Table 1 Hydrogel-based clinical trials in different tissue engineering applications

Hydrogels	Disease/result	Clinical trial/product	References
Alginate hydrogel	Improve oxygen uptake in heart failure	Intra-myocardial injection	[48]
Renal cells gelatin hydrogel	Improved levels of creatinine, and proteinuria in kidney diseases		[48]
Poly (methyl methacrylate) (PMMA)	Ocular drug delivery	I-vation	[49]
Collagen	Wound dressing	Condress	[49]
Poly (lactic acid)	Cruciate ligament reconstruction	Milagro Advance	[49]
Collagen and elastin	Soft tissue applications	Alloderm® Regenerative Tissue Matrix	[49]
Cardiac stem cells gelatin hydrogel	Improved ventricular dysfunction	Intra-myocardial injection	[48]
PEGylated fibrin	Reduced tissue damage, increased cell survival		[50]
Heparin modified gelatin	Increased vessel density		[51]
RGD modified alginate	Increased capillary density		[52]
Hyaluronic acid	Osteoarthritis of the knee	Gel-One® Hyaluronate	[49]
Fibrin	Increased the mature capillaries		[53]

development of blood vessels. To effectively enhance new tissue in tissue engineering, hydrogels must meet various design requirements. For instance, these hydrogel frameworks should possess a three-dimensional structure suitable for cell growth. This structural arrangement closely resembles natural tissues and promotes cellular morphology and gene expression that cannot be achieved in two-dimensional setups. Additionally, these design specifications should include considerations of mechanical and physicochemical properties, such as biodegradability, porosity, and biological performance measures like biocompatibility and cell adhesion, as well as the promotion of vascularization.

5.2 Classification of hydrogels

Hydrogels have been categorized in a variety of ways, as seen in Fig. 3. Below, a few of these classifications are illustrated:

(a) Composition and physical structure

Depending on the nature of the polymers used, hydrogels can be classified into the following groups: homopolymers formed from a single monomer species, interpenetrating polymers (IPN), which are made up of two natural and/or synthetic crosslinked polymers, and copolymers comprising two or more monomer with at least one hydrophilic constituent [54]. Additionally, according to their physical condition, hydrogels are further divided into crystalline, semi-crystalline, and amorphous categories [54].

(b) Source

To be employed in tissue regeneration, numerous hydrogels have been created using natural polymers that originate from natural sources [55], such as chitosan extracted from shellfish exoskeletons, whereas collagen is sourced from

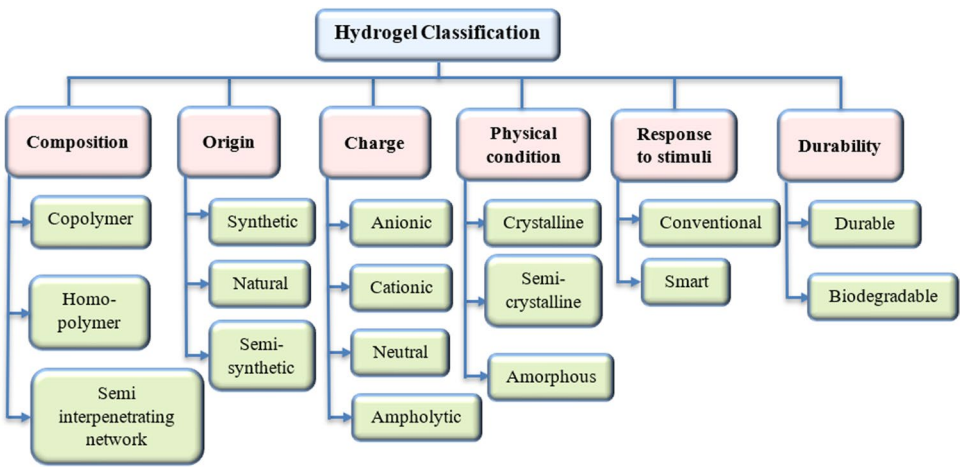

Fig. 3 A diagrammatic representation shows the different categories of hydrogels based on their composition, origin, charge, physical properties, response to stimuli, and durability