Giuliano Vanghetti and the innovation of “cineplastic operations”

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ABSTRACT

Objective: Developing functional artificial limbs for amputees has been a centuries-old challenge in medicine. We review the mechanical and neurologic principles of “cineplastic operations” and “plastic motors” used to restore movements in prostheses, with special attention to the work of Giuliano Vanghetti.

Methods: We evaluated original publications describing cineplastic operations, biographic information, writings, drawings, and unpublished letters from the Vanghetti library, preserved in Empoli, Italy, and performed a bibliographic search and comparison for similar procedures in the literature.

Results: Vanghetti’s method for cineplastic operations differs from similar previous methods, being the first aimed at exploiting natural movements of the remnant muscles to activate the mechanical prosthesis, and the first to do so by directly connecting the prosthesis to the residual muscles and tendons. This represented a frame-changing innovation for that time and paved the way for current neuroprosthetic approaches. The first description of the method was published in 1898 and human studies started in 1900. The results of these studies were presented in 1905 and published in 1906 in *Plastic and Kinematic Prosthesis*. A German surgeon, Ferdinand Sauerbruch, often acknowledged as the inventor of the method, published his first results in 1915.

Conclusions: Vanghetti was the first to accurately perform and describe cineplastic operations for patients following an upper arm amputation. He considered the neurologic implications of the problem and, perhaps in an effort to provide more appropriate proprioceptive feedback, he intuitively applied the prostheses so that they were functionally activated by the muscles of the proximal stump. **Neurology® 2017;89:1627-1632**

Upper limb amputation has always been a relatively common consequence of accidents, wars, and illness. From ancient times, prostheses have been devised for those who survived such traumatic events. Giuliano Vanghetti (figure 1A) was the first to develop an invasive prosthesis directly connecting to the internal dynamics of the arm to generate movement. He defined and applied the concepts of cineplasty (also known as “cinematic implants” or “cineplastic operations”), i.e., the prosthesis was directly linked with muscular and tendinous loops (figure 1B).

Metal prosthetic hands with mechanical grasping movements date back to the late Renaissance. In 1564, the French physician Ambroise Paré invented an artificial hand with individually moving fingers. However, this mechanism required activation by the other hand. The idea of using the residual activity of the amputated arm to control the prosthesis only emerged in the 19th century. In 1818, a German dentist, Peter Bailiff, designed an upper limb prosthesis, controlled by leather straps using tension in the residual muscles and shoulder, that was later realized by Beaufort and Larrey in Paris in 1867.¹ Vanghetti radically advanced Bailiff’s concept;

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Figure 1 Giuliano Vanghetti, a patient with a prosthetic arm, and mutilated Askaris

(A) Giuliano Vanghetti. (B) Patient drinking using an artificial limb controlled through muscle cineplasty. Photographs courtesy of the Vanghetti Collection (Renato Fucini library, Empoli, Italy). (C) Military Hospital in Abd El Kader, Massawa, Eritrea. Amputated Askaris and some Italian officers. Since Ethiopians considered Askaris traitors, they applied the traditional law, Fetha Negest (Law of Kings), and amputated their right hand and left foot. The proceedings were pitiless: after the amputation, the residual stumps were cauterized with boiling fat. Most of the prisoners died within several hours.³ Photograph from Public Domain Mark, 1986, photographer Luigi Naretto, Etnografiska Museet, Stockholm, Sweden.

the prosthesis devised by Vanghetti became an artificial extension of the body and not a tool used by the amputee. With cineplastic implants (i.e., a prosthesis connected to muscles and moved by their contraction), the patient does not have to rethink the movements to adapt them to the prosthesis, but can act in a naturalistic way.

This study reviews the earliest descriptions of cineplastic operations conducted by

Vanghetti and the methods he developed in the early 1900s.

METHODS We evaluated original publications describing cineplastic principles, as well as biographic information, writings, drawings, and unpublished letters from the Vanghetti Collection in the Renato Fucini library in Empoli, Italy. We also searched PubMed to identify case reports and case series.

RESULTS AND DISCUSSION **Biography of Giuliano Vanghetti.** Giuliano Vanghetti was born on October 8, 1861, in Greve in Chianti, in the Tuscan countryside.

Figure 2 Plastic motors drawings and human patient applications

On the left: schematic drawings of clava (A) and ansa (C) plastic motors and cineplastic muscle tunnel (E). On the right: Application of the same cineplasty operations in human patients (B, D, F). Drawings and photographs courtesy of the Vanghetti Collection (Renato Fucini library, Empoli, Italy).

