Measuring gentleness in surgery

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Your presenter

In the absence of the usual chairperson for a lecture here are pictures, and a brief bio on the notes page below.

Michael Patkin is a retired country general surgeon, who worked at Whyalla, South Australia for 30 years.

He has had a lifelong obsession with the application of ergonomics to operative practice, with many publications you can view at www.mpatkin.org

[The slide above, and others, can be seen in more detail by getting out of Notes Page View, double clicking on the diagram to select it, and increasing the magnification percentage just below the menu bar above]

The background - Ergonomics in Surgery

Ergonomics is the scientific study of people at work

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You can find a rundown on Ergonomics at web sites such as Wikipedia. Briefly, starting with the definition above, Ergonomics is based on anatomy, physiology, psychology and engineering, combined with a systems approach.

Its aims are improved productivity, quality, and safety and well-being of of workers.

Ergonomics was first applied formally to surgery in 1967, and found extensive use in solving problems of operative microsurgery. Today it is considered in three main areas which can be applied to surgery with benefit:

1, Physical ergonomics   2. Cognitive ergonomics (information and mental processing), and 3. Macro- or organizational ergonomics.

Examining the forces applied in operative and clinical surgery is part of the first of these applications. It is early to say how much use this will be, but the rapid growth of simulation in training, and increasing references to forces exerted specifieded in Newtons, suggests it has a future.

A possible advert for a talk on this topic .....

Measure gentleness at surgery !!!

Postal clerks, deli owners and greengrocers all know what weighs 500 grams.

Should surgeons recognise a force of 2 Newton when they operate, palpate or tear tissues ?

Learn all about it !

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Increasingly there are references to tensile strength of tissues, sutures and anastomoses in units such as Newtons (force) and pascals (pressure) while torque, for example applied to screws in orthopaedics, is specified in Newton-metres.

In other occupations the relevant forces, such as weights, are well known. Perhaps the time has come to replace adjectives with numbers, and not describing abdominal tenderness just as mild, moderate or severe. This possibility is described later.

Take-home messages

- A litre of milk ≈ 1 kg ≈ 10 Newton
- Forces (cf pressures) exerted in surgery
  range from Newtons to kilograms

- Too <u>little</u> force is ineffective
- Too <u>much</u> force causes damage, inaccuracy

MANY FORCES EXERTED
CAN BE MEASURED EASILY

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If you remember nothing else from this talk, remember that a Newton is a unit of force and is roughly equal to a weight of 100 grams (on the surface of the earth and not out in space, to be pedantic).

A litre of milk or watery drink weighs about 1 kg or 10 N

.... when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind:

Lord Kelvin 1883

You manage what you measure

You can't fix what you don't know about

* Scipione Riva-Rocci developed the mercury sphygmomanometer in 1896.
…[It] was spotted by the American neurosurgeon Harvey Cushing while he was travelling through Italy. …in 1901.

After the design was modified for more clinical use, the sphygmomanometer became commonplace. Cushing and George Crile were major advocates of the benefits.

We no longer rely on feeling the forehead to know a patient's temperature. Yet we rely on these same fingers to assess the degree of tenderness. While tenderness may be an old-fashioned kind of assessment, it is still a mainstay in assessing the state of intra-abdominal injury on repeated examination.

* Information from: http://www.medphys.ucl.ac.uk/teaching/undergrad/projects/2003/group_03/history.html

What is a Newton?

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We've already introduced this unit of force.

The base units of the International System are the meter, kilogram, second, ampere, *kelvin* and the *candela.*

The Newton, as we shall see, is derived from the first three of these, the meter, kilogram and second.

What is a Newton?

- That force which accelerates a mass of 1 kg by 1 metre / second / second

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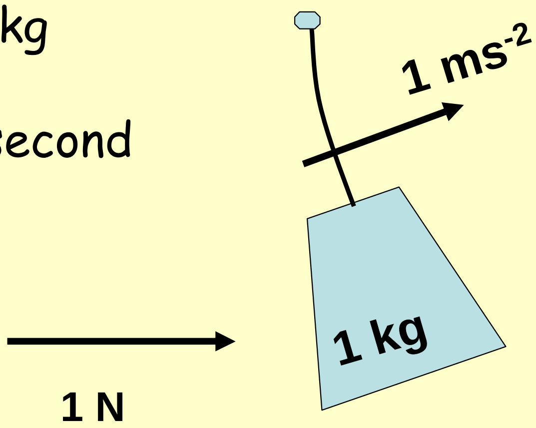
Here is a formal definition

What is a Newton?

- That force which accelerates
  a mass of 1 kg
  by 1 metre
  / second / second



Here’s my attempt at a diagram to illustrate the definition through the idea of pushing on a pendulum.

What is a Newton?

- The force which accelerates a mass of 1 kg by 1 metre / second / second

---

Gravity accelerates things by **9.8** $m.sec^{-2}$

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Gravity quickens the movement of a one kilo weight ten times as much a the force of a push of one Newton.

What is a Newton?

- The force which accelerates a mass of 1 kg by 1 metre / second / second

Gravity accelerates things by 9.8 $m.sec^{-2}$

So

1 N ≈ 1 kg / 10 ≈ 100 grams weight
≈ weight of the **small** English apple
which fell on the head
of Sir Isaac Newton

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So … a Newton is a force, which is

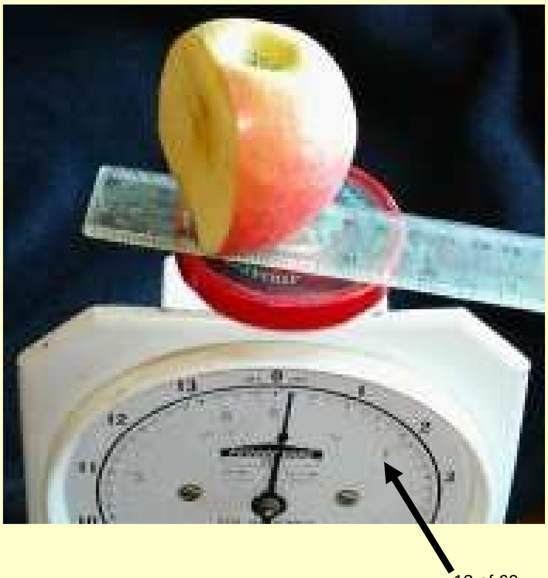
one-tenth of the weight of kilogram (on earth, not in space).

Isaac Newton is supposed to have got his insight into the nature of gravity as an attractive force while sitting under an apple tree, on holiday from Cambridge during the plague year of 1665 when he developed many new ideas such as the three laws of motion.

1 small English apple

≈ 100 grams weight

≈ 1 Newton



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1 kg

An ordinary Australian apple weights 200 or 300 grams, so you have to think of a <u>small</u> English apple, 4-5 cm in diameter, which just floats in water.

I couldn't find an apple small enough for this photo, so I had to trim it a bit.

