The Wright table of the cardiac cycle: a stand-alone supplement to the Wiggers diagram

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INTRODUCTION

The cardiac cycle, all the events that take place during a single heartbeat, is one of the most fundamental concepts in physiology. This stepwise process by which the heart works to pump blood is essential for understanding cardiac function, in both health and disease. Dr. Carl Wiggers (3) detailed the specific steps of the cardiac cycle in a 1921 publication. Included in this two-part paper and one the following year were diagrams—named in Fig. 2, A and B, respectively. In the Wright table, the same cardiac cycle events displayed within the Wiggers diagram are characterized within four phases, focusing on each phase’s four phases of slow ventricular filling, active ventricular filling, ventricular emptying, and rapid ventricular filling. It offers a method of teaching that allows students to understand and better visualize each phase in turn and then combine phases into a complete cardiac cycle. The Wright table of the cardiac cycle for the right and left sides of the heart are shown in Fig. 2, A and B, respectively.

The Wright Table of the Cardiac Cycle

The Wright table of the cardiac cycle today. A typical Wiggers diagram is shown in Fig. 1. Although the Wiggers diagram conveys a great deal of information in over two dozen events depicted on multiple graphs within a single cardiac cycle, it is not always apparent to students how it achieves its main purpose, i.e., to move a volume of blood from a low-pressure vein into a high-pressure artery by alternating pressures in the two chambers of the heart. This is partly because blood flow from venous compartment through the heart and then into an artery is not directly illustrated by this tool. Other supplementary tools based on heart anatomy can illustrate the blood flow that is missing from the Wiggers diagram. However, this still requires students to synthesize information from both tools, relating anatomical images for different points in time in the cardiac cycle with the pressure changes shown in the Wiggers diagram. Many students struggle with this. Basic concepts of physiology, such as “pressure drives flow,” are often lost in this approach, resulting in students confusing the cardiac cycle with the flow of blood within the pulmonary and systemic circulations.

To address the difficulties students face in learning the cardiac cycle and related physiology of blood flow through the heart, a new tool is offered herein, with this synthesis of concepts at its core: the Wright table of the cardiac cycle.

The Wright Table of the Cardiac Cycle

The Wright table of the cardiac cycle is a teaching tool specifically designed to illustrate how the heart acts as a pump and how the related events of the cardiac cycle all work together to achieve this. This 4 × 4 table shows how the blood moves through four volume compartments during the cardiac cycle’s four phases of slow ventricular filling, active ventricular filling, ventricular emptying, and rapid ventricular filling. It offers a method of teaching that allows students to understand and better visualize each phase in turn and then combine phases into a complete cardiac cycle. The Wright table of the cardiac cycle for the right and left sides of the heart are shown in Fig. 2, A and B, respectively.

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Other events (e.g., valve position changes and isovolumic states) are incorporated into these four phases as part of a dynamic process of forcing valve opening and closure and thereby directing flow changes from venous to arterial compartments. Instead of time being specifically depicted on an x-axis for a set heart rate of 75 beats/min, as is found in the Wiggers diagram, the time course is depicted from the top to the bottom of a table, independent of any particular heart rate.

The initial column of the Wright table is a title column naming the four phases of the cardiac cycle and the contraction status of the atria and ventricles, respectively, with ECG waves shown as transitions between phases. The next four columns display the route of blood into and out of the heart. First, a venous compartment is shown for one side of the heart (either vena cava or pulmonary veins). Next, the atrium (right or left) and then the ventricle (right or left) are shown. Finally, a column for the receiving artery is noted (either pulmonary trunk or aorta). Openings between compartments are shown as either permanently open (e.g., between vena cava and right atrium) or containing a valve (e.g., between right ventricle and pulmonary trunk). Entry and exits from the venous and arterial compartments are included as well, to reinforce the idea that these compartments are also open-ended parts of the longer pulmonary and systemic circulations.

