Fully Threaded Versus Partially Threaded Intramedullary Headless Compression Screw Fixation for Proximal Third Fractures of the Proximal Phalanx: A Biomechanical Study

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Abstract:

Purpose

The purpose of this study was to compare the maximal elastic force and deformation resistance of two commonly used headless compression screw systems – a fully threaded 2.5mm screw and a partially threaded screw of the same dimensions – in a cadaveric model of a human transverse proximal third fracture of the proximal phalanx.

Methods

Six fresh frozen cadavers were used, and the proximal phalanges of the index, long, and ring fingers of both hands were dissected. A proximal third transverse osteotomy was created, and screws were inserted in an antegrade direction. The three-point bending load-to-failure test measured the maximal elastic force and deformation resistance of each bone-screw construct.

Results

The fully threaded screw demonstrated a maximal elastic force of 121N and a deformation resistance of 134N/mm. The partially threaded screw showed superior performance with a maximal elastic force of 165N and deformation resistance of 166N/mm. The bone-screw construct with the fully threaded screw had a mean maximal elastic force of 155.2N compared to 101.8N in the construct with the partially threaded screw. Deformation resistance was 145.2N/mm for fully threaded screws and 98.6N/mm for partially threaded screws.

Conclusions

Fully threaded intramedullary headless compression screw fixation provides superior maximal elastic force and deformation resistance compared to partially threaded intramedullary headless compression screw fixation in transverse proximal third fractures of the proximal phalanx.

Clinical Relevance

The findings indicate that fully threaded intramedullary headless compression screw fixation may offer enhanced stability for treating proximal third fractures of the proximal

	phalanx, potentially leading to better patient outcomes through earlier mobilization and reduced complications compared to partially threaded screws.
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TITLE

Fully threaded versus partially threaded intramedullary headless compression screw fixation for proximal third fractures of the proximal phalanx: a biomechanical study.

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RUNNING HEAD

Intramedullary Screws for Proximal Phalanx Fractures.

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The idea and content of the manuscript were conceived by BVm, JD, JG and BOE. All technical acts – dissection of the anatomical specimens, application of the osteotomy and osteosynthesis – were performed by BVm, BVdk and LP. BVm and BVdk performed mechanical testing and data interpretation. BVm and BVdk wrote the first draft of the manuscript. All authors reviewed, edited, and approved the final version of the manuscript. BVm and BVdk equally contributed to the realization of this project and are shared first authors. BOE, JD and JG are shared last authors.

DATA STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request and with permission from the relevant institutional review boards.

DECLARATION OF GENERATIVE AI IN SCIENTIFIC WRITING

During the preparation of this work the authors used Chat GPT 3.5 in order to improve readability and language. After using this tool, the authors reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

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ABSTRACT

Purpose

The purpose of this study was to compare the maximal elastic force and deformation resistance of two commonly used headless compression screw systems, a fully threaded 2.5mm screw and a partially threaded screw of the same dimensions, in a cadaveric model of a human transverse proximal third fracture of the proximal phalanx.

Methods

Six fresh frozen cadavers were used, and the proximal phalanges of the index, long, and ring fingers of both hands were dissected. A proximal-third transverse osteotomy was created, and screws were inserted in an antegrade direction. The three-point bending load-to-failure test measured the maximal elastic force and deformation resistance of each bone-screw construct.

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The fully threaded screw demonstrated a maximal elastic force of 121N and a deformation resistance of 134N/mm. The partially threaded screw showed superior performance with a maximal elastic force of 165N and deformation resistance of 166N/mm. The bone-screw construct with the fully threaded screw had a mean maximal elastic force of 155.2N compared to 101.8N in the construct with the partially threaded screw. Deformation resistance was 145.2N/mm for fully threaded screws and 98.6N/mm for partially threaded screws.

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Clinical Relevance

The findings indicate that fully threaded intramedullary headless compression screw fixation may offer enhanced stability for treating proximal-third fractures of the proximal phalanx, potentially leading to better patient outcomes through earlier mobilization and reduced complications compared to partially threaded screws.

