



Compartmental divisions of the hand revisited

RETHINKING THE VALIDITY OF CADAVER INFUSION EXPERIMENTS

G. P. Guyton, C. M. Shearman, C. L. Saltzman

From the University of North Carolina and the University of Iowa Hospitals and Clinics, USA

The results of a cadaver dye-infusion experiment suggested that the hand has ten muscle compartments and that the volar interossei occupy a separate anatomical compartment from the adjacent dorsal interossei. This is not supported by clinical findings. With various minor modifications, we repeated the experiment, infusing Omnipaque into the second dorsal interosseus muscle of four cadaver hands. We used real-time CT imaging to monitor the spread of contrast medium and side-ported needles to measure compartmental pressures. In all four hands, the tissue barrier between dorsal and volar interossei became incompetent at pressures of less than 15 mmHg.

Our data indicate that, although cadaver infusion studies can delineate potentially significant musculoskeletal barriers, their physiological relevance must be confirmed clinically.

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Before the advent of modern pressure-monitoring techniques, Bunnell, Doherty and Curtis,¹ and Bunnell² described post-traumatic ischaemic contractures of the intrinsic muscles in veterans of World War II. Recently, compartment syndromes and their common clinical patterns have been described in a large study³ and in a number of case reports. There have been few attempts, however, to examine rigorously the functional anatomical boundaries in the hand and to assess their relevance in compartment syndromes resulting from trauma or infiltration of fluid.

Many authors^{1,4-8} have described cases involving the interossei. In a recent retrospective review of compartment syndromes of the hand, Ouellette and Kelly³ recorded elevated pressures in one or more interossei in 14 of 19 patients. They did not record the pressure in the other five patients.

Attempting to clarify the anatomy of the interossei, Halpern and Mochizuki⁷ removed the dorsal skin from a single fresh cadaver hand and injected each dorsal interosseus with 2 ml of Renograffin and green dye. They did not measure the pressures required to inject the dye. Subsequent radiographs and dissection revealed that it remained contained within the individual dorsal interossei and did not seep into the volar interossei. They concluded that the volar and dorsal interossei occupied separate anatomical compartments. Their findings have been cited in review articles, textbooks of hand surgery, and the American Association of Orthopaedic Surgeons' Orthopaedic In-Training Examination.⁹⁻¹¹ It is commonly believed that the hand has ten muscle compartments, comprising a thenar, a hypothenar and an adductor pollicis compartment, and four dorsal and three volar interosseus compartments.

Clinical findings do not support the experimental results of Halpern and Mochizuki,⁷ and there are no clinical reports of significant differences in the pressures of the two muscle belly groups. It is difficult to measure pressure in the volar interosseus spaces in the clinical setting and this is rarely done. In their series of 19 cases Ouellette and Kelly did not once record it.³

Re-examining the validity of the results of Halpern and Mochizuki⁷ we repeated the experiment with various modifications. These included increasing the number of specimens, using CT, leaving the dorsal skin undisturbed and, most importantly, monitoring compartmental pressures during infusion.

Materials and Methods

We used four fresh cadaver arms amputated above the elbow. None had any evident deformity or injury. We primed a volume-controlled infusion pump (Harvard Apparatus, Natick, Massachusetts) with contrast medium containing 17.5 mg/ml of Omnipaque and 0.5% Trypan Blue dye in normal saline. The contrast medium was infused

G. P. Guyton, MD, Assistant Professor
Department of Orthopaedics, University of North Carolina at Chapel Hill,
CB#7055, 252 Burnett-Womack Building, Chapel Hill, North Carolina,
27599-7055, USA.

C. M. Shearman, MD, Fellow
Department of Radiology
C. L. Saltzman, MD, Assistant Professor
Department of Orthopaedics
University of Iowa Hospitals and Clinics, Iowa City, Iowa, USA.

Correspondence should be sent to Dr G. P. Guyton.

