Expandable Height Trial Challenge

Abbas Mirza

THE CLINICAL PROBLEM

01

Corpectomy

Damaged vertebral body removed — trauma or tumor. A gap exists between adjacent healthy endplates.

02

The Measurement Problem

Every patient's gap is different. Wrong implant = biomechanical failure and revision surgery.

03

The Solution

An expandable trial: insert collapsed, expand to fill the space, read the height, choose the correct implant.

REQUIREMENTS: ≤18 mm collapsed | Max expansion | 50 kg lift | Hand-operated | 150 mm long | Visible tip & height

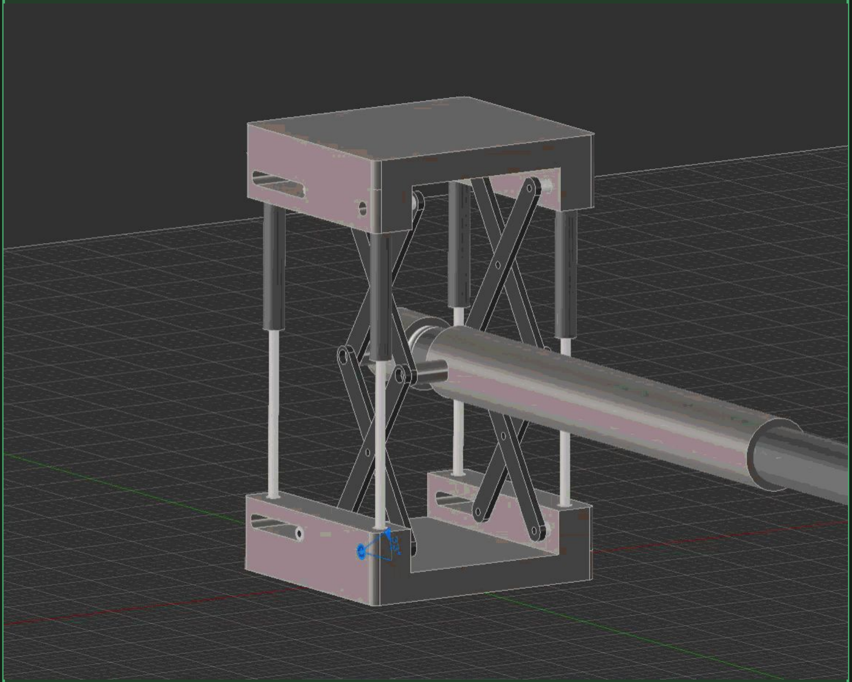
GLOBUS MEDICAL — ENGINEERING DESIGN CHALLENGE

Design 1:
Dual-Layer Scissor Jack Lead Screw Distractor

Expandable Height Trial for Thoracolumbar Corpectomy

17.393 mm → 30.643 mm | 490.5 N Distraction Force | 25.78 N Hand Force | 150 mm Total Length

HOW IT WORKS



Fusion 360 model — full range of motion

1

Handle Rotation

Surgeon turns handle. Torque applied to lead screw.

2

Lead Screw Advance

Screw advances. Horizontal compression applied to scissor mounts.

3

Scissor Expansion

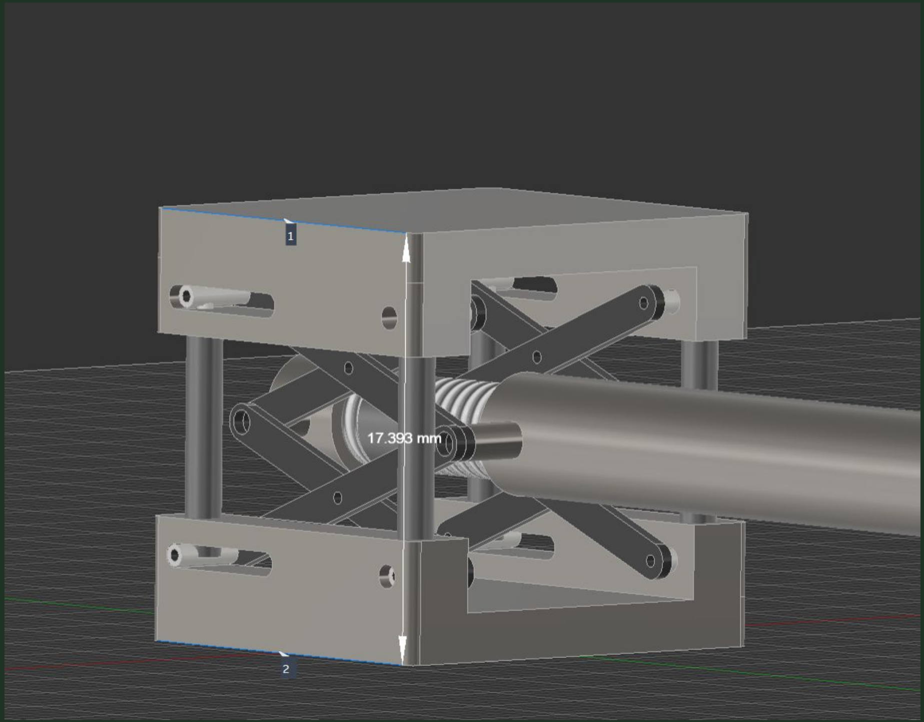
Horizontal compression forces the two scissor assemblies to expand vertically.

