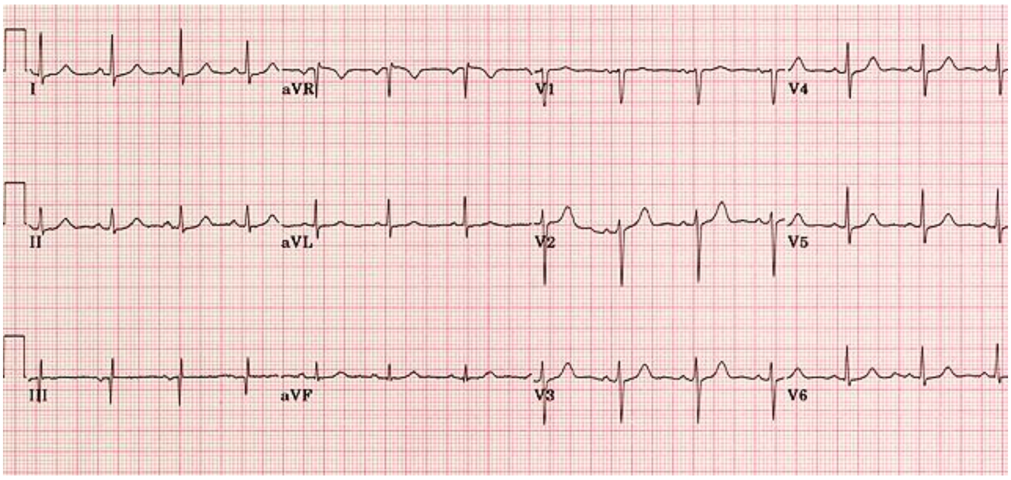

Figure 4: Analogue *ECG paper strip showing metered voltages from a 12-lead monitoring of the electrical potential of a human heart*

As shown in Figure 4, the metered cardiac cycles are printed onto a continuous paper strip of graph paper[8]. Such strips have a regular grid of large **5 mm^2 boxes** - each large box containing 5 x 5 small **1 mm^2 boxes**. In the 1920s Einthoven set the de facto standard for the running speed of the paper strips at 25 mm/second. At this speed each large grid box represents an elapsed time of 0.2 milliseconds and each small grid box represents an elapsed time of 0.04 milliseconds. The profile and amplitude of each distinct part of the various wave patterns can tell a cardiologist how the heart is performing and counting the number of grid boxes gives the time duration of the individual elements.

[7] Around 1950 galvanometers driven by vacuum tube circuitry that amplified the electrical signals generated.
[8] These days the data capture from modern ECG machines is digitally recorded.

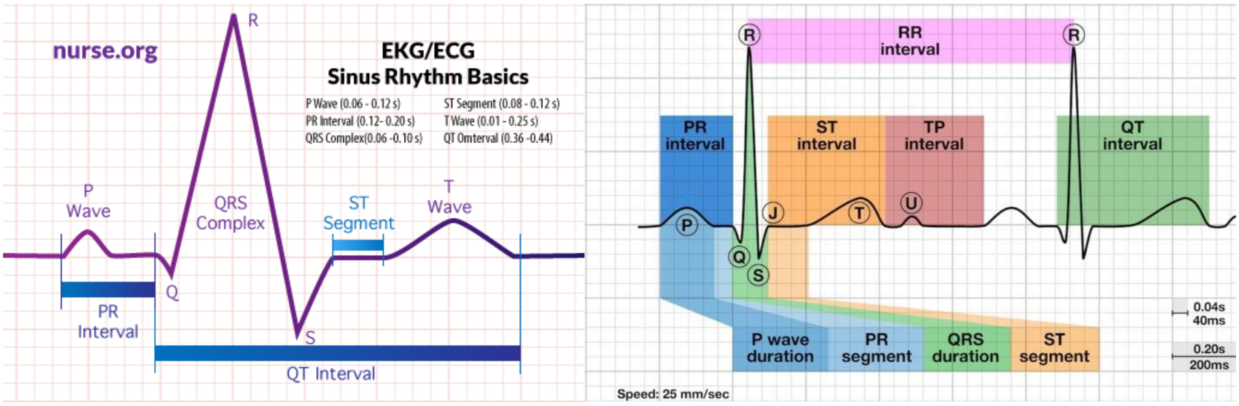

Figure 5: *Single ECG cardiac cycle enlarged to show the various elements*

Each cardiac cycle on an ECG printout has several elements. The full cycle is known as the **Sinus Rhythm**. The left-hand image in Figure 5 shows that it is made up of three major parts: (i) the P wave, (ii) the QRS Complex and (iii) the T wave. By examining the profiles of the different waves and measuring the distance in mm of the various intervals of the sinus rhythm, it is possible to analyse how a patient's heart is performing and uncover certain heart diseases or heart problems.
However, using just the interval between two consecutive signal peaks, or the **RR interval** shown in the right-hand image of Figure 5, the 1/44 can quickly and accurately calculate the fundamental heart performance-related values needed by cardiologists to analyse how any heart is performing.