The top row of the Wright table is a title row naming the cardiac cycle phases and the four compartments described above. The following four rows depict the events associated with each of the four phases in which blood is either entering or being forcibly ejected from the ventricle. In modern parlance, and beginning with that phase most typically noted as time zero in a Wiggers diagram, these are 1) the slow ventricular filling phase; 2) the active filling phase (atrial systole); 3) the ventricular emptying phase (ventricular systole); and 4) the rapid ventricular filling phase. Within each row, normal pressures of the four compartments can be seen (and, as a laboratory exercise, filled in by students) such that the pressure gradient for flow either forward or, in one case, backward for the jugular venous pulse can be clearly grasped.

A dynamic component for three of the Wright table’s four phases is specifically noted within the table. The first of these is found in phase 2, the active filling phase. A dynamic increase in atrial pressure that results from atrial muscle contraction is shown in the atrial fluid compartment. The unique blood flow pattern from the atrium during that phase is the result of increased pressure therein. Ventricular emptying involves another set of pressure changes within these compartments. It shows atrial pressure decreasing as a consequence of atrial muscle relaxation, ventricular pressure increasing as a result of ventricular muscle contraction, and arterial pressure increasing as a consequence of the blood flowing into that final compartment. These latter pressures are the same systolic and diastolic pressures from which mean arterial pressures can be determined, but in their true order from low (diastolic) to high.

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**Fig. 1.** The Wiggers diagram. From top to bottom, the lines show: 1) aortic pressure, 2) ventricular pressure, 3) atrial pressure, 4) electrocardiogram, 5) mitral and aortic valve opening and closing, and 6) heart sounds. The y-axes vary, but all share a common x-axis in time. Systole, the time in which a compartment’s cardiac muscle is contracting; P, QRS, and T, waves of the electrocardiogram; S1 and S2, specific heart sounds associated with mitral and aortic valve closings, respectively (artist: R. Joseph).
Finally, during phase 4, it shows the pressure drop in the ventricle, resulting from relaxation of ventricular muscle. For each of the four phases, the direction of the arrows depicting blood flow is always from higher to lower pressure. The speed of blood flow is indirectly shown by the thickness of the arrows. Between the row for phase 1 (slow ventricular filling) and phase 2 (active ventricular filling), the P wave is inserted to the side. This ECG wave measures the depolarization of atrial muscle that causes atrial contraction. This contraction in turn increases pressure in the atrium and thereby (systolic). Finally, during phase 4, it shows the pressure drop in the ventricle, resulting from relaxation of ventricular muscle. For each of the four phases, the direction of the arrows depicting blood flow is always from higher to lower pressure. The speed of blood flow is indirectly shown by the thickness of the arrows. Between the row for phase 1 (slow ventricular filling) and phase 2 (active ventricular filling), the P wave is inserted to the side. This ECG wave measures the depolarization of atrial muscle that causes atrial contraction. This contraction in turn increases pressure in the atrium and thereby
drives blood flow. Similarly, between phases 2 and 3, the QRS ventricular depolarization stimulates ventricular contraction and ventricular emptying. Finally, between phases 3 and 4, the T wave ventricular repolarization leads to ventricular relaxation and rapid filling.

In the Wright table of the cardiac cycle, pressures are slightly idealized for maximum student understanding. It is unlikely, for example, that the exact pressure difference in the slow filling phase is 1 mmHg between vein and atrium and then atrium to ventricle. For more advanced students, gradients closer to what can be observed in the research laboratory would be appropriate, but, as a teaching tool to novice students, this is a helpful simplification. It is also likely that some variation in pressure occurs in every compartment in every phase, but these are only demonstrated in those compartments for which changes must be shown. In addition, in the tables shown in Fig. 2, valves are depicted in their positions at the end of each phase. This too is a simplification of a dynamic process, but an appropriate one for teaching purposes.

The final feature shown within the Wright table are two boluses of blood used as markers to show in a way which all students can see how pressure gradients are driving blood into the ventricle during filling phases and out of the ventricle in the emptying phase. The first is shown entering at the beginning of the cycle and proceeding all the way through. The second starts later and shows that venous flow and atrial filling are still occurring, even when the ventricle is emptying. It will leave, too, although not until the next cardiac cycle.