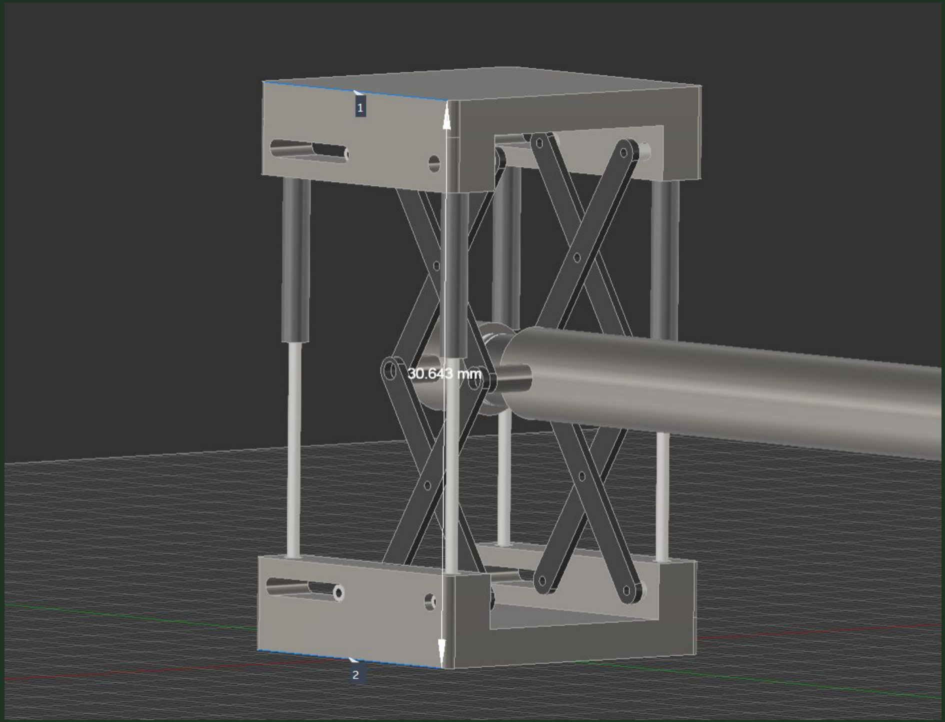
4

Jaw Plate Distraction

Top jaw plate rises against superior endplate. Vertebral space is distracted.

“The trial should start at no more than 18mm tall (at the tip) and expand as high as possible.”





ANATOMICAL BASIS FOR DIMENSIONS

Region	Mean VBH	Source
T1 (thoracic min)	~14.9 mm	Singh et al., Asian Spine J 2011
T9 (mid-thoracic)	~18.8 mm	J Anat Soc India, 2019
T12 (thoracic max)	~22.2 mm	Panjabi dataset via Singh et al.
L1–L4 (lumbar)	~23–26 mm	PMC11624215 meta-analysis, 2024
L5 (lumbar max)	~26–28 mm	Mavrych dataset, 1060 vertebrae

COLLAPSED

17.393 mm

0.607 mm below 18 mm limit
Upper thoracic range (T9)

EXPANDED

30.643 mm

13.25 mm total travel
Covers full thoracolumbar range

Starting height of 17.393 mm sits 0.607 mm below the 18 mm requirement. Expanded height of 30.643 mm covers full lumbar range through L5.

VIRTUAL WORK — THE GOVERNING PRINCIPLE

$$F_x \times d_x = F_s \times |d_s|$$

$F_x \times d_x$

Distraction Work

The required output: 490.5 N of vertical force acting through height change dx = 1.443 mm at the starting position.

$=$

Conservation of Energy

In a rigid, frictionless linkage: input work always equals output work. Energy cannot be created or destroyed.

$F_s \times |d_s|$

Lead Screw Work

The input: horizontal scissor compression force F_s acting through horizontal displacement |ds| = 0.312 mm.

Key Insight

$d_x/|d_s| = 1.443/0.312 = 4.625$ — For every 1 mm the scissors close horizontally, the jaw moves 4.625 mm vertically. By force-velocity duality, force at the jaw is LESS than force at the screw. The lead screw must generate 4.625× the distraction force.

FORCE CHAIN — From 50 kg to 25.78 N of Hand Force

490.5 N

Required Distraction Force

50 kg × 9.81 m/s²

4.625×

Virtual Work Ratio dx/|ds|

1.443 mm / 0.312 mm
geometric amplification

2,268.5 N

Required Scissor Input Force

490.5 × 4.625
worst case — starting position

25.78 N

Required Hand Force (1mm pitch)

T_raise / r_handle
= 1.289 N·m / 0.05 m

LEAD SCREW MECHANICS & SELF-LOCKING

Friction Angle

$$\varphi = \arctan(\mu) = \arctan(0.20) = 11.310°$$

μ = 0.20 (SS on SS, lightly lubricated)

Lead Angle

$$\lambda = \arctan(\ell \ / \ (\pi \times d\_m))$$

d_m = 4 mm, ℓ = pitch in meters

Self-Locking Condition

$$\tan(\lambda) < \mu = 0.20 \quad \rightarrow \quad \lambda < 11.31°$$

Thread must NOT back-drive under load

Torque (Square Thread)

$$T = F\_s \times (d\_m/2) \times \tan(\varphi + \lambda)$$

F_s = 2,268.5 N, d_m/2 = 0.002 m

Self-Locking at ℓ = 1 mm ✓

$\lambda = 4.550°$
$\tan(\lambda) = 0.0796$
$\mu = 0.20$

Margin: 2.51×

⚠️ 2mm pitch: 1.26× margin

At ℓ = 2mm: tan(λ) = 0.159, margin = 1.26×. Any surface wear from autoclave cycles could push this below threshold. Recommend 1mm pitch for production.

PITCH PARAMETRIC STUDY (d_m = 4 mm, F_s = 2,268.5 N, r_{handle} = 50 mm)

Pitch ℓ	Lead Angle λ	tan(λ)	Self-Locking?	Margin	T_{raise} (N·m)	F_{hand} (N)
0.5 mm	2.279°	0.03979	✔ YES	5.03×	1.097	21.93 N
1.0 mm ★	4.550°	0.07958	✔ YES	2.51×	1.289	**25.78 N**
2.0 mm	9.043°	0.15915	✔ YES (barely)	**1.26×**	1.683	33.66 N

★ *Recommended: 1.0 mm pitch. Robust 2.51× self-locking margin survives surface variation from repeated sterilization cycles.*

Why not 0.5 mm?