He attended 3 academic courses—mathematics, physics, and medicine—before focusing on the last discipline. He received his medical degree from the Medical School of Bologna after extended studies on July 13, 1890. After graduation, he served as an assistant at the University Hospital of Parma. He then moved to his father's hometown, Empoli, near Florence, to practice as a country doctor. Dissatisfied with this profession, he became a ship's doctor.

The news from the Battle of Adwa (March 1, 1896) played an important role in Vanghetti's life. During the Italian colonial invasion of Ethiopia, the Ethiopian Empire's army fought and completely annihilated the army of the Italian Kingdom near the town of Adwa, in Tigray.² Eight hundred Askaris (local soldiers serving in the armies of the European colonial powers in Africa) were captured, declared as traitors by the Ethiopians, and had their right hand and left foot amputated³ (figure 1C). Vanghetti was deeply involved in finding solutions to provide movement to the cosmetic prostheses the Italian government gave to the veterans.^{2,4}

Vanghetti concluded that the moving parts of the prostheses had to be linked directly to residual muscles and tendons after the amputation.⁵ He performed the first experiments on hens; Vanghetti amputated one of the legs and applied a self-made movable wooden prosthesis.^{4,6}

In April 1898, a self-published short essay on his method, "Amputazioni, Disarticolazioni e Protesi,"⁵ made no impression on the medical and scientific communities at first, even though Vanghetti sent it to several orthopedic hospitals in Italy and Germany.

In 1900, Antonio Ceci, director of the Surgical Clinic of the Hospital in Pisa, applied Vanghetti's ideas in a right forearm amputation. The surgical results and patient were presented in 1905 at the XVIII Congress of Italian Surgery⁷ and in 1906 at the XIX Congress of French Surgery.

Vanghetti gave organic form to his theories in several publications, especially in *Plastica e Protesi Cinematiche: Nuova Teoria Sulle Amputazioni e Sulla Protesi*,⁶ and was presented with an award by the Royal Accademia dei Lincei for trying to realize an artificial limb controlled and driven by the brain like the original limb.

During World War I, Professor Augusto Pellegrini hired Vanghetti to organize and head a center for amputees in the "Melino Mellini" surgical hospital, Chiari (Brescia, Italy).⁸

Astley Ashurst performed the first cineplastic operation in the United States on August 14, 1911.⁹ The reported results were excellent; as soon as healing was complete, the patient left the city and the clinician did not see him again for almost 2 years.⁹

In 1916, Vanghetti published *Vitalizzazione delle Membra Artificiali: Teoria e Casistica dei Motori Plastici (Chirurgia Cinematica per Protesi Cinematica)*.¹⁰ After initial criticism, in 1918, Alessandro Codivilla, a surgeon at the Rizzoli Orthopaedic Institute of Bologna, as well as his successor, Vittorio Putti, showed interest in kinematic prostheses.⁸

Approximately 10 years after Vanghetti's early writings, the German surgeon Ferdinand Sauerbruch¹¹ replicated his method. His first results were published in 1915.¹¹ Sauerbruch used the cineplastic muscle tunnel approach in the proximal stump, thus diverging from Vanghetti's technique, which used the distal segment of the bone (figure 2).

From the end of World War II until the 1980s, the application of Vanghetti's cineplasty (modified to Sauerbruch-Lebsche-Vanghetti cineplasty) continued, with mixed results.^{12–15}

Although the *British Medical Journal*¹⁶ stated that the idea existed before Vanghetti's work, he always defended that it was his invention. He claimed and proved to be the first one to carefully describe the technique and put it into practice, even if others might have suggested similar ideas.¹⁷

After World War I, Vanghetti returned to Empoli to take care of his family. He died in Empoli in 1940.

Description of cineplastic operations. The idea underlying this innovative method lies in the possibility of utilizing the residual functional resources of the stump to convey movement to the artificial limb.

The purpose was to construct one or more muscular (or tendinous) loops at the end of the patient's stump, so that the voluntary movements of these loops may be transmitted to the artificial hand. With a prosthesis constructed based on this principle, the patient is able, after practice, to perform motions.

Vanghetti published a list of 52 different ways to connect muscles and tendons with the prosthesis¹⁰; the most elementary and commonly used are the clava (i.e., club) and ansa (i.e., loop) motors, and those obtained by means of canalizing or tunneling the muscular masses.