Scale Layout ... looks like a Rietz

The layout and choice of scales for the 1/44 closely mirrors the mosaic included in the DBGM (see Figure 2).

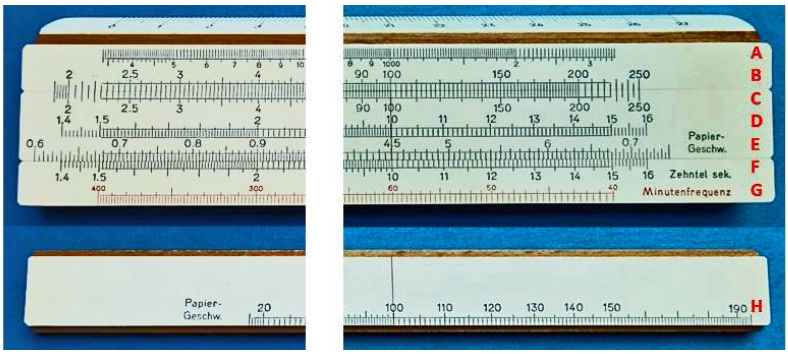

Figure 6: *Model 1/44 with the scales on the front face and slide labelled*

The scale labels shown on the right-hand end of Figure 6 are for identification only and do not appear on the 1/44.

Front face:

Top bevelled side-edge = cm scale (0-27) with a full-length cursor extension tab with a central hairline and a mini Vernier scale

A = extended 3.4-1345 cubic **K-like** scale (x^3)
B = extended 1.9-250 squares 2-cycle **A-like** scale (x^2)
C = extended 1.9-250 squares 2-cycle **B-like** scale (x^2)
D = tailored 1.4-16 time divided (milliseconds) 1-cycle **C-like** scale (x)
E = tailored 0.6-7.5 time divided (mm/minutes) "long scale" (continues/overlaps as **H**) for the graph paper speed
F = tailored 1.4-16 time divided (milliseconds) 1-cycle **D-like** scale (x)
G = tailored 400-40 reciprocal time divided (minutes) scale
Bottom straight side-edge= tailored (2-12) **L-like scale** ($\log_{10}(x)$) with a mini cursor tab extension with a central hairline

Back of the slide:

H = tailored 19-191 time divided (mm/minutes) "long scale" (continuation/overlaps of **E**) for the graph paper speed

Apart from the top and bottom edge scales and the double-length time divided scale **E** + **G**, the scales depicted in the DBGM mosaic all faithfully reappear in the layout of the 1/44. Most of them also look deceivingly familiar and common [3]. If it was not for the German language labels on the front face, it would be easy to mistake the 1/44 for a "standard Rietz" model.

Scale Layout – … but nothing like a Rietz

Most F-C special models have non-standard scales but perhaps it is a reflection of having a medical rather than an engineering background that Sandera chose to reuse common standard scales but in a refreshingly non-traditional way. For example, instead of being at the ends of the scales, Sandera opted for a single right-hand index line roughly ¾ along the scales. This can be seen in Figure 6 by a vertical graduation line running between the tick marks for 100, 100, 10, 4.5 and 10 on the scales **B**, **C**, **D**, **E**, and **F**. Sandera took further advantage of this single index line by aligning the 60-minute tick mark value on the reciprocal scale **G** under it. This also explains the unusually chosen 2-12 range for the bottom side edge L-like scale as the tick mark 0 (10) now also conveniently lines up under the same right-hand index line.
An unexpected cornerstone of Sandera's design is that it allows for a wide range of running speeds for printing the analogue strip of graph paper (see scales **E** and **H**, Figure 6). Many ECG machines still have a switch for "double speed" running to "stretch out" the ECG readings – i.e. 50 mm/second instead of the de facto 25 mm/second. This is useful when the sinus rhythm is inconclusive or the cardiologist wants to "zoom in" on

an element of the cardiac cycle. In his paper [8] Sandera states that in the 1950s the running speed was: "*between 30 mm/sec. and 50 mm/sec. of the most common ECG types*." Clearly Sandera wanted to be as accurate as possible and being an analogue printout in the 1950s, minor or major machine speed variations would have been common and not easy to recalibrate in situ. So perhaps it was just easier to time the actual running speed and use that when calculating with the 1/44 [10].