21.93 N hand force is comfortable, but 0.5 mm pitch gives very slow expansion, approximately double the turns for only 4 N less force. Not worth the trade-off.

⚠️ **Why not 2.0 mm?**

1.26× self-locking margin is borderline. After repeated autoclave cycles, thread surface roughness changes. Risk of creep-back increases significantly.

Calculations

F_x = ma = 50 kg * 9.81 = 490.5 N

W = Fd → $F_x dx = F_s|ds|$

$F_s = F_x\, dx/|ds|$ = 490.5 (1.443/0.312) = 2268.5 N

$T_{raise} = F_s$ * 0.004/2 * $\tan(\tan^{-1}(.2)+\tan^{-1}(0.002/3.14/0.004))$

T_{raise} = 1.68 N

$F_{hand} = T_{raise}/r_{handle}$ = 1.68/0.05

F_{hand} = 33.66 N

$$T_{\text{raise}} = \frac{Fd_{\text{m}}}{2}\left(\frac{l+\pi\mu d_{\text{m}}}{\pi d_{\text{m}}-\mu l}\right) = \frac{Fd_{\text{m}}}{2}\tan\left(\phi+\lambda\right)$$

Given

m = 50 kg

x_1=17.393 mm x_2=18.836 mm → dx = 1.443 mm

s_1=9 mm s_2=8.688 mm → ds = -0.312 mm

d_m= 4 mm

ϕ = angle of friction = $\tan^{-1}(\mu)$

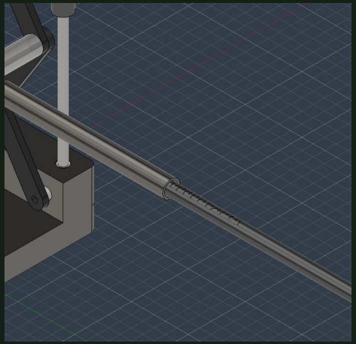
λ = lead angle = $\tan^{-1}(\ell/\pi d_m)$

μ = stainless steel 0.2

ℓ = 0.0005 or 0.001 or 0.002

Handle radius = 0.05 m

HEIGHT DISPLAY — COLLAR & ETCHED LEAD SCREW



Laser-etched millimeter scale on lead screw moves past the stationary collar

Micrometer Analogy

Exactly like a micrometer or depth gauge — the rotating shaft carries the scale, the stationary collar is the reference pointer. The reading directly equals the current jaw height. No secondary linkage, no separate indicator, no conversion needed.

Intrinsic

Scale is on the primary actuating component — no secondary indicator linkage that can misalign or fail.

Autoclave-safe

Laser-engraved 0.15 mm deep into stainless steel. Cannot fade, peel, or wash off in any sterilization process.

Non-linear calibration

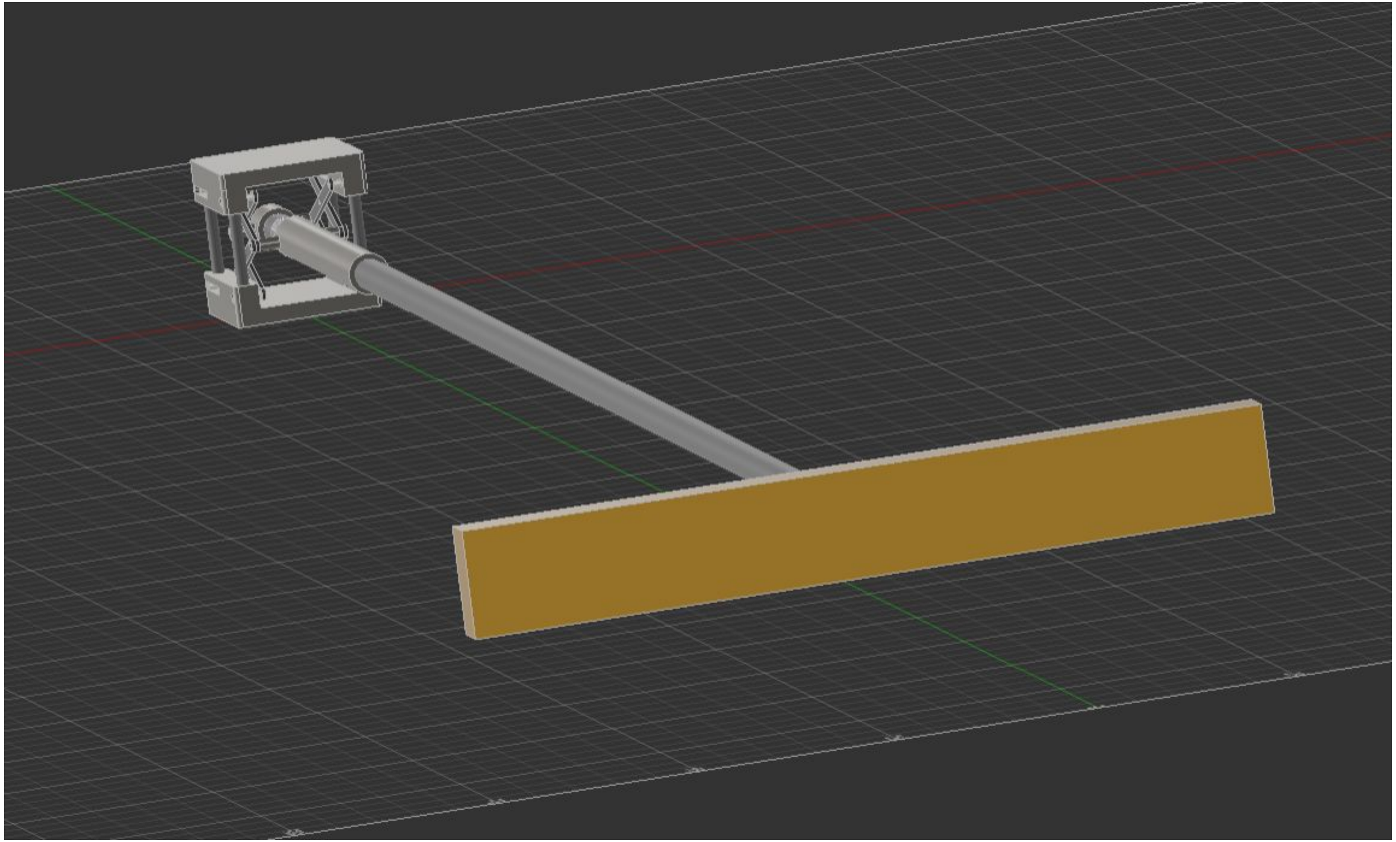
Scale markings are NOT uniformly spaced — each mm marker must be placed at the screw position corresponding to that actual jaw height (from the kinematic model).

