The Tree Branching Law: Correcting Misconceptions on Capillary Cross-Section Areas and Blood Speed

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Abstract: ***The Tree Branching Law (TBL) states: "The trunk of a branching tree does not give rise to branches that have cross-section areas larger than its own", meaning: "The sum of all tree branches' cross-section areas is less than its own trunk." The reported results demonstrate that TBL is correct. This law rule applies down the arterial tree to the terminal arterioles and capillaries, and up a green tree to its leaves. The sum of all cross-section areas of all branches at any level is less than that of the trunk. Similarly, the sum of all cross-section area of all capillaries is less than that of the aorta. The TBL thus dispels the misconceptions on "cross-section areas of all capillaries are larger than the aorta" and "red blood cells (RBCs) speed in the capillary is very slow". It provides solid evidence with RBCs speed is fast with a speed gradient between the inlet and exit of the capillary. This allows the magnetic field-like phenomena of the G tube to cause fast capillary-ISF transfer that provide for the cell viability at rest and exercise. The physiological relevance and clinical significance of TBL are discussed.***

Keywords: Hydrodynamics, Hemodynamics, Capillary physiology and anatomy, Tree branching law, Green trees, Arterial trees, Red Blood Cells (RBCs) speed

1. Introduction

Current teaching on capillary physiology indicates that the red blood cells (RBCs) speed or the Capillary Blood Speed (CBS) is "very slow" running through capillaries to allow for the slow "perfusion" to take place as based on Starling's forces. This is based on another misconception that the sum of cross-section areas of all the capillaries is very much greater than the cross-section area of the Aorta. I have previously reported that Starling's law is wrong [3-6], the Revised Starling's Principle (RSP) is a misnomer [7], and the correct replacement is the hydrodynamics of the porous orifice (G) tube [1-2]. This creates a negative side pressure gradient exerted on the wall of the G tube. A unique autonomous rapid dynamic magnetic field-like fluid circulation occurs between fluid in G tube lumen and fluid around it in a surrounding chamber C. This induces a fast fluid transfer between lumen of the G tube and fluid surrounding it in chamber C (Figure 1). The same phenomenon of the G tube explains the capillary-interstitial fluid (ISF) transfer. Here I report the new Tree Branching Law (TBL) that demonstrates that the above two well-known and received concepts concerning capillaries cross-section area is "greater than the aorta" and RBCs Speed is "very slow" are in fact erroneous misconceptions.

The Tree Branching Law (TBL):

Definition

The TBL states that: "The trunk of a branching tree does not, and cannot, give rise to branches that have sum of all its cross-section areas larger than its own". In other words: "The sum of all tree branches' cross-section areas is less than its own trunk."

This observational theory on green trees as well as the red vascular tree of the aorta and its arterial branches that was mentioned before [1] has now been investigated. The results of scientific, mathematical, and experimental evidence show that TBL is correct and are reported here. This law rule applies further down the arterial tree to the terminal arterioles and capillaries, and up a green tree to its leaves as a branch becomes a mother trunk for its own sibling branches.

The TBL is not just a scientific curiosity of trivial importance but very important issue for understanding the capillary physiology. It verifies that the cross-section areas of the sum of all functional capillaries must be less than that that of the aorta. This is the scientific basis for the wrong believe that the cross-section areas of the capillaries is "much greater" than the aorta- based on which the predicted CBS or RBCs speed is thought "very slow", while in reality it is proved fast [1]. The speed gradient of CBS or RBCs speed along the capillary must account for the magnetic field-like fluid circulation around the capillary as it occurs in the G tube (Figure 1) [1, 2]. Furthermore, the TBL will allow accurate calculation of the capillaries in a human or animal based on data concerning the aorta' maximum diameter and its cross-section area and capillaries' diameters. Currently this seems a daunting idea as based on this photograph of the micro vascular tree of the head and neck (Figure 2). This shall prove feasible in the light of the new TBL reported here, when the precision engineering data on terminal arteriole measured diameter and its number of capillaries with its measured diameters become available in a true to life arteriole-capillaries-venule diagram or picture. The currently reported diagram (Figure 3) lacks the above-mentioned engineering precision data measurements.