INTRODUCTION

Fractures of the phalanges are common injuries affecting the hand, with proximal phalanx fractures comprising 38% of all phalangeal fractures[1]. The management of these fractures depends primarily upon their stability. Non-surgical methods, involving custom made orthoses and early mobilization, have proven effective for stable, extra-articular fractures. Conversely, unstable fractures often warrant surgical intervention. Percutaneous K-wire fixation has garnered popularity for its minimally invasive nature and quick operative procedures. Nonetheless, this method comes with inherent limitations such as inadequate compression, reduced rigidity and rotational control, leading to additional immobilization and delayed rehabilitation. Eberlin et al.[2] showed moderate functional outcomes, with a notable subset of patients experiencing complications, such as the necessity for tenolysis, pin tract infections, pin loosening and non-union. Alternatively, plate and screw osteosynthesis entails extensive surgical exposure and poses risks of scarring, tendon adhesions, delayed union, and high reintervention rates[3,4,5]. Since the advent of intramedullary headless compression screws (IMHCS) for delayed unions of phalangeal fractures, this technique has emerged as a promising advancement, combining the benefits of previous methods[6]. By sparing soft tissues superficial to the fracture site and avoiding periosteal elevation and hematoma evacuation, IMHCS fixation minimizes impediments to bone healing[7]. Moreover, IMHCS fixation yields a stable construct, facilitating early range of motion restoration. Comparative studies have shown similar rigidity between IMHCS fixation and plate-and-screw osteosynthesis[8,9].

Nevertheless, literature showing convincing evidence in favor of IMHCS fixation in proximal phalanx fractures with an articular component, substantial comminution, bone loss or osteoporosis, is lacking.

The purpose of this study was to compare the maximal elastic force and deformation resistance of two commonly used compression screw systems, a fully threaded and a partially threaded 2.5mm IMHCS, across a transverse proximal-third fracture of the proximal phalanx in a human cadaveric model. We hypothesize that the fully threaded IMHCS provides superior maximal elastic force and deformation resistance compared to the partially threaded IMHCS.

MATERIALS AND METHODS

Specimens

Six fresh frozen cadavers were thawed at room temperature. The number of cadavers thawed was chosen to ensure that a suitable number of paired phalanges—at least thirteen—was obtained, as determined by a sample size calculation based on a pilot study. The proximal phalanges of index, long and ring fingers of both hands were dissected. All soft tissues were removed, except for a thin strip of volar periosteum, which was preserved to prevent malrotation during screw placement. The thumb and small fingers were not included because of their size differences. This would not allow standardization in screw size and diameter. The phalanges were paired and for each phalanx that was fixed with a partially threaded 2.5mm IMHCS, cannulated compression headless screw (Depuy Synthes, Warsaw, Indiana), the corresponding contralateral phalanx of the same cadaver was fixed with a fully threaded IMHCS, Acutrak 2 Micro (Acumed, Hillsboro, Oregon). This pairing allowed optimal comparison of both fixation methods. Both screws are composed of titanium alloy with identical composition (Ti-4Al-6V). The first screw, which is partially threaded, features a headless design. It has a threadless central shaft with threads of varying pitch at both ends, designed to facilitate fracture compression. The screw's tail diameter is 2.5mm. While the manufacturer does not provide information regarding the head diameter, independent measurements indicate a diameter of 2.8mm.

The second screw is fully threaded, has a head diameter of 2.8mm and a tail diameter of 2.5mm. This screw also employs a variable pitch design, with wider threads at the distal end, enabling the screw to engage with the bone fragments at different rates, gradually compressing the fracture as it advances. For all specimens a screw length of 30mm was chosen.

Osteotomy and Osteosynthesis

In each phalanx, a precise transverse osteotomy was fashioned using an oscillating sagittal saw, positioned exactly 15 mm distal to the most distal point of the concave base of P1 (Figure 1). The mean length of the dissected proximal phalanges was 44.4mm (SD 0.99) in the partially threaded group and 44.3mm (SD 0.89) in the fully threaded group. The osteotomy was located at a mean of 34.0% (SD 0.76) of the length in the partially threaded group and at 34.0% (SD 0.68) in the fully threaded group, modeling a proximal-third fracture of the proximal phalanx. Subsequently, a K-wire was inserted along the bone axis, spanning the osteotomy site. The proximal articular surface was predrilled using the appropriate cannulated drill, followed by screw osteosynthesis performed in an antegrade direction. While both antegrade and retrograde approaches are well-supported in the literature for managing unstable extra-articular diaphyseal fractures of the proximal phalanx, the antegrade approach was selected due to its superior fracture control for fractures located near the base of the phalanx[10,11].

Careful consideration was given to the strategic placement of the screws, ensuring that their larger heads were firmly anchored in the subchondral bone of the proximal articular surface. Through this meticulous approach, the transverse osteotomy was consistently located at the midpoint of the screw length.