COMPLETE DESIGN PARAMETERS

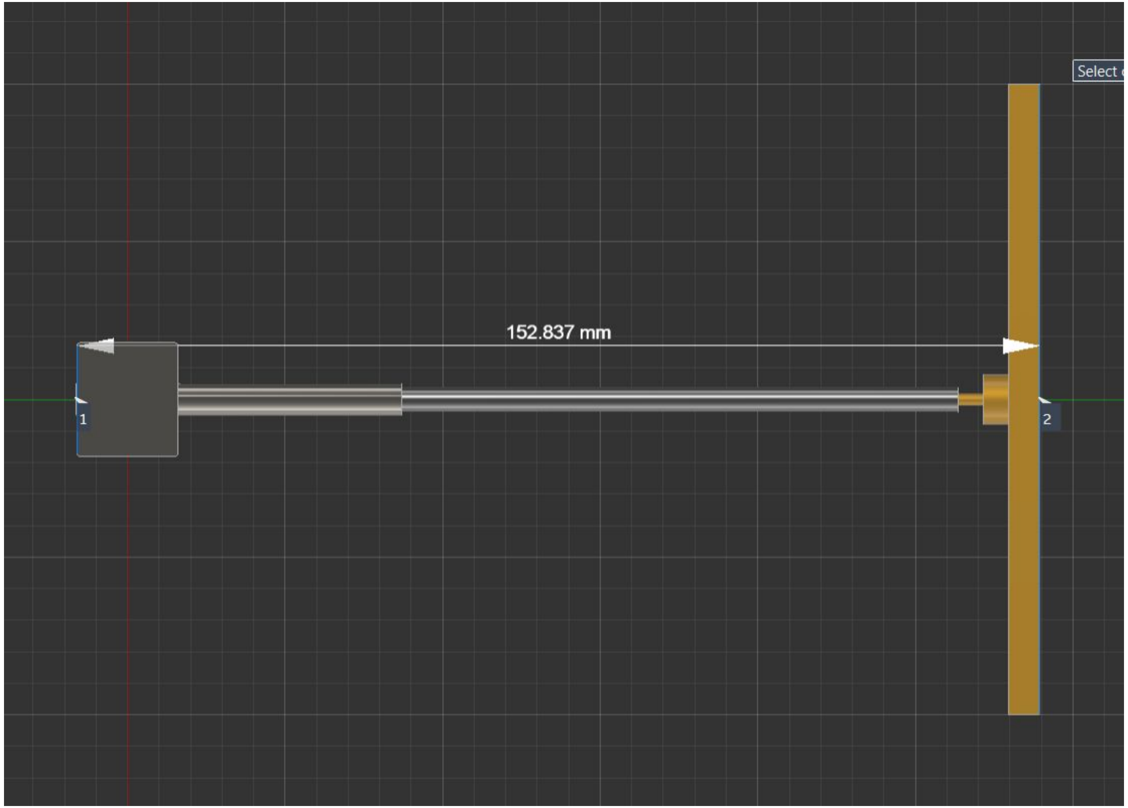
Starting height	**17.393 mm**	*Scissor geometry*
Maximum height	**30.643 mm**	*Scissor geometry*
Total travel	**13.250 mm**	*30.643 − 17.393*
18 mm margin	**0.607 mm**	*18.000 − 17.393*
Distraction force (F_x)	**490.5 N**	*50 kg × 9.81*
dx (height step)	**1.443 mm**	*Kinematic measurement*
|ds| (screw step)	**0.312 mm**	*Kinematic measurement*
Virtual work ratio	**4.625**	*1.443 / 0.312*

Scissor input force (F_s)	**2,268.5 N**	*490.5 × 4.625*
Mean screw diameter	**4 mm**	*Design choice*
Friction angle φ	**11.310°**	*arctan(0.20)*
Recommended pitch	**1.0 mm**	*Parametric optimum*
Lead angle λ	**4.550°**	*arctan(0.001/π×0.004)*
Self-locking margin	**2.51×**	*μ/tan(λ)*
T_raise	**1.289 N·m**	*F_s×(d_m/2)×tan(φ+λ)*
F_hand (recommended)	**25.78 N**	*T / r_handle*