Another non-traditional use of a common slide rule feature was the way in which Sandera used gauge marks. Normally a gauge mark appears above the needed constant or factor on a scale with a suitable range. On the 1/44 Sandera placed gauge marks **H** and **F** on the time divided (mm/minutes) **E** and **H** scales.

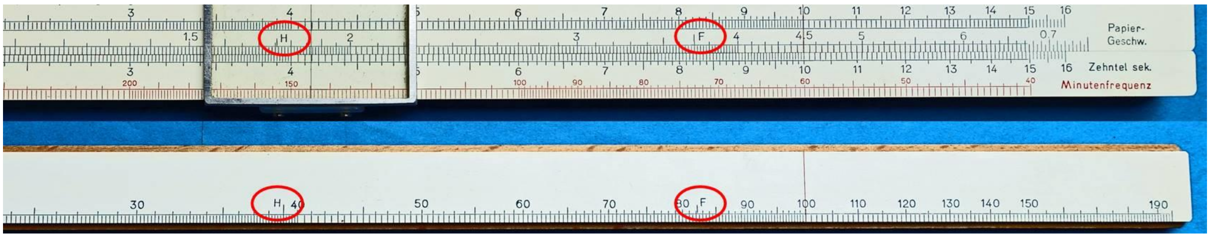

Figure 7: *Gauge marks **H** and **F** highlighted*

However, the two gauge marks do not represent values from the **E** and **H** scales they appear on! Instead when the scales are lined up on the right-hand index line (with or without the slide reversed) the gauge marks represent values off the adjacent D-like **F** scale. So the constant the gauge marks **H** represent is **39** and the constant the gauge marks **F** represent is **822** from the **F** scale. How these constants are used in some calculations is explained in the next section.

Using the EKAGNOST

The 1/44 uses the RR interval from an ECG to calculate quickly and accurately: (i) the heartbeat rate and (ii) a corrected QT interval[9] (QTc).

Calculating the heartbeat rate

Most people know that by placing two fingers over the artery found on the inside of the wrist, a pulse rate can be taken. So calculating anyone's heartbeat rate with a slide rule sounds like an "overkill". However, calculating the exact heartbeat rate from an ECG reading can highlight heart-related problems or show how well an administrated drug is working. Such insights could easily be missed if relying solely on an error-prone pulse rate. The following steps on the 1/44 are needed to calculate the heartbeat rate:

[9] QT interval = the time from the start of the QRS Complex to the end of the T wave.

1. Set the slide so that the speed of the graph paper in mm/second on scale **E** (or **H**) is coincident with the index line "10" on scale **F**.
2. Measure the length of the heart rate interval in mm, by using the top bevelled side-edge cm scale and the mini Vernier cursor extension scale or by counting the number of small graph boxes between two wave peaks or the RR interval.

Figure 8: *Vernier scale*

3. Move the cursor hairline over the heart rate interval in mm (from step 2) on scale **E**. The RR interval in seconds can now be found on scale **F** and the corresponding heart rate in beats/minute can be read off the adjacent scale **G**.

Example 1: with a paper speed of **42 mm/second** and a heart rate interval of **35.5 mm** (35½ small graph boxes) gives a RR interval of **0.845 seconds** and a heartbeat rate **71.0 beats/minute** (bpm).
Example 2: with a paper speed of **25 mm/second** and a heart rate interval of **18 mm** (18 small graph boxes) gives a RR interval rate of **0.720 seconds** and a heartbeat rate **83.3 beats/minute** (bpm).

Calculating a corrected QT interval

The QT interval (see Figure 5) is crucial because the time between the start of the QRS wave and the end of the T wave on an ECG shows when the two ventricle chambers of the heart start to contract and when they finish relaxing. Abnormally long or abnormally short QT intervals can indicate potentially serious or life-threatening heart conditions.
However, not unsurprisingly, the prevailing heartbeat rate when the ECG is taken affects the duration of the QT interval. Oversimplified, as the heart rate increases the corresponding QT interval shortens and the other way around. This makes the comparing QT intervals taken at different heart rates difficult to analyse. So over the years numerous normalising formulae[10] have been devised to correct the QT interval for the prevailing heart rate to give a **QTc**. The 1/44 was specifically designed to calculate a QTc according to one of four normalisation correction formulae popular in the 1950s:

- **Hegglin & Holzmann** devised in 1937
- **Fridericia** devised in 1920
- **Bazett** devised in 1920
- **Ashman & Hull** devised in 1941

[10] Modern ECG machines do the same process automatically.

