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Towards Deployable Implants: Conceptual Designs of a Novel Deployable Interposition Wrist Implant Using Origami, Scissor, And Sliding Block Mechanisms

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Abstract

Objective
Minimally invasive joint replacement offers benefits like little tissue damage, reduced pain, and fast recovery. Traditionally, the surgery has been adapted to the (size of the) implant limiting the true surgical potential. The aim of this study was to explore and conceptualize deployable implant spacer for minimally invasive surgery.

Methodology
Different deployment mechanisms have been researched and evaluated according to the suitability for joint implants. Origami, scissor, and sliding block were identified as most promising and integrated into a quadri-elliptical-shaped wrist implant spacer. The final designs were prototyped out of PLA using 3D printing and underwent compression testing of up to 1000 N in the lab.

Results
The deployment ratios were 140% for the origami, 150% for the scissor, and 160% for the sliding block. In the compression test, the origami prototype failed at 925 N, whereas scissor and sliding block survived the maximum load.

Conclusion
To the best of our knowledge, we explored for the first time a deployable implant spacer. Offering the highest deployment ratio and non-discrete height adaptation, the sliding block appeared to be most promising for in depth future research.

1 Introduction

Joint replacement surgery replaces a damaged/ diseased joint with an artificial implant to restore function and reduce pain. Conventional joint replacement surgeries involve large implants, extensive tissue disruption, and prolonged recovery. Minimally invasive techniques offer benefits, such as smaller incisions reduce damage to tissues, resulting in less postoperative pain and a quicker recovery [1]. However, there is a misconception for truly minimal invasive joint replacement, as large implants are inserted into the body. Deployable implants could be a solution to this problem, but they also increase design complexity with challenges regarding stability and durability. While researchers have worked on deployable stents, heart valves, and neural implants [2], joint replacements remain unexplored in this context.

Well known adjustable implants are for example expandable spinal devices, ranging from interbody cages, vertebral body reconstruction cages, to intravertebral body expansion [3]. Although their common purpose is to restore height via expansion, the mechanisms vary. Examples are screw jacks, insertion-expansion jacks, and scissor jacks. A screw jack is a mechanical device that uses a screw thread to convert rotary motion into linear motion, enabling loads to be lifted or lowered. An insertion expansion jack achieves controlled expansion by plugging one component into another, such as used in the VariLift fusion system [4]. Scissor jacks comprise four interconnected components forming a rhomboid. They operate via a screw thread running through the assembly, causing the arms to pivot. Additionally, in recent years the interest in origami in engineering has increased significantly. In biomedical engineering, origami is used in sensors, drug delivery and to deploy stents, catheters, surgical microgrippers and other small biomedical devices in the body [4].

Although the use of height adaptation is not new in orthopedics, the principle of deployable implants for functional joint reconstruction is unexplored. The aim of this paper was to analyze different deployable mechanisms and conceptualize a deployable implant spacer in the example of the wrist, as the wrist joint is highly soft tissue-constrained, non-weight bearing, and would largely benefit from a minimal invasive surgical procedure.

2 Method

The general concept of a deployable wrist implant spacer is shown in Figure 1 A. After intensively reviewing and evaluating different deployment principles according to complexity, deployment ratio and deployment procedure simplicity, we initially selected the three mechanisms origami, scissor, and sliding block to conceptualize (Figure 1 B-D). For all principles, the shape of the implant was inspired by the pyrocarbon Amandys® implant spacer (Wright™, Grenoble, France), a quadri-elliptical-shaped wrist implant replacing the lunate and a portion of the scaphoid and capital head [5]. The dimensions of the novel wrist implant were based on a carpal bone size analysis [6]. To ensure load-bearing capacity of the implant, we took typical grip strength values [7] plus a safety factor, resulting in an axial load requirement of 800 N.

The deployable implant spacer were designed in Solidworks and 3D printing was used for prototyping. The prototypes were printed out of PLA at a 200% scale to make manufacturing and testing easier. To evaluate the load-bearing capacity of the concepts, a compression test to failure was done on each prototype. The machine plates were moved on the test specimen, resulting in a small starting force, after which the compression force increased with 10 N/s . The compression testing machine had a maximum compressive load of 1000 N.