2. Results

The Fiber-Optic Light Tree (Figure 4)

The cross-section area of all fibres gathered in a trunk is 86.625 mm^2. The cross-section areas of all fibres individually calculated and summed up later is 62.857mm^2. So, the sum of cross-section areas of all fibers individually is less than (72.562%) the trunk of all fibers gathered in one bundle- a rather surprising result as I initially thought it might be equal.

The Mathematical Tree

In a mathematical tree the maximum number of branches allowed that have half the diameter of the trunk is 4.The sum of cross-section areas of 4 branches equals that of the trunk, not more. Assuming each branch will similarly divide into 4 branches of half its diameter then the cross-section area of all branches at the same level will remain equal to that of the trunk. This is a situation that does not happen in real-life trees. A trunk cannot give rise to 4 or more than 4 branches of half its diameter as the matter cannot arise from nothing.

Even in a wrong theoretical mathematical model of a trunk giving 5 branches each with a diameter half of its own that will give results that the total cross-section area of such branches is more than its own trunk, the tree will collapse and break under the weight of branches at the 2nd order branches.

The diagrammatic Tree (Figure 5).

This illustrates the same results of the mathematical tree above at the maximum division of 4 branches each has a diameter of half the trunk and it also has the same result of equal cross-section areas of all branches to that of the trunk at all levels. Never more.

The Green Trees

A. Household Miniature Croton Tree (Figure 6)

The cross-section area of the trunk is 106.27mm^2. The cross-section areas of all the 1st order branches is 96.28 mm^2. (90.599%) The cross-section areas of all 2nd order terminal branches is 94mm^2. (88.454% of the trunk) As branching continue, the cross-section of all branches is less than its own mother branch, as well as being much less than the tree trunk. These findings were confirmed in all trees examined green and red.

The number of the rather large leaves for all branches of the Croton Tree is 123 leaves with their matching stems having total cross-section areas of 244.78 mm^2. This is much greater than the trunk cross-section area representing an exception to TBL. I think this is because the leaves are terminal function units rather than a transporting conduit like tree branches.

B. Nature Big Green Trees of Gardens, Streets and Forest (Figures 7-12).

All these various types of trees obey TBL as in all trees the sum of cross-section areas of all branches is less than that of the trunk (Table 1) and a descending trend extends to the terminal branches where leaves originate.

The street tree (Tree1) gives a good representation of the TBL as it has bare branches up to the 3rd level branches.

The trunk of (Tree 1) based on (Figure 7) has a cross-section area of 101.218 mm^2 and gives rise to 2 branches of 1st order that have a sum of cross-section areas of 83.958 mm^2. (82.948%) The total cross-section area of the 2nd order branches, that were 6 branches, 3 from each mother 1st order branch, have total sum of cross-section areas of 64.661mm^2. (63.883% of the trunk) The same trend continues up the green tree to the level of terminal branches where the leaves originate. It also continues down the aortic arteries to the level of terminal arterioles and pre-capillary sphincters where the capillaries originate. So, the sum of cross-section areas of all the arterioles is much less than that of the aorta (vide infra).

C. The Red Aorta's Tree:

Daunting complex micro vascular tree of the head and neck is shown in (Figure 2) but TBL simplifies the issues and makes it amenable to mathematical calculation on capillary number and cross-section areas.

Aorta's Arterial tree in Humans (Figure 13)

The aorta gives rise to 1st order branches of 45 arteries that have different diameters (Table 2). The ascending aorta's maximum cross-section area is 112.202 mm^2-based on measurements taken from (Figure 13). The measurements of diameters were taken on the outside diameter of aorta and arteries. The 1st order arteries (directly branching from the aorta) have a total sum of cross-section areas of 105.86 mm^2. (94.348%) So, the arteries have cross-section areas that are less than the aorta. The same rule applies to all further down branching of arteries down to and including the terminal arterioles and pre-capillary sphincters. Data on micro vascular ultra structure anatomy of terminal arterioles and capillaries are lacking which does not allow calculation of their cross-section areas and comparing it to the aorta.

Whether the capillaries obey the TBL or represent another exception like the leaves of the Household Croton Tree remains unknown. The measurements of the aorta and its branching arteries were done on a photograph measuring the diameters of aorta and arteries on the outside. This is to be replaced in a future study by the actual measurements of the inner diameters of the aorta and arteries taken from a hard cast after filling the aortic tree with liquid cement, leaving it to dry and harden up, then removing the walls of the aorta and arteries that can be done on a human cadaver and/or animal models.