Initially, 18 pairs of phalanges were included in the study; however, only 13 pairs were found eligible for inclusion into this biomechanical study. The requirement for internal fixation was the ability to withstand at least 25N at three-point bending load-to-failure testing. This threshold was set based upon a biomechanical study by Fowler et al., demonstrating that the proximal phalanx experiences forces approaching 25N during common activities, such as jar opening[13].The exclusion of five pairs was attributed to issues stemming from our study design, which sought to standardize screw diameter and length to eliminate bias associated with using screws from different brands, each with varying properties and potentially even larger differences in intrinsic maximal elastic force. As a result, phalanges where the selected screw types were unsuitable—unable to sustain a minimal elastic force of 25N—were excluded from the study. Three pairs of phalanges were excluded because of improper screw sizing. The screw diameter was too small to achieve adequate purchase in the medullary canal in two pairs and too large in another pair. In the latter pair, we encountered extreme difficulty in introducing the screw into the phalanges. Stable fixation could not be achieved in one pair, due to severe osteoporosis. Additionally, another pair was excluded due to a bony malunion in one of the phalanges.

Biomechanical testing

Both screws used in this experiment were submitted to a three-point bending load-to-failure test (Zwick Z2.5, load cell 500N, resolution 0.005N), enabling comparison of their intrinsic maximal elastic force. Following intramedullary fixation of the osteotomy, phalanges from both osteotomy groups underwent a dorsal-to-palmar three-point bending load-to-failure test (Figure 2). This testing method closely mimics the classical extension-type trauma mechanism observed in proximal phalanx fractures, which arises from the interplay of various soft tissue structures. Specifically, the insertion of interosseous muscles at the base of the proximal phalanx leads to flexion of the proximal fracture fragment, resulting in an apex-volar deformity. Additionally, the longitudinal compression force exerted by flexor and extensor tendons serves to shorten the phalanx while extending the distal fragment. Outcome measures of the test included maximal elastic force (N) and deformation resistance (N/mm), with the latter determined from the linear region of the loading curves. Each test of the bone-screw construct was concluded either when the screw loosened from the bone or when the screw began to bend. The obtained results demonstrated a normal distribution, thus enabling the utilization of a parametric test (paired samples Student's t-test) for comparing the outcomes between the two groups. Statistical significance was set at a P value of < 0.05.

RESULTS

In the comparison between screw types, the three-point bending load-to-failure revealed a maximal elastic force of 121N for the fully threaded screw and 165N for the partially threaded screw, both with similar dimensions. Correspondingly, the deformation resistance measured 134N/mm and 166N/mm, respectively. The results of the dorsal-to-palmar three-point bending load-to-failure test of the bone-screw combinations are illustrated in Table 1. In this table, the key differences between the two screw groups are highlighted and they are visualized in Figure 3. Figure 4 portrays the strain or deformation resulting from force application on the bone-screw combination in specimen 3 digit III, while Figure 5 illustrates the method used to identify the bending point of both curves, signifying the elastic limit where osteosynthesis begins to fail. The slope at the onset of each curve corresponds to the reversible deformation resistance of the bone-screw combination. We established a permanent deformation threshold of 60µm (0.2% of the support span of 30mm) to denote the maximal elastic force of the osteosynthesis. Beyond this point, the force curve flattens, indicating permanent damage to the osteosynthesis device and eventual failure.

Furthermore, in the bone-screw construct with the fully threaded screw, the mean maximal elastic force reached 155.2N (95% CI: 121.1 to 189.3), compared to 101.8N (95% CI: 56.1 to 147.5) in the bone-screw construct with the partially threaded screw. This difference was statistically significant ($P < 0.05$), highlighting the superior maximal elastic force associated with fully threaded screw fixation. This was observed despite the finding that the fully threaded screw was intrinsically weaker compared to the partially threaded screw. Additionally, regarding deformation resistance, the fully threaded screw group exhibited a mean value of 145.2N/mm (95% CI: 91.8 to 198.8), while the partially threaded screw group showed 98.6N/mm (95% CI: 66.7 to 130.4). This disparity was also statistically significant ($P < 0.05$).

DISCUSSION

Fractures of the proximal phalanx pose treatment challenges due to potential malunions affecting functional outcomes. Surgical management aims to achieve stable fixation to facilitate early mobilization and prevent joint stiffness. Although plate and screw osteosynthesis, as well as K-wire fixation are still commonly used in proximal phalanx fracture management, IMHCS fixation has gained interest in the treatment of specific fracture patterns because this technique offers favorable outcomes with minimal complications[13].