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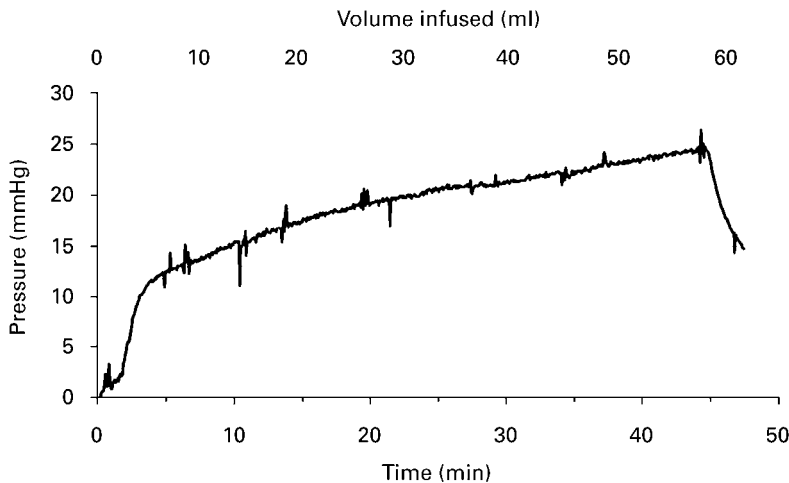


Fig. 1

Pressure in the second dorsal interosseus plotted against time and volume infused. The rapid drop at the right of the curve corresponds to the cessation of infusion.

uninterruptedly into the four hands at 1.12 ml/min. The pump lent itself easily to calibration at this rate which is approximately the rate of infusion seen in intravenous infiltration injuries, a common cause of hand compartment syndrome.

We used a separate 18-gauge side-ported needle specifically designed to measure compartmental pressures (Stryker, Kalamazoo, Michigan). Side-ported needles have in recent years, been shown to be as accurate as slit catheters.¹² The needle was connected to a physiological pressure transducer (Gould, Ballanvilliers, France) and the output run through an analogue-to-digital converter (Analog Devices, Norwood, Massachusetts) into a laboratory computer. Readings were recorded once every second.

Carefully and incrementally, we positioned both needles under CT guidance. At an angle of 20° the infusion needle entered the hand adjacent to the metacarpal head, coming to rest in the muscle belly of the second dorsal interosseus. The side-ported needle was inserted proximally and came to rest in the muscle belly of the second dorsal interosseus some 8 to 12 mm from the needle. The fascia between the dorsal and volar interossei was not violated.

Serial axial CT images of each hand were obtained and

concurrent pressure readings recorded 30 seconds after the start of the infusion and at intervals of approximately five to eight minutes. Each infusion continued until real-time CT images showed that the contrast material had breached the relevant compartmental boundary. Although it proved unnecessary, we set an arbitrary pressure limit of 35 mmHg as the point at which the infusion would be discontinued regardless of the extent of spread of the contrast material.

Results

Pressure recordings. We recorded pressures in the second dorsal interosseus of all four hands during and after infusion. Figure 1 shows the pressure readings plotted against time and volume infused. After rising sharply to approximately 10 mmHg with the first 5 ml of fluid, the pressure typically rose slowly with infusion of the next 40 ml. It did not exceed 34 mmHg. Immediately after the infusion had been stopped, the pressure fell sharply, stabilising in two to three minutes. During the infusion, dynamic resistance possibly further increased the pressure in the second dorsal interosseus. In two hands, some contrast medium leaked into the subcutaneous tissues around the infusion needle,