A range of weights & forces

1 g =	Olive pip
10 g =	Pen
100 g =	Small apple
1 kg =	Litre of milk
10 kg =	Child aged two
100 kg =	Fat man
1 tonne =	Family car

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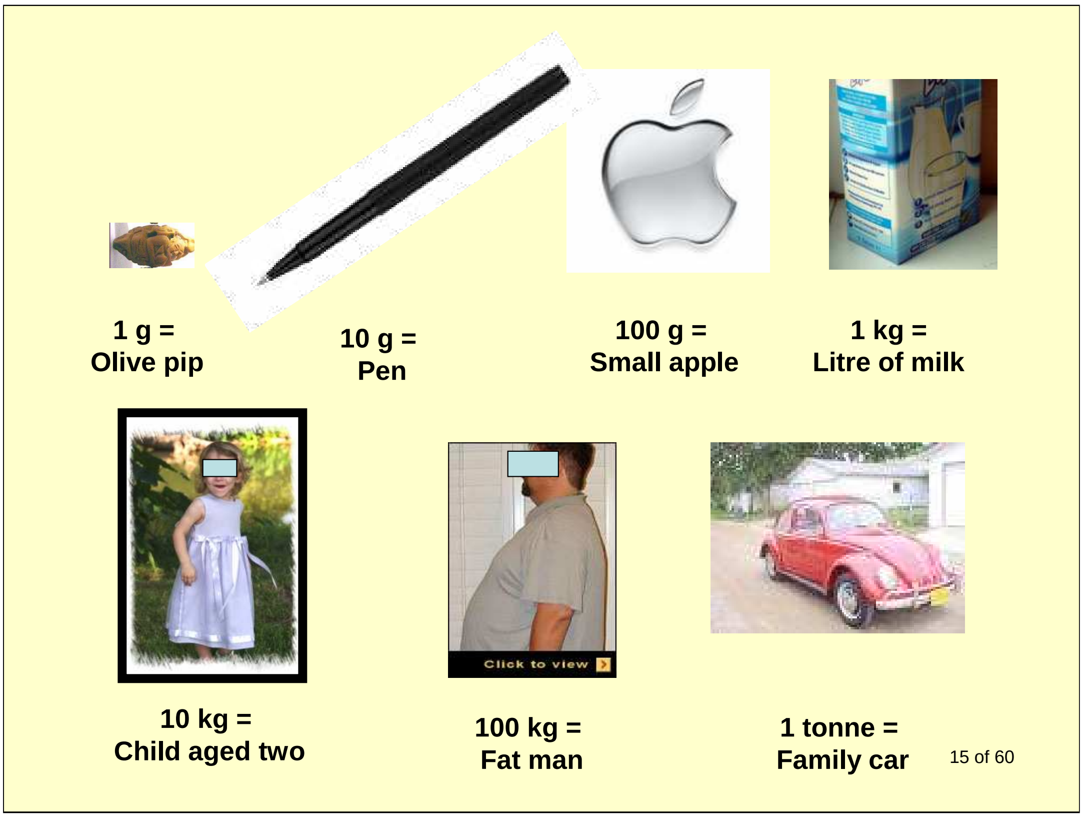
Here is a list of everyday objects whose weight corresponds to multiples of a gram.

Think of an olive pip (pit in America) as about 1 cm in each dimension (though longer and thinner). It just floats in gin, which has almost the same specific gravity or density as water – and 1 cubic centimetre of water weighs one gram.

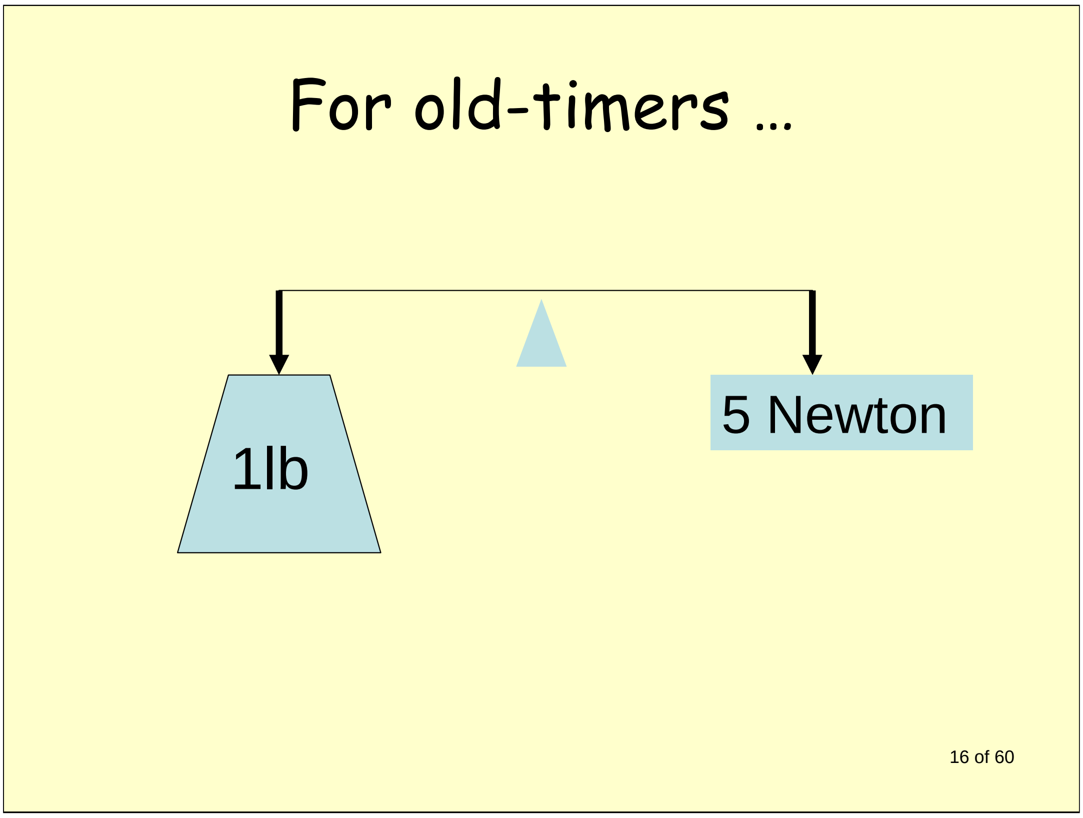
Here comes a joke, but a true story. I did this research on the olive pip and the analysis in a cocktail lounge at the Tel Aviv Sheraton in 1978 when I was speaking at a conference there.



Think of 10 olive pips lined up. They have something like the mass of a ball-point pen, heavier if metal (15-17 g) and lighter if plastic (5-7 g).

A smaller family car of 1 tonne is equal to the weight of one million olive pips, or one mega-pip, A litre of milk is one kilo-pip.

The range of forces in operative and clinical surgery ranges from a few tens of grams to a few kilograms. Heaviest is the force to reduce a dislocated hip in a young man, almost his body weight of 70-90 kg (my own estimate from the need for two assistants to press down on the pelvis.



Habit is more powerful than logic. If you grew up before the metric system was introduced it is hard to get your head round these new-fangled weights and measures.