The value of IMHCSs in managing proximal phalanx fractures has been validated in two cadaveric studies. A cadaveric study by Miles et al. demonstrated that the IMHCS provided biomechanical stability comparable to that of plate-and-screw fixation for short oblique P1 fractures[8]. Raush et al. tested torsional strength in transverse distal epiphyseal fractures of the proximal phalanx[9]. The fractures were stabilized using crossed K-wires, plate and screw osteosynthesis, and retrograde IMHCS fixation with a partially threaded screw. The results showed no significant difference in load to failure between IMHCS fixation and plate and screw fixation. In comparison, Kirschner wires appeared to be inferior in terms of displacement properties and primary stability.

In our study, we selected two IMHCS types with similar biometric dimensions, inserted in an antegrade direction. Our three-point bending test revealed an inferior maximal elastic force and deformation resistance in the fully threaded screw compared to the partially threaded screw. Nonetheless, the bone-screw combination exhibited superior stability in the fully threaded screw group, highlighting the intricate interplay between screw design and biomechanical performance.

The superior performance of the fully threaded screw in IMHCS fixation of the proximal phalanx, particularly in terms of maximal elastic force and deformation resistance compared to the partially threaded screw, can be attributed to the unique anatomy of the medullary space within the proximal phalanx. Phalanges, characterized by their flattened shape, exhibit a slightly ovoid medullary canal[14]. When selecting the appropriate diameter of the IMHCS, it is critical to measure the anteroposterior diameter rather than the latero-lateral diameter to avoid an overestimation of the required screw size, which can compromise outcome due to screw bending and fracture[15,16]. Optimal screw placement of the IMHCS in the proximal phalanx focuses on engaging the volar and dorsal cortices, rather than the lateral cortical walls. At the proximal metaphysis of the proximal phalanx, the medullary canal is broader in both anteroposterior and latero-lateral dimensions. Considering these anatomical nuances, optimizing the contact of the compression screw thread with the inner cortical surface of the proximal phalanx enhances construct rigidity. This optimization is achievable by utilizing a fully threaded screw, which provides superior performance compared to a partially threaded screw. This issue is less significant in metacarpal fractures because the metacarpals are longer bones that lack the flattened shape and ovoid medullary canal seen in phalanges. In metacarpals, selecting the appropriate screw diameter is more straightforward and should aim for a canal fill ratio between 0.75 and 0.9, as described by Chambers et al[17].

Our study has limitations that warrant consideration. First, while our focus was on evaluating the maximal elastic force and deformation of bone-screw constructs, it is important to acknowledge that this approach doesn't include the cyclic testing needed to simulate the multitude of low-load movements typical during rehabilitation. To simulate physiological loading, the combination of torsional loading and cyclic craniocaudal loading could have been an alternative testing method. Nonetheless, no testing procedure comprehensively mimics the extremely complicated arm loading conditions in the human body during daily activities[18]. Despite this, we maintain that assessing maximal elastic force and deformation resistance remains the minimum requirement for comparing fixation methods effectively.

Second, our mechanical testing lacked the inclusion of secondary fracture stabilizers, such as periosteum, flexor, and extensor tendons, as well as skin and subcutaneous tissue, all of which were intentionally removed. Additionally, given the nature of our study, we were unable to account for factors such as fracture hematoma and the inflammatory response, which are present in clinical conditions. The fracture hematoma acts as a biomechanical cushion, mitigating excessive movement at the fracture site and providing initial stability necessary for subsequent callus formation. It establishes a provisional matrix that supports the influx of inflammatory cells and the formation of granulation tissue, setting the stage for healing[7]. The inflammatory phase is essential for bone fracture healing, as it regulates the recruitment, proliferation, differentiation, and activation of hematopoietic and mesenchymal cells. Deficiencies in cell signaling, inhibition of acute inflammation, or chronic inflammation due to persistent adverse stimuli can impair fracture healing[19].

Third, in this biomechanical study, only metacarpal bones of the index, middle and ring fingers were used. No conclusions can be drawn regarding metacarpal bones of the thumb or little finger.

Fourth, variability in bone quality, size, and density among the cadaveric specimens used in this study could also influence the results, introducing another potential limitation.

