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Blood supply of the internal female genital tracts with special attention paid to the uterine cervix — an overview

Aleksandra Kot[1], Tomasz Bereza[1], Izabela Zamojska[1], Anna Yevstifeieva[1], Tomasz Kozioł[1], Wojciech Przybycień[1], Małgorzata Mazur[1], Grzegorz Lis[2], Aleksandra Szlachcic[3], Jerzy Walocha[1]

[1] Department of Anatomy, Jagiellonian University Medical College, Kraków, Poland
[2] Department of Histology, Jagiellonian University Medical College, Kraków, Poland
[3] Department of Physiology, Jagiellonian University Medical College, Kraków, Poland

Corresponding author: Jerzy Walocha, M.D., Ph.D.
Department of Anatomy, Jagiellonian University Medical College
ul. Kopernika 12, 31-034 Kraków, Poland
Phone: +48 12 422 95 11; E-mail: j.walocha@uj.edu.pl

Abstract: Blood supply of the uterus raised interest of the scientists since early 19th century. Fundamental works of anatomists from German circle brought not only solutions but also new questions. Nowadays knowledge on the vasculature of the female internag genital organs plays leading role in many procedures, mostly endovascular, i.e. embolisation techniques used for treatment of uterine fibroids, ectopic pregnancies, bleedings etc. This paper brings a short summary of our knowledge on the vascularization of the uterus with special respect to the uterine cervix. It shows the path which led the scientists from ancient times until the modern period to discover the mysteries of vascular anatomy of this specific area.

Key words: female internal genital tract, uterus, uterine cervix, blood supply, anatomy.

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Introduction

It is difficult explicitly to state when in medicine first correctly presented illustrative image of the human uterus appeared. Very scanty data allow us to suppose that structure and function of the organ was known already in the ancient times. One can deduce it from at least studying ancient notes regarded to physiology and structure of other organs. For sure pregnancy, act of delivery and all associated events, especially in animal world were objects of the earliest, and most primitive observation. Already the papyrus of Ebers contains the magical formula which probably had to order the uterus to return back to its previous position during confinement: "wax-ibis place on the charcoal and then let the smoke enter the interior of her vulva" Before 138 Greek gynecologist Soranos of Efez published work "De arte obstetrica morbisque mulierum", where he presented his imaginations on the uterine construction based on the anatomy of this organ in animals. We do not know the original of this paper but we could acknowledge its fragments thanks to the notes of so called Brussels' manuscript from 9th century. The pictures presenting the human uterus as bicornuate refer to the summary of Soranos' gynecology translated by Moschion [1]. Famous Claudius Galen also based his ideas about the structure of human uterus on the animal anatomy. His opinion caused a shadow on the anatomical knowledge on the human internal reproductive organs through entire medieval time until early Renaissance.

In 1507 Bolognese professor of surgery, Giacomo (or Iacopo) Berengario da Carpi carried out (probably as first) vaginal hysterectomy (in his wife). In 1521 he published a commentary based on "Anatomy" of Mondino de Liucci, where he reproduced illustrations of female genital organs occasionally discussing the pelvic contents [2]. Charles Estienne also presented images of female genital organs in 1545. Obviously we cannot forget about the most famous anatomist of the Renaissance — Andreas Vesalius, who in his work "De humani corporis fabrica", issued in 1543 presented a portrait of the genital tracts [3]. Also in the era of renaissance Giulio Cesare Arnazi (1530–1589) gave description of the pregnant uterus, while Hieronymus Fabrizius Aquapendente known also under the name of Girolamo Fabrizi (1537–1619) published copperplate technique prepared tables with illustrations of pregnant uterus and placenta.