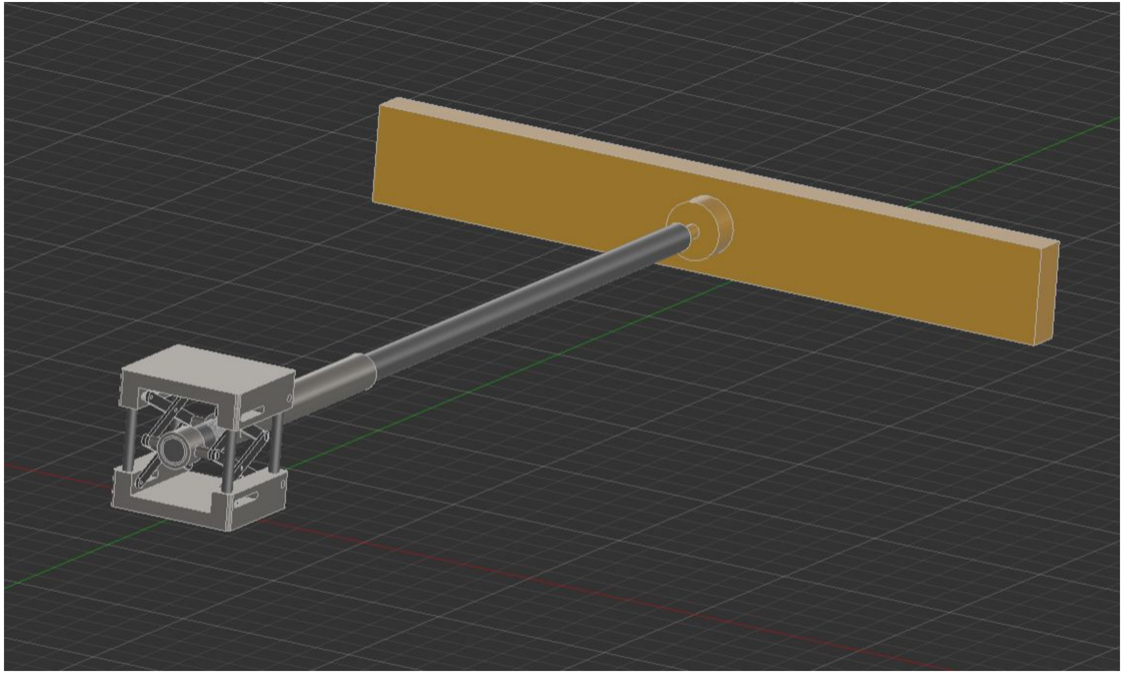
It should be operated by hand



It should be approximately 150mm long



It should be easy for the surgeon to see where the tip of the instrument is placed



STRENGTHS & WEAKNESSES

STRENGTHS

- Largest range: 17.393–30.643 mm covers full thoracolumbar spectrum
- Dual-layer gives symmetric load distribution and lateral stability
- Elegant height readout: collar on etched screw = direct micrometer-style reading
- Self-locking thread holds position passively — no ratchet needed
- All-metal construction: no seals, no bladder, simple steam sterilization
- Handle rotation provides tactile resistance feedback proportional to tissue force
- Improves with extension: mechanical advantage increases as scissor opens further

WEAKNESSES

- Geometric force disadvantage at start: screw must generate 2,268.5 N for 490.5 N output
- Tight 18 mm margin: 0.607 mm requires careful tolerance stack-up management
- Non-uniform scale: markings on screw are not evenly spaced — requires kinematic calibration
- Variable force ratio: $dx/|ds|$ changes across the stroke; worst case is at starting position
- Multiple pivot pins create crevices: validated cleaning protocol required for reusable designation

MANUFACTURING & REGULATORY

Material

17-4 PH SS, H900: Sy = 1,100 MPa
Passivation per ASTM A967 post-machining

Scissor Links

CNC milled bar stock, ±0.05 mm hole-to-hole
Hardened 2 mm dowel pins, H7/g6 clearance fit

Lead Screw

Square thread (not V-thread): no radial wedge force
Laser-etched scale at non-uniform kinematic positions

Regulatory

FDA 21 CFR Part 880, Class I
ISO 17664 cleaning/sterilization validation

Design Summary

A dual-layer scissor jack driven by a self-locking lead screw. 17.393–30.643 mm range, 490.5 N distraction force, 25.78 N hand force. Micrometer-style height readout directly from the etched screw. All-metal, no hydraulics, standard steam sterilization. Proven scissor jack geometry in a miniaturised surgical instrument.

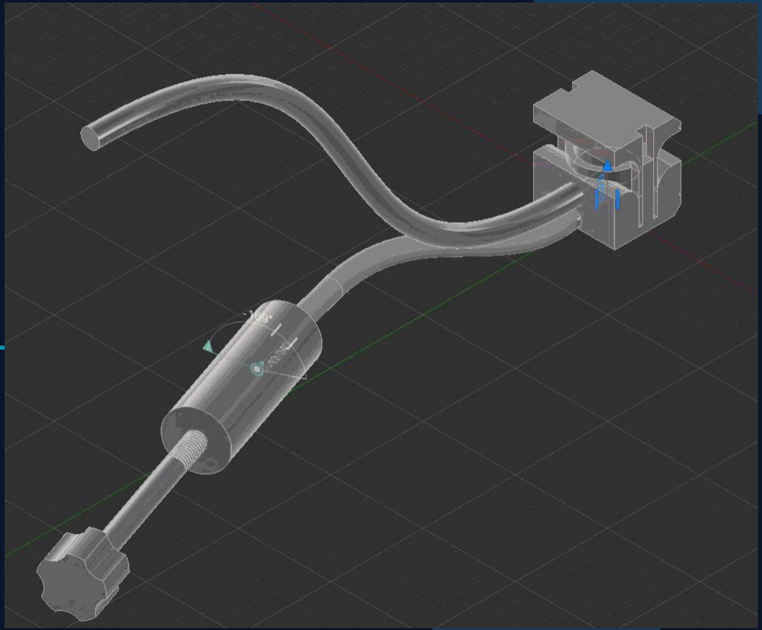
Criteria

- The trial should start at no more than 18mm tall (at the tip) and expand as high as possible.
- It should display the expanded height somewhere the surgeon can easily read it.
- It should be able to spread the vertebral bodies apart.
  - For this, it should be able to “lift” 50kg.
- It should be operated by hand
- It should be approximately 150mm long
- It should be easy for the surgeon to see where the tip of the instrument is placed

GLOBUS MEDICAL — ENGINEERING DESIGN CHALLENGE

Design 2:
Hydraulic Plunger Distractor

Expandable Height Trial for Thoracolumbar Corpectomy



HOW IT WORKS

Thumb Wheel

Surgeon turns

Lead Screw

Converts rotation to linear motion

Master Piston

Pushes saline (8 mm Ø)

Fluid Channel

Saline through 2 mm bore

Slave Piston

Distracts space (13 mm Ø)

Core Principle

The inferior jaw plate IS the hydraulic cylinder. The superior jaw plate IS the piston. Incompressible saline transmits force from the handle to the instrument tip — no linkages, no levers, no cams inside the head. Pascal's Law does all the work.