Using the Wright Table as a Teaching Tool

The Wright table shows students when, how, and why blood flows as it does during each phase of the cardiac cycle. The role of the ECG in driving the heart into different phases is shown as transitions between phases. With one exception during phase 2 (atrial systole), blood always flows in one direction, from venous toward arterial compartments, stopping only when a closed valve is reached. Simultaneously, the phenomena during right atrial systole that result in the jugular venous pulse are apparent. Pressure changes within the main pumping chamber, the ventricle, cause it to eject blood when its pressure is high and receive blood when its pressure is low. Heart sounds, which in the Wiggers diagram have their own line separate from the valve closures line, are shown within the Wright table both for the phase of the cardiac cycle in which each occurs and inside the exact chamber/compartment from which each originates.

The Wright table of the cardiac cycle is best taught as it is read, from top to bottom. The top row corresponds to “time zero” of a cardiac cycle as the moment just before a P wave begins, when the heart’s sinoatrial node is almost depolarized to threshold. This is the location of the time 0 on the x-axis of most Wiggers diagrams. The advantage of starting here and, thereby, the reason why it is both on the left side of a Wiggers diagram and on the top row of the Wright table, is that everything is in a passive state. All of the pressure gradients are low, the valves are not moving, and neither the atrial nor the ventricular muscle is depolarizing or repolarizing. It is the closest the cardiac cycle ever has to a baseline state. Other phases are driven by electrical events within the heart, which can be measured as the P wave, QRS complex, and T wave of the electrocardiogram. A step-by-step depiction of how to teach the table is shown in Fig. 3.

Starting at phase 1, when pressure gradients are low, one describes the pressures in the four compartments in that row and how this causes slow filling of the ventricle. During this phase, pressures are higher in the vena cava (5 mmHg) than in the right atrium (4 mmHg), and the atrium’s pressure is higher than the right ventricle’s (3 mmHg), but the pulmonary trunk’s pressure (12 mmHg) is higher than all of these. The combination of pressure gradients plus one-way valves produces the flow pattern of the top row, from left to right (5 > 4 > 3 mmHg), and through the one-way pulmonic valve into the ventricle. When the pressure is higher on the right (e.g., right ventricle versus pulmonic trunk, 3 < 12 mmHg), then that downstream pressure will shut the one-way valve through which blood would enter, preventing backflow into the ventricle.

In teaching this, if students have a blank table available to fill in, it becomes an easy task to fill in the pressures in this top row, draw the two valves in a tricuspid-open and pulmonic-closed position, and show a bolus of blood following this small pressure gradient from the vena cava into the right atrium.

When it is time to move to phase 2, active ventricular filling, one can insert the appropriate portion of the ECG. For example, to transition from the slow ventricular filling phase to the active ventricular filling phase, one explains to students that a P wave occurs that depolarizes and produces muscle contraction, and then with venous (5 mmHg) and ventricular (4 mmHg) pressures also shown, demonstrate how blood flows out of the atrium into the ventricle actively, because of the atrial muscle contraction. As with the phase 1, because the downstream arterial compartment still has higher pressure (4 < 10 mmHg), the pulmonic valve remains closed.

Importantly, one can also demonstrate that, during the active ventricular filling phase, the pressure gradient from atrium to vein is also reversed (5 < 6 mmHg), but, unlike the atrioventricular junction, there is no valve to prevent backflow of blood from atrium to vein. Indeed, this is perfectly normal, and the foundation for the jugular (venous) pulse.

Similarly, in transitioning to phase 3 (ventricular emptying), one describes the QRS complex leading to ventricular depolarization and muscle contraction, and mentions that the atria repolarize and begin to relax at the same time. One demonstrates the systolic contraction in the ventricle and the diastolic relaxation of the atrium and shows the pressures changing in each (6–3 mmHg in the atrium, and 4–25 mmHg in the ventricle). Students then get to see how, during this phase, that rising ventricular pressure first reverses the pressure gradient between ventricle and atrium, and then that between ventricle and artery. Rising ventricular pressure first shuts the tricuspid valve (7 mmHg and rising in the ventricle > 5 mmHg and dropping in the atrium) creating the first heart sound, and then opens the pulmonic valve (10 mmHg and rising in the ventricle > 8 mmHg in the pulmonary trunk), leading to blood being ejected into the artery. This forced entry of blood into the artery raises both its volume and its pressure. The lowest pressure in the artery during this phase is its diastolic blood pressure; the highest, its systolic. One can mention that, when
the pressure in the ventricle is between that of the atrium and the artery, a short isovolumetric contraction is occurring, which ended when the pulmonic valve opened.