For the clava type (figure 2, A and B), the surgical operation involved the creation of 2 distinct points of attachment. Two separate opposing muscle masses were isolated and covered with skin near the end of the limb. The distal part of the bone was usually resected. This procedure created a set of pseudofingers aimed at ensuring the contraction. In some cases, 2 metal rings were attached to the clubbed areas. Thus, the stump was able to give flexor or extensor movements to the prosthesis.¹⁰

In the ansa type (figure 2, C and D), the flexor/extensor tendons and muscles were sutured over the end of the stump, to form a ring or loop, and covered

with skin. When the patient contracted/relaxed either of the 2 muscles, the loop displaced itself alternatively, either in flexion or extension, and the movements were transmitted to the prosthetic limb.¹⁰

The cineplastic muscle tunnel (figure 2, E and F) is formed by the elevation of a skin flap of full thickness overlying the distal portion of the muscle to be used. The proximal and distal ends of the skin flaps are sutured to form a skin-lined tube.^{6,10}

In 1900, Vanghetti persuaded Professor Ceci to perform the first cineplastic operation on a 33-year-old patient who needed an amputation of the lower third of the arm (right radius myxosarcoma with metastasis). Professor Ceci believed that he was best candidate on whom to test Vanghetti's idea, and on December 21, he joined the biceps tendon with the triceps, thus forming a loop motor. After the recovery period, a weight of 2 kg was hung to a ring with a cord and the patient was able to lift it easily^{6,7} (figure 2D). Both in this first,^{6,7} as well as in many other patients,^{8–10} no additional medical need was reported after the operation. Furthermore, these cases also demonstrated remarkable success in terms of implantation longevity.⁷

Vanghetti's cineplastic operation should respect every residual natural function. In his writings, he stated that muscles should be selected based on their force and function. Preference falls on the muscle with the same function (agonist), otherwise on the semi-agonist muscle (synergic), and as a final choice, the antagonist.¹⁰

Vanghetti was aware of the theory of peripheral neural plasticity,¹⁸ proving that in the case of muscle adaptation, it is necessary to create a new muscle element that by means of cerebral plasticity should be able to reach an independent, self-supporting innervation. Although Vanghetti appreciated the possibility of using muscles with different functions, he considered it an extrema ratio due to the need for long training. He stated that even though it is clinically proven that the nervous system can adapt to different peripheral functional conditions, it is nevertheless difficult as they move away from the physiologic conditions.¹⁰

The interaction among the surgeon, physiologist, and mechanics¹⁹ highlights how the principle of cineplasty is strictly linked to an undeniable step forward, a century ago, in the practice of scientific work in this field, introducing a new degree of interaction among different disciplines (clinical studies, basic physiology, engineering), lying at the very core of neuroprosthetics.

From cineplastic operation to bionic limbs. Vanghetti's idea of using what is left of the arm's natural dynamics to subserve prosthetic function is the basis of the

neuroprosthetics field, leading to current efforts to develop bionic limbs.²⁰ In the last couple of decades, this idea has been extended in 2 different directions. First, the information extracted from muscle activity, using machine learning decoding, was capable of controlling a variety of finger movements in dexterous prostheses.²¹ Second, upper limb neuroprostheses are not only tackling the issue of motor control but also detecting tactile stimuli and transmitting them to the patient.^{22,23} Vanghetti's principle of reusing the remaining functionality to control movement has been extended to exploit the remaining peripheral sensory nerves to convey tactile perception. The latest generation of upper limb neuroprostheses makes use of both the remaining motor and sensory functionality of the stump.^{24,25} Moreover, recent studies show that it is possible to extend Vanghetti's principle in patients with tetraplegia, using the residual functionality of the motor cortex to control the remaining ability of the arm muscles, bypassing spinal lesions.^{26,27}

From a neurologic perspective, most brain motor programs for sensorimotor activities must be learned, and this action requires efficient information processing. In this sense, proprioceptive/tactile signals are crucial to build, reinforce, or update motor programs during practice, even though their involvement in the control of ongoing activities is poor.²⁸ During the same period that Sir Charles Sherrington²⁹ studied the proprioceptive system, Vanghetti, utilizing the residual functional resources of the stump to convey movement to the artificial limb, was the first to apply a method taking into account the proprioceptive signals from the proximal muscles to promote movement of the distal prosthetic segment. Vanghetti's procedure enabled the transmission of proprioceptive information to the brain that, although inaccurate, could be informative about the position of the effectors.³⁰ Compared with previous prostheses, this facilitated in part the acquisition of some appropriate measures necessary for motor programs and probably aided the relearning of a given movement by the person with the injured limb.

These distinctions show how Vanghetti's ideas were frame-changing innovations. They left a mark in the field of neuroprosthetics and more than 100 years later are implicitly a reference point in the most advanced research towards the full functional restoration of a missing hand.

AUTHOR CONTRIBUTIONS

Peppino Tropea: conceptualization of the study, data analysis and interpretation, and drafting the manuscript. Alberto Mazzoni: conceptualization of the study, data analysis and interpretation, and drafting the manuscript. Silvestro Micera: conceptualization of the study, manuscript revision, and study supervision. Massimo Corbo: conceptualization of the study, neurologic interpretation of the data, manuscript critical revision, and study supervision.

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