ANATOMICAL BASIS FOR DIMENSIONS

Region	Mean VBH	Source
T1 (thoracic min)	~14.9 mm	Singh et al., Asian Spine J 2011
T9 (mid-thoracic)	~18.8 mm	J Anat Soc India, 2019
T12 (thoracic max)	~22.2 mm	Panjabi dataset via Singh et al.
L1–L4 (lumbar)	~23–26 mm	PMC11624215 meta-analysis, 2024
L5 (lumbar max)	~26–28 mm	Mavrych dataset, 1060 vertebrae

COLLAPSED

16 mm

Covers smallest T1 space
4 mm below 18 mm limit

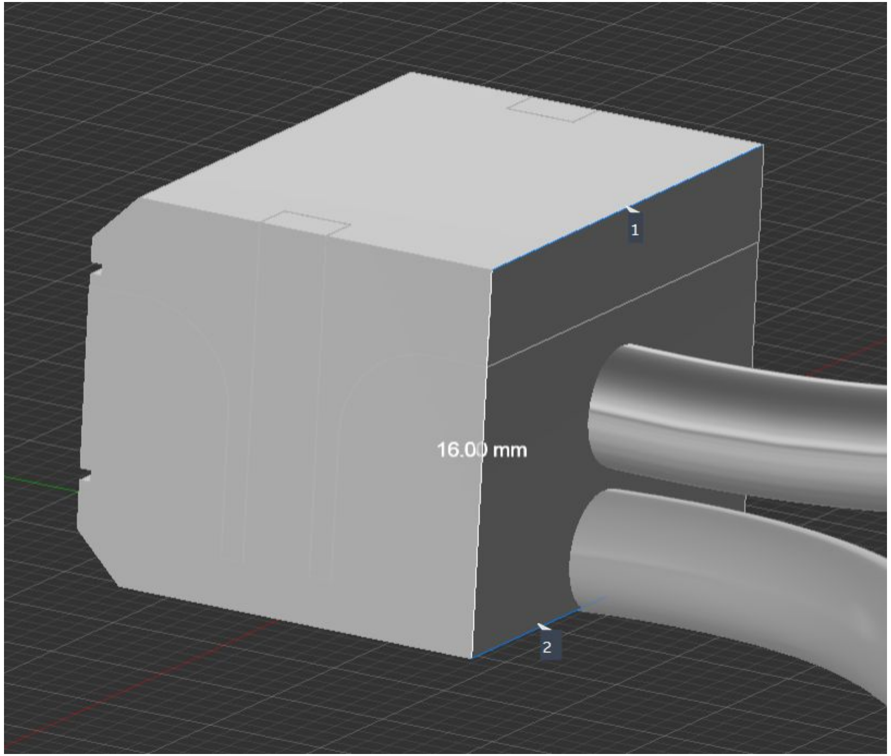
EXPANDED

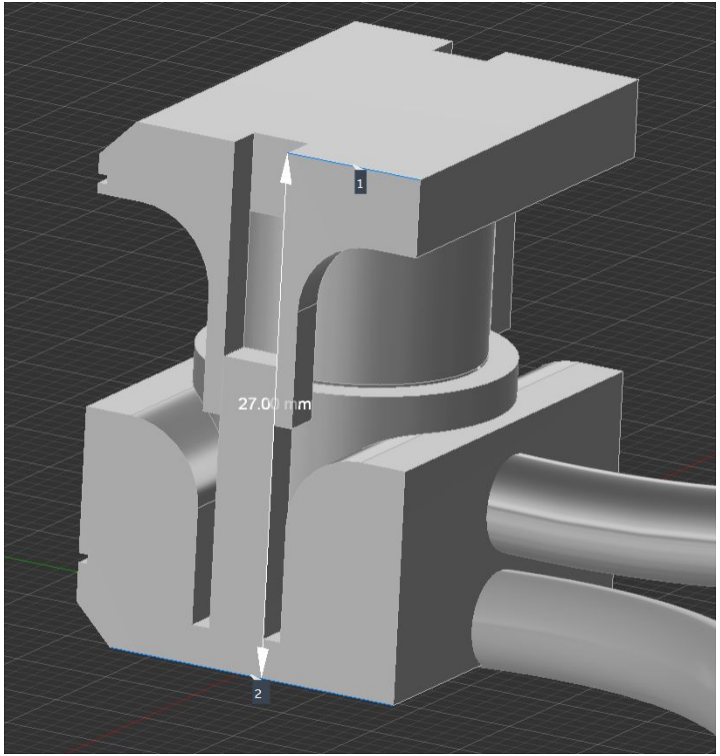
27 mm

14 mm + 11 mm slave travel
Covers thoracic + upper lumbar

Design target range: 14 mm → 25 mm (11 mm total travel) — Best suited to thoracic and upper lumbar corpectomy indications

“The trial should start at no more than 18mm tall (at the tip) and expand as high as possible.”