During the ventricular emptying phase, the first two compartments are not idle. Falling atrial pressure creates a large pressure gradient (6 → 3 mmHg), causing the atrium to rapidly fill, even as the ventricle is rapidly emptying. This readies the atrium for the next phase as it becomes quite full.

Finally, when the T wave occurs, repolarizing the ventricles and causing ventricular muscle to relax, phase 4 (the rapid ventricular filling phase) can begin. As the ventricle relaxes in this bottom row of the table, students can then show how the drop in ventricular pressure (from 25 to 0 mmHg) restores the normal pressure gradients, first between ventricle and artery (when 20 < 23 mmHg), and then between atrium and ventricle (when 4 > 0 mmHg). When the arterial pressure is higher, it slams the pulmonic valve shut, producing turbulent flow and the second heart sound. When the tricuspid valve opens later, the full atrium rapidly moves blood down its pressure gradient into the relatively empty ventricle, producing the rapid ventricular filling of phase 4. When, as a result of ventricular filling, its pressure rises, the pressure gradient becomes smaller and the flow rate drops from a rapid to a slow filling phase. Direct students to the top of the table and begin again for a new

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**Wright Table of the Cardiac Cycle for the Right Heart**

**Expanded View for Teaching**

| Cardiac Cycle Phase | Vena Cava | Right Atrium | Right Ventricle | Pulmonary Trunk |
|---------------------|-----------|--------------|----------------|----------------|
| 1. Slow Ventricular Filling (D/D) | 5 mmHg → 4 mmHg → 3 mmHg → 12 mmHg |
| 2. Active Ventricular Filling (S/D) | 5 mmHg → 4 >> 6 mmHg → 4 mmHg→ EDV → 10 mmHg |
| 3. Ventricular Emptying (Ejection) (D, S) | 6 mmHg → 6 >> 3 mmHg → S1, “LUB” → 8 >> 25 mmHg |
| 4. Rapid Ventricular Filling (D/D) | 5 mmHg → 4 mmHg → 25 >> 0 mmHg → S2, “DUB” → 23 mmHg |

**Transition: P Wave** - Atrial Muscle Depolarization >> Atrial Muscle Contraction

**Transition – QRS Complex** – Ventricular Depolarization >> Ventricular Contraction

**Transition – T wave** – Ventricular Repolarization >> Ventricular Relaxation

**Return to Row 1 of a new cardiac cycle**

Fig. 3. Expanded view of the Wright table for the right heart, for teaching. See Fig. 2A. A-V, atrioventricular; D/D, atrial and ventricular diastole; S/D, atrial systole and ventricular diastole; D/S, atrial diastole and ventricular systole; EDV, end-diastolic volume in the ventricle; ESV, end-systolic volume in the ventricle; P, QRS, and T, waves of the electrocardiogram that serve as transition points between phases; S1–S4, heart sounds. Pressures within each compartment in each phase are shown in mmHg. Solid lines encircling a box, contraction of cardiac muscle surrounding that compartment. Dotted lines encircling a box, relaxation of cardiac muscle surrounding that compartment. Arrows denote opening and closing heart valves; thicker arrows indicate faster flow.
cardiac cycle. Again, it is possible to note that, while the ventricular pressure was falling, but was intermediate between atrial and arterial pressures, a short-lived isometric relaxation of the ventricle was occurring that ended when the tricuspid valve opened.