Knowing how much force to use:

- Avoids tentative cut
- Avoids “oops!”
- Avoids hurting

- a part of skill

- a part of programming future robots

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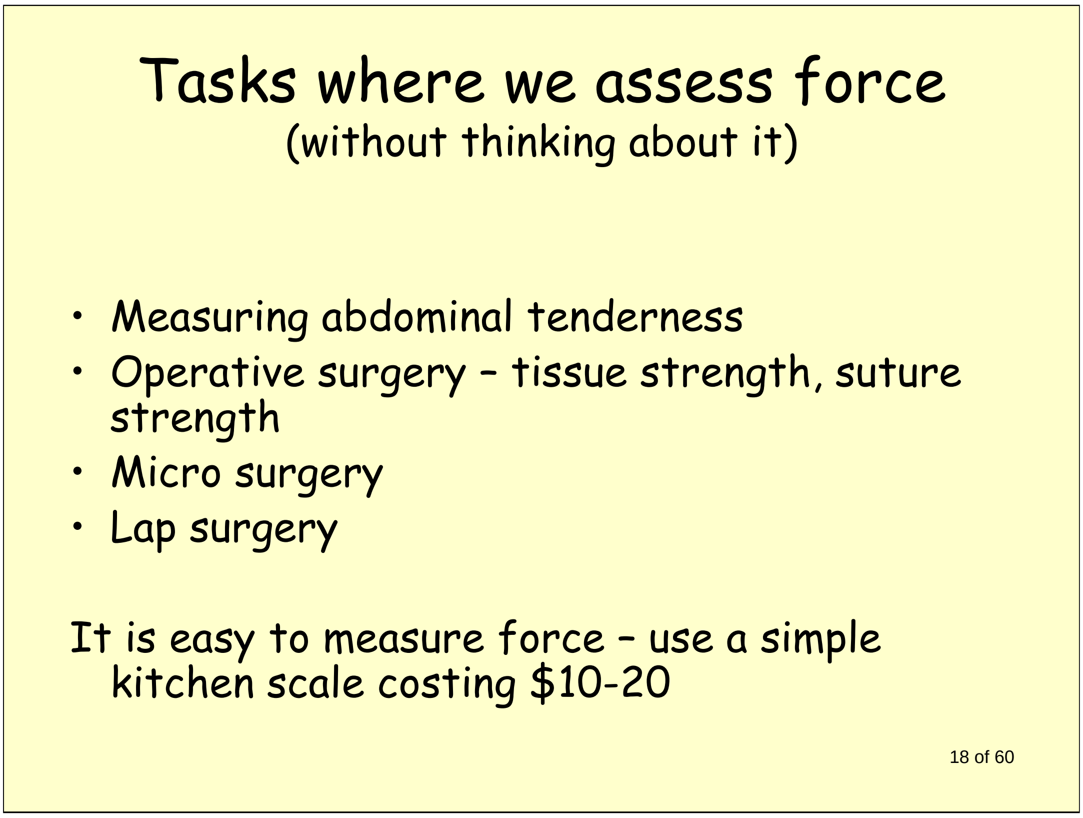
A tentative cut is the graze on the skin from a scalpel by a junior doctor making their first incision. It takes a while to get the confidence to press harder,

An “oops!” experience is cutting through the skin and linea alba of a very skinny patient when a surgeon is showing off to a visitor, and inadvertently nicks or opens the underlying bowel, making a mess and endangering life in the worst case.

Having the knuckles placed to avoid pressing through too deeply is an important skill for insuring against such damage.



These are several areas of surgical practice where it has become important to assess how hard we press or pull, without knowing what the level of force is in numerical terms. It is common to record tenderness, and to apply an adjective to it.

Applying too much force in operative surgery means damage whose consequences may be serious or lethal. Too little force means an action is ineffective.

The kitchen scale

$ 20

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This simple device, a kitchen scale costing a few dollars. Here a tin lid has been screwed in place where the pan usually rests, provides a tool for measuring forces exerted by the hand.

It was bought for a few dollars from a hardware store in about 1966, and has scales for both the metric system (kilograms, the inner paler set of numbers) and the old imperial system (pounds and ounnces, the outer darker numbers).

It has lasted well for many hundreds or perhaps thousands of demonstrations.

Measuring abdominal tenderness

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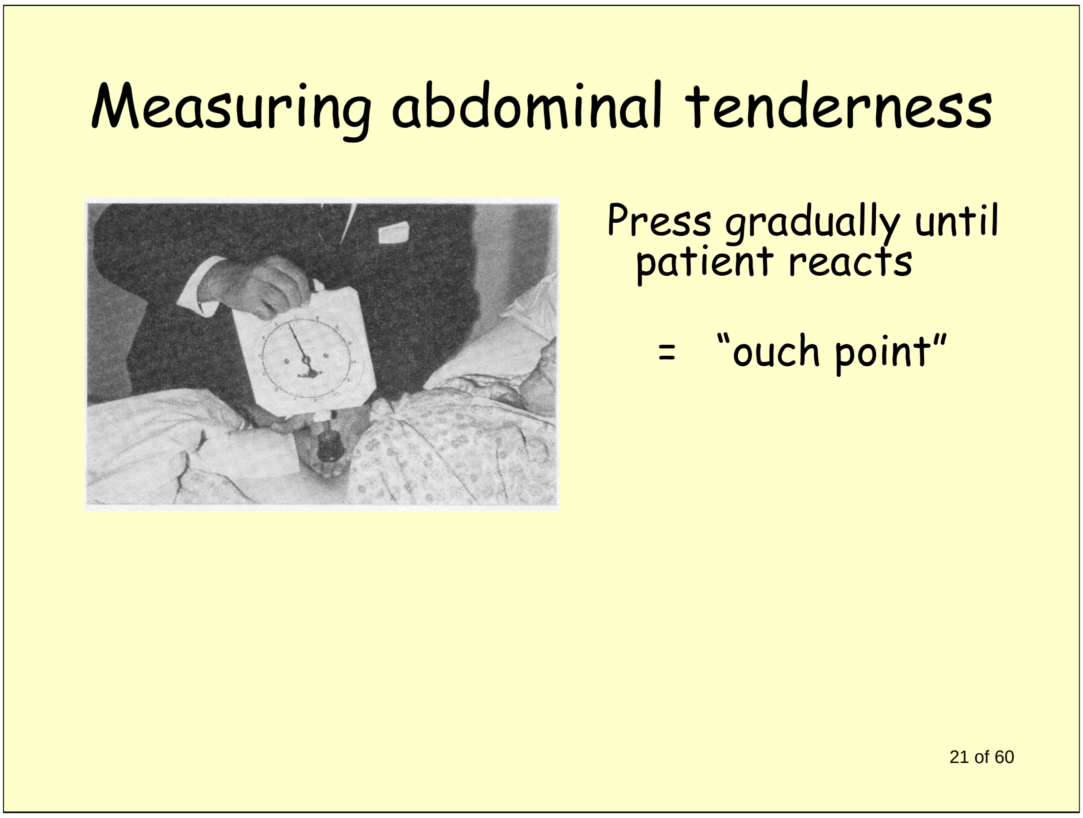
In 1968 I used the kitchen scale you have just seen to measure how hard I was pressing when I palpated the abdomen of a patient to estimate tenderness.