THE GOVERNING PHYSICS: PASCAL'S LAW

$$P = F_1 / A_1 = F_2 / A_2$$

Force Multiplication

If A_2 (slave) > A_1 (master):

→ Pressure is equal throughout
→ Slave piston generates MORE force
→ $F_2 = P \times A_2 > F_1 = P \times A_1$

Small hand force → large distraction force

The Trade-off (Conservation of Energy)

Volume is always conserved:

$A_1 \times d_1 = A_2 \times d_2 = V\_fluid$

→ More force = less stroke distance
→ You cannot gain both

The lead screw solves the stroke problem

SLAVE PISTON ANALYSIS — 13 mm Ø, 11 mm Travel

490.5 N

Distraction Force Required

$50\ kg \times 9.81\ m/s^2$

3.695 MPa

Operating Pressure

$490.5\ N \div 132.73\ mm^2$
≈ 536 psi

1.460 mL

Fluid Volume Required

$132.73\ mm^2 \times 11\ mm$
$= 1{,}460\ mm^3$

SF = 91.6

Wall Safety Factor

σ_hoop = 12.0 MPa
S_y = 1,100 MPa (17-4 PH)

THE VOLUME PROBLEM — AND THE SOLUTION

PROBLEM: Single-Stroke Syringe

If all 1.460 mL pushed in one stroke:

8 mm master piston ⟶ 29 mm stroke

6 mm master piston ⟶ 52 mm stroke

A 29 mm stroke barely fits the handle.
A 52 mm stroke is physically impossible.
Smaller pistons (lower hand force) make the geometry completely unworkable.

Force and stroke fight each other.
You cannot win both with a single stroke.

⟶

SOLUTION: Lead Screw + Thumb Wheel

Break the total stroke into 29 small steps.

Each wheel revolution = 1.0 mm plunger

Each revolution = 0.379 mm slave travel

Benefits:

⟶ Thumb wheel turns freely — no stroke limit

⟶ Lead screw adds mechanical advantage

⟶ Thread is self-locking — holds height passively

⟶ 29 turns total ≈ 3–5 seconds operation

Result: 6.68 N thumb force for 490 N output

LEAD SCREW PHYSICS & SELF-LOCKING CONDITION

Helix Angle

$$\lambda = \arctan(\, p \,/\, (\pi \times d_{screw})\,)$$

p = pitch, d = screw diameter

Self-Locking Condition

$$\tan(\lambda) \;<\; \mu = 0.15$$

μ = friction coefficient, lubricated SS/SS
Self-locking limit: λ < 8.53°

Required Thumb Torque

$$T = F_p \times r \times (\tan\lambda + \mu) \,/\, (1 - \mu \cdot \tan\lambda)$$

F_p = hydraulic back-force on plunger

Self-Locking Check ✓

p = 1.0 mm, d = 5 mm

λ = 3.643°
tan(λ) = 0.0637
μ = 0.15

Margin: 2.4× above threshold

Why It Matters

Hydraulic back-pressure cannot spin the thumb wheel backwards. The achieved height holds passively — no separate lock mechanism needed.

MASTER PISTON TRADE-OFF (Pitch = 1.0 mm fixed)

d_m	Stroke (mm)	F_plunger (N)	Turns	Thumb Force (N)	Fits?
6 mm	51.64	104.5	51.6	3.76	✗ No
7 mm	37.94	142.2	37.9	5.11	✗ No
8 mm ★	**29.05**	**185.8**	**29.0**	**6.68**	✓ Yes
9 mm	22.95	235.1	23.0	8.45	✓ Yes
10 mm	18.59	290.2	18.6	10.44	✓ Yes
11 mm	15.36	351.2	15.4	12.63	✓ Yes
12 mm	12.91	417.9	12.9	15.03	✓ Yes

★ Recommended — smallest diameter that fits the handle constraint (stroke ≤ 35 mm). At 12 mm, thumb force reaches 15 N — fatiguing for sustained use.

PITCH SELECTION (Master Piston = 8 mm fixed)

Pitch (mm/rev)	Helix Angle λ	Self-Locking?	Margin	Turns	F_thumb (N)
0.5 mm/rev	1.823°	✓ Yes	4.7×	58.1	5.66
1.0 mm/rev ★	3.643°	✓ Yes	2.4×	29.0	**6.68**
1.5 mm/rev	5.455°	✓ Yes	1.6×	19.4	7.71
2.0 mm/rev	7.256°	✓ Yes	1.2×	14.5	8.75
2.5 mm/rev	9.043°	✗ NO	—	11.6	N/A

Why not 0.5 mm?

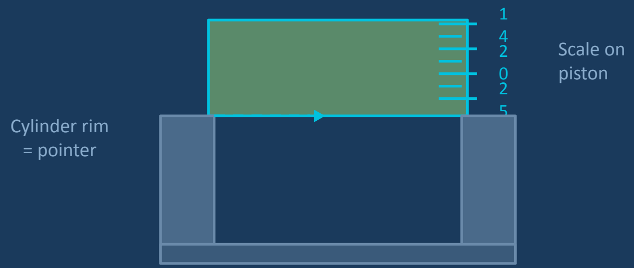
58 turns for full travel. Extra precision not needed — scale already reads to 1 mm.

Why not 2.5 mm?

$\tan(\lambda) = 0.159 > \mu = 0.15$. Back-drives under load. Height collapses when surgeon releases wheel.

HEIGHT DISPLAY — DUAL READOUT SYSTEM

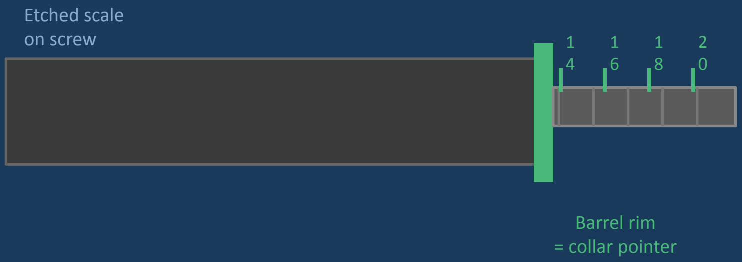
PRIMARY — Slave Piston Exposure



How it reads:
The piston extends out of the cylinder as the instrument expands. The exposed length above the cylinder rim **directly equals the expansion above the 14 mm baseline** — no conversion, no arithmetic. The cylinder rim is the zero reference; the scale on the piston reads the current height.

Like a ruler — the rim is the zero mark. The exposed piston length is the reading.

