CordAlign™ Precision Wand: Physics & Imaging Requirements

Integrating Imaging, Alignment, and Automated Delivery for Safer Dupuytren Treatment

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Physics & Imaging Requirements

Effective performance of the CordAlign™ Precision Wand (CPW) depends on the ability of its Ultrasound Cord-Position (UCP) detector to resolve small subcutaneous structures—specifically Dupuytren cords typically measuring **2–3 mm in diameter** and located within the superficial layers of the palm, generally at depths of **3–8 mm** from the skin surface. The imaging parameters must therefore be optimized for **high axial and lateral resolution**, **shallow penetration**, and **stable geometric definition** suitable for automated centerline detection.

AI-Guided Delivery and Multi-Injection Imaging Requirements

The CPW must not only visualize Dupuytren cords but also support a **multi-injection workflow** in which several closely spaced injections (typically 5–10 mm apart) are performed along the cord. Each dose must be delivered into the cord's narrow, variable centerline. This requirement places additional demands on the imaging subsystem: it must provide stable, repeatable geometric definition of the cord boundaries across small spatial increments. Ultra-high-frequency imaging enables the AI-guidance module to continuously track centerline position, verify inter-injection spacing, detect subtle changes in diameter or curvature, and ensure that each sequential injection is delivered at a validated anatomical site.

1. Choice of Ultrasound Frequency

UHF as the Preferred Technology

While conventional musculoskeletal ultrasound typically uses frequencies in the **12–18 MHz** range, CPW aims for **higher spatial resolution** than required for standard diagnostic imaging. Given that the cord is a small, superficial structure, the priority shifts from penetration depth to **maximal resolution**.

For this reason, CPW will target **ultra-high-frequency (UHF) ultrasound** in the range of **20–30+ MHz.** This frequency band offers multiple advantages:

- **Axial resolution** on the order of **50–100 microns**, allowing the UCP detector to measure cord diameter accurately and track its boundaries.
- **Superior definition of superficial tissues**, including the palmar fascia, subcutaneous fat, cord surface, and the underlying flexor tendon.
- **Enhanced ability to distinguish tendon fibrillar patterns from the more homogeneous or heterogeneous texture of a Dupuytren cord.**

Acceptability for Miniaturization

Advances in piezoelectric micromachined ultrasonic transducers (PMUTs), capacitive micromachined ultrasonic transducers (CMUTs), and compact linear arrays now allow **20–30 MHz transducers** to be made:

- Small

- Light
- Power-efficient
- With reasonable thermal profiles

All suitable for integration into a **miniature handheld wand**.

The UHF approach remains more expensive than standard MSK probes, but prices are falling steadily, especially as manufacturing for dermatologic, vascular, and micro-anatomy probes expands. The cost is acceptable for a medical device positioned as a **precision-guidance tool** rather than a general-purpose scanner.

Feasibility Summary

- UHF (20–30+ MHz) meets and exceeds resolution needs for a 2–3 mm cord
- Penetration (1–1.5 cm) is more than sufficient for palmar imaging
- Current component technology supports miniaturization
- The anticipated cost increase is justified by the precision and safety benefits

This makes UHF the preferred imaging modality for CPW.

2. Resolution Requirements for Cord Identification and Centerline Detection

For precise guidance, CPW must resolve:

1. **Cord boundaries**
2. **Cord centerline**
3. **Cord–tendon separation**
4. **Cord depth relative to skin and subcutaneous layers**

Axial Resolution

At **20–30 MHz**, axial resolution is approximately:

- **~75–150 microns**, depending on bandwidth

This is sufficient to:

- Detect the cord outline
- Identify minor changes in cord diameter
- Adjust needle position with sub-millimeter precision

High-resolution imaging is also essential for AI-driven multi-injection planning. Because injection points must be spaced approximately 5–10 mm apart, the system must detect small but meaningful geometric changes along the cord. Tens-of-microns resolution allows the AI module to confirm that each injection is far enough from prior sites, yet still within the tension-bearing portion of the cord. Precise boundary detection ensures centerline targeting remains accurate throughout the multi-injection sequence.

Lateral Resolution

Lateral resolution depends on:

- Aperture size
- Focal characteristics
- Beamforming (digital or analog)

With a compact linear aperture optimized for palm imaging, expected lateral resolution is:

- **~150–300 microns**

Adequate for distinguishing:

- Cord vs. adjacent tendon
- Surface of the cord
- Any small “flares” or angulations relevant for needle entry

3. Tissue Contrast Requirements

The UCP detector relies on structural and acoustic differences between Dupuytren cords and surrounding tissues.

Dupuytren Cord Characteristics:

- Typically **hypoechoic** or mildly heterogeneous
- Located within the **palmar fascia** layer
- Lies **superficial** to flexor tendons
- Shows **less fibrillar structure** than tendon
- Often **tethered to dermis**, producing a predictable anatomical loop

Tendon Characteristics:

- **Hyperechoic** with **distinct fibrillar pattern**
- Moves dynamically with finger flexion/extension
- Deeper location below the palmar fascia

Frequency Dependence

Higher frequencies (20–30+ MHz) improve:

- Discrimination between cord texture and tendon fibrillar architecture
- Edge sharpness, making boundary detection algorithmically simpler
- Depth resolution, aiding precise needle targeting

Thus, UHF ultrasound strengthens the reliability of automatic tissue differentiation within the CPW guidance system.