Once students have filled in the table, with all pressures, valve positions, and flows marked, the teacher can then demonstrate that, on a time basis, without worrying about what the pulse rate is or how many milliseconds each phase lasts, there is, nevertheless, a temporal sequence from beginning to end. One can choose to look at each compartment in turn from top to bottom to observe what goes on in that compartment during the cardiac cycle. Most familiar to students will be the ventricular events, as these are the same events displayed in a typical ventricular volume-pressure diagram (2), but each compartment’s changes over time can be noted separately when viewed from top to bottom.

Integration of the Wright table and Wiggers diagram in teaching the cardiac cycle. As a classroom lecture topic, the Wright table’s ideal place is before the introduction of the Wiggers diagram. In our teaching experience, if the Wright table is introduced first, those who might have had difficulty understanding the Wiggers diagram by itself can often readily do so as an application of concepts they learn first using the Wright table. Consequently, Wiggers diagram depictions of exact quantities for stroke volumes, ejection fractions, and exact times for each phase using a heart rate of 75 beats/min can be easier to grasp and use by these same students after students have learned the general process using the Wright table.

As a laboratory exercise, provided only a pulmonary vein compartment pressure of 11 mmHg, students can be assigned the task of filling in the table for the left heart by reading the Wiggers diagram, finding the correct pressure for the correct phase, and inserting these pressures. This can be done individually, but it can also be done in small groups so that students can teach one another another how to read and use the Wiggers diagram. The full applicability of use of the Wright table in other formats has yet to be explored.

Examination of student response to the Wright table of the cardiac cycle. The first author developed the Wright table in 2007, while teaching the cardiac cycle to medical students, and used it in lectures for several different classes of medical students between 2007 and 2008. He has since used it during individual tutoring of medical students. Under all circumstances, informal feedback from students has indicated a favorable response to the Wright table. A survey study was performed in January 2020 to gain more objective and quantifiable student feedback about this teaching tool.

METHODS

The authors collected student perception data using a four-item survey: 1) Did the Wright table improve your understanding of the cardiac cycle?; 2) How would you rate your knowledge of the cardiac cycle before this session?; 3) How would you rate your knowledge of the cardiac cycle now?; and 4) Would you recommend the Wright table to other medical students? The survey also included space to add free-form comments: Please share any additional comments below.

All students enrolled in the preclinical years at Ross University Medical School (RUSM) during the January 2020 semester were invited to attend a voluntary enrichment session presented by the first author under a generic name: “Cardiac Cycle Teaching Tool.” The session involved an ~90-min presentation by the first author, which included ample time for questions and discussion. At the end of the session, students were asked to complete anonymous surveys and to place them in a box near the classroom exit.

The RUSM curriculum is such that all students enrolled in semesters 2–5 had been taught the cardiac cycle using the Wiggers diagram, but the Wright table is not taught, so the whole population was of naive students. At the time of the session, students in semesters 2 and 4 were in the middle of their respective lectures in Cardiovascular Modules I (semester 2) and II (semester 4). Semester 3 students had a scheduling conflict with the voluntary session. The authors collected anonymous surveys from a convenience sample of 105 medical students who elected to attend the voluntary enrichment session. The RUSM Institutional Review Board reviewed the protocol as an exempt review and provided study approval before this session.

RESULTS

IBM’s SPSS software (version 26) was used to generate descriptive statistics. Most participants were enrolled in semester 2 (75%) or semester 4 (14.5%). The remaining 10 students were divided among semesters 1 and 5 and other; no students were enrolled in semester 3 due to an identified scheduling conflict.

Before the session, about two-thirds of participants indicated they had a fair to poor understanding of the cardiac cycle (63.8%), and one-third felt they had a better-than-fair to excellent grasp of the material (36.2%). A chi-square analysis indicated a significant pre-post understanding of the cardiac cycle (P = 0.003), with 85.4% reporting an improvement in their understanding of the cardiac cycle after exposure to the Wright table. After exposure to the Wright table, 87.6% of students indicated they would recommend it to other medical students, 10.5% were unsure, and only 1.9% would not recommend it.