It is difficult to assess today when was the time of first publications on the uterine vasculature. With no doubt the pioneer of the injection Techniques in scientific anatomy was Jacobus Sylvius (Jacques Dubois; 1478–1555) — considered also to be inventor of an injection syringe. In Kuś' elaboration [4] one can find illustration of the work of A. Nuck (1650–1692) entitled: Adenographia & Uteri anatome nova, in which the uterine vascular network is presented. In 1672 De Graaf [5] published, probably as first, information on the uterine vascular structure based on the injection and corrosion specimens. In 1774 Wiliam Hunter in his work entitled "Anatomia uteri humani gravidi tabulis illustrata" presented notes on the spiral arteries that existed in the pregnant uterus. We do not know how did he obtain this information although it must be emphasized that in the period described, in the anatomical researches there were used injection methods, so to see the vascular bed of the structures and organs different substances were used to fil lit: from the air until liquid gold. Hyrtl (1810–1884), professor of anatomy in Viena, friend of Ludwik Karol Teichmann, prepared injection mass from a wax and resin. He injected it into uterus and vessels of the placenta (see anastomoses of Hyrtl). He also used celoidine (artificial material) as first to inject the vessels [6]. Little bit more specific information of the blood supply of the uterus were given by Farre in 1859. In his work "The cyclopedia of anatomy and physiology" he postulated that the arteries of the uterine wall are characterized by corkscrew-like course in the external half of the myometrium while after a short course they become straight and run parallel one to the other. He did not present specific information on the spiral arteries in the endometrium, although he affirmed that the vessels of the mucosa are particularly arranged with respect to the glands.

In 1863 Luschka in his own manual of anatomy described that endometrial glands are separated from each other by quite irregular network of capillaries. According to him these capillaries give rise to the venules which are much bigger than in the other organs.

In 1874 German gynecologist and obstetrician Leopold injected the vascular bed of the uterus with carmine glue. Using it he observed arteries characterized by spiral course which tend to endometrium from the myometrial side and gave off numerous branches to the endometrium. Described arteries surrounded the endometrial glands and next ran to the Surface forming capillary network which gave off venules. Other Leopold's observation confirmed that uterine veins accompanied the arteries.

Particular development of the injection techniques in anatomy dates for the turn of the 19th century. The researchers using sometimes very simple (according to their chemical composition) substances filling the vascular bed, i.e. carmine colored linseed oil or barium kit, obtained surprisingly good results.

In 1899 Clark injected uterine vessels with 10% solution of gelatine with carmine red and described the course of the vessels within external myometrium. Finally in 1904 Freund presented images of the uteri where he managed to visualize the spiral arteries penetrating the endometrium, confirming Farre's observation according to accumulation of the arteries concentrated mainly around the glands.

In 19th century the blood vessels were injected with ink added to the base i.e. gelatine, animal serum, prussian blue, Latex, Microfil, also contrast media Micropaque or Chloropaque. Application of the above mentioned injection masses (for now considered to be classical) has limitations because it does not allow to distinguish arteries from the veins in each case. Because of the dimensions of their particles, high viscosity, they do not fill enough the microcirculation. This methodology requires application of at least two different dyes to make the vessels of the arterial and the venous beds independently visible [7].

In Poland the precursor and popularizer, an outstanding representative of anatomists using injection techniques, designer of numerous instruments used for filling the vascular bed of different structures, and inventor of injection masses was professor Ludwik Karol Teichmann (1823–1895) — long-term head of the Department of Anatomy, Jagiellonian University [8]. The follower of his ideas was prof. Jan Kuś, who as one of the first in Poland used plastic masses (vinyl polychloride) for filling the vessels. However neither Teichmann nor Kuś, were not involved in the studies on the vasculature of female internal genital organs [9].

Introduction of new injection media in the second half of the 20th century, i.e. synthetic resins characterized by low viscosity and small dimensions of their particles (i.e. Mercox or Batson's mass) allowed filling practically all blood vessels and after solidification of the mass allowed to obtain vascular casts which are replicas of the vascular bed of studied structures together with the capillary network.

A true mile-stone in the angiologic methodology was introduction of the scanning electron microscope (SEM) in 1970 for investigation of vascular microcasts [10, 11]. Thank to high resolution and depth of the field completely new possibilities of the Studies on the vascularization, specially of microcirculation, were opened. Further progress was possible thank to presenting by Miodoński [12, 13] morphological criteria which allowed to distinguish the type of the vessel: artery, vein, capillary, based on the picture of the imprints of the nuclei of the endothelial cells left on the surfaces of the corrosion casts. Numerous new information on the angioarchitecture of different structures, tissues, and organs, were obtained thanks to the replication method. SEM was used for studies on the female genital system under normal condition [14], and in pathologies [15, 16]. A number of interesting observations were carried out on laboratory animals [17, 18]. Several quantification Studies were also made using SEM and 3-D morphometry what seems to open quite new horizons with respect to the microcorrosion/SEM [19].