Arteriole-Capillaries-Venule Diagram (Figures 3)

The TBL applies to the aorta and its first order arterial branches and its subsequent branches of all arteries down to and including the terminal arterioles and pre-capillary sphincters. The arteries are conduits involved in transporting the blood to capillaries that are the terminal functional units that serve the cells and tissues. Capillaries being the terminal functional units may or may not obey the TBL; the currently known data on arterioles and capillaries [8] are insufficient to finalize this issue for sure now.

Furthermore, this arteriole-capillaries-venule diagram (Figure 3) contradicts Crogh's model of the capillary being strait non-branching tubule [9]. Accurate data on the human aorta's diameter and cross-section area currently available [10].

A terminal unit of arteriole-capillaries-venule based on preferably an actual photograph if feasible or an engineering precision diagram on ultra structural anatomy of the arteriole-capillaries unit which show the number of capillaries originating from the terminal arteriole, giving the capillaries' length and measured diameters, indicating whether it branches or not and the measured diameter of branches if any exist. The pressure and speed of blood flowing inside capillary lumen should be measured at both arterial and venous ends of the capillary in a future study. With these data available with known aorta's diameter, it is possible to calculate the most likely numbers of capillaries or at least the functional capillaries in a human and/or animal. Also, the total cross-section areas of all the capillaries can be accurately calculated to define its relationship with the aorta's cross-section area. I think that at least the functional capillaries have a total cross-section area that is smaller not larger than the aorta. The available evidence for this notion is presented here. The deductive evidence demonstrating that the total cross-section area of the capillaries is less than that of the aorta, not more.

Deductive evidence demonstrates that the sum of all terminal arterioles' cross-section area is less than the aorta. This is based on the evidence from the TBL that the 1st order branching arteries have a total cross-section area that is less than that of the aorta. Furthermore, the 2nd order arterial branches have a total cross-section area that is less than the preceding 1st order arteries and much less than the aorta. The trend continues down to the terminal arterioles. This trend is also seen in green trees. It was observed in every branching tree that the 1st order branches have a cross-section area that is less than that of the trunk. Further branching into 2nd order branches also show that the cross-section area is smaller than the preceding 1st order branches' cross-section area and much smaller than the trunk. From this rule it is deduced that the cross-section area of all terminal arterioles is much less than that of the aorta. The capillaries may follow suit despite its wider diameter of double the pre-capillary sphincter, but is much less than half of the arteriole diameter. Hence, the cross-section area of all capillaries is much less than the arteriole and the the aorta.

The mathematical evidence demonstrating that the total cross-section area of the capillaries is less than that of the aorta, not more.

The precision engineering diagram of terminal arteriole and capillaries demonstrate that 3 capillaries branch from the terminal arteriole each have a diameter less than half of the arteriole. The diameters of the arteriole is 2.61 mm and of the 3 capillaries it originate from it are 0.48, 1.5 and 1.3 mm which have a cross-section area for the arteriole of 5.352 mm^2 and for the 3 capillaries the sum total of cross-section area is 3.276mm^2. (61.211%) This means that the total sum of cross-section areas of the capillaries is less than that of the arterioles and therefore much less than that of the aorta, not more.

In the rarest event of case scenario that an arteriole gives rise to 4 capillaries each has a diameter that is half that of its own then the cross-section area of capillaries equals that of the arterioles, not more, and the total cross-section areas of all capillaries remain much less than that of the aorta. Almost certainly the cross-section areas of all the functional capillaries are less than that of the aorta, never more. I am happy with the above provided evidence but do not mind considering it a theory for now to be validated when future precision data on the arteriole-capillaries-venule unit's exact ultra structure anatomy with measurements becomes available.