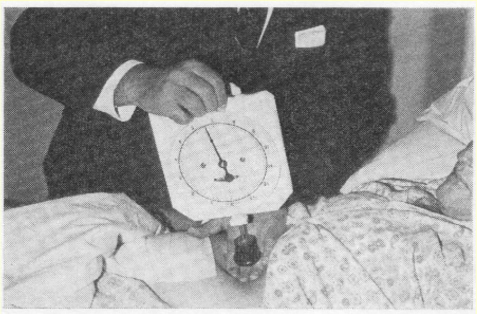


I replaced the pan with a long screw and a cotton reel over which I put a rubber crutch tip. I inverted the scale and reset the reading to zero, because it had changed slightly with the weight of the mechanism pushing the other way.

I explained to the patient that I was going to press gently and slowly wuth the scale onto the boack of my hand, which was resting on the area where they were sore, until they said "ouch" and then I would take my hand and the scale away.

When the patient said "ouch", I looked at the scale and noted the reading before I took my hand (and the scale) away.

Measuring abdominal tenderness



press gradually
until pt reacts
= "ouch point"

mild tenderness	20 – 50	Newton
moderate	10 – 20	N
marked	5 – 10	N

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Over several patients (unfortunately I didn't record how many) I estimated the forces that corresponded to different levels of tenderness, as follows:

Level of tenderness	Force exerted
mild	20-60 N (2-6 litres of milk)
moderate	10-20 N (1-2 li)
marked	5-10 N (½ -1)

MEASUREMENT OF TENDERNESS

WITH THE DESCRIPTION OF A SIMPLE INSTRUMENT

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Dungog and District Hospital, New South Wales

MJA 1969

This was the paperpublished in the Medical Journal of Australia in 1969 (you can see the full text on my website at www.mpatkin.org).

It raised barely a ripple anywhere. I had hoped it might be useful for nurses in outback regions, talking to a surgeon by phone and being able to describe the level of tenderness. I thought it might help when repeated to indicate that some intra-abdominal condition was worsening – as indeed it did in one case to be described shortly. Later I wondered if it might have similar applications for remote expeditions to Antarctica or into space. However de Dombal was to include this paper as a chaper in his textbook on abdominal pain and its assessment. (Diagnosis of Acute Abdominal Pain Churchill Livingstone; 2nd edition 1991)

Case 1: Boy aged 9, ruptured spleen

Hrs	Pulse	Ouch point
0	92	
0.5	98	
1	100	
1.5	98	
2	100	
2.5	120	
3	116	
3.5	122	12.5 N ("moderate")
4	120	9.0 N ("marked")
4.5	115	transfer to OR

Findings: 300 ml in abdo cavity

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Here was a great clinical application of the tenderometer. A small boy had fallen off a horse and was hurt in the left upper part of the abdomen. A couple of days earlier, at the little country hospital where I was working, I had shown the nurses there how the tenderometer worked. On her own initiative the nurse on duty applied it to the child's abdomen and made the observations recorded above over 4 hours.

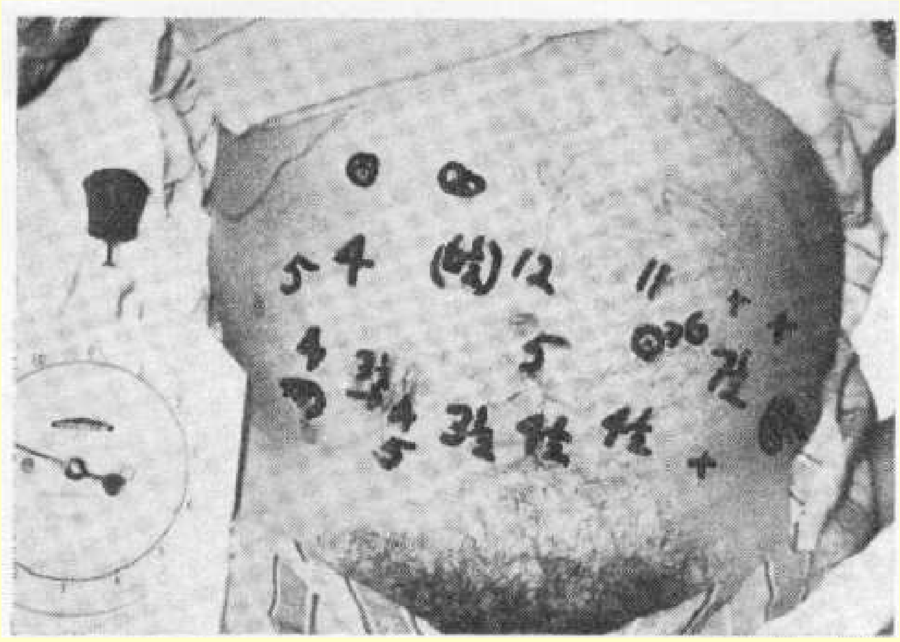
When the tenderness increased and the pulse rose, I diagnosed a ruptured spleen and drove to the hospital where I operated, confirmed the diagnosis, and removed the spleen.

These days there is a trend to wait longer before operating because at times the bleeding stops on its own, but the treatment at the time was in occardance with was accepted then.

Case 1: Post-op tenderness RIF   3.5 kg weight (35 N)

Here is the child a few days later showing mild tenderness only.

Case 2: Acute appendicitis



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This was another case where I used the tenderometer, a fat hairy man with features of acute appendicitis. I measured the “ouch” point in a number of different parts of his abdomen and wrote the force level at each point of measurement.

These formed an “ouchogram” which I thought gave a nice demonstration of what might become a useful clinical tool. Alas, but no.

Since then an experienced trauma surgeon has told me that serial estimates of tenderness are one of the most useful guides as to when to operate in some case of abdominal stab wounds.

Forces in operative surgery

Stiffness of instruments

- Ratchets of clamps
- Dissectors
- Vascular clamps

Needle sharpness
Suture strength
Tissue strength
Retraction – sternal retraction

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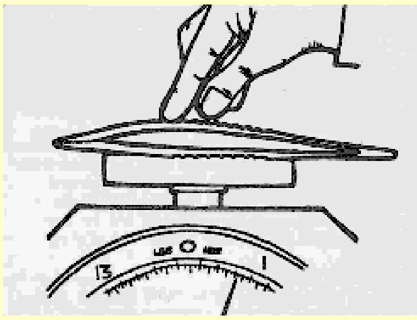
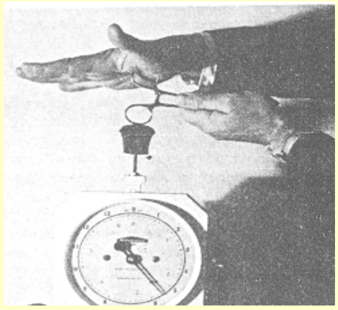
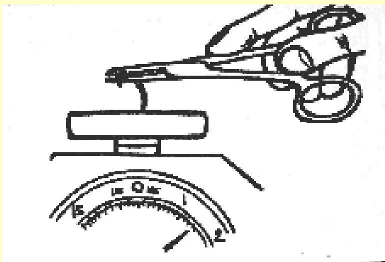
Here are other instances of forces which can or have been measured.

Some of them are illustrated over the next few slides.







The upper left picture shows measurement of the stiffness of dissecting forceps (one arm looks too curved, please ignore). Force is applied at the usual fingertip position until the tips of the instrument touch.