In conclusion, our study demonstrates that fully threaded IMHCS fixation, applied in an antegrade direction, provides superior resistance to failure compared to the partially threaded IMHCS fixation in a cadaveric fracture model involving transverse proximal third fractures of the proximal phalanx of the second, third, and fourth fingers. While the fully threaded IMHCS technique demonstrates enhanced resistance to failure compared to the partially threaded technique, the latter still provides adequate fracture stabilization and remains valuable across various fracture types.

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FIGURE LEGENDS

Figure 1

Osteotomy and osteosynthesis of the cadaveric phalanges. A Proximal phalanx with a fully threaded screw. B Proximal phalanx with a partially threaded screw. C Transverse osteotomy at 15mm distal from the proximal articular surface of the proximal phalanx. D screw insertion in an antegrade direction.

Figure 2

Biomechanical testing: dorsal-to-palmar three point bending load-to-failure test. A Starting point of the test. B Failure of the osteosynthesis by downward bending.

Figure 3

The comparison of the maximal elastic force of the bone-screw construct with the fully threaded screw and the partially threaded screw is displayed in plots A and B. The comparison of the deformation resistance of both bone-screw constructs is displayed in plots C and D. Paired samples student's t-tests demonstrated significant differences in maximal elastic force as well as deformation resistance, highlighting the superior maximal elastic force associated with fully threaded screw fixation. (* = $p<0.05$)