3. Discussion

The TBL is a new original physics discovery first conceived based on observations and intellectual consideration on green and red arterial trees only but has now been validated by the above reported experimental and mathematical evidence results. In all trees the law applies up to and including the smallest branches in a green tree and down to the terminal arterioles in an aortic arterial tree. The only exception to the law is leaf stems of the household miniature Croton Tree with its big leaves and relatively thick leaf stems. The cross-section areas of all the stems are greater than the trunk of the tree. This exception is perhaps because the leaf is a functional terminal unit not involved as transport conduit like tree branches and arteries down to terminal arterioles. It remains unknown whether the capillary obeys TBL or is another exception to the law like the leaf stems of the Croton Tree. This issue should be finally settled when precision engineering data on the microvasculature of the terminal arterioles and capillaries become available. However, available evidence indicates that the capillaries obey the TBL and the sum of the total cross-section areas of all capillaries is less than the aorta.

The capillaries' total cross-section area is less than that of the aorta.

Substantial deductive evidence demonstrates that the capillaries have a total cross-section area that is less than that of the aorta, not more. The evidence is based on the finding that TBL in branching, and re-branching, the last generation of branches have a total cross-section area that is less than the preceding one and much less than the trunk. Hence in the arterial tree the cross-section area of all terminal arterioles is very much less than the aorta. To produce capillaries that have a cross-section area that is larger than the arteriole, the capillary number must be 4 or more with a diameter half that of the arteriole. That doesn't happen in a natural tree, and certainly not in the arterial tree. If in the odd chance 4 capillaries arise from a terminal arteriole each with a diameter half that of the arteriole diameter then the cross-section areas becomes equal to the arteriole, and the total cross-section areas of all capillaries remain less than that of the aorta.

The RBCs speed in the capillary is fast.

The issue on red blood cells (RBCs) speed or capillary blood speed (CBS) has already been settled elsewhere [1]. The state of very slow perfusion equilibrium dictated by the wrong Starling's law [6, 7] should be replaced by the new magnetic field-like fluid transfer discovered in the porous orifice (G) tube (Figure 1) [1-7] to explain the fast capillary interstitial fluid (ISF) transfer [1, 2]. This fast autonomous dynamic magnetic field-like fluid transfer efficiently provide for the cells at rest and during the demands of strenuous exercise with oxygen and nutrients while removing carbon dioxide and waste products. So, irrespective whether the capillaries have a cross-section area that is larger or smaller than that of the aorta, a fast capillary-ISF transfer occurs as based on the hydrodynamics of the G tube that is built on the ultra structure of capillary anatomy of having pre-capillary sphincter and wide intercellular slits pores [1-7].

From the above results and discussion it is demonstrated that TBL has dispelled the two misconceptions on the cross-section area of capillaries wrongly thought greater than the aorta and RBCs Speed that is wrongly thought very slow in the capillary. Also the formula should yield the correct fast speed of RBCs in the capillary, once the cross-section area of the capillaries is corrected to become less than that of the aorta not more.

The physiological relevance and clinical significance of TBL.

Correcting the above misconceptions is not merely a scientific theoretical exercise of trivial value. It has serious physiological relevance and clinical importance and significance. It is part of the substantial evidence that currently exist to demonstrate Starling's law is proved wrong [1-6], the Revised Starling's Principle (RSP) is a misnomer and wrong [7] and the correct replacement is the hydrodynamics of the porous orifice (G) tube as based on the new physics discoveries [1-5] and physiological evidence [6]. Many errors and misconceptions have accumulated over the decades that produced the wrong Starling's law that have misled physicists, physiologists and physicians. This has caused most grievous situation in clinical practice where two new types of shocks are recognized [11, 12] to complicate fluid therapy because Starling's law dictates the wrong rules on fluid therapy that mislead physicians into giving too much fluid during the resuscitation of shock. This induces volumetric overload shocks (VOS) or volume kinetic (VK) shocks [11, 12] and cause the acute respiratory distress syndrome (ARDS) [13, 14] also known as the multiple organ dysfunction syndrome (MODS). These syndromes cause serious morbidity and mortality affecting hundreds of thousands of ARDS patients every year all over the world but has remained unrecognized and underestimated. Not only the exact patho-aetiology of ARDS has been precisely identified but also a possible curative and prevention therapy has been found [13, 14]. Please excuse me for much using self-references here as there is no other alternative references to use.

4. Material and Methods

The proof that TBL is correct is based on the investigations of different type trees. The diameters (D) were accurately measured using the Digital Vernier Caliber and the cross-section-area (A) was calculated from the formula Area (A) $= \pi * (D/2)^2$. Data for D is mm and for A is mm^2. For the π the figure of (22/7) is used.