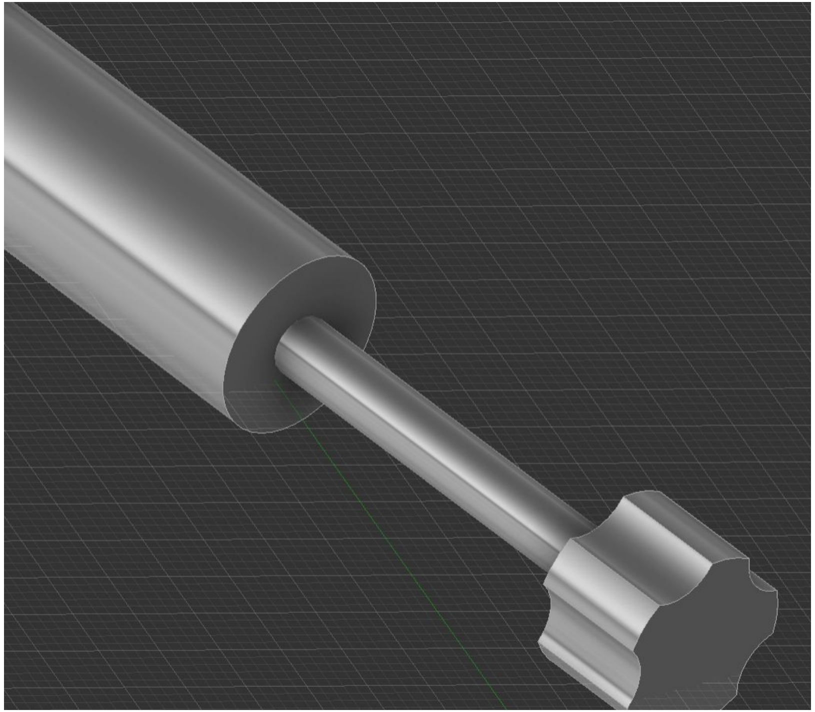
SECONDARY — Etched Lead Screw + Barrel Collar



How it reads:
Millimeter marks are laser-etched onto the lead screw shaft where it protrudes beyond the syringe barrel. As the thumb wheel is turned and the plunger advances, more of the screw emerges. The barrel's distal rim acts as the **stationary collar** — a fixed pointer against the moving scale. Functionally identical to a micrometer thimble.

Like a micrometer — the barrel rim is the reference, the emerging screw carries the scale.

It should display the expanded height somewhere the surgeon can easily read it.



RECOMMENDED DESIGN PARAMETERS

Slave Piston Ø	13 mm	*Given*
Slave Travel	11 mm	*Given*
Collapsed Height	14 mm	*From T1 morphometry*
Expanded Height	25 mm	*14 + 11 mm*
Operating Pressure	3.695 MPa	*490.5 N ÷ 132.73 mm²*
Fluid Volume	1.460 mL	*Fixed by slave geometry*

Master Piston Ø	8 mm	*Parametric optimum*
Plunger Stroke	29.05 mm	*1,460 ÷ 50.27 mm²*
Lead Screw Pitch	1.0 mm/rev	*Self-locking, 2.4× margin*
Helix Angle	3.643°	*arctan(1.0 / π×5)*
Total Turns	29 turns	*≈ 3–5 seconds operation*
Thumb Force Required	6.68 N	*Effectively effortless*

STRENGTHS & WEAKNESSES

STRENGTHS

- Intrinsic height readout — piston exposure directly = expansion
- Uniform endplate force distribution — critical in osteoporotic bone
- Minimal head complexity — just a cylinder, a piston, one O-ring
- Self-locking thread holds height with zero additional mechanism
- 6.68 N thumb force — effectively effortless for any surgeon
- Saline is biocompatible — small leaks are clinically inconsequential
- Clinical precedent: analogous to balloon kyphoplasty (Kyphon, 400–600 psi)

WEAKNESSES

- O-ring is single point of failure — requires tight Ra ≤ 0.4 μm bore tolerance
- High pressure (3.695 MPa / 536 psi) — demands careful sealing validation
- System must be primed with saline and bled of air before each use
- 29 thumb turns for full travel — slower than a mechanical ratchet design
- Internal fluid channel (2 mm bore) needs validated cleaning protocol if reusable
- Failsafe mechanical stop required to prevent jaw snap-shut on O-ring failure

MANUFACTURING & CONCLUSION

Material

17-4 PH SS, H900 condition
Sy = 1,100 MPa. O-ring: medical-grade EPDM (ISO 10993)

Key Tolerances

Bore & piston: Ra ≤ 0.4 µm (honed)
H7/f7 clearance fit. O-ring groove: internal form tool

Fluid Channel

2 mm bore: gun-drilled through shaft
Validated saline flush for reusable designation (ISO 17664)

Regulatory

FDA 21 CFR Part 880, Class I. Cleaning per ISO 17664.
Single-use or reusable — validation path differs

Design Summary

A self-contained hydraulic distractor with 14→25 mm range, 490 N distraction force, and 6.68 N of required thumb force. No moving parts in the head. Intrinsic height readout from piston exposure. Self-locking lead screw holds position passively. Clinical precedent from balloon kyphoplasty validates the core hydraulic approach.

DESIGN 1 vs DESIGN 2 — CHOOSING BETWEEN THEM

	DESIGN 1 — Scissor Jack	DESIGN 2 — Hydraulic Plunger
Range	17.4–30.6 mm (13.25 mm travel)	14–25 mm (11 mm travel)
Hand Force	25.78 N (at 1mm pitch)	6.68 N
Head Complexity	Scissor links + pivot pins	Cylinder + piston + O-ring only
Height Readout	Etched screw + collar (micrometer)	Piston exposure (direct ruler)
Fluid Required	No — all mechanical	Yes — sterile saline, priming needed
Sterilization	Standard steam autoclave	Validated flushing protocol required
Best For	Broad thoracolumbar range	Osteoporotic bone (uniform force)

Design 1 offers broader range. Design 2 offers simpler head and superior force distribution. Neither is strictly better — the choice depends on clinical context.