The British Standard at the time I made these studies specified a force of 10 ounces or 3N approximately. Similarly the force to close the first step on the ratchet of artery forceps was 2 ½ to 3 ½ pounds weight (10-20 N) and lateral force to unlock it was 1 lb.

Also shown is my method of measuring how much force it took to put a needle througha piece of skin supported on a perforated platform. The skin was spare from the edge of a mastectomy or similar operation. Later I was to make many more such measurements using a sophisticated Instron machine at the local Institute of Technology.

It takes about 10-20 N to push a needle through average adult skin.

Stiffness of syringe plunger in barrel

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It was very easy to measure how much force it took to push a plunger into a syringe, typically 5 N for a 10 ml syringe and proportionately less for those of smaller size and diameter.

There was a time when Boots, the big British pharmacy chain, was in the syringe making business, but their syringes were very stiff. The result was patients got a trail of haematomas along their forearm from the unsteadiness of the use that resulted, and they went out of business.

I used the same technique later for lparascopic instruments.

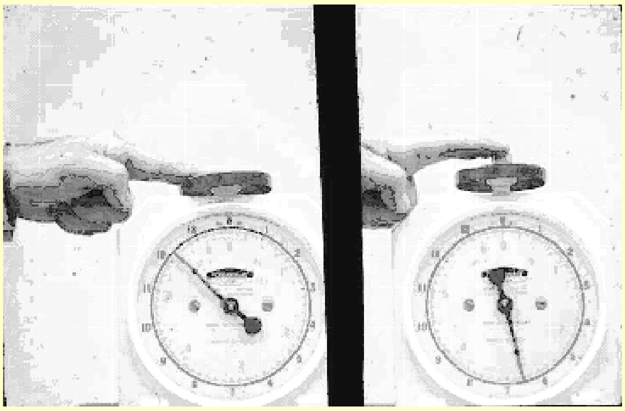
Suture breaking strength (N)

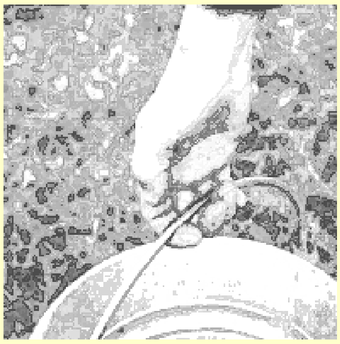
	3-0		4-0		5-0		6-0	
	Str	Knot	Str	Knot	Str	Knot	Str	Knot
Silk	25	16	17	11	9	7	6	4
Ethilon	27	16	17	11	11	7	6	4
Prolene	28	20	19	13	11	8	6	5

The various suture companies publish data for the breaking strains of their products, which must meet various published national and military standards.

Surgeons learn not to exceed these limits through experience, especially for the finer sutures.

Perception of force depends on surface area





Pull on Gillies' skin hook cf. Doyen retractor

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Estimating forces with the hand and fingers depends on pressure, or force per unit area as well as on the total force. The weight of a bucket with a thin handle gives a more drastic impression than if it has a thicker, broader handle. The finger cannot press nearly as hard onto an edge as on to a flat surface.

For delicate retracting during hand surgery, a Gillies skin hook with a thin handle is easier to pull accurately than another instrument with a thicker handle.

Microsurgery

- Stiffness of micro forceps, needleholders
- Measured 1972, presented at workshops, taken up by manufacturers, published 1978
- Breaking strain of 10/0 nylon
- Force for 10/0 needle to penetrate cornea

When I first got involved with microsurgery in 1969, both needleholders and tissue forceps were far too stiff, the former taking as much as 10 N to close. A group of 5 experienced microsurgeons chose a level of 0.6 - 0.8 N as best out of a range of instruments I offered them to try. Manufacturers quickly came to make their instruments much less stiff and by 1974 were advertising theirs as “ergonomically designed”. I got no credit but a lot of satisfaction.

10/0 nylon breaks with a pull of 0.15 N , about the weight of a mosquito forceps or fine haemostat. Operators had to get used to a new scale of gentleness.

Stiffness of microsurgical needleholder (0.5 – 0.7 N)

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This Chatillon push-pull gauge and the motorised platform which applied force at a steady pre-determined rate was a $1500 present from Davis and Geck, the suture makers, with no strings attached or obligation. It was obviously more reliable than a kitchen scale, or even the little diabetic food-weighing scale (not illustrated here) which had been a big advance.

Forces in dental scaling (N)

Simulation of dental scaling

Hyg no	Probing force	Scaling force	
		min	max
1	. 30	10	20
2	. 30	15	30
3	. 25	20	30
4	. 20	7	37
5	. 15	20	40
6	. 15	4	37

And now, a change of scene from microsurgery to the work of dental therapists. When they are removing tartar (“calculus”) from teeth, they have to press unusually hard for a task carried out in the precision (pen-holding) grip of the hand.

I got six experienced dental hygeinists to mimic the force they used, pressing onto the scale shown, resting their hand on a pile of books just as they steady their hand against a patient’s jaw. The force for probing was light. A third of a Newton or less. For scaling they pressed with a force of 20 – 40 N.

When they start their studies, students of dental hygeine get quite sore hands and are advised to strengthen them by squeezing a squash ball. There are very activities where people press as hard as this pushing something shaped like a pen.