The Fiber-Optic Light Tree (Figure 4)

The diameter and cross-section area of the all fibres individually and gathered in a trunk were calculated and compared. It gave an instant proof of the correctness of the TBL. The numbers of fibers were calculated, the diameter of the individual equal fibers was measured, and the diameter of the trunk made of all fibers gathered as one trunk was also measured using a Digital Vernier Caliper (Figure 4). The sum of total cross-section areas of all fibers was compared to the trunk.

The Mathematical Tree

In a mathematical tree the maximum number of branches allowed with half the diameter of the trunk is 4. If the trunk is divided into 2 or 3 branches of half its diameter then the sum of cross-section area of the branches will be less than the trunk. Assuming each branch will similarly divide into 4 branches of half the diameter of the mother branch then the cross-section area of all branches will equal that of the trunk. A trunk cannot give rise to more than 4 branches of half its diameter as matter cannot arise from nothing.

The Mathematical Tree: demonstrating that a trunk may give rise to 2 branches and up to a maximum of 4 branches of equal diameters that each is half the diameter of the trunk, and no more. Matter cannot be created from nothing. The same principle applies with further branching where a mother branch acts as the trunk for its daughter branches. The sum of all branches at any level equals that of the trunk which is rare or never occurs in real life trees.

The diagrammatic Tree (Figure 5)

This illustrates the same results of the mathematical tree above at maximum division of 4 branches of half its diameter, and it also has the same result of equal cross-section areas of all branches to that of the trunk at all levels. Never more.

The Green Trees

Household Miniature Croton Tree (Figure 6)

The diameter and cross-section areas of the trunk and all the branches and sub-branches were measured and compared. The cross-section areas of the all-1st order branches was determined. The cross-section areas of all 2nd order terminal branches were summed up. As branching continues, the cross-section of all branches is less than its own mother branch, as well as being much less than the trunk.

B. Nature Big Green Trees From Garden, Streets and Forest (Figures 7-12)

The street tree (Tree1) gives a good representation of the TBL as it has bare branches up to the 3rdorder of branching. The trunk of Tree 1 diameter was measured, and cross-section areas were calculated. The tree trunk gives rise to 2 branches of 1st order whose diameters and cross-section area were also calculated. The total cross-section area of 2nd order branches that were 6 branches, 3 from each mother 1st order branch, were similarly calculated. The same trend continues up the green tree to the level of terminal branches where the leaves originate.

Aorta and its arterial branches down to arterioles and pre-capillary sphincters

The same principle applies to the aorta and its primary arteries originating from its trunk. The aorta gives rise to 45 named arteries of various diameters; the sum of all arteries' cross-section areas is not greater than that of the aorta. In fact. it is less than the aorta (Table 2). The same principle applies further down as arteries divide into into smaller arterial branches and so on down to the smallest arteriole and its own capillaries. The rule still applies to the capillaries despite having a bigger diameter than the pre-capillary sphincter but not bigger than the preceding arteriole. Remember also that not all the capillaries work at the same time, large number are functional but not all. It also continues down the aortic arteries to the level of terminal arterioles and pre-capillary sphincters where the capillaries originate. So, the sum of cross-sections area of all the arterioles as compared to that of the aorta is less than, not more than, its trunk. The sums of cross-section areas of all the capillaries are also less than the feeding arterioles and accordingly less than the aorta.

The measurements of the aorta and arteries diameters in this study are taken on the outside of the aorta and arteries wall from the photograph (Figure 13). A more accurate method is to measure the internal diameter of the aorta and its arterial branches. The best way to achieve that is to make a rigid cast ot the aorta, the 1st order arteries and the 2nd order branches using liquid cement injected into the aorta, leaving it to dry and harden, then remove the outer aorta and arteries walls, leaving the hard cast intact for measurements of diameters. This is a worthwhile project for a young researcher working on his MD degree in cardiovascular anatomy or physiology. This article has been cited in 3 recently published books related to the above discussed issues available from amazon.com and the publishers [15-17].