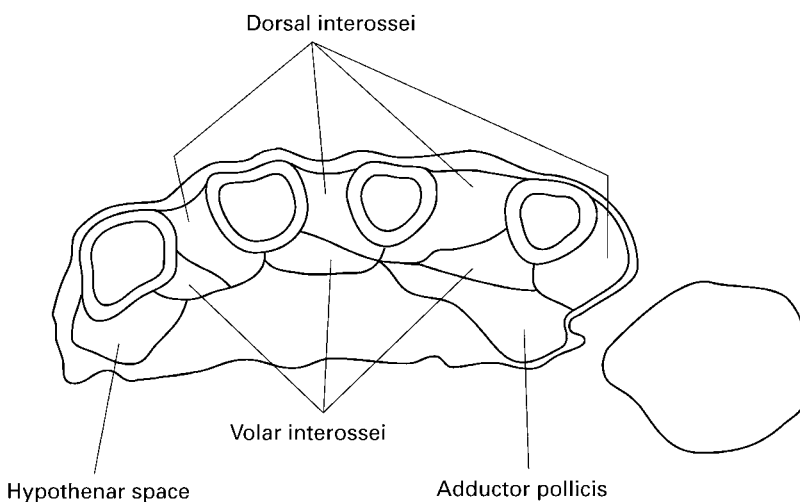


Fig. 2

Diagram showing the cross-sectional scheme of the muscular anatomy of the hand at midmetacarpal level.