The gauge marks included on the 1/44 are only needed for the Hegglin & Holzmann and Fridericia QTc formulae. However, all four formulae are listed as part of the K.17 paper Table on the back of the 1/44.

Figure 9: *K17 paper Table*

Hegglin & Holzmann

These days the largely defunct Hegglin & Holzmann normalisation formula is expressed by Sandera as **0.39 * √RR** where RR is the RR interval in seconds. The following steps on the 1/44 are needed to calculate a **QTcH&H**:

1. Set the index line on the slide ("100" on scale **C**) coincident to the RR interval in seconds on the squares scale **B** (2nd decade).
2. Move the cursor hairline to gauge mark/indicator line **H** on scale **E** and read off the corrected QTc interval in seconds from the adjacent scale **F**.

Example 1: an RR interval of **0.845 seconds** gives a corrected QTcH&H interval of **0.359 seconds.**
Example 2: an RR interval of **0.720 seconds** gives a corrected QTcH&H interval of **0.331 seconds**.

Fridericia

Although older, the Fridericia normalisation formula used to be popular because it neatly divided ECG patients into two main groups: (i) those with good prospects and (ii) those potentially at risk. In his DBGM, his published medical paper and on the 1/44 Table[11] Sandera expresses Fridericia's normalisation formula as **8.22 * ³√RR** where RR is the RR interval in seconds. But Sandera's version is mathematically incorrect and gives **wrong answers!** The mistake was probably caused by Sandera trying to include a mathematically incongruous cubic root of a time period in a simple to use formula [10]. To work correctly Sandera should at least have expressed this normalisation formula as **0.0822 * ³√(100 * RR)** where RR is the RR interval in seconds. With this version the following steps on the 1/44 are needed to calculate a **QTcFri**:

1. Set the index line on the slide ("100" on scale **C**) coincident to 100 times the RR interval in seconds (2nd decade) on the cubic scale **A**.
2. Move the cursor hairline to gauge mark/indicator line **F** on scale **E** and read off the corrected QTc interval in seconds from the adjacent scale **F**.

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[11] No known copies of the original F-C instructions for the 1/44 exist.

Example 1: an RR interval of **0.845 seconds** gives a corrected QTcFri interval of **0.360 seconds**.
Example 2: an RR interval of **0.720 seconds** gives a corrected QTcFri interval of **0.342 seconds**.

Bazett
Although from the same era as the Fridericia, the Bazett gender specific normalisation formulae are still in use[12]. The Sandera Bazett formula is **0.37 * √RR for men** and **0.40 * √RR for women** where RR is the RR interval in seconds. The following steps on the 1/44 are needed to calculate a **QTcB**:

1. Set the index line on the slide ("100" on scale **C**) coincident to the RR interval in seconds on squares scale **B** (2nd decade).
2. Move the cursor hairline to **0.37** for men and to **0.40** for women on scale **D** and read off the gender adjusted corrected QTc interval in seconds from scale **F**.

Example 1: an RR interval of **0.845 seconds** gives a corrected QTcB interval of **0.340 seconds for a man** or a corrected QTcB interval of **0.368 seconds for a woman**.
Example 2: an RR interval of **0.720 seconds** gives a corrected QTcB interval of **0.314 seconds for a man** or a corrected QTcB interval of **0.339 seconds for a woman**.

Ashman & Hull
Although the youngest of the four supported formulae, it is no longer used. The formula gives gender specific and age group specific (children, adults and the elderly)[13] results. The Sandera Ashman & Hull normalisation formula is **k * (log (10 (RR + 0.07))** where RR is the RR interval in seconds and where the constant **k** is: (i) 0.375 for children and young men, (ii) 0.380 for elderly men and (iii) 0.385 for girls and women[14].
On a traditional Rietz layout a 1-cycle **D** scale is paired alongside an **L** scale. Fortunately on the 1/44 the time divided (millisecond) scale **F** can double up as a pseudo-D scale and work in the same way with the bottom side-edge L-like scale. The following steps on the 1/44 are needed to calculate a **QTcA&H**:

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[12] These days the Bazett formula is pre-programmed into modern digital ECG machines.
[13] No specific or scientifically devised/proven age band for each age group is known.
[14] The values listed for the constant "k" are as on the back of the 1/44 – see Figure 9.