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Figures and Legends

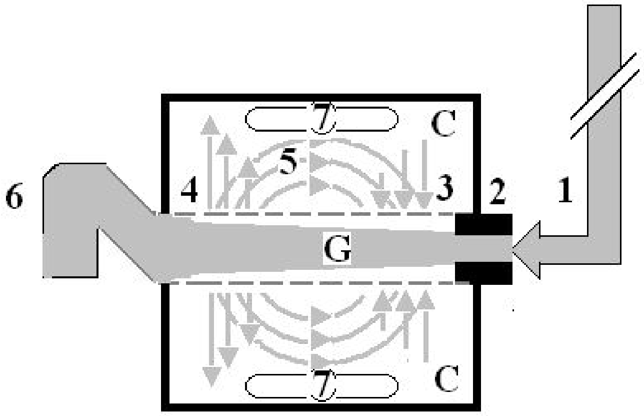


Figure 1 shows a diagrammatic representation of the hydrodynamic of G tube based on G tubes and surrounding chamber C. This 37-years old diagrammatic representation of the hydrodynamic of G tube in chamber C is based on several photographs. The G tube is the plastic tube with narrow inlet and pores in its wall built on a scale to capillary ultra structure of pre-capillary sphincter and wide inter cellular cleft pores, and the chamber C around it is another bigger plastic tube to form the G-C apparatus. The chamber C represents the ISF space. The diagram represents a capillary-ISF unit that should replace Starling's law in every future physiology, medical and surgical textbooks, and added to chapters on hydrodynamics in physics textbooks.

The numbers should read as follows:

1. The inflow pressure pushes fluid through the orifice
2. Creating fluid jet in the lumen of the G tube**.
3. The fluid jet creates negative side pressure gradient causing suction maximal over the proximal part of the G tube near the inlet that sucks fluid into lumen.
4. The side pressure gradient turns positive pushing fluid out of lumen over the distal part maximally near the outlet.
5. Thus, the fluid around G tube inside C moves in magnetic field-like circulation (5) taking an opposite direction to lumen flow of G tube.
6. The inflow pressure 1 and orifice 2 induce the negative side pressure creating the dynamic G-C circulation phenomenon that is rapid, autonomous, and efficient in moving fluid and particles out from the G tube lumen at 4, irrigating C at 5, then sucking it back again at 3,
7. Maintaining net negative energy pressure inside chamber C.

**Note the shape of the fluid jet inside the G tube (Cone shaped), having a diameter of the inlet on right hand side and the diameter of the exit at left hand side (G tube diameter). I lost the photo on which the fluid jet was drawn, using tea leaves of fine and coarse sizes that runs in the center of G tube leaving the outer zone near the wall of G tube clear. This may explain the finding in real capillary of the protein-free (and erythrocyte-free) sub-endothelial zone in the Glycocalyx paradigm/ It was also noted that fine tea leaves exit the distal pores in small amount maintaining a higher concentration in the circulatory system than that in the C chamber- akin to plasma proteins and ISF space.

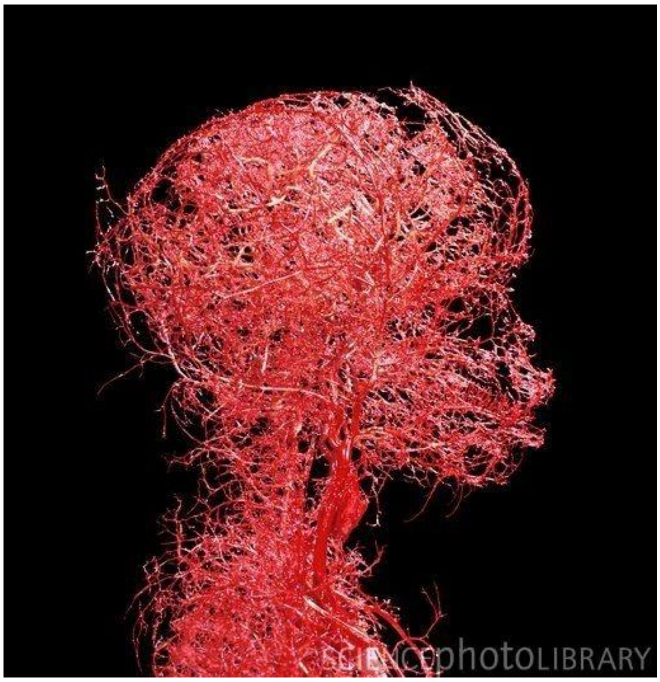


Figure 2 shows the microvasculature tree of head and neck showing arterial branching down to terminal arterioles but not the capillaries. It looks obvious that counting the number of terminal arteriole and the capillaries and calculating its total cross-section area is a daunting impossible task. Yet it is possible and easier than one might think. It may be easier only when the TBL applies, please see text.