Uterine cervix — anatomy and histology

Uterine cervix is the lowest part of the uterus. Both the body and the isthmus develop from the fusion of the caudalmost fragments of the paramesonephric (Müllerian) ducts.

Lower part of the cervix is embraced by the vagina at vaginal fornices. On can distinguish anterior, posterior and two lateral fornices of vagina respectively. Such mutual arrangement of the cervix and the vagina allows to distinguish the supravagnal and vaginal portion of the uterine cervix. Vaginal portion is rounded in its inferior fragment and possess uterine os in its apex, known also as external orifice of the cervical canal. In the parous females this orifice is usually wide and transversely oriented. This allows to distinguish two lips: anterior and posterior lip. Cervical canal widens upwards to reach the uterine cavity. The inferior angle of the uterine cavity is known previo is internal uterine os.

Differences in the composition of the uterine body and cervix consider both mucous membrane as well as muscular layer. Comparing to rather smooth endometrium the cervical mucosa is folded and presents so called *plicae palmatae*. Histologically the cervix contains cervical glands characterized by extensive branching patters comparing to the uterine glands. Epithelial cells of the glands undergo changes in their structure depending on the influence of the hormones released by the ovaries. Cervical epithelium is mono-layer, cuboidal (cylindrical). One can find rather high exocrine cells, also cilliated cells. Such epithelium extends downwards until the orifice of the cervical canal and continues with non-keratinizing multi-layer of the vaginal portion of the uterine cervix, similar to the vaginal epithelium. The border between the epithelia is not sharp and often courses in the form of the zigzag line. Its position changes throughout female's life. Proper lamina of the cervical mucosa is composed of the connective tissue which contains large amounts of collagen fibers, single fibers of elastine, and densely packed cells, mostly fibroblasts. Mucosal membrane of the uterine cervix is not dependent on the hormonal changes and is not peeled during the menstrual cycle contrary to the uterine endometrium. It is caused, among other, by the lack of spiral arierioles.

Muscular membrane is thinner than that in the body. It contains lots of connective tissue elements. Connective tissue located between the smooth muscle cells contains particularly numerous collagen fibers and small amount of elastine fibers. Such construction of the muscular membrane of the uterine cervix causes that this part of uterus shows only a limited range of contractions.

Current views on the normal uterine vasculature with special attention to uterine cervix

There are numerous descriptions in the literature of the vascular compositions which supply the uterus. These elaborations consider mostly observation carried out on the injection specimens studied mostly macroscopically. These Studies very often accepted known previous findings published by classical anatomists, mostly from French circle — L. Dieulafe et R. Dieulafe, 1935, Testut and Latarjet, 1949, Rouviere1962 [20–22].

The main vessel which supplies the female internal genital tracts is a paired uterine artery. Its course studied on the dissection specimens of unchanged organ was studied using injection, radiological, also corrosion methods by Moshkov [23], Davydov [24], Palczak and Gawełko [25], Pilarczyk [26], Pilarczyk *et al.* [27] and others [28]. Aranyi *et al.* [29], Borell and Fernstrom [30], Gomez-Jorge [31], Osemlak [32] studied variation of uterine artery branches. Osemlak estimated also the vascular system of the bicornuate uterus [33].

Special attention should be paid to studies of Czerwiński and Pilarczyk [34, 35] who investigated blood supply of the uterine wall using microangiography methods.

Classical anatomy reports that internal iliac artery, main vessel supplying pelvic organs, divides into two divisions — the anterior and the posterior division, which divide (give off) parietal and visceral branches respectively. The terminal branches or as a matter of fact the extensions of the main divisions are the superior and the inferior gluteal arteries. In recent times, especially in radiological descriptions [36] it is postulated that internal iliac artery divides immediately into the superior and the inferior gluteal arteries, and these are source of all branches. This view is not without some logic [37].