Over one-half of the students offered written comments. Among the students who wrote comments, over 74% were positive, e.g.: “Helpful for deconstructing the concept. Thank you”; “Great breakdown. Should be taught like this”; “Amazing presentation wish we could have been shown this at the beginning of the cardio block”; “Good supplement to the Wiggers, made me think.” The other 23% were neutral, offering ideas about when or how to add the table to the curriculum, asking questions about the cardiac cycle, or stating something incidental; e.g.: “This is very similar to how thermodynamics is taught to engineers.” Many students, particularly those from semester 4, also requested specific examples in which the Wright table could be used to illustrate clinical conditions, but, at the time of the session, none had been developed.

Illustrating Clinical Conditions and Pathophysiology with the Wright Table

The Wright table can be readily adapted from its basic form to effectively and efficiently illustrate the pathophysiological phenomena underlying a variety of clinical conditions, thus extending the teaching tool’s value beyond cardiac physiology for novice learners. For example, one adaptation retains the form of the Wright table illustration of a single phase of the cardiac cycle. Within that form, both the right and left hearts are depicted so that they can be directly compared. Using this composite model, one could contrast cardiac events at two time
points within that phase, as previously described for isovolumic contraction. Alternatively, one could directly compare normal versus pathology findings for a single point in time. Figures 4 and 5 display two different ways to show two different pathologies using the right-heart/left-heart composite table.

**Example 1:** Using the Wright table to explain paradoxical splitting of the S2 heart sound associated with left bundle branch block. As shown in Fig. 4, one specific condition that could be displayed in a Wright table format is the “paradoxical split S2” heart sound associated with a left bundle branch block (LBBB). This distinct sound is often described to students studying heart sounds associated with this condition in which the right side of the heart is depolarized and in consequence also repolarized before the left side of the heart. It is paradoxical in that it reverses the usual pattern in which aortic valve closure precedes pulmonic valve closure (4). The physiological basis for this paradoxical heart sound is difficult to see on a Wiggers diagram. Indeed, a Wiggers diagram would have to be even more complex, displaying both right and left sides of the heart simultaneously, to show it at all. In contrast, the Wright table makes this phenomenon easy to see and describe.

In this variation of the Wright table, both the right and left sides of the heart are shown during two distinct times during a given phase 4 in this patient: first, at the moment that the pulmonic valve normally closes, and second, when the aortic valve finally closes following its compartmental repolarization. In the Wright table, this can be directly visualized as originating from the arteries themselves as each valve closes in turn. It also shows that, at time point 1, the pressures in the left heart and aorta are too close to one another to allow aortic valve closure when the pulmonic valve is closing. At time point 2, the pulmonic valve is still closed as the aortic valve finally closes and makes its half of the split S2. This format clearly illustrates how one side of the heart can respond normally to rapid depolarization through an intact Purkinje system, while the other side (in LBBB, the left heart) responds late due to disruption of the normal Purkinje system, too late, in fact, to produce a single S2 heart sound.

**Example 2:** The Wright table in aortic stenosis: effect on both left and right heart. Another clinical application variation of the Wright table with potential to illustrate an even wider range of cardiac pathologies, is shown in Fig. 5. In this Wright table variant, the arrangement looks similar to that shown in Fig. 4, although it is substantially different. Both the right and left heart are displayed, and, as in Fig. 4, all four compartments usually displayed by the Wright table are shown. However, unlike Fig. 4, instead of contrasting two time points, this Wright table contrasts normal function to a given pathological presentation. The top two boxes show what a normal heart cardiac cycle will look like for any one phase, identified in this example in the top left as the phase 3: ventricular ejection. The bottom two boxes show what a normal heart cardiac cycle will look like for any one phase, identified in this example in the top left as the phase 3: ventricular ejection. The bottom two boxes provide a direct contrast to the normal, by displaying the changes in pressures, valve positions, and consequences of a relatively mild aortic stenosis. Note that, even when the primary pathology is within the left heart, the earliest consequences of this condition on right heart function will be displayed as well. In this mild
stenosis, the only consequence is an elevation in pulmonary trunk diastolic pressure as fluid begins to back up from the left atrium all the way through the lungs, for which the right ventricle begins to generate more pressure during its contraction. In a more severe case, one could demonstrate how the right heart would have to deal with increasing pulmonary hypertension and the adverse effects this would have on its function as well.