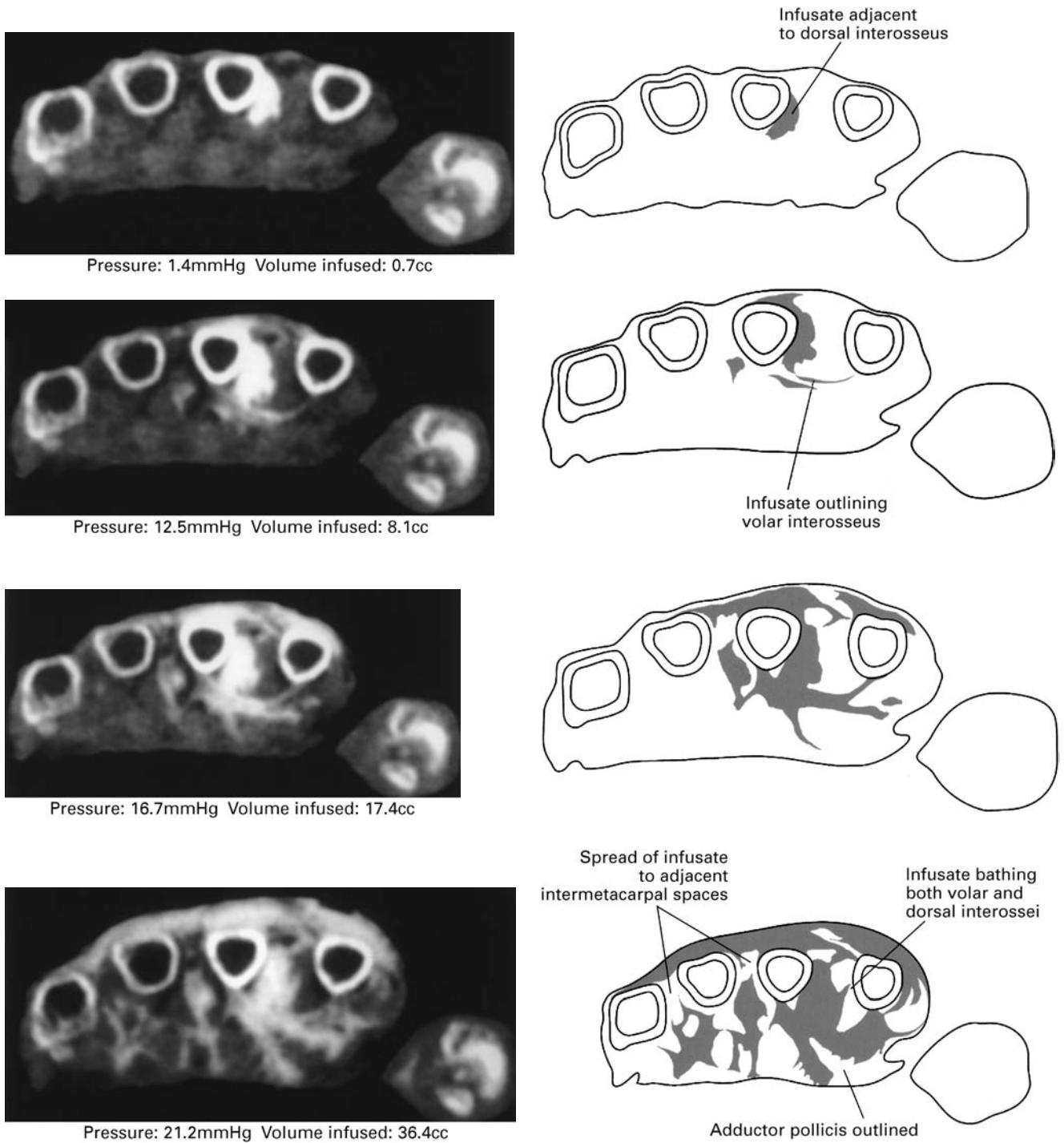


Fig. 3

Serial CT images obtained at the midmetacarpal level during infusion. The bones appear 'washed-out' owing to the use of soft-tissue windows. The infused volumes and pressures are those plotted in Figure 1.

and pressure within the second dorsal interosseus rose more slowly because not all the medium went into the muscle belly itself.

Imaging data. Over the course of infusion we carried out seven or more axial CT scans, each consisting of 40 1 mm slices, for each hand. We recorded the pressures within the second dorsal interosseus at the time of each scan and

assessed on the CT images the extent of the spread of contrast medium into the intrinsic muscles (Figs 2 and 3).

In all hands the contrast medium was confined to the second dorsal interosseus for the first 30 seconds of infusion. The volume infused after 30 seconds was less than 1.5 ml and in all hands pressures of less than 5 mmHg were recorded.

In all hands we observed contrast medium in the adjacent first and second volar interossei before pressure in the second dorsal interosseus reached 15 mmHg. As the infused volume increased, we saw contrast medium also in the first and third dorsal and third volar interossei. By the final CT image, contrast medium had spread through all the interossei to the fourth dorsal interosseus in three of the four hands. In two hands we also observed contrast medium subcutaneously.

Discussion

Compartment syndromes involving a single interosseus compartment can and do occur. Overuse of the first dorsal interosseus can lead to a chronic compartment syndrome,¹³ and overuse compartment syndrome with isolated partial necrosis of the second dorsal and volar interossei has been reported.⁵ This clinical evidence indicates that the fasciae between adjacent interosseus spaces can support pressure differentials across their bounds. The tissue separating the volar from the dorsal interossei is more tenuous. Halpern and Mochizuki⁷ demonstrated that the fasciae of the dorsal interossei are capable of containing a very small volume of fluid injected at an unmeasured, presumably low, pressure. Our data, however, indicate that when the pressure and the volume of fluid in the muscle bellies increase even modestly, the tissue barrier between the dorsal and volar interossei rapidly becomes sufficiently incompetent to allow the free passage of fluid.

We made a number of changes to the design of the experiment of Halpern and Mochizuki.⁷ We used a large volume of infusate and took real-time pressure measurements. We used CT imaging and, to avoid the fluctuations in pressure which can accompany manual injection, a calibrated mechanical pump. These subtle modifications produced a dramatically different result. We do not contend, however, that the changes necessarily increased the validity of the experiment. Rather, they point to the profound limitations of relying on cadaver infusion studies to ascertain whether a muscle space exists as a separate physiologically relevant compartment, particularly if they use very low pressures and infused volumes.

Many connective tissues are too elastic or tenuous to contain any substantial pressure. The subjective distinction between an 'epimysium' and a 'fascia' is not based on

definitive anatomical criteria. Pressure-permeable and pressure-impermeable layers are composed of the same biological structures, and many spaces bounded by connective tissue can contain small quantities of slowly-injected fluid.

Furthermore, there are differences between cadaver and living limbs. The in vivo interaction of lymphatic, arterial and venous flows, as well as the diffuse leak of fluid from damaged capillary beds, alters interstitial pressures. This observation is borne out by the occasional occurrence of a compartment syndrome despite partial disruption of the compartmental boundary after an open fracture.

Although cadaver infusion experiments can delineate potentially significant musculoskeletal barriers, their physiological accuracy and pathological relevance must be confirmed clinically.

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