Following the anatomical textbooks the uterine artery arises as on of the strongest branches in the females from the anterior division of the internal iliac artery. Gomez-Jorge [31] studied mostly radiographs and presented four most common variations of the origin of the uterine artery (Fig. 1–4).

According to Gomez-Jorge types of origin of the uterine artery in the whole materials he studied were: type I — 45%; type II — 6%; type III — 43% — type IV — 6%, respectively.

In rare cases the uterine artery arises together with another visceral branch of the anterior division of the internal iliac artery or from non-obliterated portion of the umbilical artery (5%).

Rarely found anomalies in the vascular supply of the uterus consists of:

- Unilateral absence of the uterine artery (1%),
- Bilateral absence of the uterine arteries — then intrauterine blood supply comes from the branches of the ovarian arteries (0.3%) or from numerous minute branches arising from the internal iliac arteries (1%).

Typically the course of the uterine artery can be divided into the descending, transverse, and the ascending portions. Lateral branches arise mostly from the transverse and the ascending parts of the vessel. This group includes also the arteries which supply the cervix. They arise as one or even four thick stems, which after a short course give rise to large, quite variable number of branches supplying not only the cervix but also the upper vagina. Lower cervix is usually supplied by the vaginal artery, which originates from the uterine artery in its transverse portion (running between the layers of the broad ligament) at the point where it crosses the ureter. There are also descriptions of the single vascular stem, named cervico-vaginal artery which existed at the level of the internal os of the cervical canal [29]. Probably the first who used this term was Debreuil-Chambardel [38]. According to him the vessel originates from the main stem of the uterine artery in 91% or directly from the internal iliac artery. Other scientist report that the vessel originates at the level of the external os.

In 60-ties of the 19th century Fanger and Barker, Lierse, Zinser and Rosenbauer [39–41] created classical model of the arterial and venous blood supply of the uterine cervix, describing also intracervical pattern of blood vessels.

Zinser and Rosenbauer isolated among others two systems of arteries:

- system supplying the vicinity of the cervical canal, associated with cuboidal epithelium, depended on the uterine artery (Fig. 5 — red).
- system supplying mostly the vaginal portion of the uterine cervix (multi-layer plane epithelium) dependent on the vaginal artery (Fig. 5 — green).

Detailed two arterial systems are separated from each other by a narrow zone with few vessels. Arteries are accompanied by the veins, although poor vascularity in the specimens presenting the venous blood supply was much more difficult to observe.

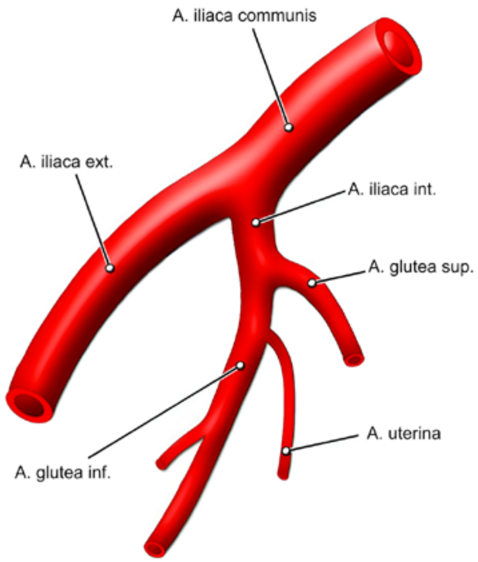

Fig. 1. Type I: High origin of the uterine artery from the anterior division of the internal iliac artery (inferior gluteal artery) — after Gomez-Jorge.

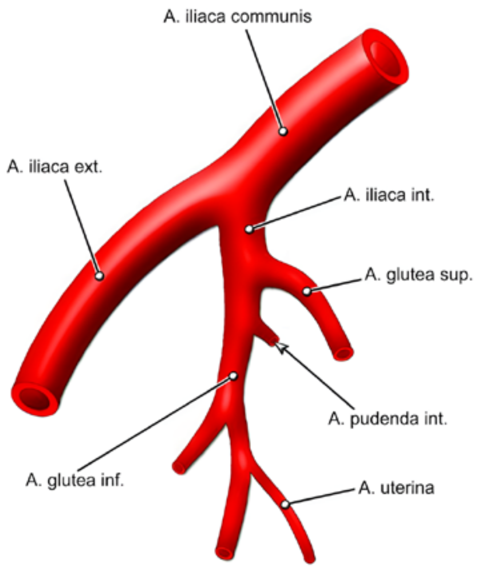

Fig. 2. Type II: Low origin of the uterine artery from the internal iliac artery (inferior gluteal artery) after Gomez-Jorge.