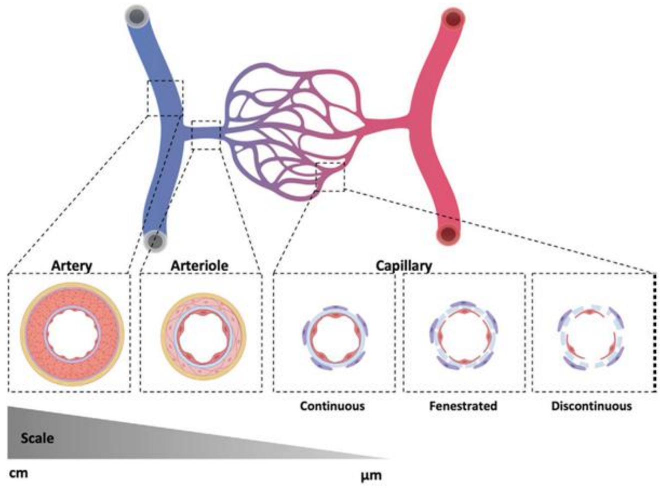
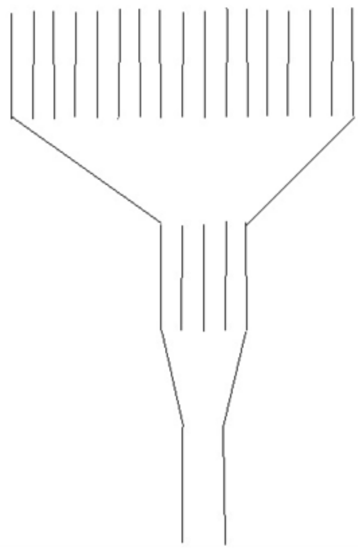


Figure 3 is afigure reproduced from article [5] with its legend stating: “Figure 1. Organization of the vascular tree. The vascular tree is organized into a hierarchical network of arteries, arterioles (blue), capillary beds, veins, and venules (red) that span several orders of magnitude in diameter. All vessels are characterized by an inner layer of endothelium and an outer layer of basement membrane. Arterioles and venules are further bound by a second layer of SMCs as well as elastin and collagen fibers. Capillaries have a varying extent of basement membrane and pericyte coverage and can be continuous, fenestrated, or discontinuous. Created with BioRender.com”.

There are important missing data on terminal arteriole and capillaries arising from it that concern its number, length and diameters. Also, according to Crogh’s model [6] a capillary tube does not branch- need to be validated by a future study. The arteriole should be shown in red and the venule should be shown in blue. If this diagram is proportionally correct, then the arteriole giving rise to 3 capillaries should obey the TBL and the calculated sum of cross-section area of all capillaries is less than that of the aorta, not more!

Figure 4 shows the Fiber optic tree and Digital Vernier Caliber for precise measurements. This tree obeys the TBL. The sum of all fibers as individuals are less than the all fibers gathered in one trunk: a surprising result- see text!?

Diagrammatic Tree



3rd order branches (64) with 0.5 cm each.

2nd order branches (16) with 1 cm diameter each.

1st order branches (4) with 2 cm diameter each.

Trunk with 4 cm diameter

Figure 5 shows the diagrammatic tree having the maximum branches of 4 that each had a diameter half the trunk. The four branches give another 4 branches each with a diameter half its mother branch’s trunk. The total cross-section area of all branches at the same level equal that of the trunk. This does not occur in real life trees where the sum of all branches’ cross-section areas is usually less than that of the trunk.

Figure 6 shows Monira’s Household Croton Tree. It applies the TBL down to and including the terminal branches. The leaf stems, however, represent an exception to the law perhaps because it represents terminal function unit rather that the transport conduit that all branches represent.

Figure 7: shows a street tree (Tree 1) with bare and measurable branches up to the 3rd order. It applies the TBL

Figure 8: shows (Tree 2) another tree that applies the TBL

Figure 9: shows another tree (Tree 3) with big thick branches.