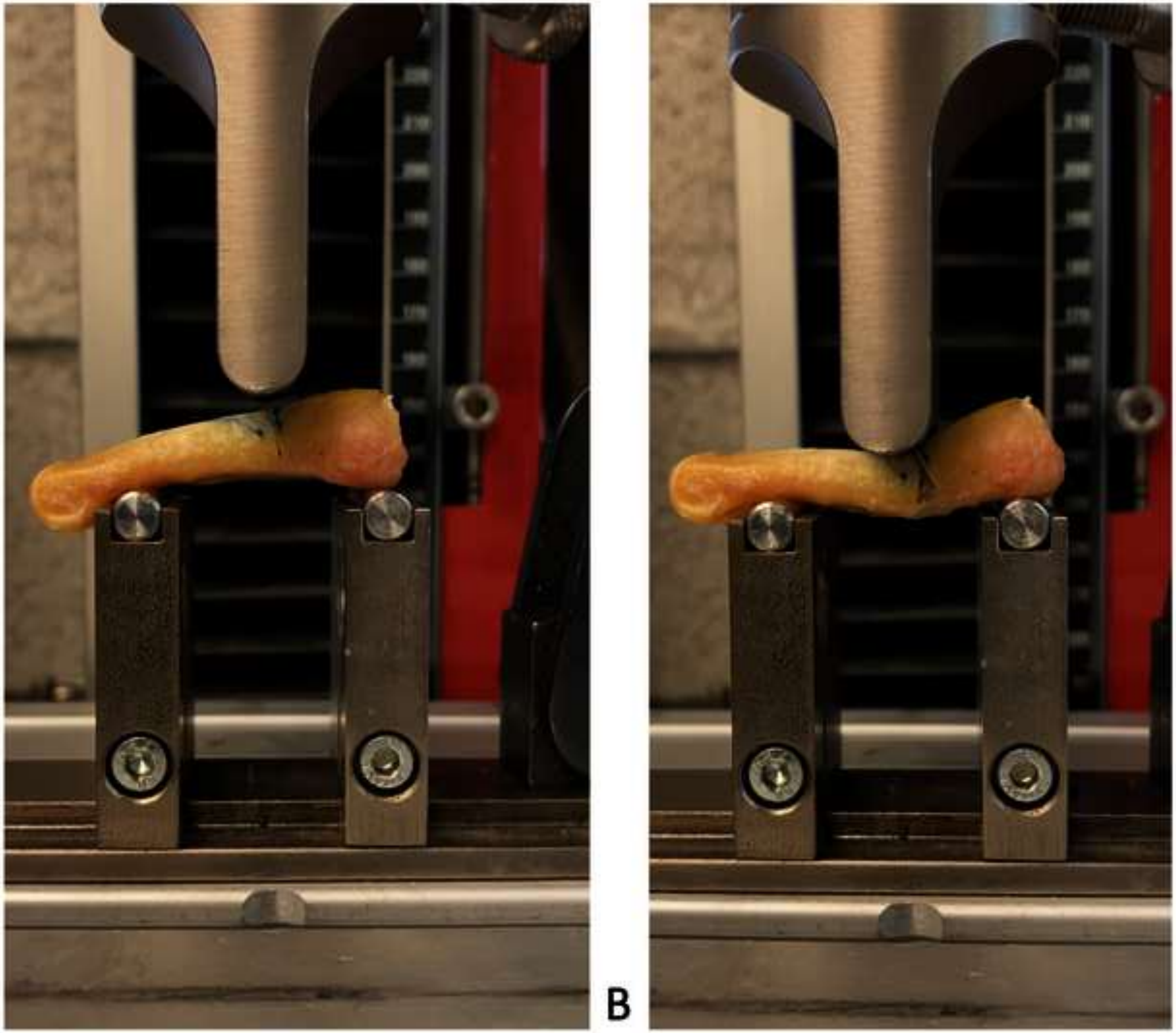
Figure 4

The strain or deformation resulting from the force applied to the bone-screw combination in specimen 3, digit III. The purple curve corresponds to the fully threaded screw and the green curve to the partially threaded screw.

Figure 5

The slope of the curve represents the elasticity of the bone-screw combination in specimen 3, digit III. A line parallel to the slope of the curve was drawn, indicating a 0.2% permanent deformation. The point where the curve intersected this second line was considered the maximal elastic force of the osteosynthesis. A Maximal deformation resistance in the antegrade screw insertion. B Maximal deformation resistance in the retrograde screw insertion.


A
B
C
D



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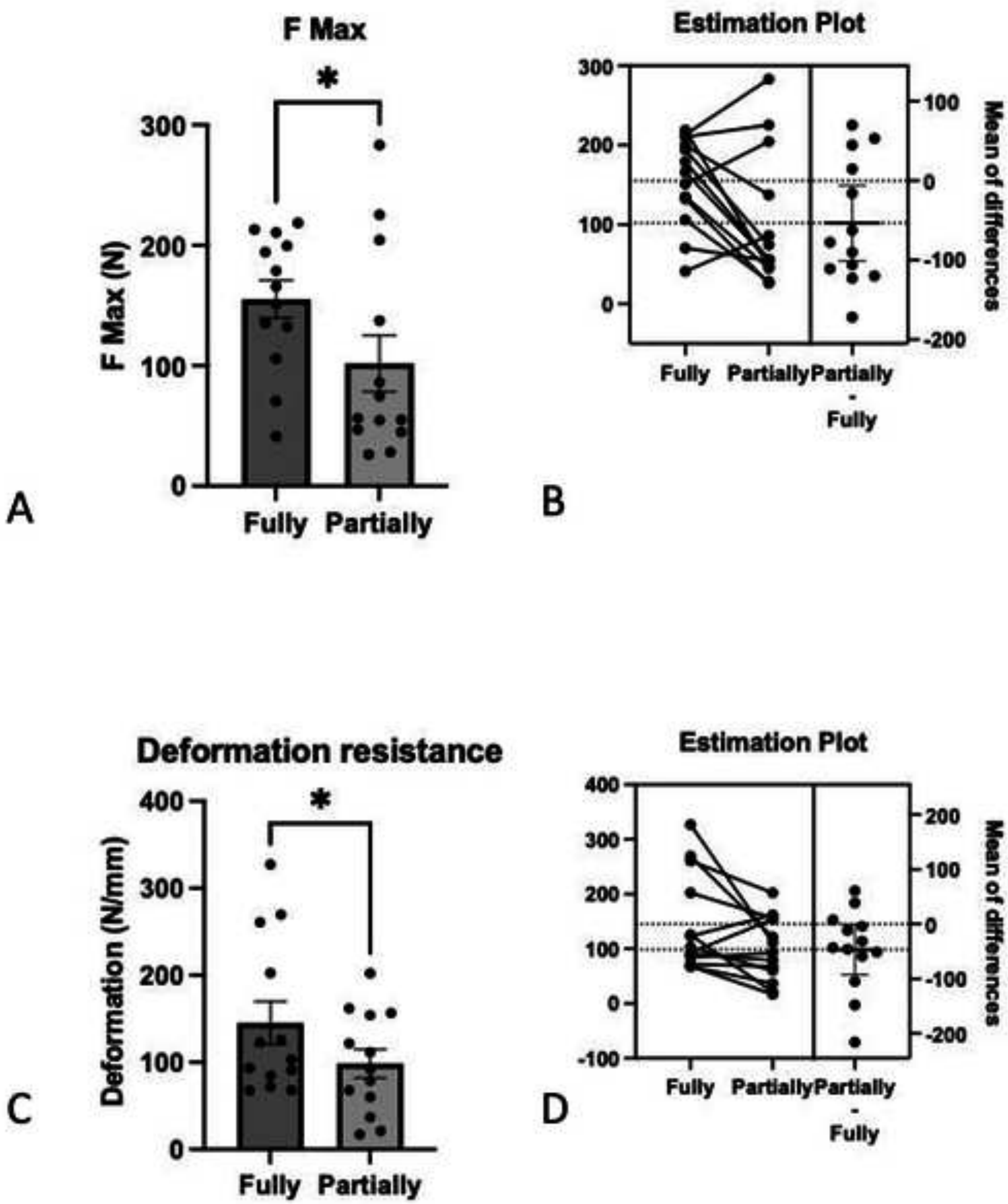
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Figure