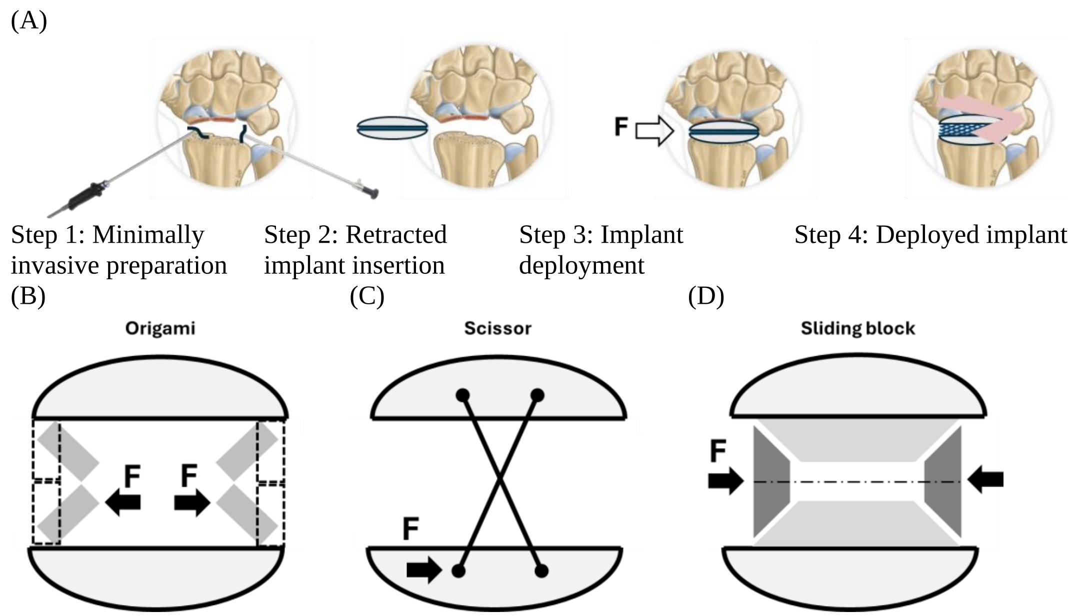


Figure 1: (A) Implantation steps of a deployable implant spacer in the example of the wrist, (B) Origami mechanism, (C) Scissor mechanism, (D) Sliding block mechanism. 'F' indicates the force needed for deployment.

3 Results

The final designs of the deployable implant spacer can be seen in Figure 2. The deployment ratios were 140% for the origami, 150% for the scissor, and 160% for the sliding block mechanism. Only the origami prototype failed before the end of the experiment at 925 N, because the origami panel was pushed into the implant half.

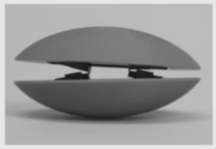
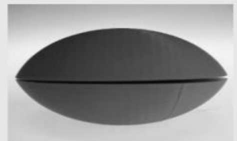
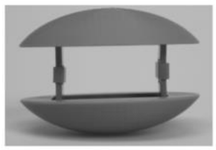
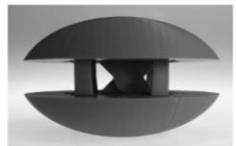
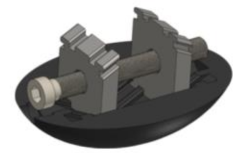
	Origami	Scissor	Sliding block
Retracted implant			
Deployed implant			
Deployment ratio	140%	150%	160%
Load transfer	925 N	1000 N (end of experiment)	1000 N (end of experiment)
Position	Discrete	Discrete (for blocking)	Non-discrete
Motion	Complex	Simple	Simple
Dimensions	Compact	Large	Large
Complexity	Medium	High	Low

Figure 2: (A) SolidWorks render of the final design, (B) 3D printed prototype in retracted state, (C) 3D printed prototype in deployed state, (D) Compress test.

4 Discussion

This paper identified origami, scissor, and sliding block as promising deployable mechanisms and conceptualized a novel deployable wrist implant spacer using three different principles. The mechanisms showed different performances in deployment ratio and load transfer capabilities, but also distinguished according to the principles' nature.

The lowest deployment ratio was observed for the origami mechanism (140%) and the highest for the scissor mechanism (160%), which is in the range of expandable interbody fusion cages, such as the Concorde Lift™ (162%) [8]. The prototypes all met the set requirement of 800 N vertical load transfer, although made of PLA.

While origami mechanisms are inherently compact, allow complex deployment motions, allow lightweight construction, and have reduced friction and wear, this concept turned out to be sensitive for horizontal loads and could not playing its advantages in the example of a quadri-elliptical-shaped implant. A scissor mechanism can collapse or fold into a compact form, making it highly space-efficient when not in use [9], but the actuation and stable blocking counter-acted this benefits. The sliding block is the most simple mechanism, but specifically suitable for high load transfers as the loads are transferred through solid, continuous surfaces. Although friction and wear are general disadvantages, they did not appear to be relevant in this application.

This study must be interpreted with caution due to the following limitations: First, the concepts were developed based on limited technical requirements. Second, the designs were made of PLA, which implies significantly different material properties than conventional orthopedic implants. Third, the articulating surfaces were not considered in this study. Fourth, the tests were conducted under lab conditions.

5 Conclusion

We have identified and conceptualized three promising mechanisms origami, scissor, and sliding block in the example of a wrist interposition implant. Although the concepts have principle-related advantages and disadvantages, the sliding block mechanism proved to be particularly promising in longitudinal designs due to its high-load transfer capacity and simplicity. Non-discrete adaptation could be an interesting feature for soft-tissue tension adjustment in the future.

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