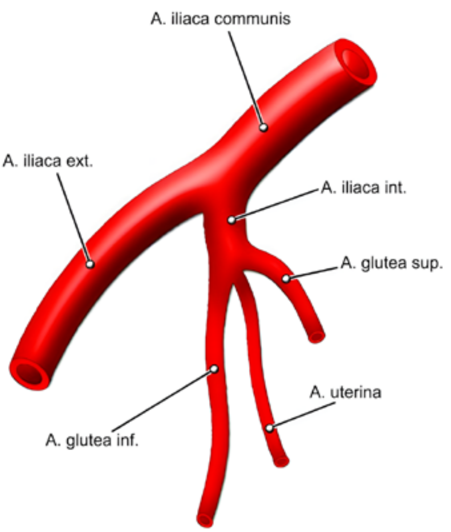

Fig. 3. Type III: "Trifurcation" of the internal iliac artery — the uterine artery originates as one of the main branches — apart from the anterior and the posterior divisions (superior and inferior glueal arteries) after Gomez-Jorge.

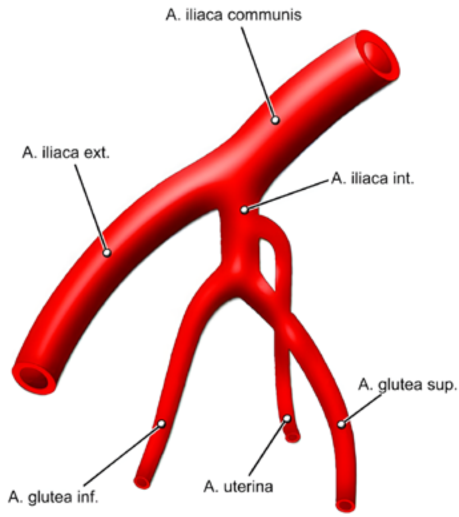

Fig. 4. Type IV: The uterine artery originates from the internal iliac artery before it divides into the anterior and the posterior divisions — after Gomez-Jorge.

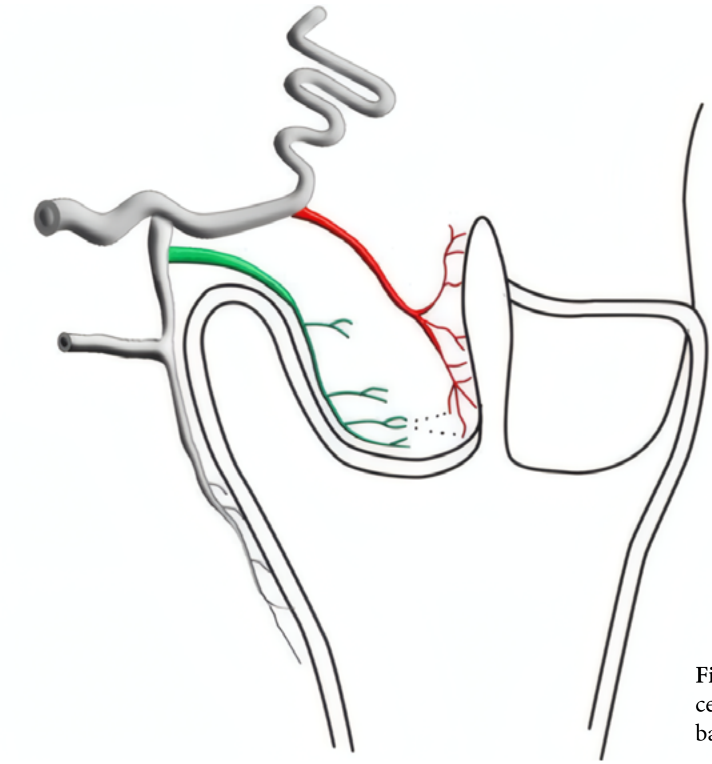

Fig. 5. Blood supply of the uterine cervix — after Zinser and Rosenbauer.