1. Move the cursor hairline extension to 10 times RR interval in seconds + 0.07 on the bottom side-edge L-like scale and read off the $\log_{10}$ value from under the cursor hairline on scale **F**.
2. Set the index line on the slide ("100" on scale **C**) coincident to the $\log_{10}$ value from step 1 on scale **B**.
3. Move the cursor hairline to the suitable **k** constant value (2nd decade) on squares scale **C** and read off the gender and age group specific corrected QTc interval in seconds from scale **B**.

Example 1: an RR interval of **0.845 seconds** gives a corrected QTcA&H interval of **0.361 seconds for a child or a young man** or a corrected QTcA&H interval of **0.368 seconds for an elderly man** or corrected QTcA&H interval of **0.370 seconds for a girl or a woman**.
Example 2: an RR interval of **0.720 seconds** gives a corrected QTcA&H interval of **0.337 seconds for a child or a young man** or a corrected QTcA&H interval of **0.341 seconds for an elderly man** or corrected QTcA&H interval of **0.346 seconds for a girl or a woman**.

Of the four QTc correction formulae the 1/44 was designed to calculate, only the Bazett normalisation formula is still used.

Conclusions

Despite the mistake in the Fridericia QTc correction formulae, the F-C model 1/44 is an **impressive and unparalleled slide rule**.
This F-C special has many non-traditional features. It is probably refreshingly "different" because Sandera was a Doctor of Medicine rather than an Engineer. With his medical background he was not "blinkered" by the traditional concepts of how to design and use a slide rule.
So when designing a special slide rule why not as Sandera:

- have a single index line and reposition it ¾ of the way along the scale layout?
- reuse the standard scales found on a Reitz type but with slightly adjusted ranges?
- position a tailored time scale so that the 60-minute/hour value lines up under the repositioned index line?
- adjust the range of the L scale on the bottom side edge so that 0 (10) value lines up under the repositioned index line
- reinvent gauge marks so that when lined up they represent a value from an adjacent scale?
- find a practical use for the standard 2-cycle x^2 scales?

The 1/44 is the "holy grail" for many traditionalists – finally a scale layout where including the classical pair of 2-cycle x^2 standard squares scales[15] was worthwhile and effective. Burns Snodgrass was an influential and an outspoken critic of such squares scales [11]. He felt Frenchman's Amédée Mannheim original inclusion of two such x^2 scales in the standardised Mannheim layout[16] was a waste of space and of little importance. However, Sandera's inclusion of such scales **was not only inspired but also essential for his design to work**.

Before being made obsolete by digital recording/reporting ECG machines in the 1970s, the F-C special 1/44 slide rule undoubtedly helped cardiologists make quicker and more accurate analyses. It is just strange the model 1/44 was only in production for 6 years and why F-C did not exploit its obvious potential outside the German home market.

Acknowledgements & Bibliography

My only cardiologic knowledge comes from over 30 years ago and the one time I underwent an ECG check. So in 2019 I contacted a fellow collector, the late **Rodger Shepherd** (1932-2020), for some expert medical help. Rodger was willing to help and patiently guide me through the medical maze. Luckily Rodger was not only a retired Doctor of Medicine but also a trained paediatric cardiologist. But unknown to me Rodger was seriously ill. So sadly Rodger only ever got to see my work-in-progress notes.

I also need to thank **Andries de Man** for his help. Online academic medical and scientific archives are not usually accessible to the general public. Andries kindly found the medical references and the Sandera-related articles I needed. Lastly a word of thanks to **Peter Holland** for sending me a copy of the marketing leaflet F-C published for the 1/44.

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[3] **Sweetman, David**: "*Slide Rule Listing Conventions*", JOS Vol. 24 No. 1, Spring 2015, ISSN 1061-6292, Pg. 47-51.

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[15] The standard A and B scales traditionally found as part of the layout on any Mannheim, Rietz or Darmstadt type of slide rule.

[16] A layout of scales that was fashionable from circa 1850 to the demise of the slide rule.

Pg. 31 - https://www.rechenschieber.org/2020/12/neuauflage-von-peter-hollands-faber-castell-buch/ .
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