Figure 10: Shows one more tree {Tree 4) with many 1st orders branches

Figure 11: shows a bare leafless tree (Tree 5)

Figure 12: shows a great tree (Tree 6) on which calculations for TBL were made

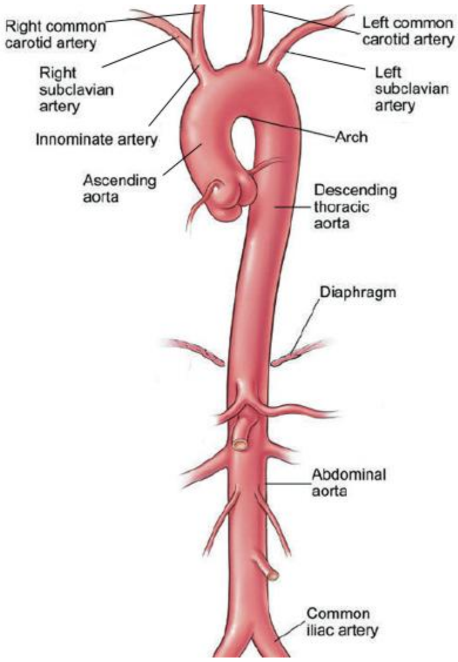


Figure 13: shows the Aorta (Trunk) and its main first level arteries (Branches)

The aorta gives rise to 45 first degree order arteries that vary in diameters but are all measurable; hence the cross-section area is calculated and compared to that of the aorta. When the precise engineering measurement data on terminal arterioles and capillaries become available it should be possible to calculate an approximate correct number of capillaries based on known capillary diameter and its number arising from the terminal arteriole. (This f1gure is reproduced from an article on the aorta by Cleveland clinic.)

	Trunk D	Trunk Area	All Br Area	Br 1	Br 2`	Br 3	Br 4	Br 5	Br 6	Br 7
Tree 1	10.65	89.118	70.295	4.08	4.04	4.66	4.06	3.45	4.89	
Tree 2	5.4	22.911	16.467	0.63	2.05	3.3	3.02	1.5	0.54	1.62
Tree 3	5.5	23.768	23.085	3.03	3.13	3.69	2.91			
Tree 4	7.71	46.706	40.352	2.2	1.69	1.52	5.4	2.52	0.76	1.11
Tree 5	6.89	37.300	26.755	2.54	3.89	5.95	3.21			
Tree 6	7.79	47.680	21.254	2.4	1.34	1.7	1.1	1.28	4.08	2.37

Table 1 shows data for the 6 big trees on diameters and cross-section areas. The trunk cross-section area is compared to the sum of all branches are shown in red for comparison. All the big green trees obey TBL and have total cross-section area of all branches that less than that of the trunk.

Showing or Not	Aorta D	Branch Name	Br No	D	A mm^2	total Area
Showing	11.95	Coronary	2	1	0.78571429	1.57142857
Showing	5.975	Innominate A	1	3.96	12.3212571	12.3212571
Showing		L Common Carotid A	1	2.56	5.14925714	5.14925714
Showing		L Subclavian A	1	2.57	5.18956429	5.18956429
Showing		Coeliac A	1	4.18	13.7283143	13.7283143
Showing		Super Mesentric A	1	2.4	4.52571429	4.52571429
Not Showing		Suprarenal A	2	0.5	0.19642857	0.39285714
Showing		Renal A	2	2.9	6.60785714	13.2157143
Showing		Gonadal A	2	1	0.78571429	1.57142857
Showing		Inferior Mesenteric A	1	2	3.14285714	3.14285714
Showing		R Common iliac A	1	5	19.6428571	19.6428571
Showing		L Common Iliac A	1	4.94	19.1742571	19.1742571
Not Showing		Intercostal Arteries	18	0.5	0.19642857	3.53571429
Not Showing		Inferior Diaphragmatic A	2	0.5	0.19642857	0.39285714
Not Showing		Lumbar Arteries	8	0.5	0.19642857	1.57142857
Showing		Sacral Artery	1	1.2	1.13142857	1.13142857
	112.202	Total	45		92.577	**105.864**

Table 2 shows the data on the aorta and its branching arteries. The number in bald red compares the cross-section area of the aorta to the total number of branches' cross-section area.