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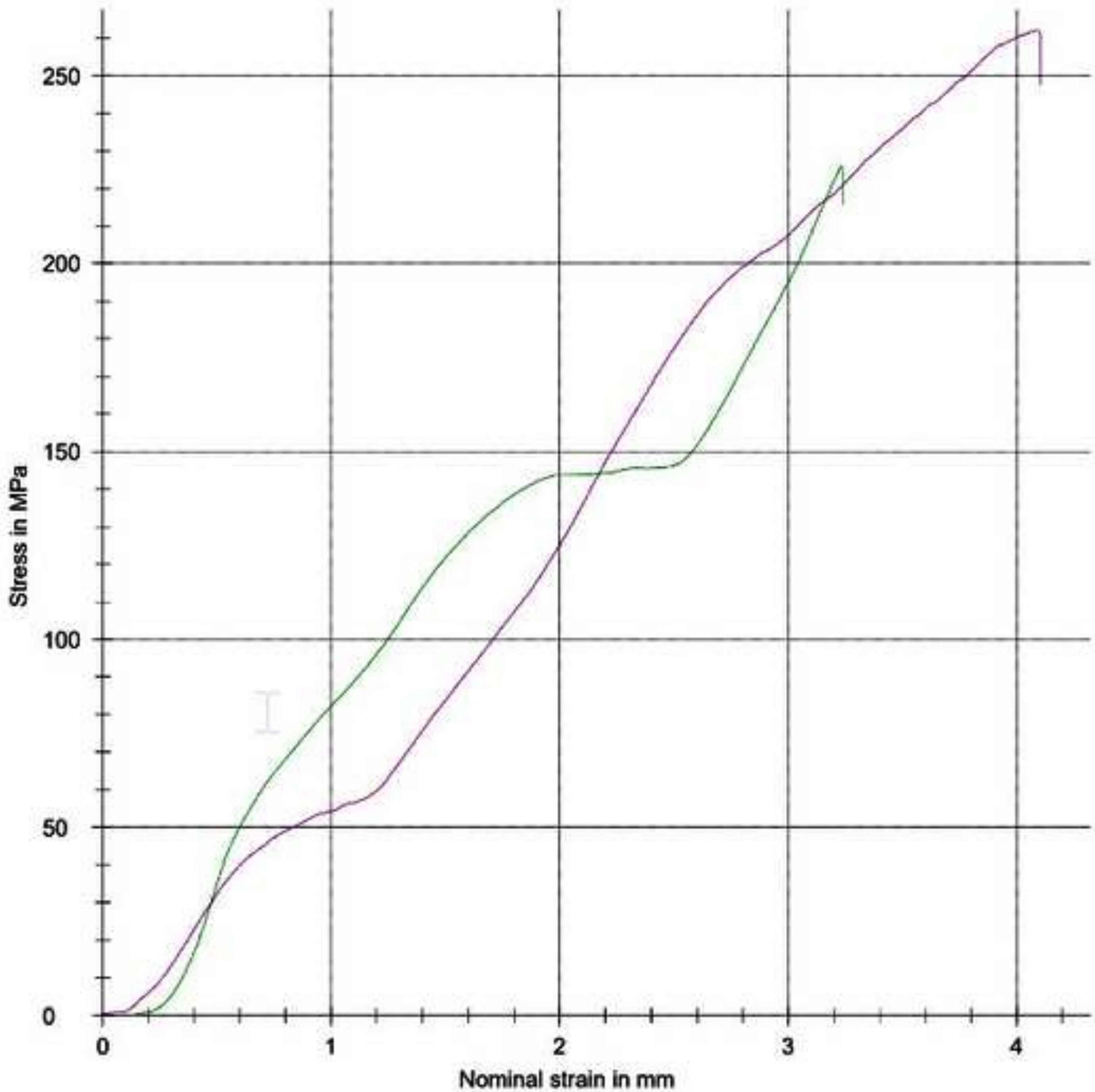