In the upper cervix, in the vicinity of the junction with uterine body one can distinguish the superficial cervical vessels which run mostly circular. The arise from the branches of the uterine artery.

Next these vessels give birth to radial vessels which penetrate the cervical wall and run deep to the cervical canal, and next they give off branches in the upper part of the cervix. Their course is horizontal. In the middle and lower parts of the cervix the arteries run more and more obliquely and downwards until the external os of the cervix. The blood vessels system in the vaginal portion, covered with multi layer plane epithelium is responsive to the form of the cervix and usually consists of vaginal branches which run mostly vertical. The veins in this part are rather dense and are well visible.

Zinser and Rosenbauer proved in their papers that the border between the multi layer plane epithelium and the cylindrical is the same as the border between the border between the vascular systems described earlier. In the normal cervix this border is adjacent to the external os of the cervical canal. In this case the entire vaginal portion of the uterine cervix is supplied by vaginal arteries, which supply the vaginal fornices.

In case when the borders between the epithelia moves i.e. of ectopy — outside, the region of the vaginal portion covered with cylindrical epithelium is supplied by the vessels dependent on the uterine system. The vessels become more vertical. It all means that such rearrangement of the vessels causes shifting the vaginal-dependent system outside the cervical canal.

There are no significant differences between the number of cervical branches and the density of the vascular network of the uterine cervix in non-parous and parous females.

Studies on the venous blood flow in the uterine cervix were undertaken rather early. In 1927 Stieve [42] described two venous plexuses:

- first — was situated at the border between the isthmus and the uterine cervix and was giving birth to so called ascending vessels
- second was located within the vaginal portion and was result of multiple anastomozing veins.

Venous blood from the aforementioned plexuses flows via one-named veins into the uterine veins or to utero-vaginal venous plexuses which finally empty into the internal iliac veins. Special attention should be paid to the fact of existence of the valves in the uterine veins and veins of the surrounding organs, confirmed by Aleksandrowicz and Czerkwiński [43, 44].

Clinical application of the knowledge on the blood supply of the uterus and its cervix

The studies on the blood supply of the uterine cervix were performed using the techniques applying new methods of visualization of the blood flow: cervicography [45], magnetic resonance [46], Doppler ultrasonography [47, 48], 3D color angiography [49], termography [50, 51] and others [52–57].

Because of intense development of the gynecological organ-saving procedures, the studies on the anastomoses of the uterine artery and its branches became clinically significant [58, 59].

The anastomoses can be divided into:

- unilateral — which exist mainly in the lateral borders of the uterus (vertical anastomoses) between the branches to the cervix and the body located directly one above the other
- bilateral — which are transverse and located in the median line on the anterior and posterior surface of the uterus, quite numerous, capillary-type, uniting two uterine arteries (right and left), supplying two halves of the organ originated from the unin of paired paramesonephric ducts.
- Anastomoses with the neighboring arteries — with the ovarian artery via ovarian branch and the branch to the oviduct; with the inferior epigastric artery via artery of the round ligament of uterus; with other visceral branches of the internal iliac artery via vesical and vaginal branches.

The existence of these connections was used in uterine artery embolization techniques as a new method of treatment of the symptomatic uterine fibroids, described for the first time in 1995 by Ravina [60]. Embolisation of the vessels found its application in the treatment of the cervical pregnancy. Administration of the embolisation material into the cervical vessels significantly decreases the bleeding which was the major complication of the pathological implantation of the pregnancy within uterine cervix [61–63]. Embolisation has been used also in palliative treatment of the bleeding associated with advanced form of the cervical cancer.

As already mentioned the topic of the uterine vascularisation is predominantly interesting for the clinicians — specially facing the interventions undertaken in case of severe bleeding (cancer, ectopic cervical pregnancy) or fibroid treatment. In 1934 Belou published a monograph "Stereoscopic Atlas of Human Arterial Anatomy", where he mentions about the blood supply of the lower female genital tracts, and discusses also the anastomoses, specially between the arteries. These anastomoses unify the arterial bed of the uterus with the networks of the neighboring structures: bladder, vagina, perineum, rectum.