Laparoscopic surgery

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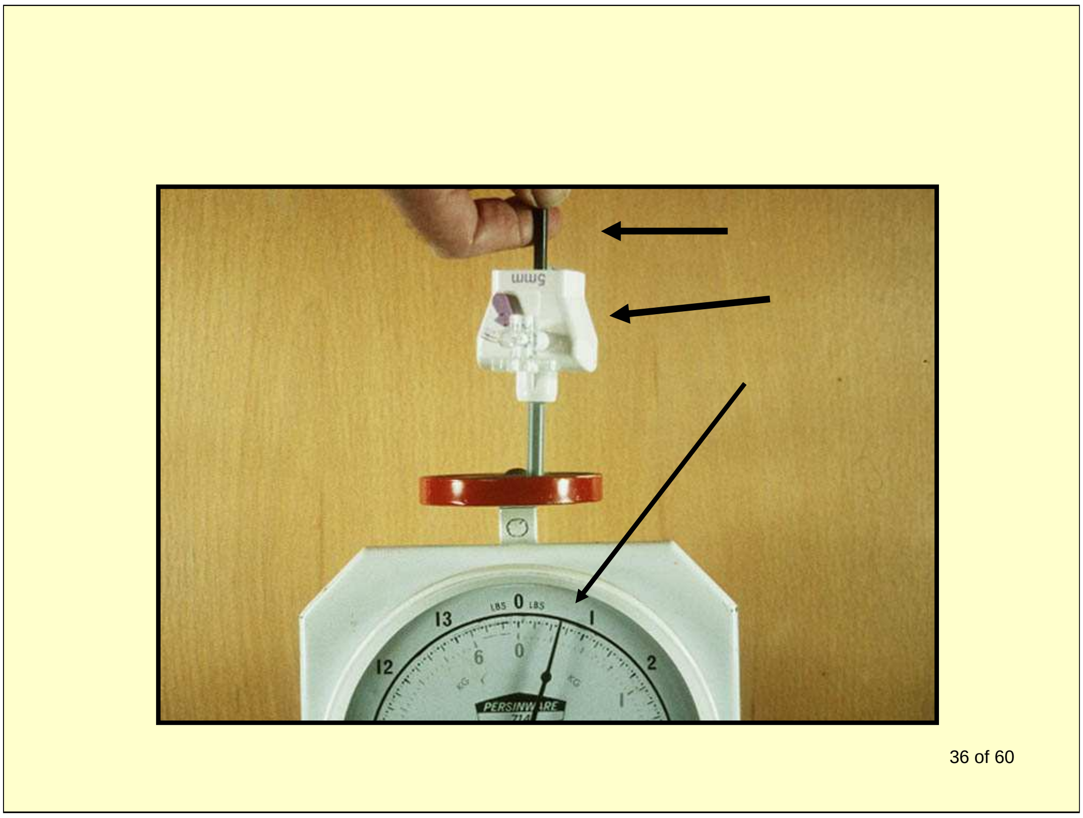
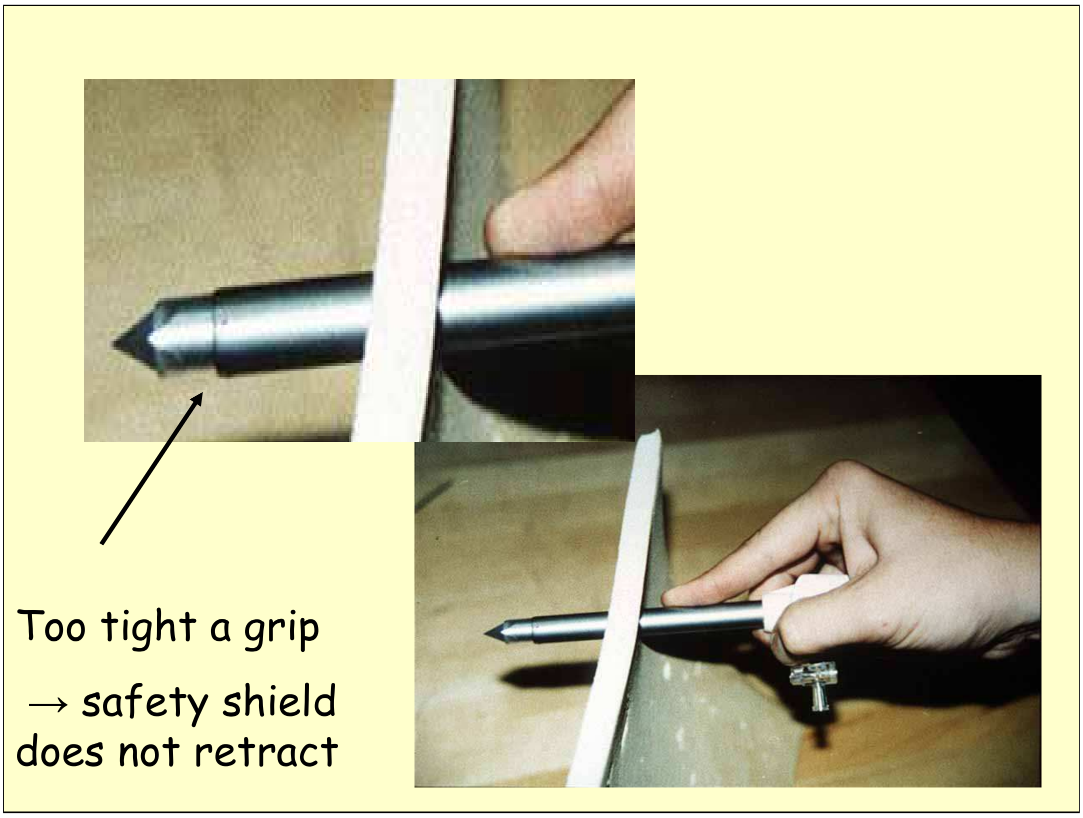
Laparoscopic, endoscopic or “Key-hole” surgery emerged from just before 1990, and brought challenges to surgeons who suddenly had to learn a new set of eye-hand co-ordinations if they were to keep up in the competition to have patients referred to them. (See my paper with Luis Isabel on the ergonomics of endosurgery on this website).

They also had to learn how hard to push to insert trocars and manipulate long thin instruments.



One of the problems was loss of sense of tocuh because of friction between instruments and the cannulas they were slid through. It was easy to measure this friction by the simple arrangement shown – a port resting on the scale, and an instrument pushed downwards through it. This might take several N, results I never recorded formally or published then.

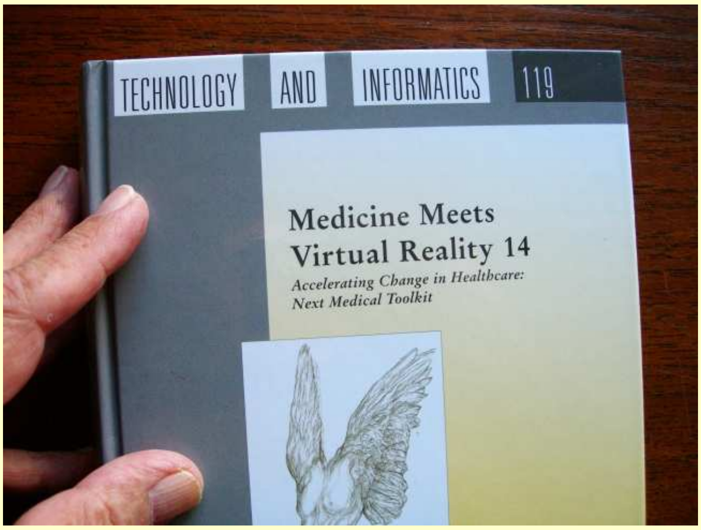
Since I first tried this there have been a number of publsihed studies by others. The dilution of tactile “haptic” feedback can be reduced by moistening and lubricating the instrument, and by the design of newer ports with less sticky rubber or neoprene seals.



However there are a few traps. At ECRI (the world’s largest biomedical consulting group) scientists showed how a tight hand grip on the trocar and cannula stopped the safety mechaism allowing the point to spring back inside the cannula once the skin had been penetrated. The persisting point could cause severe and even lethal damage during the inisial setting up for laparoscopic surgery.

Examples from MMVR 2006

[San Diego]



The next few slides show a variety of different situations in which forces exerted in operative or clinical surgery were measured.

At a conference in San Diego on simulation in surgery. MMVR 2006 (Medicine Meets Virtual Reality), 119 papers were included in the conference proceedings. Of these, just under 20 had data of the kind I was interested in.

Many of the studies were of models, both physical and virtual mediated by computer, for training students or surgeons, and the designers tried to build in realistic levels of force that had to be exerted, which meant they had to specify these, and often cited the levels.

Pugh pelvic simulator (2002)

Figure 1 The complete system.

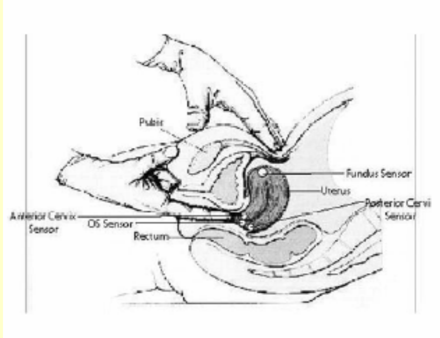


Figure 3 Sensor locations.