These contrast differences also enable **sequential injection site validation**. Because the cord and tendon exhibit distinct acoustic signatures, UHF imaging allows the AI module to confirm that each proposed injection site lies within the cord rather than drifting toward the deeper tendon layer—a critical safeguard when performing several injections along a narrow fascial band.

4. Geometric Stability and Image Field Requirements

The UCP imaging field is intentionally small:

- Width: **~10–20 mm**
- Depth: **~10–15 mm**

This allows:

- **Higher frame rates**
- **Lower data-processing load**
- **Improved signal-to-noise ratio**
- **Fine-grained alignment guidance**

The CPW does not need wide-field imaging—only a **narrow gate** aligned with the cord and needle path. This simplifies both physics and processing requirements.

A narrow, stable imaging field is particularly important for the **AI-guided multi-injection workflow**, which depends on consistent spatial reference as the wand advances in 5–10 mm increments. High frame rates and geometric stability ensure that each new site is mapped accurately, cord curvature is continuously traced, and spacing metrics remain reliable even when the wand is translated slowly along the palm.

5. Real-Time Image Processing Requirements

For alignment guidance, UCP must deliver:

1. **Real-time boundary detection**
2. **Cord centerline computation**
3. **Depth measurement**
4. **Angulation deviation alerts**
5. **Needle position verification, if included in the system**
6. **Sequential injection site computation**

UHF imaging inherently improves:

- Edge detection
- Shadowing characteristics
- Reflection patterns

All of which help the AI-based control system maintain precise alignment.

6. Summary of Physics & Imaging Requirements

To meet the objectives of the CordAlign™ Precision Wand:

Frequency

- **Preferred:** 20–30+ MHz (UHF)
- **Acceptable:** 15–18 MHz (mid-high frequency)

Resolution

- **Axial:** ~75–150 microns
- **Lateral:** ~150–300 microns
- Fully adequate for 2–3 mm cords

Tissue Contrast

- Distinguishable by depth, texture, motion characteristics
- UHF improves boundary clarity and discrimination

Penetration

- Required depth is low: **0.5–1.5 cm**
- UHF penetration is more than sufficient

Device Feasibility

- UHF arrays can be miniaturized
- Power/heat remain manageable
- Cost is rising but still practical for a specialized, high-precision medical device

Conclusion

The physics and imaging requirements for CPW are fully compatible with modern ultra-high-frequency (UHF) ultrasound technology. We deliberately selected the 20–30+ MHz range because the added spatial clarity and boundary definition in the real-time video stream significantly enhance the performance and reliability of the AI-based image-processing algorithms. Higher-resolution input improves tissue discrimination, cord boundary detection, and centerline extraction, allowing the guidance system to operate with greater precision and confidence. A 20–30+ MHz UCP detector therefore provides the optimal balance of resolution, device size, AI interpretability, and clinical performance—matching our design philosophy of a miniature, high-precision injection-guidance wand. This same clarity enables AI-guided multi-injection delivery by providing the spatial stability and boundary resolution required to plan, validate, and execute several closely spaced injections along the cord with consistent centerline accuracy.

APPENDIX

Are tendon vs. Dupuytren cord properties different enough to distinguish reliably?

Short answer: **yes**—both in anatomy and in ultrasound appearance, there is usable contrast.

Anatomical / positional differences

- **Normal flexor tendons** are deep to the palmar fascia and Dupuytren cords.
- **Dupuytren cords/nodules** arise from the **palmar fascia (palmar fibromatosis)** and lie **superficial to the flexor tendons**, often adhering to the dermis and to the tendon margins.

This layered arrangement alone is a strong cue for an algorithm: skin → subcutaneous tissue → **palmar fascia / cord** → flexor tendon.

Echotexture / acoustic differences

- Normal tendons on ultrasound are **echogenic** with a characteristic **fibrillar pattern**—parallel bright lines or dots depending on the scan plane—because of ordered collagen bundles.
- Dupuytren nodules/cords are usually described as **hypoechoic bands or nodules** lying directly superficial to the flexor tendons and deep dermis; these hypoechoic bands adhering to the tendon margin and dermis are considered **almost pathognomonic**.
- Early nodules tend to be **hypoechoic and hypervascular** on Doppler; older cords become **iso- to hyperechoic**, but still lose the regular fibrillar tendon texture and remain in the palmar fascia plane.

So there are several discriminators:

1. **Depth / layer** relative to skin and tendon
2. **Texture:** fibrillar (tendon) vs. homogeneous/heterogeneous band (cord)
3. **Shape and continuity** along the expected cord trajectory
4. **Vascularity pattern** (optional if you add Doppler capability)

Frequency considerations for discrimination

Although the 15–20 MHz range is already sufficient to separate superficial layers of the hand and to visualize nerves, tendons, arteries, and connective tissue with near-microscopic resolution, in this device we deliberately select ultra-high-frequency ultrasound (UHFUS, approximately 22–30 MHz as a practical subset of the 22–70 MHz range). This provides tens-of-microns spatial resolution in the first 1–3 cm of tissue—exceeding the minimum requirements for cord visualization, but offering additional safety margin and robustness for automated cord–tendon discrimination, centerline extraction, and future software upgrades, while remaining compatible with a miniature handheld form factor.