In 2007 Palacios-Jaraquemada *et al.* [64] found three main sources of blood vessels which supply the lower female genital tract:

- Uterine artery
- Cervical arteries — arising
  - — in 67% from the uterine artery
  - — in 23% from the vaginal arteries
  - — in 10% from the inferior vesical arteries
- Vaginal arteries — arising from the uterine artery, internal iliac artery or internal pudendal artery

According to these authors the vaginal arteries were subdivided into the superior, middle, and inferior. At the border between the cervix and the body (isthmus-vagina)numerous arterial transversely oriented, rather large anastomoses were observed, which could be compared to the caliber of the uterine artery, described as *transmedial transuterine anastomosis*. This anastomosis was found in 15 out of 39 dissected female pelves (Fig. 6).

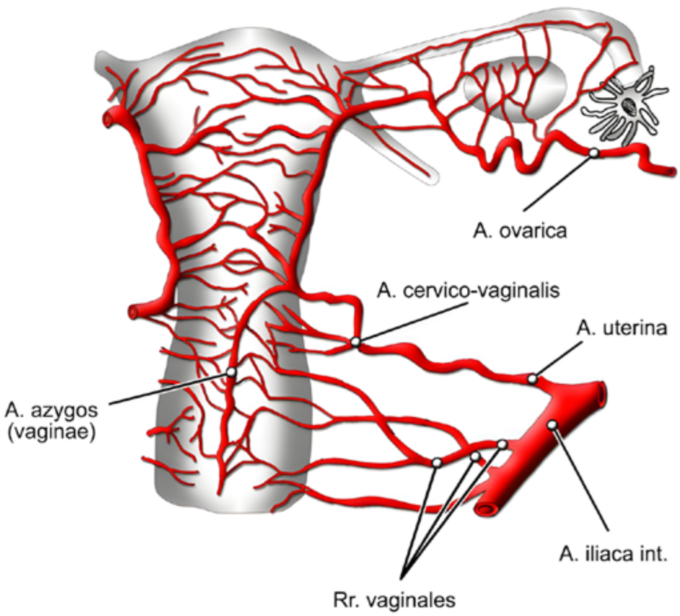

Fig. 6. Blood supply of the uterine cervix (after Palacios-Jaraquemada).

It seems that the knowledge on such connections is pivotal for the specialists who perform embolisation procedures, specially because of ischaemic complications as a consequence of the operation [65–69]. Many times undertaken speculations on the reflux of embolic material haven't been undoubtedly confirmed although they are listed between the leading factors of the unexpected necrosis. A much better explanation is the passage of the embolic material through noted anastomoses, specially while using small particle diameter embolic material.

Traditionally it is estimated that the main stream of the arterial blood flows predominantly from the uterine artery, secondary may come from the anastomoses with ovarian arteries.

However based on these hypotheses it is difficult to explain why uterus "endures" embolisation after bilateral obstruction of the uterine and ovarian arteries. Some findings suggest the existence of collateral circulation which occur through the cervical arteries, arteries of the round ligaments and others, non-indentified vessels [70], although it is difficult to believe first of all because of very small caliber of these connections. Cicinelli [71–73] proved the flow of the stream of blood from the vaginal arteries toward the uterus. Besides it was found that bilateral occlusion of the vaginal and uterine arteries causes only slight changes of the partial pressure of the oxygen in the arterial blood. This phenomenon can be explained only by the existence of relatively large anastomoses and significant contribution of the vaginal arteries in uterine blood supply.

The cadaveric studies confirmed the existence of the stable, large anastomoses between vaginal and uterine vessels, they confirmed also existence of thick anastomosis described in the literature as *arteria azygos vaginae* [64]. Finally, same authors were able to fill the uterine vessels in vivo after cannulation of the vaginal arteries — so it is not excluded that noted anastomoses play key role in the regulation of the flow in the uterine vessels and the vessels of the surrounding structures. What is worse, the existence of the anastomoses calls into question: are all these endovascular embolisation procedures effective, reasonable, and necessary.

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