### Prototype for other pathologies: Aortic stenosis, mild

| PHASE 3: Ventricular Emptying | Above: Vena Cava Below: Pulm. Veins | Above: Rt. Atrium Below: Left Atrium | Above: Right Vent. Below: Lt. Vent. | Above: Pulmonary Trunk Below: Aorta |
|-------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Normal Vent. Contraction:     | 6 mmHg                              | 6 -> 3 mmHg                         |                                     | 8 -> 25 mmHg                       |
| Right Heart (D/S)             |                                     |                                     |                                     | Pulmonic valve opens                |
| Normal Vent. Contraction:     | 14 mmHg                             | 14 -> 5 mmHg                        |                                     | 80 -> 120 mmHg                     |
| Left Heart (D/S)              |                                     |                                     |                                     | Aortic valve opens                  |
| Pathology: Aortic Valve Stenosis (D/S) | 6 mmHg | 6 -> 3 mmHg | 12 -> 30 mmHg | Pulmonic valve opens |
| Pathology: Aortic Valve Stenosis (D/S) | 20 mmHg | 20 -> 5 mmHg | 75 -> 105 mmHg | Aortic v. partially opens |

Fig. 6. The Wright table in pathology: mild/moderate aortic stenosis. See Fig. 2 legend for general description, with the following additions. Columns show pulmonary wedge pressure within a capillary-level fluid compartment. Pink/red arrows show movement of blood between compartments. A double arrow indicates turbulent blood flow. Thicker colored arrows indicate faster flow. Murmur, midsystolic murmur produced by turbulent flow through partially opened aortic valve.
Example 3: The Wright table in aortic stenosis: effects of this pathology throughout the cardiac cycle. While there are times as in the first two examples in which showing both the right and left heart is very useful, sometimes a more typical one-side-of-the-heart Wright table that shows every phase and every compartment can illustrate details of a given pathology in a unique way. Figure 6 demonstrates this for another case of aortic stenosis that is transitioning from mild to moderate. As the clinical description of what separates mild from moderate aortic stenosis is actually quite complex (1), based on jet pressures and other specific criteria that are not necessary to duplicate here, it is sufficient for this demonstration to stay between the two categories.

As both Figs. 5 and 6 illustrate, the primary dysfunction in aortic stenosis is an aortic valve that cannot fully open. This requires the left ventricle to generate extremely high systolic pressures in phase 3 to force enough blood through the partially opened aortic valve, so that aortic pressures are preserved as close to normal as possible. Flow across the stenotic valve will become turbulent, producing a diagnostic midsystolic murmur as the condition progresses from very mild to moderate. At this time, fluid backup into the atria, pulmonary veins, and even pulmonary capillaries produces higher-than-normal pressures that are necessary to ensure that filling of the hypertrophied less compliant left ventricle will still take place.

Of particular note in this clinical illustration is what is happening during phase 2, active ventricular filling. While it is normal for atrial muscle contraction to force some blood backward into the venous compartment, this is usually not clinically significant. However, in this and all other occurrences of early left heart failure with functioning left atrial muscle, it is precisely this contraction and atrial pressure rise that first drives pulmonary wedge pressures into the “danger zone” in which pulmonary congestion first occurs. Since the Wiggers diagram rarely shows the venous compartment at all, and anatomical heart depictions do not trace the pulmonary veins all the way into the lungs, this is an important transition into cardiopulmonary dysfunction that can uniquely be displayed by the Wright table of the cardiac cycle.

Other Pathophysiological Conditions: Potential for Wright Table Modeling

Though only two clinical conditions are detailed as prototypic pathophysiological models, many more can be illustrated and explained using the Wright table of the cardiac cycle (e.g., mitral insufficiency, atrial septal defects, and left myocardial infarctions), a work that is, in fact, currently in progress. Nonetheless, these prototypes sufficiently display the potential of this entire graphical format to illustrate advanced clinical scenarios in teaching, laboratory, and clinical settings.