• new students	palpate too gently
• early students	6-8 pounds (30-40 N)
• exp students, clinicians	4-6 pounds (20-30 N)

Carla Pugh, a professor of gynaecology, wanted to teach students how hard to press up the vagina for pelvic examination – enough to palpate and not so hard as to cause the patient unnecessary discomfort or pain.

The levels of force were in the same range as I had found in my own studies for estimating mild or moderate abdominal tenderness, about 20 – 40 N.

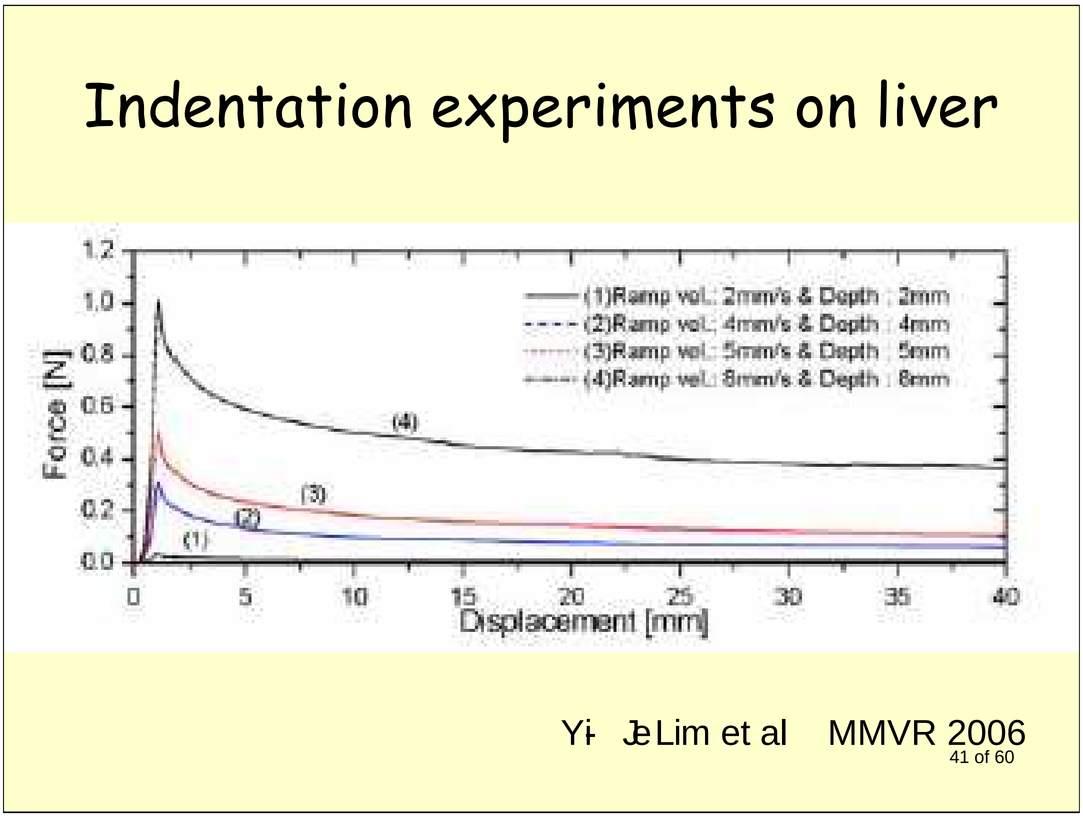
Forces applied to pig tissues at Lap Nissen [from MMVR 2006]

	crus	esoph	fundus	gr omentum
Force (N)	5.8 ±1.2	3.3 ± 0.6	1.5 ± 0.2	1.6 ± 0.1
Rate (N/s)	7.4 ± 1.9	3.3 ± 1.1	1.1 ± 1.4	0.9 ± 0.2

Lamata P et al MMVR 2006

Another study, cited above, showed more gentle levels of force applied to pig tissues at laparoscopic fundoplication. These forces went down to a very gentle level of just over one N for simply displacing the greater omentum, flopping freely in the abdomen.

Of great interest were measurements of the rate at which the forces were applied. One important aspect of gentleness is applying force gradually and not with a sudden jerk, unless you want to transfix a structure with a needle, discussed shortly.



The force to indent liver for different distances at experimental laparoscopic surgery was also quite light, as shown in the family of curves above.

[The slide above, and others, can be seen in more detail by getting out of Notes Page View, double clicking on the diagram to select it, and increasing the magnification percentage just below the menu bar above]

Guide wire insertion in radiology

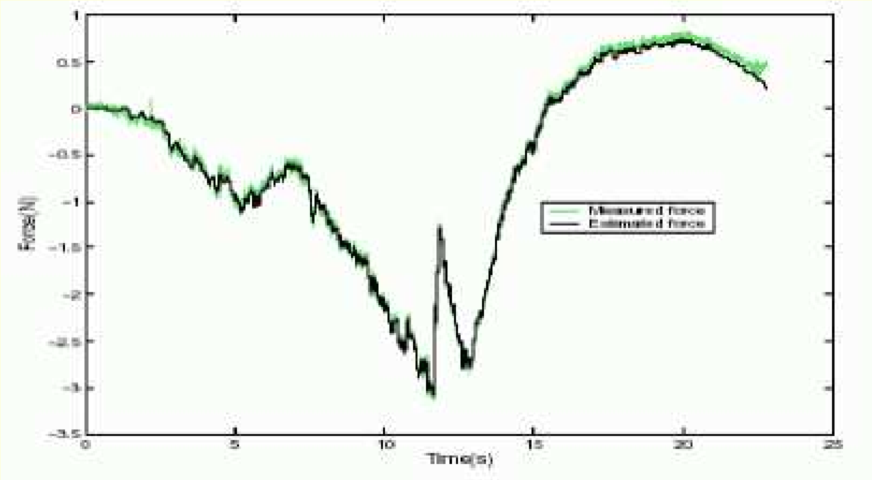
5 FG catheter force ≈ 1.5 N
torque ≈ 4.5 mNm

Moix T et al MMVR 2006

Radiologists as well as surgeons have to push through tissue to enter hollow structures. With fine needles and tubes the force required is little more than the force to press a key on a keyboard (which is in the range of 0.6-0.9 N on a typical computer).

A screwing movement facilitates this, measured in Newton-metres, measured in this study.