Figure

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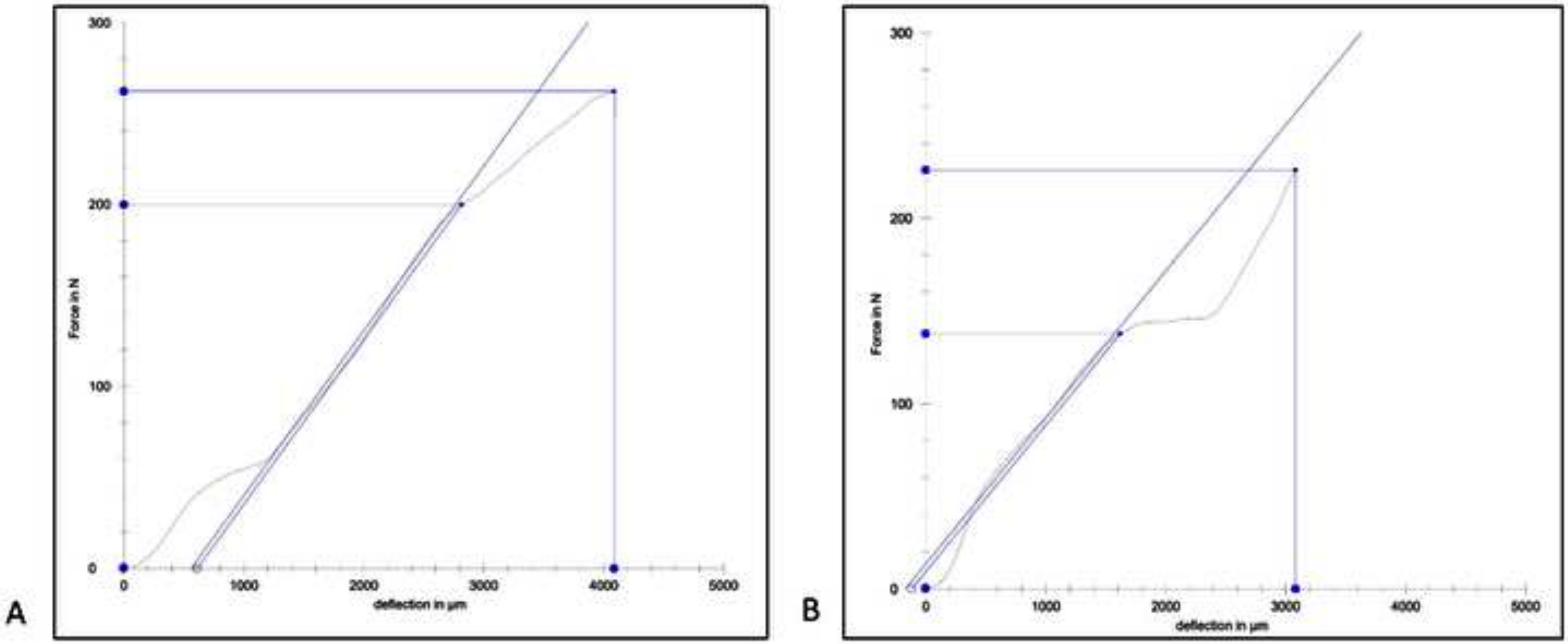

Table 1

Specimen	**Group 1 – Fully threaded**		**Group 2 – Partially threaded**	
	F Max (N)	Deformation (N/mm)	F Max (N)	Deformation (N/mm)
1 – digit II	135	125.4	44.9	21
2 – digit II	218.7	67.7	46.8	36.7
2 – digit III	166.0	103.2	55.1	60.2
2 – digit IV	105.8	68.2	28.2	17.1
3 – digit II	213.2	84.5	283.3	92.1
3 – digit III	199.7	90.7	137.4	79.0
3 – digit IV	210.5	93.1	225.5	154.1
4 – digit IV	194.3	72.0	74.5	67.8
5 – digit III	151.1	260.8	204.4	202.3
5 – digit IV	132.3	327.0	26.0	111.4
6 – digit II	70.3	202.4	54.6	156.4
6 – digit III	179.0	269.5	56.3	121.6
6 – digit IV	41.2	123.0	86.1	161.9

Results of the biomechanical testing. F Max = maximal elastic force.

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Manuscript Number: N.A.

Date: 15 June 2024

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