Conclusion

The Wright table is a unique stand-alone supplement to the Wiggers diagram. Although other supplements may complement the Wiggers diagram, no single supplement in common use today incorporates all of the following: 1) phases that indicate action initiated by electrical activity; 2) demonstration of direction of flows that sometimes go “backwards”; 3) demonstration of exactly how, when, and why blood flows from venous to atrial to ventricular and then to arterial compartments; and 4) demonstration of how and why pressures and flows vary in each individual compartment from the beginning to the end of the cardiac cycle. The Wright table addresses these deficits and is, therefore, able to uniquely illustrate many clinical conditions affecting heart function. A comprehensive review comparing and contrasting the most common tools used in teaching the cardiac cycle would be valuable but is outside the scope of this article.

In a one page-sized figure, the Wright table demonstrates how the heart actually acts as a pump, illustrating almost all the actions of the cardiac cycle in a way that novices can understand, showing how actual pressures drive blood first from low-pressure veins into relaxed ventricles, and then, with ventricular contraction, from high-pressure ventricles into arteries. For the purpose of teaching and reviewing the cardiac cycle, it is designed to overcome inherent weaknesses of the Wiggers diagrams.

Medical students with prior exposure to the Wiggers diagram overwhelmingly reported that the Wright table improved their understanding of the cardiac cycle, although many requested clinical applications. The three pathophysiological applications described within justify their interest and may be just the tip of the iceberg for future use of the Wright table as an aid for advanced students, clinical practice, and researchers alike. Thus, taught in conjunction with the Wiggers diagram, as a pure teaching tool, the Wright table can facilitate a more comprehensive understanding of the cardiac cycle, proving Aristotle’s famous aphorism that the whole is truly greater than the sum of its parts.

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DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the authors.

AUTHOR CONTRIBUTIONS

B.E.W. and G.L.W. conceived and designed research; B.E.W. and G.L.W. performed experiments; B.E.W., G.L.W., and N.J.S. analyzed data; B.E.W., G.L.W., and N.J.S. interpreted results of experiments; B.E.W. prepared figures; B.E.W. drafted manuscript; B.E.W., G.L.W., and N.J.S. edited and revised manuscript; B.E.W. approved final version of manuscript.

REFERENCES

1. de Jong J. Classification of valve stenosis and regurgitation (Online). Echopedia.org. https://www.echopedia.org/wiki/Classification_of_valve_stenosis_and_regurgitation [14 Feb 2020].
2. Hall JE. The volume-pressure diagram demonstrating changes in intraventricular volume and pressure during a single cardiac cycle. In: Guyton and Hall Textbook of Medical Physiology (13th ed.). Philadelphia, PA: Elsevier, 2015, chap 9, p. 118.
3. Landis EM. Carl John Wiggers 1883–1963: A Biographical Memoir by Eugene M. Landis. Washington, DC: National Academy of Sciences, 1976, p. 361–397.
4. Loscalzo J, O’Gara PT. Cardiac auscultation. In: Harrison’s Principles of Internal Medicine (19th ed.), edited by Jameson JL, Fauci AS, Kasper D,
Hauser SL, Longo DL, Loscalzo J. New York: McGraw-Hill Education, 2015, p. 1447–1448.

5. Wiggers CJ. Studies on the consecutive phases of the cardiac cycle. I. The duration of the consecutive phases of the cardiac cycle and the criteria for their precise determination. *Am J Physiol* 56: 415–438, 1921. doi:10.1152/ajplegacy.1921.56.3.415.

6. Wiggers CJ. Studies on the consecutive phases of the cardiac cycle. II. The laws governing the relative durations of ventricular systole and diastole. *Am J Physiol* 56: 439–459, 1921. doi:10.1152/ajplegacy.1921.56.3.439.

7. Wiggers CJ, Katz LN. The contour of the ventricular volume curves under different conditions. *Am J Physiol* 58: 439–475, 1922. doi:10.1152/ajplegacy.1922.58.3.439.

8. Wright BE. The Wright Cardiac cycle table: a novel tool to teach the cardiac cycle. *FASEB J* 31, Suppl S1: 574.54, 2017. doi:10.1096/fasebj.31.1_supplement.576.54.