In vivo needle insertion (pig skin to liver)



Barbe L et al MMVR 2006

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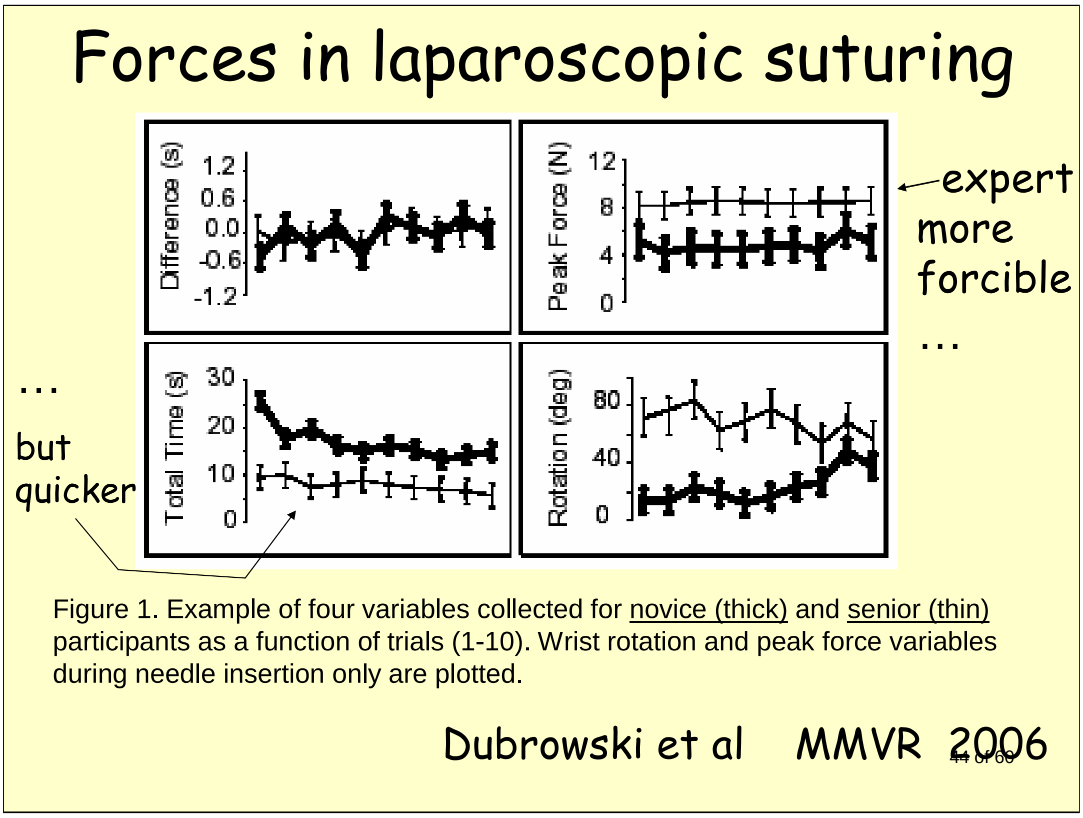
Inserting biopsy needles through skin into liver also takes measureable force, which varies according to the layer being traversed.

Careful control to avoid an “oops!” is important in avoiding severe damage and drastic consequences. (This is achieved by having the knuckles hit the skin before the needle can be pushed too deeply.)



Here’s an interesting study which shows both forces exerted and rate of needle movement through tissue during laparoscopic suturing. These studies compare experts with inexperienced operators. They show that the expert gives a more vigorous and quicker thrust to penetrate the tissue, while the beginner is far more tentative, doubtless worrying about the damage they might do.

The levels of force applied are in the range of 4 – 6 N.

Data for virtual epidural

Skin to epidural space 4 to 10 cm.

Force to penetrate:

skin	3.6 N
ligamentum flavum	6.0 N

Glassenberg R MMVR 2006

Teaching trainee anaesthetists to carry out epidural puncture, it becomes clear they have to learn to feel with the needle. They need to penetrate skin and tough fibrous tissue between the vertebrae, without puncturing the dura which lie just past soft fat deep to the fibrous tissue. They have to learn not to go further once the tough layer is passed.

Physical models which simulate the characteristics of the living tissue are made which incorporate the necessary mechanical properties, and checked against the levels of force in the real situation for the authenticity needed for the learner.

Discussion points

- Many workers estimate weights and forces – postal clerks, fruiterers, deli owners
- Surgical forces can be taught:
  - on the job (unfair to patients)
  - using simulation (expensive, scarce)
  - using a $20 kitchen scale

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We have now seen a couple of dozen different examples in which the level of force exerted by a surgeon and by other types of doctor is important – enough to be simulated in the teaching situation.

The time has probably arrived when a tool as simple as a $20 kitchen scale can be used to teach such levels of forcefulness and gentleness to doctors, just as they are learned in many other everyday occupations.

Possible applications

- Teaching medical students – eg
  - cricoid pressure (30-50 N)
  - epidural needle resistance [skin 4 N, lig. flavum 6 N]
  - force during pelvic exam [20-30 N]
- Serial assessment in trauma, acute abdo
- Remote consultations (cattle stations, Antarctica, astronauts)

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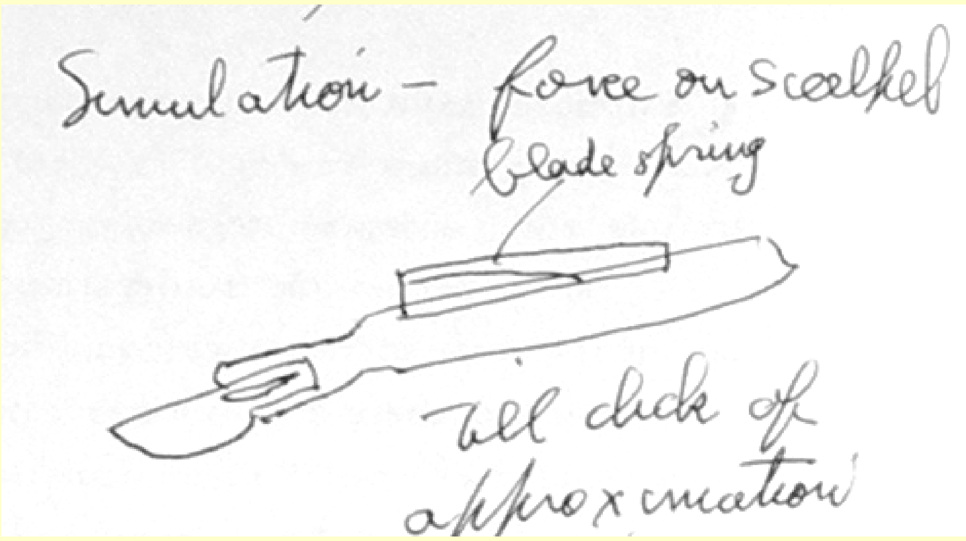
An example I haven't mentioned till now is cricoid pressure – pressing on the crycoid cartilage hard enough against the cervical spine so that reflux of acid stomach content does not occur during emergency intubation of the trachea in an urgent anaesthetic when the patient has not been fasted. The force needed is about 40 N, the weight of 4 litres of milk which the novice assistant may be reluctant to achieve. There are now training models to teach just this.



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Here’s a rough sketch of a spring leaf on the back of a scalpel handle, which might be used to teach a novice how firmly to press with the blade – enough to make the spring leaf just touch the back of the handle.

Current & future research

- Flinders University project
- Palpation
- Dissection heuristics
- Haptics generally - Darzi et al
- Robotic surgery – tissue properties

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There is actually current research going on in this area, including the many projects just described in the field of surgical simulation.

Such measurements are going to be important in the area of computer-assisted surgery, when desired levels of force will need to be programmed into the systems that will be used in 10 or 20 years time.

References

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A few of many possible references are listed here. The main one is MMVR 2006, a volume of conference proceedings.

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